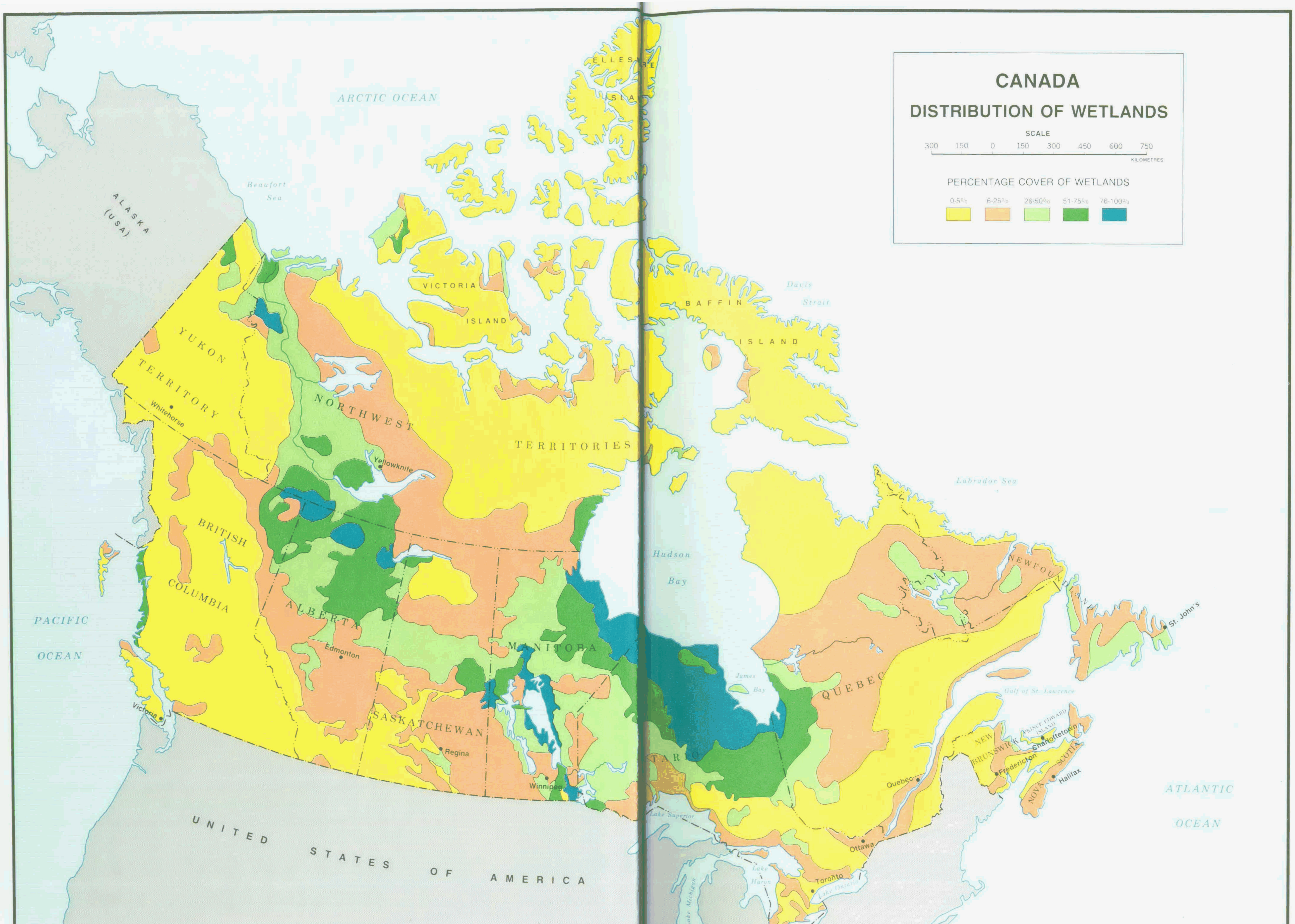
Wetlands of Canada



Source: National Wetlands Working Group (1986). *Canada's Wetlands*, Map Folio. Energy, Mines, and Resources Canada and Environment Canada. Ottawa, Ontario.

Wetlands of Canada

by

National Wetlands Working Group
Canada Committee on Ecological Land Classification

1988

Sustainable Development Branch
Canadian Wildlife Service
Conservation and Protection
Environment Canada

Ecological
Land Classification
Series, No. 24

Wetlands of Canada represents the 24th publication in the Ecological Land Classification Series published by the Sustainable Development Branch of Environment Canada. This series, which was initiated in 1976, has presented national standards, terminology, methodological examples, and perspectives on ecological land survey and classification in Canada. It also has been the publishing focus for reports by the various national working groups of the Canada Committee on Ecological Land Classification.

Bibliographic Citation

National Wetlands Working Group. 1988. Wetlands of Canada. Ecological Land Classification Series, No. 24. Sustainable Development Branch, Environment Canada, Ottawa, Ontario, and Polyscience Publications Inc., Montreal, Quebec. 452 p.

Published by Polyscience Publications Inc., in cooperation with Environment Canada and the Canadian Government Publishing Centre, Supply and Services Canada.

Cat. No. EN 73-3/24E
ISBN No. 0-921317-13-1

Wetlands of Canada Coordinator

C.D.A. Rubec

Scientific Review Committee

C. Tarnocai
F.C. Pollett
C.D.A. Rubec
S.C. Zoltai

Chapter Leaders

G.D. Adams, Environment Canada (Chapter 5)
V. Glooschenko, Ontario Ministry of Natural Resources (Chapter 6)
W.A. Glooschenko, Environment Canada (Chapter 9)
P. Lynch-Stewart, Environment Canada (Appendix I)
E.T. Oswald, Canadian Forestry Service (Chapter 8)
C.D.A. Rubec, Environment Canada (Chapter 10)
C. Tarnocai, Agriculture Canada (Chapter 2)
E.D. Wells, Canadian Forestry Service (Chapter 7)
S.C. Zoltai, Canadian Forestry Service (Chapters 1,3,4)

Production Credits

Design concept: Maruska Studios, Ottawa, Ontario
Graphics: Carisse Graphic Design Ltd., Ottawa, Ontario
and Conservation and Protection Drafting Unit,
Environment Canada, Hull, Quebec
Editing and proofreading: R. Tabacnik and J. Wilson,
Words Associated Ltd., Chelsea, Quebec
Typesetting and layout: Graph Comp Design Ltd., Ottawa, Ontario
Word Processing: APH (MICOT) Ltd., Hull, Quebec
and Environment Canada staff

Contents

Preface ix

Foreword xi

1 **Wetland Environments and Classification** 1

Wetland Distribution 4

Factors Influencing Wetland Development 4

Evolution of Wetlands since Deglaciation 7

Wetland Classification 9

Wetland Regionalization 17

Methodologies 19

Summary 22

References 23

2 **Wetlands of Arctic Canada** 27

Environmental Setting 30

Arctic Wetland Regions 33

Arctic Wetland Forms 36

Dynamics of Arctic Wetlands 47

Arctic Wetland Values and Conservation 50

References 51

3 **Wetlands of Subarctic Canada** 55

Environmental Setting 58

Subarctic Wetland Forms 60

Regional Wetland Development 85
Subarctic Wetland Values 92
References 93

4 **Wetlands of Boreal Canada** **97**
Environmental Setting 100
Boreal Wetland Regions and their Vegetation 101
Boreal Wetland Forms 103
Regional Wetland Development 139
Boreal Wetland Values 148
References 151

5 **Wetlands of the Prairies of Canada** **155**
Environmental Setting 158
Prairie Wetland Regions and Subregions 161
Wetland Distribution and Abundance 162
Hydrology of Prairie Wetlands 164
Prairie Wetland Classification 166
Development, Formation, and Dynamics 180
Prairie Wetland Values 187
Prairie Wetland Conservation 192
References 194

6 **Wetlands of Eastern Temperate Canada** **199**
Environmental Setting 203
Wetland Forms of the Eastern Temperate Wetland Region 205
Dynamics of Eastern Temperate Wetlands 224
Values of Eastern Temperate Wetlands 227
Important Eastern Temperate Wetland Complexes 233

Wetland Losses 237
Wetland Conservation Initiatives 239
Wetland Evaluation Programs 240
References 243

7 Wetlands of Atlantic Canada 249

Environmental Setting 252
Atlantic Wetland Regions 253
Atlantic Peatlands 254
Salt Marshes in Atlantic Canada 265
Atlantic Freshwater Marshes 282
Atlantic Swamps 288
Atlantic Wetland Values 288
References 297

8 Wetlands of Pacific Canada 305

Environmental Setting 309
Pacific Wetland Forms and Types 312
Dynamics of Pacific Coast Wetlands 337
Pacific Wetland Values 342
References 345

9 Salt Marshes of Canada 347

Environmental Setting 350
Canadian Salt Marshes 353
The Ecological Significance of Salt Marshes 367
Losses of Canadian Salt Marshes due to Human Activities 369
Conclusions 370
References 371

10 Wetland Utilization in Canada **379**

The Conservation Perspective 383

The Conversion Perspective 389

Trends in Wetland Conversion Across Canada 398

Conclusions 406

References 408

Appendix I: The Canadian Wetland Classification System **413**

Appendix II: Authors' Affiliations **429**

Glossary **433**

General Index **447**

Preface

As a recurring element throughout our vast nation, wetlands form an integral component of Canada's environmental mosaic. Unlike most other ecosystems, wetlands transcend typical ecological boundaries. They are often the home for a rich diversity of vegetation and wildlife, and are found in all parts of the country, fringing its coastlines, dotting its prairies, woodlands, and waterways, and giving life to many northern and mountainous landscapes.

Canada's captivating variety of bogs, fens, marshes, and swamps comprise nearly one quarter of the total global wetland resource. This shared international resource is crucial to the livelihood of many of our people and the natural resources that are associated with wetland habitats. Through federal policies relating to land, water, and wetlands, and through international agreements such as the North America Waterfowl Management Plan, Canada is committed to conservation of wetland ecosystems for the heritage of this nation and, indeed, the world.

This book, Wetlands of Canada, *describes in practical terms, for the first time, the variety, extent, and status of wetlands in all regions of Canada. It also provides the reader with an appreciation of the origins, the functions, and the critical links of wetlands to our ecological and socio-economic systems.*

Tom McMillan

The Honourable Tom McMillan, P.C.
M.P. Hillsborough
Minister of the Environment

Foreword

The long-term nature of the preparation of Wetlands of Canada *has involved the leadership of two chairmen of the National Wetlands Working Group. Observations by Fred Pollett, Chairman from 1976 to 1980, and Charles Tarnocai, Chairman from 1981 to 1988, are presented in the Foreword below.*

Past Chairman's Observations

"Bogs. These strange wetlands have always haunted us. Misty moonscapes of mosses that quake underfoot. From their soggy depths, steeped in preservative humic acids, have emerged—literally—the faces of our ancestors and a treasure chart of their possessions . . ."

So wrote Louise Levathes in a recent article entitled "Mysteries of the Bog" in *National Geographic* magazine. It entices the reader into the world of blanket bogs and ribbed fens through lead-in anecdotes about human bodies preserved in peat, with fingerprints and hair intact after thousands of years. Wetlands such as bogs, fens, marshes, and swamps generate special interest among archaeologists, biotechnologists, poets, farmers, and a plethora of other groups and individuals. Despite this widespread interest, our ignorance of Canada's natural wetland ecosystems and of their initiation, growth, and development ensures that many "mysteries of the bog" will remain mysteries for future generations of scientists and poets.

Until the 1970s, the wetlands of Canada had not been studied in a systematic manner. There were many local and regional studies but only generalized estimates had been made of the total area of wetlands and the quantity of peat in Canada. It was only with the formation of the group now known as the National Wetlands Working Group (NWWG) of the Canada Committee on Ecological Land Classification (CCELC) that this situation began to change. It has been a strangely successful, active, and somewhat unconventional "committee" in an age of sometimes cumbersome bureaucracy, as demonstrated in the accompanying comments of my friend Charles Tarnocai, current chairman of the NWWG.

The success of the NWWG is not the result of a definite desire to conduct research and to publish. Rather, it can be attributed more to the development of an understanding of the common problems each scientist faces in his or her own region of Canada. I remember this cluster of scientists standing on a large ribbed fen in the remote Gaff Topsails of Newfoundland. Previous correspondence on this wetland type had generated heated debate on terminology and classification.

But here in the field on this wetland that defied conventional classification, there was accommodation followed by unanimity on type and description. Since then, the Group has stood together on low-centre polygon fens in the Arctic, on blanket bogs in the Queen Charlotte Islands, on the edges of prairie potholes, in salt marshes in New Brunswick, and on swamps in southern Ontario. It is this knowledge of wetlands in all parts of Canada that has contributed to the improvement of our nation's wetland classification, to the preparation of national maps, and to the publication of numerous authoritative articles and this particular book.

The information we have obtained on wetlands forms an important ecological data base which will help in regional and national programs on wetland conservation. Our timing is important because, today, wetlands are arousing more interest as potentially productive forest lands, high-quality farmlands, waterfowl nesting sites, desirable recreation spots, and sites for mining peat moss and peat fuels. In this era of environmental consciousness, we must develop land use programs that show a genuine concern for environmental quality.

We in Canada are trustees of enormous wetland resources. It is estimated that 14% of Canada, some 1 270 000 km^2, are wetlands. Few people may know that included in this area is the world's second largest peatlands resource base, forming one of the principal water storage reservoirs in the northern hemisphere. This is a landscape where peat is both the retaining and the delivery mechanism for a large portion of North America's freshwater supply. These peatlands also use carbon dioxide in plant production and store it in their peat layers. Many scientists also believe that these peatlands act as natural sinks for absorbing atmospheric carbon dioxide and pollutants. It can be seen that the vast wetlands of Canada are intimately related to some of the world's greatest environmental concerns, such as freshwater supply, energy use, and the quality of our atmosphere.

My boyhood was spent in Newfoundland. It was only later, when I became a specialist on environmental issues, that I needed to be concerned with precise definitions and terminology. In the Newfoundland vernacular, wetlands were often called the "marsh, mish, mesh, mash, bog or swamp". To me they were part of growing up—for picking bakeapples, marshberries, cranberries, and scattered blueberries, or for using as pathways through dense fir and spruce forest to favourite fishing haunts. Peatlands were popular habitats for moose, caribou, and small game. They were places where blackflies and mosquitoes bred, but by divine blessing they were also subject to strong, fly-dispersing breezes—at least on most days. One learned, too, that peatlands have a peculiar variety of flora, including many wildflowers, both common and rare, and an intriguing group of insect-eating plants, the most striking of which is the pitcher plant, *Sarracenia purpurea*, Newfoundland's floral emblem.

The wetlands of Newfoundland were ripe for discovery. Now, *Wetlands of Canada* offers the scientist and student a chance to understand better the nature, variety, and extent of our wetlands. It will provide the basic framework within which new knowledge will be incorporated in future editions. This book will also to a large extent reinforce the national message, as stated by Canada in its report to the 1986 World Conservation Strategy Conference, that "wetlands are a major component of Canada's conservation strategy and must be considered in association with both land and water conservation efforts". This will occur only through the joint efforts of all levels of government and the public.

Environment Canada and the National Wetlands Working Group deserve our thanks for bringing this important document to the public domain.

Fred Pollett
Chairman, 1976–1980
National Wetlands Working Group

Current Chairman's Observations

As my colleague, Fred Pollett, has noted above, wetlands are a common feature of the Canadian landscape. However, no comprehensive book has been published which describes Canadian wetlands uniformly throughout the country. Fred recognized that this was needed and encouraged the NWWG to prepare such a book.

The NWWG has roots dating to 1970, when the National Committee on Forest Lands formed the Subcommittee on Organic Terrain Classification. This subcommittee was established to develop a system of organic terrain classification applicable to various land use purposes. The subcommittee was active from 1970 to 1976, producing a first approximation of a national organic terrain classification system in 1973. Although the National Committee on Forest Lands became dormant, the Organic Terrain Classification Subcommittee remained active. In 1976, with the creation of the Canada Committee on Ecological Land Classification, several new national working groups were formed, including one directed to continue and expand the wetland work of the previous Organic Terrain Classification Subcommittee. Hence, this working group, now called the National Wetlands Working Group, has been active for over 17 years.

Working group members were selected on the basis of their expertise, with little concern for institutional or scientific affiliation. Since the initial formation some members have left, with very capable people replacing them, but the original goals remain intact. The NWWG acts with the informal, volunteer contributions and resources support of numerous federal, provincial, territorial, and non-governmental agencies and individuals. In particular, its activities are supported by the CCELC Secretariat provided by the Lands Branch of Environment Canada. All members of the NWWG, which is now composed of G.D. Adams, V. Glooschenko, W.A. Glooschenko, P. Grondin, H.E. Hirvonen, D.G. Keys, G.F. Mills, E.T. Oswald, C.D.A. Rubec, C. Selby, C. Tarnocai, E.D. Wells, and S.C. Zoltai, contributed their knowledge and time to the preparation of various parts of this book. Many other Canadian wetland scientists also provided valuable input and nationally recognized expertise during its preparation. The NWWG wishes to thank all these people and the many others who provided valuable suggestions and critical reviews of drafts of chapters or sections during the course of this work.

Since 1977, the NWWG has held annual meetings with wetland field trips in various parts of Canada. This has been done to familiarize members of the Group with the diversity of wetlands, to assist in refinement of the Canadian Wetland Classification System, and to plan and complete *Wetlands of Canada* as well as other projects dealing with wetland regionalization and distribution. The broad knowledge of regional conditions thus obtained, together with a detailed knowledge of problems in various parts of Canada, led to the approach used in this book. Wetland regions, forming the basis of seven chapters of the book, place wetlands within an ecological framework. This includes all the main components which play a role in the ecological structure of wetlands.

This book presents the current state of knowledge concerning Canadian wetlands, not only giving an overall national picture but also providing detailed regional information. It should be noted, however, that this regional information is not always complete since it is dependent on the scientific information currently available. The approach followed and the diversity of regions and disciplines represented by the authors have required many compromises to minimize discrepancies and incorporate the authors' different points of view.

Special thanks are due to Fred Pollett since it was under his chairmanship of the NWWG from 1976 to 1980 that the idea for preparing such a book was formulated. His continued support and very pertinent advice have been especially valuable. The Lands Conservation Branch of Environment Canada also deserves special thanks since it provided financial and technical support for NWWG activities, as well as a national commitment to wetlands research, all of which have been essential for the publication of this book. The continued support for this project by Jean Thie, Director, Lands Conservation Branch, and Ed Wiken, Chief, Ecological Research and Integrated Programs Division, is gratefully acknowledged. Also, the contribution of Clayton Rubec must be specially acknowledged as he has shouldered the responsibility for coordinating the book's compilation, editing, and production.

Charles Tarnocai
Chairman, 1981–1988
National Wetlands Working Group

1 Wetland Environments and Classification

S.C. Zoltai

Wetland Environments and Classification

Mires . . . moors . . . muskegs . . . peatlands . . . wetlands—all these terms describe areas that are waterlogged all or most of the time. They are neither firm "lands" in the conventional sense nor bodies of open water; hence they occupy a transitional position between land and water. The ecosystems that develop on such lands are dominated by the persistent presence of excess water. Wetland is defined as "land that has the water table at, near, or above the land surface or which is saturated for a long enough period to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to the wet environment" (Tarnocai 1980).

Thus defined, wetlands include waterlogged soils where in some cases the production of plant materials exceeds the rate of decomposition. The remnants of such plant materials, peat, are common in many wetlands, often forming extensive peatlands. However, not all wetlands are peatlands. Under certain circumstances, for climatic, edaphic, hydrologic, or biotic reasons, peat may not be formed or preserved. In Canada, a thickness of 40 cm of peat was chosen as a minimum requirement for wetlands to be classified as peatlands, based on ecological and land use considerations (Zoltai *et al.* 1975). Shallow open water, generally less than 2 m deep, is also considered to be a wetland. Areas periodically inundated by water are wetlands only if the waterlogged condition is dominant throughout the development of the ecosystem.

Wetlands occupy very large areas in many parts of Canada. For years these "boggy wetlands" were considered as obstacles that blocked progress. "It just lies there, smeared across Canada like leprosy . . . It slurps up roads and railways, gobbles buildings and airfields, swallows the least trace of humanity" (Alderman 1965). Lately, however, in the wake of more studies, wetlands have been recognized as special places that sustain enormous numbers of waterfowl (Hochbaum 1983), store and slowly release large quantities of water (Ingram 1983), produce large amounts of energy in the form of peat (Tarnocai 1984), and, when drained, serve as extremely productive agricultural areas. Wetlands are often regarded as places of beauty, where colourful orchids grow and highly specialized and unique plants are found.

Wetland Distribution

Wetlands occur in many parts of the world, but are most common at mid-latitudes (between 45 and 75°N) and in equatorial regions (Gore 1983). In the Soviet Union there are 83 million ha of peatlands and additional non-peaty wetlands (Botch and Masing 1983), with estimates of total wetlands running as high as 150 million ha (Kivinen and Pakarinen 1981). In the British Isles 8.6% of the land, some 2.7 million ha, is covered by peat (Taylor 1983). In Finland peat covers about 30% of the land, some 10.4 million ha, Sweden has about 7 million ha of peatlands, about 17% of the land, and 9.4% of Norway (3 million ha) is covered by peat (Kivinen and Pakarinen 1981). Many of these wetlands have been altered by man; some are being exploited for peat, others have been drained for agricultural or forestry use.

The extent of wetlands in Canada is not known with any degree of accuracy. In some provinces, such as New Brunswick (Keys *et al.* 1982) and Newfoundland (Wells *et al.* 1983), a survey of peatlands has been completed; in others it is underway or is in the planning stage. Other sources of information are resource maps (soils, forest cover, biophysical data, surficial geology) that cover significant portions of the country (Tarnocai 1983). Nevertheless, for large parts of Canada the distribution of wetlands can be estimated only by resource managers familiar with those areas. Based on such information of variable reliability, a generalized map of the distribution of wetlands within Canada has been prepared by the National Wetlands Working Group (1986a) (see Inside Front Cover).

The most recent estimates indicate that about 14% of Canada, or 127.2 million ha, is covered by wetlands (Table 1–1). The most extensive wetland concentration occurs in the central provinces of Ontario and Manitoba, and the least in the Far North and in mountainous areas (see Inside Front Cover). The peatland component of the wetlands has been estimated at about 111.3 million ha (Table 1–1). The total peat volumes have also been estimated on the basis of known average peat thicknesses in various parts of Canada. The indicated peat volumes are 3 trillion m^3 for all of Canada. The weight of this peat at 50% water content is estimated at 507 billion tonnes (Tarnocai 1984).

Factors Influencing Wetland Development

The distribution of wetlands in Canada is determined chiefly by the climate and by the morphology of the land surface, alone or in combination. Climate determines the amount of water that different areas receive through precipitation. Incoming energy plays an important role in the fate of the precipitated water through evapotranspiration: the lower the incoming radiation, the less the evapotranspiration and hence the more water remaining on the land. At the same time, low energy levels can restrict the rate of growth of the wetland vegetation. The wetland

Table 1–1. Occurrence of wetlands and peatlands in the provinces and territories of Canada

Province or territory	Peatland area		Total wetland area	
	ha × 10^3	% of land area in province or territory	ha × 10^3	% of land area in province or territory
Alberta	12 673	20	13 704	21
British Columbia	1 289	1	3 120	3
Manitoba	20 664	38	22 470	41
New Brunswick	120	2	544	8
Newfoundland–Labrador	6 429	17	6 792	18
Northwest Territories	25 111	8	27 794	9
Nova Scotia	158	3	177	3
Ontario	22 555	25	29 241	33
Prince Edward Island	8	1	9	1
Quebec	11 713	9	12 151	9
Saskatchewan	9 309	16	9 687	17
Yukon Territory	1 298	3	1 510	3
Canada	111 327	12	127 199	14

Sources: National Wetlands Working Group (1986a); Tarnocai (1984).

itself can modify its own local climate, as much of the heat available from radiation and convection is used for evaporating excess moisture rather than warming the soil (Williams 1968). Low incoming energy is associated with the initiation of permafrost; small permafrost bodies occur in peat where the mean annual temperature is in the 0 to − 1°C range (Dionne 1984).

The morphology of the land exerts an influence on the distribution of surplus water and therefore the location of wetlands. On large, flat plains of fine-textured soils the internal and external drainage is slow, resulting in a water surplus. In undulating areas wetlands may be formed in small, poorly drained depressions. Wetlands seldom develop on sloping terrain where the external drainage is rapid. A notable exception occurs in oceanic areas with high rainfall, where wetlands can be found even on steep slopes.

In some areas the presence of wetlands depends on a supply of water from external sources. On floodplains or in coastal areas inundations may saturate the soil sufficiently to initiate wetland development. In cool areas with low rainfall, wetlands usually develop only in depressions where water collects from the surrounding slopes or from the upstream part of a catchment basin. Other external water sources occur at groundwater discharge points. Here, a steady supply of water from a spring can initiate and sustain wetlands even on sloping surfaces. Similarly, late-melting snowbanks can be a source of water in the Arctic, maintaining wetlands on the slopes below them.

In addition to climate and the surface configuration of the land, the physical and mineralogical characteristics of surface materials also influence wetland development. The texture of the surface material determines the porosity of the soil and therefore the proportion of water that can percolate into the soil. Such materials as dense, hard bedrock and fine-textured soil allow minimal water penetration and therefore much of the precipitation remains on the surface. In addition, hard, dense surface materials resist erosion and the development of integrated drainage systems. On such dense materials undrained depressions may develop into wetlands.

The mineralogical composition of bedrock and soil materials influences the quality of the water that drains from the land. The waters from inherently nutrient-poor areas are low in many elements; therefore wetlands that are nourished by nutrient-poor water will support vegetation that can thrive on such low levels of nutrients. Conversely, in areas where the soils or bedrock are rich in nutrients, surface waters will contain large amounts of various nutrients. The water quality data from two rivers illustrate this point (Table 1–2). Haultain River in northern Saskatchewan drains an area entirely underlain by Precambrian granitic bedrock and covered by discontinuous, thin deposits derived from granitic materials. The Qu'Appelle River in southern Saskatchewan drains an area underlain by Upper Cretaceous shales and sandstones (Douglas *et al.* 1970), and is covered by materials largely derived from this bedrock. Nutrient levels are much higher in the Qu'Appelle River, leached from nutrient-rich soil and bedrock. Wetlands developing in such areas will reflect the nutrient status of the waters that feed them.

The dependence of wetlands on climate and landform is clearly illustrated by the distribution of wetlands in Canada. The greatest concentration of wetlands occurs in a belt across northern Ontario, central Manitoba and Saskatchewan, northern Alberta, and the Mackenzie Valley (see Inside Front Cover). This is an area of cool climate with very cold winters (mean January temperature = − 20 to − 29°C) and cool summers (mean July temperature = 15–17°C), with relatively low mean annual precipitation (400–500 mm); such

Table 1–2. Water quality in two rivers in Saskatchewan draining mineralogically different areas

Nutrients	*Haultain River Lat. 56°15′ N, Long. 106°34′ W Mean discharge 12.2 m³/sec*	*Qu'Appelle River (at Tantallon) Lat. 50°30′ N, Long. 102°15′ W Mean discharge 12.3 m³/sec*
Specific conductivity	26 μS/cm	1 390 μS/cm
Total alkalinity ($CaCO_3$)	11 mg/L	279 mg/L
pH	5.9–8.0	7.8–8.9
Dissolved Ca	1.3 mg/L	88.0 mg/L
Dissolved K	0.6 mg/L	13.8 mg/L
Dissolved Na	1.3 mg/L	191.0 mg/L
Total organic C	6.2 mg/L	17.3 mg/L
Total N	0.5 mg/L	1.2 mg/L
Total P	0.011 mg/L	0.190 mg/L

Sources: Inland Waters Directorate (1977); Inland Waters Branch (1970).

conditions are favourable for wetland development. Within this belt the highest concentration of wetlands occurs in areas of low relief, such as in the Hudson Bay Lowland and around Lake Winnipeg. Conversely, the area of low wetland concentration south of Lake Athabasca is underlain by sand over sandstone bedrock and is therefore well drained.

Further concentrations of wetlands occur in the Pacific and Atlantic coastal areas of Canada, which have high levels of precipitation. On the west coast of British Columbia the mean annual precipitation exceeds 1 950 mm (Table 1–3), allowing the development of wetlands even on steep slopes. On the east coast of Newfoundland there is also a concentration of wetlands. The high level of precipitation (1 300 mm per year) allows the development of extensive wetlands, some on sloping lands, blanketing the landscape. The hummocky moraines of the Prairies contain innumerable depressions, many of which have developed into wetlands, possibly covering between 15 and 20% of the area. Such depressions are filled with water in the spring, but may become dry during the summer. Peat-forming vegetation cannot survive under such conditions and most depressions are occupied by shallow water and a marshy fringe.

The smallest number of wetlands occurs in the mountainous cordilleran region of western Canada and in the Arctic. In the mountainous areas the rocky slopes prohibit the development of wetlands. In the Arctic, both the temperature regimes and the precipitation are very low (mean July temperature = 5–9°C, mean annual precipitation = 200 mm). Under such extreme conditions few peat-forming plants can survive even in sheltered local depressions.

The development of wetlands in a given location is influenced and determined by several interact-

Table 1–3. Mean daily temperature and mean precipitation values in the wetland regions of Canada

Wetland region	*Mean daily Jan. temp. (°C)*	*Mean daily July temp. (°C)*	*Mean annual total precip. (cm)*	*Mean annual snowfall (cm)*
High Arctic	−33	5	10	70
Mid-Arctic	−29	7	20	110
Low Arctic	−29	9	15	80
High Subarctic	−29	13	35	190
Low Subarctic	−29	15	50	310
Atlantic Subarctic	−5 to −15	12–15	85–130	270–460
High Boreal	−23 to −25	13–16	40–70	160–260
Mid-Boreal	−20	17–19	50–80	120–280
Low Boreal	−13	18	95	250
Atlantic Boreal	−5 to −20	13–18	95–135	190–450
Continental Prairie	−15 to −18	18–19	35–45	110–120
Intermountain Prairie	−7	19	35	120
Eastern Temperate	−9	20	95	210
Pacific Temperate	3	16	155	70
Atlantic Oceanic	−3	14	135	190
Pacific Oceanic	2 to 3	14	195–305	110
Coastal Mountain	−4 to −19	13–17	30–105	130–270
Interior Mountain	−8 to −27	13–18	30–50	120–250
Rocky Mountain	−13 to −28	14–15	34–55	155–250
Eastern Mountain	−23	12	70	370

Source: National Wetlands Working Group (1986b).

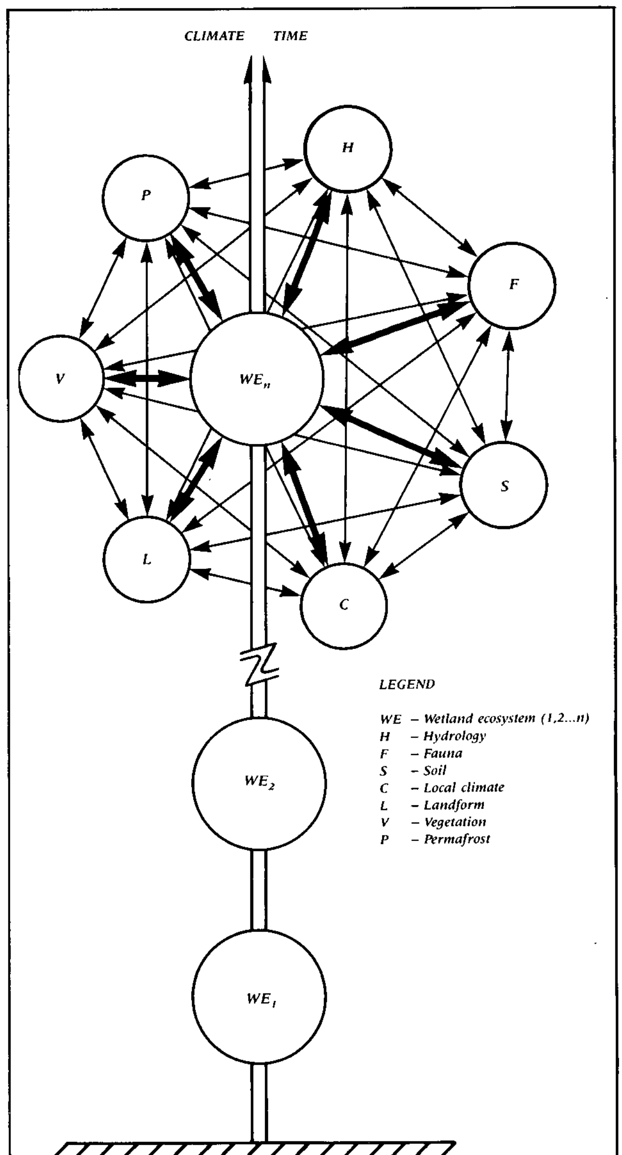
ing biotic and abiotic factors. Such abiotic components as hydrology (quantity and quality through periodic fluctuations), soil material of the wetland (frequently peat), micro- and macrotopography of the surface (landform), local climate, and permafrost in the northern regions interact to form wetland ecosystems of plant and animal communities. These interactions take place over a period of time and within given climatic parameters (Zoltai and Tarnocai 1976). Each of the abiotic and biotic components influences the others and is influenced by them (Figure 1–1). Changes in climate may radically disrupt and alter the ecosystems. However, barring catastrophic external interferences (such as climatic change, fire, or diversion of water flow), wetland ecosystems are generally stable, gradually adjusting to changes brought about by the development of wetlands. Even the seemingly unstable prairie marsh ecosystems, which are vulnerable to seasonal and annual variations in precipitation, show a long-term stability.

The time available for adjustments to changing conditions is of great importance, especially in peatlands. Constant change, triggered by the accumulation of peat, is a part of peatland development. An ecosystem that currently occupies any given wetland is merely the latest stage in a series of ecosystems that had a part in the creation of the wetland and in its development to its present form.

Evolution of Wetlands since Deglaciation

The length of time available for wetland development in Canada is determined by the disappearance of glacier ice from the land surface. During the Pleistocene epoch, glaciers covered most of Canada. Only about 3% of Canada escaped glaciation, an area in northwestern Yukon and a small area on the southern Prairies (Prest 1970), although some mountain peaks, small portions of the Arctic Islands, and west-coast refugia may also have escaped glaciation. There were four major glacial events, interrupted by interglacial intervals. During the most recent of these events, the late-Wisconsin glaciation, glacier ice covered most of Canada, except for the areas mentioned. The maximum extent of glaciation during the late-Wisconsin period was reached about 17 000–18 000 years ago, and deglaciation began to uncover parts of Canada by about 13 000 years before the present (BP). By about 6 000 years BP the glaciers had virtually disappeared from most of Canada, leaving only a few remnants in the Arctic and the cordilleran region.

Not all areas vacated by glacier ice became immediately available for colonization by vegetation. Large marginal lakes were formed in front of the retreating ice. Many coastal areas, still depressed by the weight of the ice, were submerged in the sea. In ground moraines the drainage was disorganized until the rivers deepened their channels,



Source: Zoltai and Tarnocai (1976).
Figure 1–1.
Diagram of interactions between environmental parameters and wetland ecosystems through time and changing climate.

establishing an effective drainage system. Thus wetlands did not always begin their development immediately after the disappearance of glacier ice 8 000–13 000 years ago, as in many cases glacial lakes and marine inundations persisted for thousands of years.

The climatic change terminating the Pleistocene epoch was rapid, as shown by pollen studies (Wright 1964); the climate became warmer and drier than at present ("hypsithermal period"). This occurred at slightly different times in different areas some 8 000–9 000 years ago (Hebda 1983; Webb *et al.* 1983; Ritchie 1976; Ritchie *et al.* 1983; Blake 1972) and terminated about 4 000–5 000 years ago when the climate returned to about the present precipitation and thermal levels. This pattern has been substantiated by a number of studies of pollen and driftwood, all indicating that warmer and drier conditions prevailed during the climatic optimum period.

In the wake of the deglaciation of the land, wetland formation could have begun as soon as wetland plants invaded suitable habitats. Yet it has been found that usually there is a gap of several hundreds to thousands of years between deglaciation and the beginning of peat formation. The oldest radiocarbon dates are from lake sediments; the age difference between basal lacustrine and peat ages in the same area may be as much as 3 000 years (Webb *et al.* 1983). Such a time lag was noted in all those parts of Canada where basal peat dates were determined (Dionne 1979; Nichols 1967; Tarnocai 1978; Terasmae 1963, 1970). The reason for this lag is not clear. It might have been because the climate was not suitable for wetland formation at the end of glaciation, it might simply have been a matter of slow plant migration, or it might have been because of a more complex relationship between pioneer wetland communities and peat-forming wetland communities.

Peat deposition within the Glacial Lake Agassiz basin was delayed to an even greater degree. At its greatest extent Lake Agassiz occupied what is now southern and central Manitoba and northwestern Ontario, extending into Saskatchewan and south into Minnesota and North Dakota. Here, peat formation began about 4 000 years ago in the south (Wright and Glaser 1983) and about 5 000 years ago in the central part of the basin. Griffin (1977) found that 3 m of peat, with a basal date of 3 170 years BP, rests on a prairie soil profile. The interpretation is that prairie vegetation, or prairie wetland vegetation, occupied the wetland after the drainage of Lake Agassiz during the hypsithermal period. Peat formation began only after the climate became cooler and moister, and it still continues.

An opposite effect of the warm post-glacial climate can be observed in the Arctic, where the present rate of peat formation is very slow. On inactive, eroding, high-centre polygons the basal and surface peat ages range between 5 600 and 10 100 years BP (Zoltai and Tarnocai 1975). A possible interpretation of this is that the warmer post-glacial climate created suitable conditions for peat formation, but the return of the present cooler climate restricted further peat deposition to favourable, protected locations.

Wetland systems are considered to be primary if they form in basins or depressions (Moore and Bellamy 1974). Secondary systems are found in places where the peat develops past the physical confines of the depression and acts as a reservoir for surplus water. Tertiary systems occur in areas where peat develops above the physical limit of groundwater, with a perched water table. Taking glaciation as time zero, all wetlands were initially primary systems. Climatic and other environmental factors permitting, some of these wetlands have evolved into secondary, and even tertiary, systems. The ultimate point of development is not known, as the present wetland systems have evolved in only 8 000 years in Canada, and in most areas peat is still accumulating.

Several processes are at work in the development of wetlands. A most common occurrence is the establishment of wetlands in areas with a high water table. A gradual peat build-up can eventually convert these wetlands into peatlands. Infilling occurs when a depression, occupied by a lake or pond, is filled first with lacustrine sediments (organic detritus or inorganic marl) and then is invaded by peat-forming vegetation such as that found in fens or bogs (Wells and Pollett 1983). Paludification occurs when peat deposits expand to cover previously dry lands. This can take place as the level of the water table slowly rises during peat build-up in a depression, leading to the peripheral expansion of the peatlands. Another process, primary peat production, occurs where peat-forming plants establish themselves on moist, but not waterlogged, soils (Sjörs 1976). This process takes place in areas with a climatic regime of high rainfall but low evaporation.

Study of the stratigraphy of wetland deposits gives evidence of the gradual development of wetlands. Macrofossils reveal the composition of the plant communities that were present at different times during the formation of the wetlands. By comparing the indicated fossil plant communities with the present ones, a broad indication of the environmental conditions prevailing at various times during the development of a wetland can be determined. By the use of radiocarbon dating or volcanic ash chronology, the developmental phases can also be reconstructed with a reasonable degree of confidence (Zoltai and Johnson 1985).

Wetland Classification

The purpose of classification is to group like elements into units that can be defined and characterized. Those that are simple can be readily grouped into homogeneous units but complex elements, when grouped together, may be similar in many aspects but different in others. In complex subjects homogeneity of groupings can be achieved only at a detailed level of classification. Wetlands, being complex dynamic ecosystems, are difficult to categorize and classify. It is therefore very important that a common terminology be used to facilitate cross-disciplinary communication.

Over the years, many classification approaches have been taken, based on different aspects of wetlands. Some systems have evolved to satisfy the specific needs of a discipline, others to characterize the wetlands of a particular geographic area. A universally accepted classification has not emerged because of the diversity of users and the regional variations of wetlands. The following is an overview of some of the basic principles used in wetland classification, with a more detailed review of the classifications used in North America.

One of the earliest classifications was based on the shape of peatlands: the high ("Hochmoor") and low ("Niedermoor") mires. This classification gradually evolved to differentiate between various kinds of Hochmoor according to regional variations in their shape or tree cover (Osvald 1925). However, because this classification was developed in northern Europe, in an oceanic, cool climate, its applicability is limited to areas of similar climatic conditions.

The chemistry of water in wetlands forms the basis of another classification. It was recognized that the chemical properties of the groundwater within broad mire types are distinctly different (Du Rietz 1949). This observation was developed into a classification based on the chemistry and perceived origin of the water. The concepts of oligotrophy and eutrophy were introduced to indicate nutrient status with terms such as "ombrotrophic" (rain-fed) and "minerotrophic" (mineral-enriched) connoting the nutrient content of groundwater (Du Rietz 1954). The salinity of water in prairie wetlands became the basis of another classification (Stewart and Kantrud 1972; Cowardin *et al.* 1979).

Sjörs (1950, 1961, 1963, 1969) elaborated the ideas introduced by Du Rietz (1954). He determined the chemical characteristics that differentiate bogs and fens, dividing the fens into poor, intermediate, and rich fens. Each class was characterized by its water chemistry and plant assemblage. Gauthier (1980) defined ombrotrophic bogs, very poor fens, moderately poor fens, intermediate fens, and moderately rich fens on the basis of water chemistry and vegetation indicators. These classes have been applied and further refined by Couillard (1978), Grondin and Ouzilleau (1980), Wells (1981), Rainville (1983), Gerardin *et al.* (1984), Lebel (1986), and Foster and King (1984).

Sjörs (1961, 1963, 1969) noted the importance of the microtopography of peatland surfaces. Such features indicate habitat variations, especially in moisture regime and, often, water chemistry. Sjörs introduced a classification in which microhabitats such as hummocks, ridges, flarks, and lawns are recognized. Many other authors use these terms with minor variations, including Couillard and Grondin (1986).

Mire systems have been classified according to the hydrological character of the waters that affect them. "Rheophilous" mire systems develop in mobile groundwaters, "ombrophilous" mire systems in immobile groundwaters, and "transitional" mire systems either in rheophilous systems without adequate groundwater supply or in areas where the mire is in the process of changing from a rheophilous to an ombrophilous system (Kulczynski 1949). These hydrological mire types have demonstrable differences in major ion content in their waters (Moore and Bellamy 1974). The source of water supply, combined with basin configuration, is the basis for another classification, summarized by Damman (1986): (1) "limnogenous" (water source: bodies of water from ponds or streams and precipitation); (2) "topogenous" (water source: runoff and precipitation; topography: depressional);

(3) "ombrogenous" (water source: precipitation); and (4) "soligenous" (water source: drainage and precipitation; topography: slope).

Investigations of the floristics of wetlands also led to the recognition of plant communities that grow on different wetland types (Tansley 1911). Later classifications became highly structured according to the principles of phytosociology, utilizing the occurrence, dominance, and fidelity of various species to identify specific plant associations related to wetlands. In Canada, an example of this approach was provided by Gauthier and Grandtner (1975). A related approach has classified wetlands on the basis of the morphology of the main vegetation layer (Botch and Masing 1983). Here distinctions result in mires classified as wooded, shrubby, or graminoid.

As the various classifications evolved, they tended to have a broader base and to be less rigidly concerned with a single discipline. The "Hochmoor" became "bogs" and the bogs became characterized by nutrient levels, origin of water, surface morphology, and by specific kinds of vegetation (Wells 1981). Such gradual evolution emphasizes the need for broadly based, multidisciplinary approaches to the classification of wetlands.

A distinctly Canadian muskeg classification system was developed to suit Canadian conditions. This muskeg classification is based on vegetation structure and on patterns seen from the air (Radforth 1969a, 1969b). In this classification the vegetation is expressed as cover formulae (Table 1–4; MacFarlane 1958), either as pure coverage classes or as mixtures. It was found that, in northern Canada, only 18 such cover combinations occur with any frequency, and these consist of combinations of no more than two or three cover classes. The importance of each class is shown by its position in the formula: the predominating class is in the first position (Radforth 1969a). If the cover class is less than 25%, it is not shown in the cover formula.

The information on surface cover is complemented by a characterization of peat, based on structure (Radforth 1969a). The main characteristics are amorphous–granular, fine–fibrous, and coarse–fibrous, each further subdivided by such features as granules, fibres, or wood content. A total of 17 peat structure categories have been identified.

The main feature of this classification is the identification of the morphology of the organic terrain (muskeg), as shown by patterns formed by vegetation or structures in the peat. This morphology is identified as the wetland is viewed from the air, forming an "airform" pattern. When viewed from a low altitude (330 m) or mid-altitude (3 300 m), the wetland morphology can be classified into six basic patterns and three subpatterns (Table 1–5; Radforth 1969b).

At the broadest level, the classification of wetlands is based on airform patterns, with subcategories according to the cover formula and to the type of peat structure. This classification was originally designed for the use of engineers

Table 1–4. Properties designating nine pure coverage classes in the muskeg classification system

Coverage class	*Woodiness vs. non-woodiness*	*Stature (approximate height)*	*Texture (where required)*	*Growth habit*
A	Woody	5 m or over	—	Tree form
B	Woody	1.6–5 m	—	Young or dwarfed tree or bush
C	Non-woody	0.6–1.6 m	—	Tall, grasslike
D	Woody	0.6–1.6 m	—	Tall shrub or very dwarfed tree
E	Woody	Up to 0.6 m	—	Low shrub
F	Non-woody	Up to 0.6 m	—	Mats, clumps, or patches, sometimes touching
G	Non-woody	Up to 0.6 m	—	Singly or loose association
H	Non-woody	Up to 10 cm	Leathery to crisp	Mostly continuous mats
I	Non-woody	Up to 10 cm	Soft or velvety	Often continuous mats, sometimes in hummocks

Source: Radforth (1969a).

Table 1–5. Description of airform patterns for 330–1 650 m altitudes over organic terrain for the classification of muskeg

Planoid	An expanse lacking textural features; plane
Apiculoid	Fine-textured expanse; bearing projections
Vermiculoid	Striated, mostly coarse-textured expanse; featured markings tortuous
Vermiculoid I	Striations webbed into a close net and usually joined
Vermiculoid II	Striations in close association, often foreshortened and rarely completely joined
Vermiculoid III	Striations webbed into an open net, usually joined and very tortuous
Cumuloid	Coarse-textured expanse with lobed or fingerlike "islands" prominent; components shaped like cumulus clouds
Polygoid	Coarse-textured expanse cut by intersecting lines; bearing polygons
Intrusoid	Coarse-textured expanse caused by frequent interruptions of unrelated, widely separated, mostly angular "islands"; interrupted

Source: Radforth (1969b).

(Radforth 1952) who have minimal background in life sciences but who are concerned with the physical characteristics of wetlands.

A wetland classification has been developed in the United States in which wetland habitats that share the influence of similar hydrologic, geomorphologic, chemical, and biological factors are grouped together (Cowardin *et al.* 1979). The system is hierarchical, as the broadest units (systems) are divided into subsystems, and further into classes. A feature of this classification is that it is objective; it does not require any pre-judgement of the habitats.

There are five systems (marine, estuarine, riverine, lacustrine, and palustrine) which are divided into subsystems on the basis of hydrological characteristics (such as tidal, subtidal, intertidal, perennial, intermittent, or littoral). The subsystems are further divided into classes mainly on the basis of substrate (such as aquatic bed or rock bottom), but, in the case of the palustrine subsystems, they are also categorized on the basis of vegetation (moss–lichen wetland, scrub–shrub wetland, for example). The wetland classes can be further divided into subclasses according to the predominant life form of the covering vegetation. A forested wetland may be divided into such subclasses as needle-leaved evergreen or broad-leaved evergreen, for example. If the vegetation covers less than 30% of the substrate, the physiography and composition of the substrate are used to distinguish the subclasses. In the case of vegetated subclasses, these can be further subdivided into dominance types, on the basis of dominant plant species.

The wetland classes and their subdivisions in this United States national classification system can be further described by the use of modifiers. Water chemistry modifiers include salinity and pH values. The soil modifier may be limited to mineral or organic, based on the criteria of the United States Soil Conservation Service (1975). Other special modifiers include anthropogenic influences on wetlands, such as drainage, impoundment, or farming.

This system clearly demonstrates the advantages of an objective classification. Non-judgemental decisions based on descriptive features are applied at least at the subclass level. However, parameters such as the origin, quality, or quantity of water, and the genesis of the wetland, are not considered. This system has been designed for use in the United States, where non-peaty wetlands predominate. Its application in Canada would be difficult, as about 96% of the wetlands in Canada would fall into the category of the palustrine system, leaving very little room for the differentiation of classes.

Organic Soil Classification in Canada

A system of classification of soils in Canada which can be applied to wetlands has been developed by the Canada Soil Survey Committee (1978). Soil, including that of wetlands, is viewed as the material at the earth's surface that is capable of supporting plant growth. This concept considers soil in an environmental context: soils are an integral part of an ecosystem. This allows the use of soil classification to map the distribution and to describe the characteristics of those soils that are associated with various kinds of wetlands.

The hierarchical structure of the Canadian soil classification system consists of orders, subdivided into great groups, and further divided into subgroups. Soil phases are descriptive, *ad hoc* distinctions that can be applied to subgroups. Wetland soils are categorized in the Organic, Cryosolic, and Gleysolic orders.

All great groups of the Organic order are wetland soils, except the Folisol great group which consists of forest litter over bedrock in areas of high rainfall. To qualify as an organic soil, the surface layer must be over 60 cm thick if fibric (poorly decomposed), or over 40 cm thick if mesic or humic (moderately to well decomposed). The control section (top 160 cm) of a soil profile is divided into three tiers: surface, 40 cm thick; middle, 80 cm thick; and bottom, 40 cm thick. The classification at the great group level is based mainly on the properties of the middle tier.

Soils in the Fibrisol great group have a predominantly fibric middle tier, consisting of 40% or more rubbed fibre by volume. Mesisols have a predominantly mesic middle layer where the rubbed fibre content is 10–40%. Humisols contain few recognizable fibres, and the rubbed fibre volume is less than 10%. The soils of each of these great groups are divided into subgroups on the basis of the occurrence of layers of different materials or on the basis of shallowness over mineral soil.

In the Cryosolic order, the soils in the Organic Cryosol great group are wetland soils. In order to qualify, the organic layer has to be over 40 cm thick and the permafrost table has to be within 1 m of the surface. The various subgroups are identified by the degree of decomposition within the control section or by the shallowness of peat over mineral soil or ice.

Some wetlands have soils in the Gleysolic order. This order is characterized by dull colours of low chroma (strength of colour) or by distinct mottles of high chroma within 50 cm of the surface. However, not all Gleysolic soils occur in wetlands. By definition, wetlands are areas where the water table is near or above the mineral soil surface. This is reflected in the soils by the development of gleyed layers at the surface, created by reducing, waterlogged conditions. The severity of waterlogging is shown by the gray, blue, or greenish colour of the gleyed soil, rather than the mottles produced by periodic oxidizing conditions. On some Gleysols a shallow peaty layer may be present, causing that soil to be classified as a peaty phase (15–60 cm fibrous peat, 15–40 cm other peat).

Canadian Regional Wetland Classification Systems

A system of classifying the wetlands of the Prairies of western Canada has been developed by Millar (1976). This classification is based on vegetation zones that develop in response to the depth and duration of periodic flooding, modified by water chemistry and by the size and position of the wetland in the watershed. Four zones with emergent vegetation have been recognized, three of which represent stable conditions (wet meadows, shallow marsh, emergent deep marsh); the fourth, the disturbed zone, reflects anthropogenic or natural disturbances. Salinity affects the composition and extent of the vegetation zones. Four categories have been found to be ecologically significant, each defined by a range of salinity from fresh to hypersaline. The position of the wetlands in the watershed was considered, as this has an important bearing on their water regime. The main categories are isolated, overflow, channel, and terminal wetlands. The final coding for each wetland includes information on wetland size class, position in watershed, vegetation zone, and water depth.

A classification of wet environments in Quebec has been developed by Couillard and Grondin (1986), based on the published material of numerous authors including Jaques and Hamel (1982) and on their own observations. Three wetland systems are recognized on the basis of distinct ecological processes: the tidal, the riverine, and the peatland. These systems are further subdivided to provide various levels of classification.

The tidal system includes wetlands influenced by tides. It is first divided into three levels—the high, medium, and low stages—defined on the basis of extreme high and low water levels. The second level of classification is based on the physiognomy of the tidal wetlands, resulting in marsh, swamp, wet meadow, submerged vegetation, and bare surface categories. The third level of classification is based on vegetation groupings that have developed in response to duration and frequency of inundation, water chemistry, slope, microrelief, drainage, and soil characteristics.

The riverine system includes wetlands influenced by seasonal fluctuations of permanent or seasonal water bodies. It is divided into generally water-dominated and dry-land stages, determined by normal and extreme water levels in the water bodies. At the second level of classification physiognomic classes such as aquatic vegetation (wettest), marsh, wet meadow, and swamp (driest) are recognized. These are further subdivided according to vegetation groups that have developed as a result of differences in flooding during the growing season, chemical and physical properties of the water, exposure, properties of the substrate, and depth of the water table.

The peatland system includes those wetlands in which peat is produced. It is subdivided into ombrotrophic and mesotrophic peatlands according to the chemical properties of surface peat and water. The next level of classification is based on the surface morphology of the peatlands. The presence or absence of various patterns serve to identify five minerotrophic (fen), five ombrotrophic (bog), and two mixed peatland categories. Vegetation groupings are used at the most detailed level of classification to identify the various parts of the peatlands occurring in ridges, laggs, carpets, and plateaus.

A wetland classification system for Ontario has also been proposed (Jeglum *et al.* 1974). There are five hierarchical levels, in increasingly detailed classes: (1) formation, (2) subformation, (3) physiognomic group, (4) dominance type, and (5) site type. The broadest units correspond to the wetland classes of the Canadian wetland classification system (see below). The subformation is based on the presence or absence of trees (open or treed). The physiognomic level is based on the introduction of finer physiognomic distinctions, such as graminoid-rich, low shrub, hardwood, or conifer. The dominance types are defined on the basis of the dominant species in the uppermost stratum of continuous plant cover. The site types are defined by the dominant species in the stratum directly under the uppermost stratum.

This system is compatible with and comparable to the Canadian wetland classification system, as the broadest categories (forms) are identical in both systems. Level two (subforms) is based on different features, but level three (wetland types and physiognomic groups) is again similar. The Ontario approach employs a further two levels, to satisfy vegetation-oriented needs.

The Canadian Wetland Classification System

A wetland classification system has been developed by the National Wetlands Working Group to classify the wetlands of Canada (Zoltai *et al.* 1975; Tarnocai 1980). It is based on ecological parameters that influence the growth and development of wetlands. These parameters are both biotic (flora, fauna, peat) and abiotic (hydrology, water quality, basin morphology, climate, bedrock, soil). The classification uses well-known concepts developed in Europe and North America, rather than taking a radically new approach. Information on the wetlands is organized hierarchically from a broad, generalized level to progressively more specific, detailed levels.

The most generalized category, the *wetland class*, is based on broad vegetation physiognomy, hydrology, and water quality. At the next level, each class is divided into *wetland forms* on the basis of three criteria: surface form of wetlands caused by differences in water quality or peat thickness; landform or drainage characteristics of the basin; and proximity to water bodies. The wetland forms are then divided into *wetland types* on the basis of vegetation morphology. The formal classification ends at this point to allow more specific subdivisions according to the needs of various disciplines, based on such criteria as floristics, engineering or land use qualities, and soil.

The goal of this classification is to provide a framework that can be used by different disciplines as a basis for communication. Application of the classification is relatively simple to allow its use by persons whose primary specialities do not include wetland ecology. Once the broad wetland class is determined, the wetland forms and types are readily apparent, as they are based on morphological differences. To aid in the standardization of terminology for the wetland forms, a national wetland registry was initiated in which various wetland forms, deemed to be typical, were described in full detail (Tarnocai 1980). This classification system and its terminology, developed by the National Wetlands Working Group, are used in this and subsequent chapters and are outlined in Appendix I.

Wetland Classes

There are five wetland classes in the Canadian classification system: *bog*, *fen*, *swamp*, *marsh*, and *shallow open water*. These are terms familiar to the layman and wetland ecologist alike. It is not surprising, therefore, that a close examination shows that there are many subtly or substantially different definitions of these terms. One solution is to abandon them completely, as is done by Cowardin *et al.* (1979), just as the term "muskeg" has been abandoned because of conflicting definitions. The other solution is to define them, keeping in mind the possibility of other usage but putting them into a Canadian context. The resulting definitions would then be applicable to the wetland classes found in Canada, from cool temperate to polar regions, and from perhumid oceanic to semi-arid continental climatic conditions.

Wetlands are not synonymous with peatlands. Peatlands are those wetlands which have a peat layer of 40 cm or more in thickness (Tarnocai 1980). This limit was chosen because at this thickness the vast majority of wetland plants are rooted in peat.

BOGS are peat-covered wetlands in which the vegetation shows the effects of a high water table and a general lack of nutrients. The bog surface is often raised, but if it is flat or level with the surrounding wetlands, it is virtually isolated from mineralized soil waters. Hence the surface waters of bogs are strongly acid and the upper peat layers are extremely deficient in nutrients. Peat is usually formed *in situ* under closed drainage and oxygen saturation is low. The thickness of peat exceeds 40 cm. Cushion-forming *Sphagnum* mosses are common, along with heath shrubs. Trees may be absent; if present, they form open-canopied forests of low, stunted trees.

This definition of bogs is intended to correspond to extremely nutrient-poor ("ombrotrophic" or "oligotrophic") wetlands where the living vegetation is not nourished by mineral-enriched ("minerotrophic") groundwater. The pH value of the groundwater is generally less than 4.6 with conductivity values below 80 µS/cm (Table 1–6). These low conductivity values reflect the low calcium (Ca) and magnesium (Mg) values in the water: the combined value of these elements is less than 5 mg/L. The low nutrient levels are also reflected in the total mineral content of the peat within the rooting zone (Table 1–7). The pH value of the peat is less than 4.7 and the combined Ca and Mg content is generally less than 5 000 mg/kg.

FENS are peatlands characterized by a high water table, but with a very slow internal drainage by seepage down very low gradient slopes. The oxygen (O) saturation is relatively low but higher than in bogs. A slowly moving water table is enriched by nutrients from upslope materials and thus fens are more minerotrophic than bogs. The thickness of peat generally exceeds 40 cm. The vegetation in fens usually reflects the water quality and quantity available, resulting in three basic types: graminoid fens without trees or shrubs, shrub fens, and treed fens.

The nutrient content of fen waters and fen peat is always higher than that of bogs in the same area. However, analyses show that some "rich fens" may be highly mineral-rich ("eutrophic") with alkaline reaction and very high Ca and Mg values (Tables 1–6 and 1–7). Under certain circumstances, however, other fens are almost as poor in nutrients as bogs (and are considered "poor fens"). Such circumstances occur where the groundwater is derived from mineral-poor areas, such as the Swan Hills of Alberta (Vitt *et al.* 1975), and where the water originates in domed bogs (Glaser *et al.* 1981). However, most fens have

Table 1–6. Chemical properties of waters from North American wetlands; average values, with range in brackets

Wetland class	*No. of samples*	*pH*	*Conductivity (µS/cm)*	*Exchangeable cations*		*Source*
				Ca (mg/L)	*Mg (mg/L)*	
Bog	18	4.0 (3.7–4.4)	—	2.3 (1.2–3.7)	0.4 (0.2–0.9)	Schwintzer (1981)
	13	(4.6–5.1)	(35–62)	(0.2–0.8)	(0.1–0.2)	Gauthier (1980)
	10	(3.8–4.4)	31	0.2	0.1	Foster and King (1984)
Fen (poor)	193	(4.6–5.2)	(18–59)	(0.4–4.8)	(0.1–0.7)	Gauthier (1980)
	14	(4.7–5.5)	49	0.3	0.2	Foster and King (1984)
	1	5.0	—	2.4	0.4	Vitt *et al.* (1975)
Fen (moderately poor)	42	5.2	65	1.1	0.2	Gauthier (1980)
Fen (intermediate to rich)	9	7.2 (6.8–7.9)	281 (140–456)	28 (18–37)	11 (4–28)	Slack *et al.* (1980)
	21	6.1 (5.2–6.9)	59 (33–128)	10 (4–18)	—	Glaser *et al.* (1981)
	5	6.5 (5.4–7.1)	—	43 (7–124)	10 (2–15)	Schwintzer (1978)
Swamp (coniferous treed)	12	7.2 (6.9–7.8)	—	40 (22–52)	12 (8–17)	Schwintzer (1981)

Table 1–7. Chemical properties of peat (top 30 cm) from Canadian wetlands; total nutrients expressed as average value, with range in brackets

Wetland class	No. of samples	pH	Exchangeable cations: Ca (mg/kg)	Exchangeable cations: Mg (mg/kg)	Source
Bog	—	3.5–3.8	1 240–3 090	1 170–1 870	Pollett (1972)
	28	—	4 370	690	Stanek *et al.* (1977)
	8	—	1 725 (700–4 400)	1 312 (700–1 700)	Damman and Dowhan (1981)
Fen	—	5.0–6.5	16 130–30 630	1 310–3 210	Pollett (1972)
	11	—	11 080	1 540	Stanek *et al.* (1977)
Swamp (coniferous treed)	33	—	19 340	3 160	Stanek *et al.* (1977)
Marsh	5	—	13 420	5 100	Stanek *et al.* (1977)

moderate levels of nutrients and are considered "mesotrophic" with slightly acid (pH 5.5–6.0) reaction.

SWAMPS are wetlands where standing or gently moving waters occur seasonally or persist for long periods, leaving the subsurface continuously waterlogged. The water may also be present as a subsurface flow of mineralized water. The water table may drop seasonally below the rooting zone of vegetation, creating aerated conditions at the surface. Swamp waters are circumneutral to moderately acid in reaction, and show little deficiency in oxygen or mineral nutrients. Their substrate consists of mixtures of mineral and organic materials, or woody, well-decomposed peat deposited *in situ*. The vegetation may consist of dense coniferous or deciduous forest, or tall shrub thickets.

Swamps are usually nutrient-rich, productive sites where trees and shrubs show luxuriant growth. Generally, the nutrient levels are high both in the groundwater and in the peat (Tables 1–6 and 1–7). Most peat-forming mosses are absent, or present only in a subordinate role. The peat being deposited in swamps is usually woody and highly humified and in many swamps, peat formation is minimal. In some cases, swamps develop on the surface of other peatlands, such as fens or bogs, as shown by the sequence of peat deposition.

MARSHES are wetlands that are periodically inundated by standing or slowly moving water and hence are rich in nutrients. Marshes are mainly wet, mineral-soil areas, but shallow, well-decomposed peat may be present. Marshes are subject to a gravitational water table, but water remains within the rooting zone of plants for most of the growing season. Waters are usually circumneutral to slightly alkaline, and there is a relatively high oxygen saturation. They are characterized by an emergent vegetation of reeds, rushes, or sedges.

The surface water levels of marshes may fluctuate seasonally (or even daily due to tides in coastal situations), with declining levels exposing drawdown zones of matted vegetation or mudflats. The vegetation shows a distinct zonation according to water depth, frequency of drawdowns, or salinity.

SHALLOW OPEN WATERS, locally known as ponds or sloughs, are relatively small, non-fluvial bodies of standing water representing a transitional stage between lakes and marshes. The surface waters impart an open aspect, free of emergent vegetation, but floating, rooted, aquatic macrophytes may be present. The depth of water is usually less than 2 m at midsummer levels.

Wetland Forms

At the next level of classification, in which wetland forms are considered, such features as surface morphology of the wetland (including raised, flat, or sloping), presence of patterns (such as ridges, nets, palsa mounds, or polygons), position in the landscape (such as valley, delta, or basin), tidal effects, and proximity to water bodies are used to differentiate the wetland forms (Tarnocai 1980). These forms reflect the differences caused by environmental factors: origin of the water (rainwater, groundwater flow, water bodies), differential peat development (various patterns), and permafrost (palsas, polygons). The wetland form level of classification is open-ended: new wetland forms are expected to be added to a growing list. So far, 18 bog forms, 17 fen forms, 15 marsh forms, 7 swamp forms, and 13 shallow open water forms have been identified. Detailed examples of the majority of these forms, as listed in Table 1–8, are included in the following nine chapters which describe the would then be applicable to the wetland classes found in Canada, from cool temperate to polar regions, and from perhumid oceanic to semi-arid continental climatic conditions.

Wetlands are not synonymous with peatlands. Peatlands are those wetlands which have a peat layer of 40 cm or more in thickness (Tarnocai 1980). This limit was chosen because at this thickness the vast majority of wetland plants are rooted in peat.

BOGS are peat-covered wetlands in which the vegetation shows the effects of a high water table and a general lack of nutrients. The bog surface is often raised, but if it is flat or level with the surrounding wetlands, it is virtually isolated from mineralized soil waters. Hence the surface waters of bogs are strongly acid and the upper peat layers are extremely deficient in nutrients. Peat is usually formed *in situ* under closed drainage and oxygen saturation is low. The thickness of peat exceeds 40 cm. Cushion-forming *Sphagnum* mosses are common, along with heath shrubs. Trees may be absent; if present, they form open-canopied forests of low, stunted trees.

This definition of bogs is intended to correspond to extremely nutrient-poor ("ombrotrophic" or "oligotrophic") wetlands where the living vegetation is not nourished by mineral-enriched ("minerotrophic") groundwater. The pH value of the groundwater is generally less than 4.6 with conductivity values below 80 μS/cm (Table 1–6). These low conductivity values reflect the low calcium (Ca) and magnesium (Mg) values in the water: the combined value of these elements is less than 5 mg/L. The low nutrient levels are also reflected in the total mineral content of the peat within the rooting zone (Table 1–7). The pH value of the peat is less than 4.7 and the combined Ca and Mg content is generally less than 5 000 mg/kg.

FENS are peatlands characterized by a high water table, but with a very slow internal drainage by seepage down very low gradient slopes. The oxygen (O) saturation is relatively low but higher than in bogs. A slowly moving water table is enriched by nutrients from upslope materials and thus fens are more minerotrophic than bogs. The thickness of peat generally exceeds 40 cm. The vegetation in fens usually reflects the water quality and quantity available, resulting in three basic types: graminoid fens without trees or shrubs, shrub fens, and treed fens.

The nutrient content of fen waters and fen peat is always higher than that of bogs in the same area. However, analyses show that some "rich fens" may be highly mineral-rich ("eutrophic") with alkaline reaction and very high Ca and Mg values (Tables 1–6 and 1–7). Under certain circumstances, however, other fens are almost as poor in nutrients as bogs (and are considered "poor fens"). Such circumstances occur where the groundwater is derived from mineral-poor areas, such as the Swan Hills of Alberta (Vitt *et al.* 1975), and where the water originates in domed bogs (Glaser *et al.* 1981). However, most fens have

Table 1–6. Chemical properties of waters from North American wetlands; average values, with range in brackets

Wetland class	*No. of samples*	*pH*	*Conductivity (μS/cm)*	*Exchangeable cations*		*Source*
				Ca (mg/L)	*Mg (mg/L)*	
Bog	18	4.0 (3.7–4.4)	—	2.3 (1.2–3.7)	0.4 (0.2–0.9)	Schwintzer (1981)
	13	(4.6–5.1)	(35–62)	(0.2–0.8)	(0.1–0.2)	Gauthier (1980)
	10	(3.8–4.4)	31	0.2	0.1	Foster and King (1984)
Fen (poor)	193	(4.6–5.2)	(18–59)	(0.4–4.8)	(0.1–0.7)	Gauthier (1980)
	14	(4.7–5.5)	49	0.3	0.2	Foster and King (1984)
	1	5.0	—	2.4	0.4	Vitt *et al.* (1975)
Fen (moderately poor)	42	5.2	65	1.1	0.2	Gauthier (1980)
Fen (intermediate to rich)	9	7.2 (6.8–7.9)	281 (140–456)	28 (18–37)	11 (4–28)	Slack *et al.* (1980)
	21	6.1 (5.2–6.9)	59 (33–128)	10 (4–18)	—	Glaser *et al.* (1981)
	5	6.5 (5.4–7.1)	—	43 (7–124)	10 (2–15)	Schwintzer (1978)
Swamp (coniferous treed)	12	7.2 (6.9–7.8)	—	40 (22–52)	12 (8–17)	Schwintzer (1981)

Table 1–7. Chemical properties of peat (top 30 cm) from Canadian wetlands; total nutrients expressed as average value, with range in brackets

Wetland class	No. of samples	pH	Exchangeable cations Ca (mg/kg)	Exchangeable cations Mg (mg/kg)	Source
Bog	—	3.5–3.8	1 240–3 090	1 170–1 870	Pollett (1972)
	28	—	4 370	690	Stanek *et al.* (1977)
	8	—	1 725 (700–4 400)	1 312 (700–1 700)	Damman and Dowhan (1981)
Fen	—	5.0–6.5	16 130–30 630	1 310–3 210	Pollett (1972)
	11	—	11 080	1 540	Stanek *et al.* (1977)
Swamp (coniferous treed)	33	—	19 340	3 160	Stanek *et al.* (1977)
Marsh	5	—	13 420	5 100	Stanek *et al.* (1977)

moderate levels of nutrients and are considered "mesotrophic" with slightly acid (pH 5.5–6.0) reaction.

SWAMPS are wetlands where standing or gently moving waters occur seasonally or persist for long periods, leaving the subsurface continuously waterlogged. The water may also be present as a subsurface flow of mineralized water. The water table may drop seasonally below the rooting zone of vegetation, creating aerated conditions at the surface. Swamp waters are circumneutral to moderately acid in reaction, and show little deficiency in oxygen or mineral nutrients. Their substrate consists of mixtures of mineral and organic materials, or woody, well-decomposed peat deposited *in situ*. The vegetation may consist of dense coniferous or deciduous forest, or tall shrub thickets.

Swamps are usually nutrient-rich, productive sites where trees and shrubs show luxuriant growth. Generally, the nutrient levels are high both in the groundwater and in the peat (Tables 1–6 and 1–7). Most peat-forming mosses are absent, or present only in a subordinate role. The peat being deposited in swamps is usually woody and highly humified and in many swamps, peat formation is minimal. In some cases, swamps develop on the surface of other peatlands, such as fens or bogs, as shown by the sequence of peat deposition.

MARSHES are wetlands that are periodically inundated by standing or slowly moving water and hence are rich in nutrients. Marshes are mainly wet, mineral-soil areas, but shallow, well-decomposed peat may be present. Marshes are subject to a gravitational water table, but water remains within the rooting zone of plants for most of the growing season. Waters are usually circumneutral to slightly alkaline, and there is a relatively high oxygen saturation. They are characterized by an emergent vegetation of reeds, rushes, or sedges.

The surface water levels of marshes may fluctuate seasonally (or even daily due to tides in coastal situations), with declining levels exposing drawdown zones of matted vegetation or mudflats. The vegetation shows a distinct zonation according to water depth, frequency of drawdowns, or salinity.

SHALLOW OPEN WATERS, locally known as ponds or sloughs, are relatively small, non-fluvial bodies of standing water representing a transitional stage between lakes and marshes. The surface waters impart an open aspect, free of emergent vegetation, but floating, rooted, aquatic macrophytes may be present. The depth of water is usually less than 2 m at midsummer levels.

Wetland Forms

At the next level of classification, in which wetland forms are considered, such features as surface morphology of the wetland (including raised, flat, or sloping), presence of patterns (such as ridges, nets, palsa mounds, or polygons), position in the landscape (such as valley, delta, or basin), tidal effects, and proximity to water bodies are used to differentiate the wetland forms (Tarnocai 1980). These forms reflect the differences caused by environmental factors: origin of the water (rainwater, groundwater flow, water bodies), differential peat development (various patterns), and permafrost (palsas, polygons). The wetland form level of classification is open-ended: new wetland forms are expected to be added to a growing list. So far, 18 bog forms, 17 fen forms, 15 marsh forms, 7 swamp forms, and 13 shallow open water forms have been identified. Detailed examples of the majority of these forms, as listed in Table 1–8, are included in the following nine chapters which describe the various wetland regions of Canada. Each form is defined in Appendix I.

Wetland Types

Wetland types are based on the general physiognomy of the vegetation cover. At this tertiary level, species are not introduced, but such general terms as coniferous or hardwood treed, tall shrub, low shrub, rush, or moss are used. There are 16 wetland types defined in Appendix I, as expanded from Tarnocai (1980). These are: (a) treed (coniferous and hardwood), (b) shrub (tall, low, and mixed), (c) forb, (d) graminoid (grass, reed, tall rush, low rush, and sedge), (e) moss, (f) lichen, (g) aquatic (floating and submerged), and (h) non-vegetated. In various chapters of this book additional terminology is introduced on a regional basis to identify "subforms" of the wetland forms and "phases" of the wetland types based on floristics, salinity, water depth, and other factors.

Table 1–8. Wetland forms in the Canadian wetland classification system with detailed examples in chapters of this book

Wetland class/form	*Chapter(s) with example*
Bog	
Atlantic plateau	*
Basin	Pacific, Boreal, Eastern Temperate, Atlantic
Blanket	Atlantic
Collapse scar	*
Domed	Pacific, Boreal, Atlantic, Eastern Temperate
Flat	Pacific, Boreal, Eastern Temperate
Floating	Pacific
Lowland polygon (high-centre)	Boreal, Pacific, Arctic
Mound	*
Northern plateau	Boreal
Palsa	Subarctic
Peat mound	Arctic
Peat plateau	Subarctic, Boreal, Atlantic
Polygonal peat plateau	Subarctic
Shore	Pacific, Eastern Temperate
Slope	Pacific, Atlantic
String	Atlantic
Veneer	Subarctic
Fen	
Atlantic ribbed	Atlantic
Basin	Arctic, Boreal, Prairie
Channel	Subarctic, Eastern Temperate
Collapse scar	Boreal, Subarctic
Feather	Boreal
Floating	Boreal
Horizontal	Boreal
Ladder	Atlantic
Lowland polygon (low-centre)	Arctic
Net	*
Northern ribbed	Subarctic, Boreal
Palsa	*
Shore	Pacific, Eastern Temperate
Slope	Pacific, Atlantic
Snowpatch	Arctic
Spring	Boreal
Stream	Pacific, Eastern Temperate
Swamp	
Basin	Eastern Temperate, Pacific
Flat	*
Floodplain	Subarctic, Arctic, Pacific
Peat margin	Boreal, Eastern Temperate
Shore	Eastern Temperate
Spring	Eastern Temperate, Pacific
Stream	Boreal, Pacific, Eastern Temperate
Marsh	
Active delta	Boreal, Arctic
Channel	Prairie
Coastal high	Salt Marshes
Coastal low	Salt Marshes
Estuarine high	Salt Marshes
Estuarine low	Salt Marshes
Floodplain	Prairie, Subarctic, Arctic
Inactive delta	*
Kettle	Prairie
Seepage track	*
Shallow basin	Prairie
Shore	Boreal, Eastern Temperate
Stream	Prairie
Terminal basin	Prairie
Tidal freshwater	Eastern Temperate
Shallow Water	
Channel	*
Delta	*
Estuarine	*
Kettle	Prairie
Non-tidal	*
Oxbow	*
Shallow basin	*
Shore	*
Stream	*
Terminal basin	Prairie
Thermokarst	Subarctic
Tidal	*
Tundra pool	Arctic

**Detailed examples are not given in this book for these forms but they are defined in Appendix I.*

Size is not a criterion of this classification, or indeed of the traditional classifications on which this approach is based. The definitive criteria relate to environmental parameters that influence the development of the wetland ecosystem. Thus, it is entirely possible to have a small (single-cushion) bog community developing on a fen. Such communities may remain small, may be overwhelmed by the fen, may merge with others, or may expand laterally, depending on environmental conditions.

A clear distinction should be drawn between classification and mapping. Classification is a conceptual grouping of similar units, and mapping is the delineation of similar units as they occur in nature. Whereas a clear distinction between the various classification units can be made, in nature wetlands often consist of a mixture of various units. Marshes are often associated with shallow open waters and may even have swamps on their margins. Fens and bogs often have a swamp margin where mineralized water reaches the wetland from the slopes. Bogs can often have fen drains. Such consistent combinations are accommodated in terms of classification at the wetland form level. In such cases, however, mapping may require presentation of complex map units and identification of dominance factors for individual wetland classes, forms, or types, as needed.

Wetland Regionalization

It has long been recognized that particular wetland forms occur in broad climatic zones. Katz (1948) recognized eight broad climatic zones in the Soviet Union, each associated with specific vegetation zones. Currently, seven main zones are recognized, each with numerous subzones (Botch and Masing 1983). In Finland three main divisions were discerned, each dominated by a particular mire form—"palsa mire", "aapa mire", and "raised bog" (Ruuhijärvi 1960; Eurola 1962)—and each with several subzones. Bellamy (1972) recognized nine zones in Europe. Sjörs (1983) demonstrated that particular mire complex types occur in distinct geographic areas, although some types may overlap in distribution. In Canada, similar regionalization was noted, mainly along a north–south temperature and an east–west precipitation gradient. Initially five major zones and six subzones were identified (Zoltai *et al.* 1975). These were later refined to constitute 20 *wetland regions* (National Wetlands Working Group 1986b) (see Inside Back Cover).

Climatic implications of the wetland regions are apparent from their orientation on maps produced in different countries. While it is recognized that wetlands are complex ecosystems with many interacting relationships, climate provides energy to the ecosystem and influences moisture availability. Other parameters interact within the macroclimatic framework to develop characteristic wetlands within a broad region. Wetland regions are areas where characteristic wetlands develop within given climatic limits through the interaction of components of the wetland ecosystem. Distribution and abundance of wetlands are not distinguishing criteria because these are greatly influenced by the surface topography of the land. Subdivisions of the wetland regions, *wetland subregions*, may be established if certain parts of the region are somewhat different from others but the differences are not great enough to warrant the establishment of a new region. Local variations in wetland form, differences in the abundance of some forms, or different proportions of the area occupied by wetlands may differentiate particular wetland subregions from other parts of the region.

The orientation of the wetland regions generally resembles that of broad vegetation regions (Rowe 1972), and in some instances their boundaries coincide. However, in general, vegetation of bogs and fens resembles the upland vegetation of more northerly regions. For example, the vegetation of a bog in the High Subarctic Wetland Region (treeless heath–lichen) resembles the upland (non-wetland) vegetation of the more northerly Low Arctic Wetland Region (see map, Inside Back Cover). Similarly, the open-canopied *Picea*–lichen forest growing on permafrost peatlands of the Low Subarctic Wetland Region resembles the upland vegetation of the High Subarctic Wetland Region. The hardwood swamps dominated by maple (*Acer* spp.) in the Eastern Temperate Wetland Region resemble the forests of the more northerly Low Boreal Wetland Region. The waterlogged soils and depressional location of the wetlands apparently create colder, local conditions, allowing the establishment and persistence of more northerly vegetation.

Climate-related dynamic processes that result in the development of particular wetlands in various parts of Canada are discussed in the following sections. Although the subject will be treated more fully in subsequent chapters, such an overview will put the regional differences into a sharper focus and place them in a continental perspective.

Arctic Wetlands

The main climatic factors influencing wetland development in arctic wetland regions are very low precipitation and cold temperatures (Table 1–3). The low amount of precipitation restricts wetlands to poorly drained depressions or to areas where additional water is available. Permafrost underlies the wetlands at shallow depths during all stages of their development. Permafrost prohibits free internal drainage, tending to concentrate the available moisture at the surface or to freeze it into the permafrost near the surface. The wetlands are influenced by frost churning (cryoturbation) which tends to mix the peat with the underlying mineral soil and heave boulders to the surface through the peat. They are also subject to frost cracking by the intense winter cold, allowing the development of ice-wedge polygons.

Subarctic Wetlands

These wetland regions are characterized by intensely cold winters but relatively warm summers (Table 1–3). Precipitation levels, although higher than in the arctic wetland regions, are still relatively low. However, the higher precipitation levels in the eastern part, as in the Hudson Bay area and eastwards, have an impact on wetland development in the High Subarctic Wetland Region. Permafrost is present in all wetlands in the drier Continental High Subarctic Wetland Subregion, but sporadic in the Humid High Subarctic Wetland Subregion and in the Low Subarctic Wetland Region. In contrast to wetland development in the arctic wetland regions, permafrost affected the peatlands after the peat was formed in the fens and bogs, as shown by numerous stratigraphic studies (Zoltai and Tarnocai 1975). The characteristic wetland forms such as palsa and peat plateau bogs (the "flat palsas" of Botch and Masing 1983; the "palsa plateaus" of Åhman 1977) are all affected by permafrost. In the Continental High Subarctic Wetland Subregion ice-wedge polygons commonly develop in peat plateau bogs and some of the peat plateau bogs in the Humid High Subarctic Wetland Subregion may have such ice wedges.

Boreal Wetlands

These wetland regions have cold winters but warm summers (Table 1–3). Amounts of precipitation are moderate in the centre of the continent, but become high in maritime coastal areas. Although basically similar wetlands occur throughout the four boreal wetland regions, a thermal differentiation is apparent, as small permafrost bodies can still be found as palsa and peat plateau bogs in the High Boreal Wetland Region. A continental gradient in atmospheric moisture is apparent in the occurrence of various wetland forms and in the degree of their development. In the subhumid western part of the boreal wetland regions, wetlands occur only in depressional areas or where an additional source of water nourishes the wetland. The dominant wetlands are fens, nourished by minerotrophic groundwater. Bogs are scarce, and their surface is often barely above the mineral-rich water table. In the more humid eastern part of the boreal wetland regions, raised bogs become much more frequent. The precipitation levels are high, prompting the growth of peat-forming mosses. The result is raised bog surfaces, each with a water table much above the gravitational water table of the original depression. In the most temperate boreal wetland region, the Low Boreal, raised bogs and various forms of fens are common. The development of luxuriant coniferous and hardwood treed swamps indicates a definite affinity to more southerly regions.

Prairie Wetlands

These wetland regions are influenced by low precipitation, with cold winters and warm summers (Table 1–3). The low levels of precipitation and the long periods of drought do not allow the growth of peat-forming vegetation; hence there are few fens and no bogs. The marshes and shallow open waters that occur in many depressions may be subject to severe drawdowns. This results in a concentration of salts in the depressions which may be diluted by meltwater in the spring and precipitated out in the summer, frequently with a remnant saline lake in the deepest part of the depression.

Temperate Wetlands

Mild winters and warm summers characterize these wetland regions, with moderately high amounts of precipitation (Table 1–3). The mild climate and plentiful precipitation promote a luxuriant growth of plants in wetlands. Swamps, covered by densely forested vegetation, are common in the moderately wet areas, and marshes develop in the wetter depressions. Swamps may consist of coniferous forests or a variety of hardwood species. Peat development is usually limited to well-humified, woody peat. Many swamps develop on previously deposited peat formed during an earlier phase of wetland development. Bogs, usually with a somewhat raised centre, develop in hydrologically suitable areas. Fens are relatively rare.

Oceanic Wetlands

Very high levels of precipitation and mild temperatures characterize these wetland regions (Table 1–3). Rainfall is so abundant that hydrophytic vegetation, including peat-forming mosses and sedges, can invade even steep slopes. Peat thickness may exceed 1 m on such sloping peatlands. Small pools are often formed on the slopes, enclosed by dams of compact, tenacious peat.

Mountain Wetlands

The main feature of mountainous areas is that the climate is much affected by an altitudinal gradient. The wetlands generally resemble those of a climatically corresponding area which may occur farther north in the lowlands. The distribution of wetlands is restricted by the steep topography, and limited wetland development can be found in valleys or on flat saddles or ridges. A notable exception occurs in mountains affected by an oceanic climate, where peatlands may be found on steep slopes.

Methodologies

Physical and chemical parameters of peat, mineral soil, and water can be measured using different analytical methods (Clymo 1983). Similarly, living vegetation can be sampled and described by the use of different approaches ranging from detailed plot sampling to rapid reconnaissance-level sampling. The characterizations of wetlands presented throughout this book have been prepared by over 75 authors working in different regions of the country and employing different sampling and analytical techniques. They reflect the purpose for which the information was gathered and, therefore, no single standard has been used.

Following is a brief listing of some of the sampling techniques most successfully employed and the analyses most commonly performed. These include collection of samples of peat and water, analyses of the physical and chemical properties of these samples, and sampling and site description of wetland vegetation. Other ecological parameters such as those relating to sampling of wildlife, waterfowl, insects, land use, and site sensitivity and values are not the focus of this book and are not specifically discussed in this section or subsequent chapters. An attempt is made to identify equivalent units that can be encountered in the literature. Various disadvantages of these methods are noted to help the reader evaluate the results presented in this book or in the literature.

Sampling of Water and Peat

The components of wetlands most commonly sampled are water and peat from various depths. Sampling procedures are usually tailored to the information required and can therefore vary greatly. In all cases, however, it is important to avoid contamination or alteration of the sample between the time of sampling and analysis. In some cases, especially when organic compounds are to be analyzed, immediate chilling of the sample is necessary to minimize biological or chemical activity.

Water is usually sampled from small, shallow depressions dug in the peat surface. Water can be siphoned, withdrawn with a syringe, or pumped with a hand vacuum pump into a tightly sealed container after the suspended particles have settled (Schwintzer 1978). Water samples from greater depths can be obtained by sinking a slotted plastic pipe into the ground. The pipe is sealed at the bottom and slotted to provide access for water and to keep peat particles out. After a suitable period of time, water can be withdrawn from the desired depths with a vacuum pump.

There are a number of peat samplers available for use in various circumstances to obtain the accuracy of sampling demanded by a project. The Hiller sampler consists of a hollow sampling tube slotted on one side. A sample is obtained by rotating the sampler at the desired depth, allowing a short vane to sweep a sample into the chamber.

The sample is therefore disturbed, but provides a quick indication of the nature of peat at any depth. Piston samplers, similar to those successfully used for lake sediment sampling, often compress the peat, especially if the peat is fibrous or contains wood. The Russian peat sampler, also known in North America as the Macaulay peat sampler (Jowsey 1966), is used extensively to provide undisturbed peat samples from any depth. The sampler consists of a half-cylindrical chamber (shuttle) which is closed when the probe is inserted into the peat. At the desired depth the probe is given a half-turn, cutting the peat against an anchor plate and enclosing the sample in the shuttle to protect it from contamination as the sampler is withdrawn from the peat. Samplers with diameters up to 5 cm can be operated by hand to a depth of 8 m. However, dry fibrous moss or living roots often make it difficult to obtain samples from the top 30 cm of many peatlands.

A portable peat profile cutter has recently been developed in the Netherlands (E.C.P. Wardenaar, personal communication). It consists of a rectangular stainless steel box, split lengthwise into two halves, each with sharp cutting edges. As the cutter is inserted into the peat, a rocking motion is used to advance each half in turn. The resulting peat column is completely undisturbed and free of compression, suitable for description, subsampling, or mounting for display as a monolith (Figure 1–2). The sampling is restricted to the upper 1 m of the peat deposit.

Perennially frozen peat presents problems associated with penetration into the frozen material. A completely portable, small-diameter, modified Hoffer probe was found to be suitable for extracting small samples of frozen peat from depths down to 5 m (Zoltai 1978). Hand- or power-driven core samplers give good results in peat. Problems with large-diameter corers can be overcome by using shorter and smaller-diameter (3.8–7.6 cm inside diameter) core barrels (Veillette and Nixon 1980). As the sample is obtained by cutting a groove around the core, the core is completely undisturbed.

Physical Properties of Peat

The moisture content of peat is obtained by drying the peat in an oven at 105°C to a constant weight (Sheldrick 1984). The weight lost during drying is the amount of water contained in the sample. The results can be expressed as a percentage on a gravimetric (weight) or volumetric basis. Moisture content expressed as dry weight often gives very large numbers that are difficult to interpret. Moisture on a wet weight basis gives readily interpretable results for saturated peat. The disadvantages of the gravimetric methods are: (1) peat with high ash content will give low moisture content readings; and (2) the moisture content readings of unsaturated peat will be exaggerated. These disadvantages are eliminated if the volumetric moisture content is determined. However, it is often difficult to obtain peat samples of known volume. Bulk density of peat can be obtained by determining the weight of 1 cm^3 of oven-dried peat. The unit weight used in geotechnical studies (Landva *et al.* 1983) is the weight of a certain volume (such as 1 cm^3) of an intact sample.

The ash content of peat is determined by oxidizing the oven-dried peat sample. The weight loss on ignition or digestion will give the organic portion of the peat, and the remainder is the ash content. There are various ashing techniques (Andrejko *et al.* 1983), but, generally, ashing at moderate temperatures (375–550°C) gives good results. The results are expressed as a percentage of the dry weight of peat. Wet ashing techniques that remove

Figure 1–2.
A peat profile being lifted from a treed fen.

organic matter through digestion with severely caustic solutions also give reliable results, but they require rigorous safety procedures (Andrejko *et al.* 1983).

The degree of decomposition can be determined by the pyrophosphate solubility of the peat (Schnitzer and Desjardins 1965). A common field determination of decomposition (humification) is obtained by squeezing a handful of peat and observing the colour and substance of the material passing between the fingers. The results are rated on the von Post humification scale (von Post 1922). The determination of the rubbed and unrubbed fibre content of the peat also gives a measure of decomposition (McKeague 1978). A comparative study (Stanek and Silc 1977) found that the von Post method gives reliable results for the experienced field-worker.

Chemical Analysis of Peat and Water

Determination of the hydrogen ion (H) concentration of water in pH units is best obtained immediately upon sampling in the field, as a delay of even a few hours can result in substantial changes in the readings. Even portable pH meters or indicator strips are more reliable than delayed accurate determinations. Specific conductivity can be determined in the field or in the laboratory with a conductivity meter. The results are expressed as mS/cm or μS/cm. In older publications the equivalent units of mmhos/cm or μmhos/cm are found. The conductivity contributed by hydrogen ions is often subtracted (correction factor "K") to make the results from waters of varying acidity more comparable (Sjörs 1950). The corrections in μS/cm shown in Table 1–9 can be subtracted from specific conductivity readings at 20°C (Sjörs 1950). Specific conductivity is a very useful indication of the trophic status of water. In peatlands, much of the conductivity is attributed to the calcium content of the water (Gorham 1956).

The chemical composition of peat can be determined using various extracts, depending on the purpose of the study. The ammonium acetate extractable elements are believed to approximate the amount of nutrients available to plants. Total elemental composition, on the other hand, is thought to indicate a potential reservoir of nutrients. For the ammonium acetate extractable nutrients, the dried, ground peat is saturated with the chemical, and the major elements (potassium [K], Ca, Mg, sodium [Na]) are determined in the extract, usually by atomic absorption spectrophotometry (McKeague 1978). The results are usually expressed as milliequivalents (me or meq) in 100 g of dry peat.

Table 1–9. Specific conductivity correction factors (K) in μS/cm for a range of pH values

pH	Correction factor (K)	pH	Correction factor (K)
3.5	103	4.5	10
3.6	82	4.6	8
3.7	65	4.7	6
3.8	52	4.8	5
3.9	41	4.9	4
4.0	32	5.0	3
4.1	26	5.1	3
4.2	20	5.2	2
4.3	16	5.3	2
4.4	13	5.4	1

For total elemental analysis, the sample is ashed. Wet ashing is preferred, as during dry ashing some elements, especially sulphur (S), may volatilize. This ash is then treated with hydrochloric and nitric acids. The extract is analyzed by atomic absorption spectrophotometry or by more advanced techniques, such as inductively coupled plasma spectrophotometry. At the present state of technology, most elements, except nitrogen (N), oxygen (O), and carbon (C), can be determined from a single extract. Such elements as mercury (Hg), selenium (Se), and arsenic (As), because of low concentrations and large dilution levels present in the extracts, are not reliably determined and special procedures are employed for their analysis.

Results are expressed as milligrams per kilogram (parts per million), milligrams per gram, or as a percentage of dry weight. More rarely, the nutrients are given as compounds, such as oxides. In such cases a conversion to elements is necessary, based on atomic weights such as those developed for calcium by Lishtvan and Tanovitsky (1979). The nitrogen content of peat is often determined. In general, total nitrogen, including nitrate and nitrite, is obtained by the Kjeldahl procedure (McKeague 1978) or by other methods. The amount of organic carbon is also often calculated (Sheldrick 1984). The presence of various organic compounds (organic acids, sugars, and cellulose fractions, for example) is often determined to gain specialized knowledge of the composition of peat.

Analysis of Vegetation

There are a number of standard methods for collecting vegetation distribution data, their subsequent analysis, and their correlation with each other or various environmental parameters. Care must be exercised to employ a method that is sensitive enough to accommodate the vegetation in various microhabitats often found in wetlands. A comprehensive field data sheet was developed by the National Wetlands Working Group (Tarnocai 1980) and published by Agriculture Canada in 1983.

The pollen content of peat is often analyzed by standard palynological methods (Faegri and Iversen 1975). The results include pollen from local sources, from neighbouring environments, and from the general regional pollen rain. This could limit the usefulness of pollen analyses for indicating wetland development, unless the results are carefully interpreted. On the other hand, peat samples containing no macrofossils often have pollen that can be attributed to the local wetland vegetation.

Macrofossils in the peat can be examined to indicate the plant communities that contributed to the peat's formation. Many plant remnants can be identified to species or at least to genus, depending on the state of their preservation and on the skill of and time available to the investigator. When interpreting the results, it must be kept in mind that even a thin slice of peat may have taken a century to accumulate. During this time there may have been several changes in the vegetation community. Furthermore, once formed, the peat becomes soil for successive generations of vegetation and may contain root remnants of these plants.

In this book the nomenclature for vascular plants follows Scoggan (1978), the only comprehensive study of flora that treats the entire country. Where this conflicts with regional preferences, the regional nomenclature is given in brackets. The terminology for mosses follows Ireland *et al.* (1980), and lichens are named according to Hale (1979).

Summary

In the following nine chapters the wetlands of Canada are examined in greater detail. Environmental conditions that determine the development of wetlands, such as climate, landscape physiography, and vegetation, are discussed for the various wetland regions. The wetlands that are common to or characteristic of these regions are discussed in some detail, using published material supplemented by new information. Each form of wetland is presented as part of the complete environment—the vegetation, hydrology, and chemistry of the present and past wetland environments are discussed and possible developmental paths are identified. This information is then summarized to chart the environmental processes that formed the wetlands in each broad wetland area. Finally the wetlands are considered from the human perspective and their present utilization and future prospects are examined. Appendix I provides definitions and an outline of the Canadian Wetland Classification System. A glossary of terms used in this book and a listing of author affiliations both follow at the end of the book.

In this book the currently available knowledge of our wetlands is presented to a relatively wide technical public: geographers, hydrologists, botanists, foresters, biologists, soil scientists, engineers, and others concerned with the study and wise use of our wetland resources. Undoubtedly, some may not be fully satisfied with the detail provided. In such cases the references will show the sources of more detailed information. In other cases the information does not exist and deficiencies in our knowledge are exposed.

In Canada, vast wetland areas remain unexplored; their examination would undoubtedly yield new and exciting knowledge. New applications of analytical techniques and new technological developments are also expanding our horizons. Thus the contents of this book merely provide, in a single reference source, an account of the state of much of our knowledge at the present, in the hope that further research of wetlands will be stimulated, increasing our store of knowledge. Such information and public awareness of wetlands are essential for the effective development and implementation of wetland conservation programs in Canada.

Acknowledgements

Comments and reviews by the following have assisted in the completion of this chapter: G. Adams, P. Grondin, R. Hebda, H. Hirvonen, J. Johnson, G. Mills, E. Oswald, J. Pojar, C. Rubec, C. Tarnocai, and H. Veldhuis. Table 1–8 was prepared by C. Rubec.

References

ÅHMAN, R. 1977. Palsar i Nordnorge. The Royal University of Lund, Sweden. Department of Geography Series. Avhandlingar No. 78. 165 p.

ALDERMAN, T. 1965. It's a nuisance. Imperial Oil Review 49(3):6–10.

ANDREJKO, M.J., F. FIENE, AND A.D. COHEN. 1983. Comparison of ashing techniques for determination of the inorganic content of peats. *In* Testing of peats and organic soils. P.M. Jarrett, editor. American Society for Testing and Materials. Special Technical Publication No. 820. pp. 5–20.

BELLAMY, D.J. 1972. Templates of peat formation. *In* Proceedings, 4th International Peat Congress. Volume 1. Helsinki, Finland. pp. 7–18.

BLAKE, W., JR. 1972. Climatic implications of radiocarbon-dated driftwood in the Queen Elizabeth Islands, Arctic Canada. *In* Climatic changes in arctic areas during the last ten-thousand years. Y. Vasari, H. Hyvarinen, and S. Hicks, editors. Acta Universitatis Ouluensis, Series A, Sciientiae Rerum Naturalium No. 3, Geologica No. 1. pp. 77–104.

BOTCH, M.S., AND V.V. MASING. 1983. Mire ecosystems in the USSR. *In* Ecosystems of the world. Volume 4B. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 95–152.

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication No. 1646. Ottawa, Ontario. 164 p.

CLYMO, R.S. 1983. Peat. *In* Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 159–224.

COUILLARD, L. 1978. Étude de la végétation de deux tourbières de l'Île à Samuel, archipel de Mingan. Mémoire de fin d'études, Department of Biology, Laval University, Quebec, Quebec. 153 p.

COUILLARD, L., AND P. GRONDIN. 1986. La végétation des milieux humides du Québec. Les publications du Québec. Quebec Ministry of Environment. Quebec, Quebec. 400 p.

COWARDIN, L.M., V. CARTER, F.C. GOLET, AND E.T. LAROE. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, United States Department of the Interior. Report No. FWS/OBS-79/31. 103 p.

DAMMAN, A.W.H. 1986. Hydrology, development, and biochemistry of ombrogenous peat bogs with special reference to nutrient relocation in a western Newfoundland bog. Canadian Journal of Botany 64:384–394.

DAMMAN, A.W.H., AND J.J. DOWHAN. 1981. Vegetation and habitat conditions in Western Head Bog, a southern Nova Scotia plateau bog. Canadian Journal of Botany 59:1343–1359.

DIONNE, J.C. 1979. Radiocarbon dates on peat and tree remains from James Bay area, subarctic Quebec. Canadian Journal of Forest Research 9:125–129.

DIONNE, J.C. 1984. Palses et limite méridionale du pérgélisol dans L'Hemisphère Nord: le cas de Blanc-Sablon, Québec. Géographie physique et Quaternaire 38:165–184.

DOUGLAS, R.J.W., H. GABRIELSE, J.O. WHEELER, D.F. STOTT, AND H.R. BELYEA. 1970. Geology of western Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 367–488.

DU RIETZ, G.E. 1949. Huvudenheter och Huvudgränser I Svensk Myrvegetation. Svensk Bot. Tidskr. Volume 43. Uppsala, Sweden. pp. 274–309.

DU RIETZ, G.E. 1954. Die Mineralbodenwasserzeigergrenze als Grundlage einer natürlichen Zweigliederung der nord- und mitteleuropäischen Moore. Vegetatio 5-6:571–585.

EUROLA, S. 1962. Über die regionale Einteilung der südfinnischen Moore. Annals of the Botanical Society. "Vanamo" 33(2):1–243.

FAEGRI, K., AND J. IVERSEN. 1975. Textbook of pollen analysis. Hafner Press. New York, New York.

FOSTER, D.R., AND G.A. KING. 1984. Landscape features, vegetation and developmental history of a patterned fen in south–eastern Labrador, Canada. Journal of Ecology 72:115–143.

GAUTHIER, R. 1980. La végétation des tourbières et les sphaignes du parc des Laurentides, Québec. Forest Ecology Laboratory, Laval University. Études écologiques No. 3. Quebec, Quebec. 634 p.

GAUTHIER, R., AND M.M. GRANDTNER. 1975. Étude phytosociologique des tourbières du Bas Saint-Laurent, Québec. Naturaliste canadien 102:109–153.

GERARDIN, V., P. GRONDIN, AND M. LEBEL. 1984. Les tourbières de la Moyenne-et-Basse-Côte-Nord: description et distribution. Service des inventaires écologiques, Quebec Ministry of Environment. Inventaire du Capital-Nature Series No. 4. Quebec, Quebec. 155 p.

GLASER, P.H., G.A. WHEELER, E. GORHAM, AND H.E. WRIGHT, JR. 1981. The patterned mires of the Red Lake peatland, northern Minnesota: vegetation, water chemistry and landforms. Journal of Ecology 69:575–599.

GORE, A.J.P. 1983. Introduction. *In* Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 1–34.

GORHAM, E. 1956. The ionic composition of some bog and fen waters in the English Lake District. Journal of Ecology 44:142–152.

GRIFFIN, K.O. 1977. Paleoecological aspects of the Red Lake peatland, northern Minnesota. Canadian Journal of Botany 55:172–192.

GRONDIN, P., AND J. OUZILLEAU. 1980. Les tourbières du sud de la Jamésie. Géographie physique et Quaternaire 34:267–299.

HALE, M.E. 1979. How to know the lichens. The Pictured Key Nature Series. William C. Brown Company Publishers. Dubuque, Iowa. 246 p.

HEBDA, R.J. 1983. Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, British Columbia. Canadian Journal of Botany 61:3172–3192.

HOCHBAUM, G.S. 1983. Waterfowl of the prairie provinces and Northwest Territories: populations, habitat and management. *In* 1st Western Hemisphere Waterfowl and Waterbird Symposium. H. Boyd, editor. Canadian Wildlife Service, Environment Canada. pp. 34–36.

INGRAM, H.A.P. 1983. Hydrology. *In* Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 67–158.

INLAND WATERS BRANCH. 1970. Surface water data, Saskatchewan. Water Survey of Canada, Environment Canada. Ottawa, Ontario. 147 p.

INLAND WATERS DIRECTORATE. 1977. Water quality data, Saskatchewan 1961–1975. Water Quality Branch, Fisheries and Environment Canada. Ottawa, Ontario. 300 p.

IRELAND, R.R., C.D. BIRD, G.R. BRASSARD, W.B. SCHOFIELD, AND D.H. VITT. 1980. Checklist of the mosses of Canada. National Museum of Natural Sciences. Publications in Botany No. 8. 75 p.

JAQUES, D., AND C. HAMEL. 1982. Système de classification des terres humides du Québec. Laboratory for Aquatic Macrophytes Studies, Department of Biological Sciences, University of Quebec at Montreal, for the Wildlife Directorate, Quebec Ministry of Recreation, Hunting and Fishing, Quebec, Quebec. 131 p.

JEGLUM, J.K., A.N. BOISSONNEAU, AND V.F. HAAVISTO. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report O-X-215. Sault Ste Marie, Ontario. 54 p.

JOWSEY, P.C. 1966. An improved peat sampler. New Phytology 65:245–248.

KATZ, N.Y. 1948. Tipy bolot S.S.S.R. i Zapadnoi Yevropy i ikh geograficheskoe rasprostranenie. Geografgiz. Moscow, Soviet Union. 320 p.

KEYS, D., D.E. GEMMELL, AND R.E. HENDERSON. 1982. New Brunswick peat: resources, management and development potential. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 222–236.

KIVINEN, E., AND P. PAKARINEN. 1981. Geographical distribution of peat resources and major peatland complex types in the world. Annales Academiae Scientarium Fennicae, Series A, III. Geologica-Geographica No. 123. 28 p.

KULCZYNSKI, S. 1949. Peat bogs of Polesie. Memoires de l'Academie polonais de sciences et lettres, Série 15. Cracovie, Poland. 356 p.

LANDVA, A.O., E.O. KORPIJAAKKO, AND P.E. PHEENEY. 1983. Geotechnical classification of peats and organic soils. *In* Testing of peats and organic soils. P.M. Jarrett, editor. American Society for Testing and Materials. Special Technical Publication No. 8320. pp. 37–51.

LEBEL, C. 1986. La végétation des tourbières de la région Mistassini-Sainte-Marguerite-Marie, Lac-Saint-Jean, Québec. M.Sc. thesis, Faculty of Arts, University of Sherbrooke, Sherbrooke, Quebec. 94 p.

LISHTVAN, I.I., AND I.G. TANOVITSKY. 1979. Actual problems pertaining to efficient use and protection of peat deposits. *In* Proceedings, International Symposium on Classification of Peat and Peatlands, International Peat Society. Helsinki, Finland. pp. 318–328.

MACFARLANE, I.C. 1958. Guide to a field description of muskeg. National Research Council of Canada. Technical Memorandum 44. 36 p.

MCKEAGUE, J.A. 1978. Manual on soil sampling and methods of analysis. Canadian Society of Soil Science. 2nd edition. 212 p.

MILLAR, J.B. 1976. Wetland classification in western Canada. Canadian Wildlife Service, Environment Canada. Report Series No. 37. Saskatoon, Saskatchewan. 38 p.

MOORE, P.D., AND D.J. BELLAMY. 1974. Peatlands: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Springer-Verlag New York Inc. New York, New York. 221 p.

NATIONAL WETLANDS WORKING GROUP. 1986a. Distribution of wetlands. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NATIONAL WETLANDS WORKING GROUP. 1986b. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NICHOLS, H. 1967. Pollen diagrams from sub-arctic central Canada. Science 155:1665–1668.

OSVALD, H. 1925. Die Hochmoortypen Europas. Veroff. Geobot. Inst. Eidg. Tech. Hochsch. Stift. Volume 3. Rubel. Zurich, Switzerland. pp. 707–723.

POLLETT, F.C. 1972. Nutrient contents of peat soils in Newfoundland. *In* Proceedings, 4th International Peat Congress. Volume 3. Helsinki, Finland. pp. 461–468.

PREST, V.K. 1970. Quaternary geology of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 675–764.

RADFORTH, N.W. 1952. Suggested classification of muskeg for the engineer. Engineering Journal 35:1199–1210.

RADFORTH, N.W. 1969a. Classification of muskeg. *In* Muskeg engineering handbook. I.C. MacFarlane, editor. University of Toronto Press. Toronto, Ontario. pp. 31–52.

RADFORTH, N.W. 1969b. Airphoto interpretation of muskeg. *In* Muskeg engineering handbook. I.C. MacFarlane, editor. University of Toronto Press. Toronto, Ontario. pp. 53–77.

RAINVILLE, A. 1983. Étude de la végétation des tourbières de Natashquan. Mémoire de fin d'études, Faculty of Forestry and Geodesy, Laval University, Quebec, Quebec. 72 p.

RITCHIE, J.C. 1976. The late-Quaternary vegetational history of the western interior of Canada. Canadian Journal of Botany 54:1793–1818.

RITCHIE, J.C., L.C. CWYNAR, AND R.W. SPEAR. 1983. Evidence from north-west Canada for an early Holocene Milankovitch thermal maximum. Nature 305:126–128.

ROWE, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Environment Canada. Publication No. 1300. Ottawa, Ontario. 172 p.

RUUHIJÄRVI, R. 1960. Über die regionale Einteilung der nordfinnischen Moore. Annals of the Botanical Society. "Vanamo" 31(1):360.

SCHNITZER, M., AND J.G. DESJARDINS. 1965. Carboxyl and phenolic hydroxyl groups in some organic soils and their relation to the degree of humification. Canadian Journal of Soil Science 45:257–264.

SCHWINTZER, C.R. 1978. Vegetation and nutrient status of northern Michigan fens. Canadian Journal of Botany 56:3044–3051.

SCHWINTZER, C.R. 1981. Vegetation and nutrient status of northern Michigan bogs and conifer swamps with a comparison to fens. Canadian Journal of Botany 59:842–853.

SCOGGAN, H.J. 1978. The flora of Canada. National Museum of Natural Sciences. Publications in Botany No. 7. Ottawa, Ontario. 1711 p.

SHELDRICK, B.H. 1984. Analytical methods manual 1984. Land Resource Research Institute, Agriculture Canada. Contribution No. 84-30. Ottawa, Ontario.

SJÖRS, H. 1950. On the relation between vegetation and electrolytes in north Swedish mire waters. Oikos 2:241–258.

SJÖRS, H. 1961. Surface patterns in boreal peatlands. Endeavour 20:217–224.

SJÖRS, H. 1963. Bogs and fens on Attawapiskat River, northern Ontario. National Museums of Canada. Bulletin No. 186. Ottawa, Ontario. pp. 45–133.

SJÖRS, H. 1969. Bogs and fens in the Hudson Bay Lowlands. Arctic 12:3–19.

SJÖRS, H. 1976. Successional trends in boreal peatlands. *In* Proceedings, 5th International Peat Congress. Warsaw, Poland. pp. 22–28.

SJÖRS, H. 1983. Mires of Sweden. *In* Ecosystems of the world. Volume 4B. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 69–94.

SLACK, N.G., D.H. VITT, AND D.G. HORTON. 1980. Vegetation gradients of minerotrophically rich fens in western Alberta. Canadian Journal of Botany 58:330–350.

STANEK, W., J.K. JEGLUM, AND L. ORLOCI. 1977. Comparisons of peatland types using macro-nutrient contents of peat. Vegetatio 33:163–173.

STANEK, W., AND T. SILC. 1977. Comparisons of four methods for determination of degree of peat humification (decomposition) with emphasis on the von Post method. Canadian Journal of Soil Science 57:109–117.

STEWART, R.E., AND H.A. KANTRUD. 1972. Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors. *In* Hydrology of prairie potholes in North Dakota. United States Geological Survey. Professional Paper 585-D. 36 p.

TANSLEY, A.G. 1911. Types of British vegetation. Cambridge University Press. Cambridge, UK. 416 p.

TARNOCAI, C. 1978. Genesis of organic soils in Manitoba and the Northwest Territories. *In* Proceedings, 3rd York University Symposium on Quaternary Research, Geographical Abstracts. Norwich, UK. pp. 453–470.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–39.

TARNOCAI, C. 1983. Peatland inventory methodology used in soil surveys. *In* Proceedings, Peatland Inventory Methodology Workshop. S.M. Morgan and F.C. Pollett, editors. Land Resource Research Institute, Agriculture Canada, and Newfoundland Forestry Research Centre, Environment Canada. Ottawa, Ontario. pp. 13–22.

TARNOCAI, C. 1984. Peat resources of Canada. National Research Council of Canada. Publication No. 24140. Ottawa, Ontario. 17 p.

TAYLOR, J.A. 1983. The peatlands of Great Britain and Ireland. *In* Ecosystems of the world. Volume 4B. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 1–46.

TERASMAE, J. 1963. Three C-14 dated pollen diagrams from Newfoundland, Canada. Advances in Frontiers of Plant Science (New Delhi) 6:149–162.

TERASMAE, J. 1970. Postglacial muskeg development in northern Ontario. Associate Committee on Geotechnical Research, National Research Council of Canada. Technical Memorandum No. 99. Ottawa, Ontario. pp. 73–90.

UNITED STATES SOIL CONSERVATION SERVICE, SOIL SURVEY STAFF. 1975. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. United States Soil Conservation Service. Agricultural Handbook 436. 754 p.

VEILLETTE, J.J., AND F.M. NIXON. 1980. Portable drilling equipment for shallow permafrost sampling. Geological Survey of Canada. Paper 79-21. Ottawa, Ontario. 35 p.

VITT, D.H., P. ACHUFF, AND R.E. ANDRUS. 1975. The vegetation and chemical properties of patterned fens in the Swan Hills, north central Alberta. Canadian Journal of Botany 53:2776–2795.

VON POST, L. 1922. Sveriges geologiska undersöknings torvinventering och nagra av dess hittills vunna resultat. Svensk Mosskulturförening, Tidskr. 1:1–27.

WARDENAAR, E.C.P. (personal communication). June 1986. University of Amsterdam, Amsterdam, The Netherlands.

WEBB, T., P.J.H. RICHARD, AND R.J. MOTT. 1983. A mapped history of Holocene vegetation in southern Quebec. *In* Climatic change in Canada. Volume 3. C.R. Harington, editor. National Museums of Canada. Syllogeus Series No. 49. Ottawa, Ontario. pp. 273–329.

WELLS, E.D. 1981. Peatlands of eastern Newfoundland: distribution, morphology, vegetation, and nutrient status. Canadian Journal of Botany 59:1978–1997.

WELLS, E.D., AND F.C. POLLETT. 1983. Peatlands. *In* Biogeography and ecology of the Island of Newfoundland. G.R. South, editor. Dr. W. Junk Publishers. The Hague, The Netherlands. pp. 207–266.

WELLS, E.D., F.C. POLLETT, AND E.R. DAWE. 1983. Peatland inventories for Newfoundland: methodology and application. *In* Proceedings, Peatland Inventory Methodology Workshop. S.M. Morgan and F.C. Pollett, editors. Land Resource Research Institute, Agriculture Canada, and Newfoundland Forestry Research Centre, Environment Canada. Ottawa, Ontario. pp. 25–34.

WILLIAMS, G.P. 1968. The thermal regime of a *Sphagnum* peat bog. *In* Proceedings, 3rd International Peat Congress. Quebec, Quebec. pp. 195–200.

WRIGHT, H.E., JR. 1964. The classification of the Wisconsin glacial stage. Journal of Geology 72:628–637.

WRIGHT, H.E., JR., and P.H. GLASER. 1983. Postglacial peatlands of the Lake Agassiz plain, northern Minnesota. *In* Glacial Lake Agassiz. J.T. Teller and L. Clayton, editors. Geological Association of Canada. Special Paper No. 26. pp. 375–389.

ZOLTAI, S.C. 1978. A portable sampler for perennially frozen stone-free soils. Canadian Journal of Soil Science 58:521–523.

ZOLTAI, S.C., AND J.D. JOHNSON. 1985. Development of a treed bog island in a minerotrophic fen. Canadian Journal of Botany 63:1076–1085.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12:28–43.

ZOLTAI, S.C., AND C. TARNOCAI. 1976. Basis for regional wetland studies. Associate Committee on Geotechnical Research, National Research Council of Canada. Technical Memorandum No. 116. Ottawa, Ontario. pp. 49–57.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

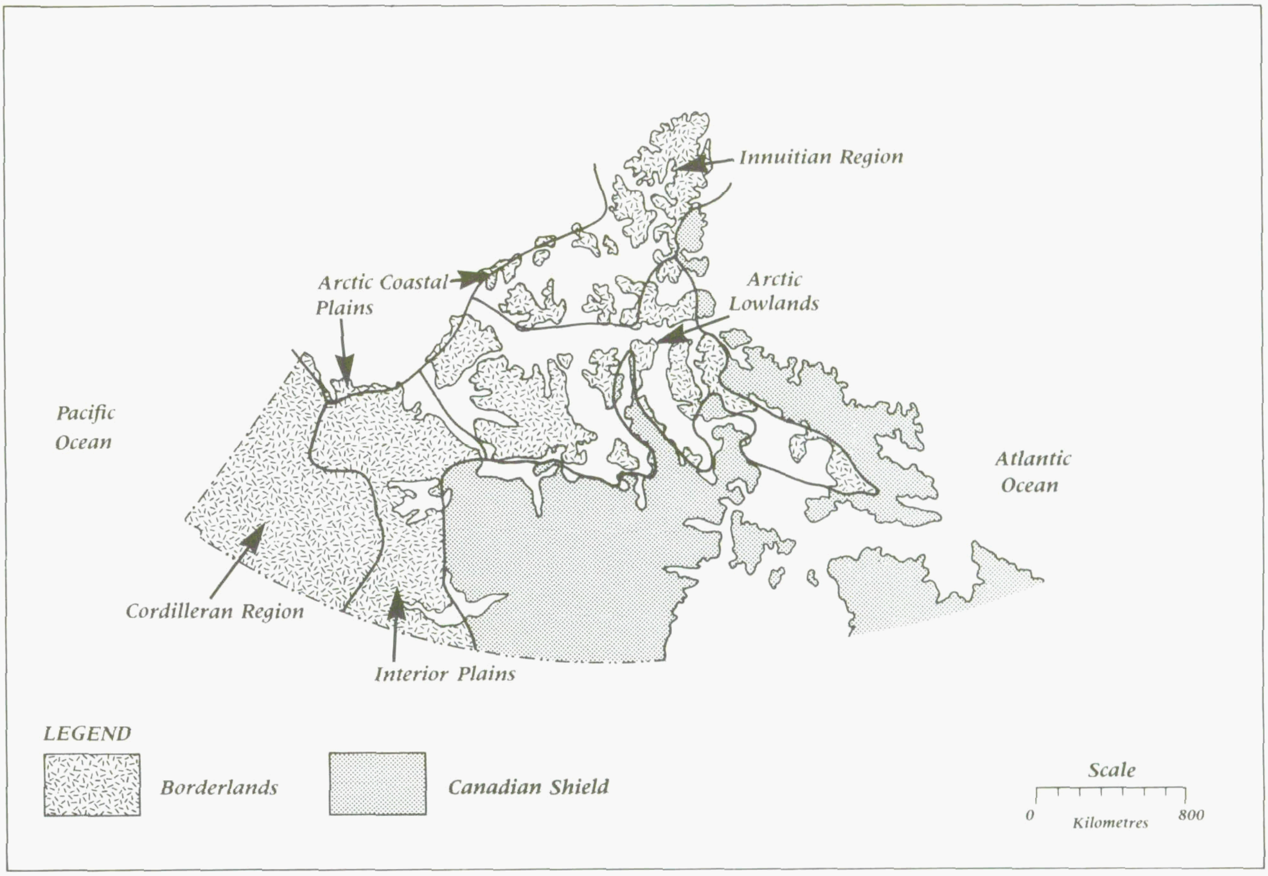
2 Wetlands of Arctic Canada

C. Tarnocai
S.C. Zoltai

Wetlands of Arctic Canada

The Canadian Arctic is the area (2 759 940 km²) that extends northwards from the arctic tree line and covers approximately 30% of Canada's total area. Wetlands, which occur throughout this area, are very common in the southern portion of the Arctic (Low Arctic Wetland Region) and less common in the middle and northern portions (Mid- and High Arctic Wetland Regions) (National Wetlands Working Group 1986). Almost all arctic wetlands are associated with permafrost, which plays a very important role in their development.

In this chapter all arctic wetland forms are discussed, with the exception of salt marshes, which are considered in Chapter 9.



Source: Bostock (1970).

Figure 2–1.
Physiographic regions of arctic Canada.

Environmental Setting

Geography

Physiographically and geologically, arctic Canada is composed of two distinctly different areas: a core of old, massive, Precambrian crystalline rocks forming the Canadian Shield, and a surrounding younger, predominantly sedimentary rock area forming the borderlands. A further subdivision of these great physiographic units in arctic Canada is shown in Figure 2–1; the descriptions in the following sections come mainly from the works of Bostock (1970) and Prest (1970).

At one time a mountainous area, the Canadian Shield was planed down over a long period of erosion to an undulating, bedrock-dominated peneplain. It was further eroded and modified by successive glaciations over the last million years. This area is composed mainly of wide expanses of rolling hills and valleys, spattered with many lakes and wetlands. Wetlands are common in the Keewatin District and on southern Baffin Island, two areas which occur in the low arctic portion of the Shield. In these areas lowland polygons, fens, and marshes are the most common wetland forms. Marshes are most frequent along the coast, although freshwater marshes are also found inland. Wetlands, especially those associated with peat (peatlands), are less common in the northern Shield areas of the Boothia Peninsula and central and northern Baffin Island.

The Arctic Lowlands physiographic region consists of gently rolling to mountainous terrain. The most common wetlands are low-centre polygons, peat mound bogs, and marshes; peatlands which occur in the form of high-centre polygons are rare. These high-centre polygons are most frequently found on Banks Island and on the southern portion of Victoria Island. Salt marshes are common along the coast and, where the coastline is flat, they often merge into shallow waters and freshwater marshes. This situation is generally found on the northeast coast of Victoria Island, on Stefansson Island, and on the west–central portion of Prince of Wales Island.

The Innuitian Region, to the north of the Arctic Lowlands, has a varied topography. Flat to rolling terrain characterizes the high arctic islands in the central and western portions of the region while rugged mountains are associated with the eastern portion. The most common wetlands in this area are marshes, both salt marshes along the coast and freshwater marshes. One of the largest concentrations of these freshwater marshes occurs in the Polar Bear Pass area of Bathurst Island.

The Arctic Coastal Plain is a coastal strip 50–100 km wide, along the shores of the Arctic Ocean from Meighen Island to Alaska. The arctic islands portion is generally composed of marine or alluvial plains and low rolling hills and terraces. The Mackenzie Delta portion includes not only the present-day delta but also the remnants of earlier deltas and some fluvial–marine features. The Yukon coastal portion consists of rolling terrain with low-lying, poorly drained areas adjacent to the coast. Wetlands are widespread in both the Yukon coastal and Mackenzie Delta portions of this region, with low- and high-centre polygons, fens, marshes, and shallow water being the most common forms. The arctic islands portion is dominated by marshes although peatlands in the form of low- and high-centre polygons are common on Banks Island.

The extreme northern edge of the Interior Plains and Cordilleran regions also extends into the Arctic. The arctic portion of the Interior Plains is composed of rolling and hilly terrain with some low-lying plains occurring along the coast. Wetlands are common in the eastern portion of this area, with low- and high-centre polygons, fens, marshes, and shallow lakes being very numerous. Although salt marshes occur along the whole coast, wetlands are much rarer in the area of the Hornaday Plateau and Bluenose Lake. In these areas, freshwater marshes along the margins of shallow lakes and in low-lying areas are the most common wetlands. The Cordilleran areas of the Arctic have a rugged, mountainous topography, devoid of wetlands except for small areas along the rivers and in poorly drained depressions where some marshes occur.

Climate

Atmospheric circulation, distance from the equator, continental and maritime influences, and the nature of the land surface are some factors which control climate and are of prime importance in shaping the climate of the Canadian Arctic. These factors are responsible not only for the extreme seasonal fluctuation of day length but also for the low angle at which the sun's rays strike the earth. The absence of incoming radiation from the sun during the long arctic winter nights results in sustained cooling of the snow- and ice-covered surfaces. During the summer, in the continuous arctic daylight, large amounts of solar radiation penetrate the atmosphere over the arctic terrain, the ice-filled seas, and the ice-covered glacial surfaces. Because of the relatively high reflectivity of these surfaces and the frequent cloud cover, only a small portion of the energy is available to heat the land surface. Thus, not only is there an extremely large seasonal fluctuation in incoming radiation from the sun, but the solar energy received during the year is much less than that received at lower latitudes.

The climate of the Canadian Arctic Archipelago is of a marine-modified continental type. During the three coldest months, average temperatures range from $-27°C$ in the southern areas to $-33°C$ in the central and northern areas. The temperatures generally remain below $-20°C$ during this whole period and seldom rise above freezing from October to May. Record low temperatures, which have been measured at some Yukon stations, do not occur on the arctic islands because of the marine influence. During this season of continuous ice cover on the seas and channels, the Arctic is relatively cloud-free. Although low-pressure systems occasionally cross the region, the cold air is too dry to permit formation of effective snow-producing clouds and, as a consequence, snowfall is very light. Although the steady arctic cold and the light snowfall are characteristic phenomena of the arctic winter climate, it is only when they occur in combination with strong winds that outdoor activities, such as travel, become hazardous; if they also result in heavy blowing snow, such activities may even become impossible. The most uncomfortable areas, where blizzards are most frequent, are not in the high arctic islands but in the coastal section of the eastern Arctic and in the Keewatin coastal area along Hudson Bay. In these areas, cyclonic activity is much greater and strong winds more frequent than elsewhere in the arctic region.

In the summer months (June, July, and August), low-lying stratus clouds and coastal fogs are common features. During these months water bodies lose much of their ice cover and all land surfaces are snow-free, with the exception of the ice-capped mountains in the eastern part of the Canadian Arctic Archipelago. A large percentage of the land area, especially in the southern part of the Arctic, is associated with wetlands and water-saturated soils because moisture from incoming precipitation and snowmelt is retained in the active layer as a result of the underlying permafrost acting as a barrier to water movement. Rainfall, which accounts for less than half of the annual precipitation, is approximately 70–140 mm in the continental portion, 17–68 mm in the high arctic islands, and 46 mm at the southern end of Baffin Island. The water-saturated terrain and cold, partially ice-covered waterways influence the climate by adding sufficient moisture to create extensive, low-lying clouds and fog banks, while holding air temperatures to within a few degrees above 0°C. These summer months, the mildest of the year, are characterized by a uniform temperature pattern along the coasts and the islands, with temperatures generally remaining between 3 and 6°C on the arctic islands and between 8 and 11°C on the arctic mainland. The temperature only occasionally, during brief interludes of sunny weather, exceeds 31°C in the continental Arctic and 20°C on the arctic islands. These higher summer air temperatures occur much more frequently in the southern Arctic, especially in areas away from the coast.

Regional Ecology and Wetlands

For ecological purposes, the arctic tree line is recognized as the boundary between the arctic and subarctic regions (Savile 1972). Plant species that attain tree size in the Subarctic do not occur in the Arctic due to limitations imposed on regeneration and growth by the extremely harsh climate. The wetlands in the Arctic are distinctive, having been formed under climatic conditions that make them unique.

There are differences in plant distribution and growth within the Arctic as defined here. As in any other region, plant communities react to differences in soil (texture, nutrients, and moisture) and local climate. Three vegetation units have been recognized on a continental scale: tundra, polar semidesert, and polar desert. Tundra refers to those cold, treeless lands where plants (including mosses and lichens) cover 80–100% of the soil surface (Bliss 1979). Polar semi-deserts have a 5–20% cover of vascular plants (Bliss *et al.* 1973) and a total cover of 10–80%. Polar deserts have a vascular plant cover of up to 5% and a total plant cover of up to 10% (Bliss *et al.* 1973). Arctic wetlands characteristically support tundra vegetation even under the most severe climatic conditions.

Although elements of these broad vegetation units may occur in any part of the Arctic, tundra vegetation is dominant on the mainland portion while polar semi-desert vegetation dominates the southern portion of the Arctic Archipelago and polar desert vegetation dominates the northern portion (Bliss 1977). These three areas correspond to the wetland regions of the Canadian Arctic (as presented in a following section of this chapter): High, Mid-, and Low Arctic, respectively. Certain wetland forms occur throughout the Arctic but some, because of their form, genesis, or peat development, are characteristic of a particular region.

High Arctic

In the high Arctic, polar desert vegetation is characteristic on upland sites. This vegetation consists of only scattered cushion plants and rushes. Wetlands, having a continuous plant cover of mosses and sedges, occur in depressions and on slopes where perennial or late-thawing snow beds provide a constant water supply. Permafrost is present under all land surfaces, with a shallow (20–25 cm) active layer in the wetlands and a deeper (50–60 cm) active layer on the bare uplands. Ice-wedge polygons and domed peat mounds are the most common patterned ground types associated with wetlands.

Mid-Arctic

In the mid-Arctic the characteristic vegetation of the uplands is dwarf shrub–sedge, which usually covers less than 50% of the surface. On slopes, cushion plants, sedges, and forbs form a discontinuous cover. Sedges and mosses dominate the moist slopes, especially those associated with snowbanks. In wetlands, sedges and mosses form a continuous cover. *Sphagnum* spp. are largely absent; if present, they occur in such small amounts that they are not significant peat-forming plants. Permafrost is present both on uplands and in wetlands. The active layer is about 70 cm deep on uplands and 30 cm deep in wetlands. Frost-induced ground phenomena are very common, with ice-wedge polygons being more widespread in wetlands.

Low Arctic

In the low Arctic the characteristic vegetation of uplands is heath–lichen tundra. Shrubby vegetation, mainly *Betula glandulosa* and *Salix* spp., occurs on slopes and along rivers. In the wetlands a sedge and cotton grass type of vegetation is dominant. Various species of *Sphagnum* are still abundant in wetlands and on some moist slopes in this area. Permafrost is present under all land surfaces. The seasonally thawed active layer varies from 1 to 2 m deep on the uplands to about 50 cm deep in wetlands. Frost-induced phenomena are common both on uplands and in wetlands, with ice-wedge polygons being more prevalent in wetlands.

Criteria for and Distribution of Arctic Wetlands

Arctic wetlands are associated with peatlands and Organic Cryosols, and also occur on wet mineral soil. This wet mineral soil either has a water table at, near, or above the surface or is found in areas which are periodically inundated by tides. These mineral wetlands are associated with Gleysolic Cryosols or, in recent alluvial deposits, with Gleysols. Gleysolic Cryosols associated with earth hummocks and tussocks are not considered to be wetlands since the water table is well below the surface, generally lying just above the permafrost table. Some of the strongly eroded, high-centre polygons, especially those occurring in the mid- and high Arctic, are also not considered to be wetlands; they developed under wetland conditions that existed in the past but, due to changes in drainage resulting from glacial rebound or other natural processes, the wetland condition has ceased to exist.

Wetlands in the Arctic are generally sparsely distributed but with significant local occurrences. Overall, wetlands are restricted to less than about 3–5% of all the lands north of the tree line in Yukon and the Northwest Territories. Significant areas of wetland concentration include the Yukon Northern Coastal Plain, the Mackenzie Delta, western Banks Island, the northeast coast of Victoria Island, Bathurst Island Central Lowland, the Queen Maud Gulf Lowland, Native Bay and the Boas Plain on Southampton Island, Truelove Lowland on northern Devon Island, Lake Hazen on Ellesmere Island, Murchison Lowland on the Boothia Peninsula, Creswell Bay on Somerset Island, and portions of Prince Charles, Spicer, Rowley, and Air Force islands, as well as the Great Plain of the Koukdjuak on southwestern Baffin Island. All of these areas generally have over 20% and up to 75% wetland cover (National Wetlands Working Group 1986).

Several regional, reconnaissance land resource surveys have included an inventory of arctic wetlands. The most extensive covers all areas of the Beaufort Sea coastal zone and Northwest Passage, and comprises 19 map sheets at a scale of 1:500 000. The project conducted by Environment Canada also includes a two-page fact sheet providing information on wetland classification, vegetation, soils, land use, sensitivity, and legal status for each of over 400 wetland-dominated areas identified on the accompanying maps (Lynch-Stewart *et al.* 1984). Surficial geology and vegetation surveys at various scales have also provided mapping of wetland or organic soils in extensive areas including Melville Island (Edlund 1986), the Boothia Peninsula, Cornwallis Island, and the northern Keewatin District (Tarnocai *et al.* 1976), the Mackenzie Valley and Delta (Zoltai and Pettapiece 1973), and southwestern Baffin and Coats islands (C.D.A. Rubec, personal communication; Rubec *et al.* 1983). The Northern Land Use Information Series (NLUIS) maps produced by Environment Canada and Indian and Northern Affairs Canada cover all the area of Yukon and the Northwest Territories, except that north of latitude 76°N. These maps present an ecological overview with notes on wetland occurrence, soils, land form, vegetation, and wildlife use at a map scale of 1:250 000.

Arctic Wetland Regions

Regional differences in the occurrence and development of various wetlands are readily apparent in the Arctic. Wetland regions represent areas with similar ecological conditions, resulting in a similar type of wetland development. The three arctic wetland regions are shown in Figure 2–2 and their descriptions are given below.

High Arctic Wetland Region (AH)

This wetland region covers all the high arctic islands of Canada, including the northern and northeastern parts of Baffin Island. The climate of this region is a marine-modified continental type, characterized by short cool summers, long cold winters, and very low precipitation. Climatic summaries are given in Table 2–1. The mean annual temperature of this region is −14.7°C with a mean July temperature of 4.4°C and a mean January temperature of −29.1°C. The mean number of degree-days above 5°C is 46.9. The average annual precipitation is 165 mm and the average annual snowfall is 120.8 cm. Permafrost is present under all land surfaces. The active layer is about 20–30 cm deep in peatlands and 30–40 cm deep under wet fens. Peat development is minimal, the average thickness of peat being about 50 cm. Marshes of this region are generally not associated with peat.

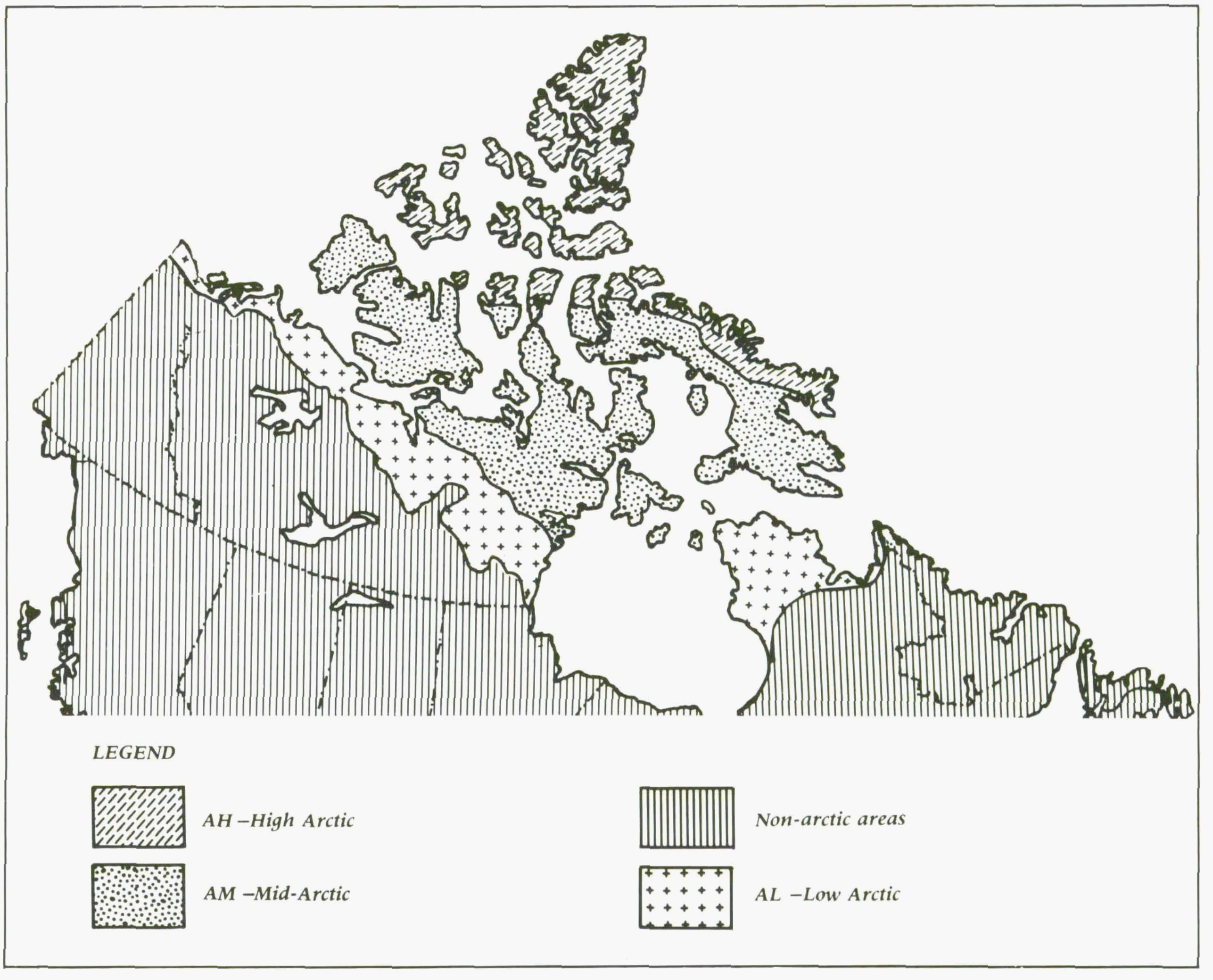


Figure 2–2.
Arctic wetland regions of Canada.

The common wetland forms in the High Arctic Wetland Region are low-centre lowland polygon fens—often with shallow water tundra ponds—and peat mound bogs. Peat accumulation is very slow. Active high-centre lowland polygons are nonexistent. The strongly eroded high-centre polygon bogs found on the high arctic islands developed under a milder climate and are considered to be relict phenomena. Along the coast and in low-lying areas, marshes and shallow water wetlands are common. Because of the aridity of the High Arctic Wetland Region, wetlands are scarce; they occur mainly in local lowlands and along coastal lowlands.

The vegetation on fens is mainly *Carex* spp. and *Drepanocladus revolvens*. High-centre polygons are unvegetated because of their actively eroding nature. The peat mounds are associated with lichen and moss types of vegetation.

Mid-Arctic Wetland Region (AM)

This wetland region covers some of the Canadian arctic islands (Banks, Victoria, southern Prince of Wales, and Somerset), a large part of southern and northwestern Baffin Island, and the northern and north–central Keewatin District. The climate of this region is a marine-modified continental type, characterized by short cool summers, long cold winters, and very low precipitation. Climatic summaries are given in Table 2–1. The mean annual temperature of this region is −13.6°C with a mean July temperature of 6.6°C and a mean January temperature of −30.9°C. The mean number of degree-days above 5°C is 138.2. The average annual precipitation is 185.9 mm and the average annual snowfall is 103 cm. Permafrost is present under all land surfaces. The active layer is about 30 cm deep in peatlands and 40 cm deep under wet fens. The thickness of the peat is less than 150 cm on peat mounds and usually less than 50 cm on fens. Marshes in this region are not associated with peat.

In the Mid-Arctic Wetland Region the most common wetlands are low-centre lowland polygon fens. High-centre lowland polygon bogs are rare except in eroding forms. Some small horizontal fens are also present, especially in depressions and on seepage slopes associated with snowbanks. Elevated peat mounds are often found on these fens. Salt marshes are common along the low-lying coastal lowlands.

Table 2–1. Climatic data for arctic wetland regions

Wetland region	*Statistics*	*Mean annual temp. (°C)*	*Mean daily July temp. (°C)*	*Mean daily January temp. (°C)*	*Mean degree-days above 5°C*	*Mean annual total precip. (mm)*	*Mean annual snowfall (cm)*
High Arctic	No. of stations	13	13	13	13	11	11
	Mean	−14.7	4.4	−29.1	46.9	165.0	120.8
	Range	−7.9 to −19.7	3.2 to 5.6	−19.8 to −34.7	21.4 to 77.2	61.0 to 313.3	28.6 to 250.0
Mid-Arctic	No. of stations	15	15	15	15	15	15
	Mean	−13.6	6.6	−30.9	138.2	185.9	103.0
	Range	−8.7 to −16.1	5.9 to 7.9	−25.6 to −36.0	70.7 to 210.2	103.1 to 432.6	39.9 to 255.5
Low Arctic	No. of stations	10	10	10	10	10	10
	Mean	−10.6	9.1	−28.6	287.4	244.3	109.8
	Range	−6.7 to −12.2	6.2 to 11.7	−22.2 to −33.0	142.0 to 393.9	109.4 to 386.5	40.6 to 170.8

Source: Atmospheric Environment Service (1982).
High Arctic: Alert, Arctic Bay, Broughton Island, Cape Dyer (precipitation not used), Cape Hooper, Clyde, Eureka, Isachsen, Mould Bay, Pond Inlet (no precipitation data), Rea Point, Resolute, Resolution Island.
Mid-Arctic: Cambridge Bay, Cape Parry, Frobisher Bay, Gladman Point, Hall Beach, Holman Island, Jenny Lind Island, Lady Franklin Bay, Longstaff Bluff, Mackar Inlet, Nottingham Island, Pelly Bay, Sachs Harbour, Shepherd Bay, Spence Bay.
Low Arctic: Baker Lake, Chesterfield Inlet, Clinton Point, Contwoyto Lake, Coppermine, Coral Harbour, Inoucdjouac, Koartak, Nicholson Peninsula, Shingle Point.

The vegetation cover on fens is *Carex* spp. and *Eriophorum* spp., with mosses such as *Aulacomnium turgidum* and *Drepanocladus revolvens* also occurring. Small isolated cushions of *Sphagnum fuscum* and *Sphagnum nemoreum* may also occur on these fens. These *Sphagnum* mosses often occur on rocks submerged in fens and in some cases the *Sphagnum* cushions coalesce to form peat mounds. As a result of ice accumulation in the peat, these peat mounds may be up to 50 cm higher than the fen surface and may be regarded as an arctic form of palsa. The peat mounds are covered by lichen, *Sphagnum* mosses, ericaceous shrubs, and dwarf birch (*Betula glandulosa*). The high-centre polygons are commonly eroded by wind and are usually devoid of vegetation cover.

Low Arctic Wetland Region (AL)

This wetland region covers most of the mainland Canadian Arctic. The climate of this region is continental with the exception of areas along the arctic coast of the mainland, where the climate is marine-modified continental. The arctic continental climate is characterized by short cool summers, long cold winters, and low precipitation. Climatic summaries are given in Table 2–1. The mean annual temperature of this region is −10.6°C with a mean July temperature of 9.1°C and a mean January temperature of −28.6°C. The mean number of degree-days above 5°C is 287.4. The average annual precipitation is 244.3 mm and the average annual snowfall is 109.8 cm. Permafrost is present under all land surfaces. The active layer is approximately 40 cm deep under high-centre polygons, 60–80 cm under wet fens, and 90–180 cm under marshes. The usual maximum thickness of peat is approximately 1.5 m on high-centre polygons but only 50 cm on polygonal fens. Marshes in this region have no surface peat layer.

In the Low Arctic Wetland Region, low-centre lowland polygon fens and bogs are by far the most widespread wetlands. Marshes are common along the coast and in the deltas while shallow water ponds, a common phenomenon of the tundra, are also prevalent. Other wetlands occurring in this region are peat mound bogs and horizontal fens with peat cushions. Although peatlands are common in the extreme western part of the region, they are scarce elsewhere. These peatlands occur mainly in depressional areas where the precipitation is concentrated either by runoff or by small creeks. Large expanses of tundra, covered with tussock-forming graminoid species such as *Carex bigelowii* and *Eriophorum vaginatum*, are not considered to be wetlands since they are not waterlogged throughout the year (Zoltai and Pollett 1983). This view is in agreement with the definition of tundra bogs in Siberia used by Botch (1974).

The vegetation cover on low-centre polygons mainly consists of sedges (*Carex* spp.) and cotton grasses (*Eriophorum* spp.) with mosses such as *Calliergon giganteum* and *Drepanocladus revolvens* also present. The polygonal shoulders (along the trench) and the better-drained portions of the high-centre polygons are colonized by dwarf birch and ericaceous shrubs. The shoulders of the water-filled trenches, especially near the water surface, are colonized by *Sphagnum* spp. Some high-centre polygons are being eroded, mainly by wind, and have only a scattered vegetation cover. Marshes in river deltas are associated with low willows (1–2 m tall), sedges, and grass vegetation.

Arctic Wetland Forms

Lowland Polygon Bogs and Fens

Two basic forms of lowland polygons occur in the arctic wetland regions: polygons with either low or high centres (Péwé 1966). Low-centre lowland polygons are considered fens while high-centre lowland polygons are classified as bogs.

Internal and External Morphology

Low-centre polygon fens represent the early stage of lowland polygon development while the high-centre bog forms are considered to represent the mature stage of development.

The morphology of a low-centre polygon resembles a bowl in which the ridges pushed up by the ice wedge under the trough form a rim and create a small pond (Figures 2–3 and 2–4b). The peat development is thin, averaging only a few centimetres in the arctic islands and up to 66 cm in the Mackenzie Delta (Zoltai and Tarnocai 1975). Some *Sphagnum* peat overlies the sedge peat in the trenches and on the shoulders (Figure 2–5b), but sedge and sedge–moss peat are dominant in the centre. The vegetation is dominated by sedge (*Carex* spp.) in the central portion of the low-centre lowland polygon while the polygonal trenches are dominated by Labrador tea (*Ledum palustre* var. *decumbens*) and *Sphagnum* spp. Permafrost is found under the entire landform, even under the shallow central pool.

High-centre lowland polygons form domes, rising from the polygonal trenches (Figures 2–3 and 2–4a). The diameters and depths of these polygons vary, but average diameters of 8 m and average depths to the mineral soil of 155 cm have been found in the Mackenzie Delta area (Zoltai and Tarnocai 1975). The peat materials associated with high-centre polygons are moderately to well decomposed woody moss, sedge, and brown moss peat. The vegetation on the central portion of high-centre polygons is composed of willows (*Salix* spp.), Labrador tea, mosses, and lichens. The polygonal trenches are associated with *Sphagnum* mosses and some Labrador tea.

(a)

(b)

(c)

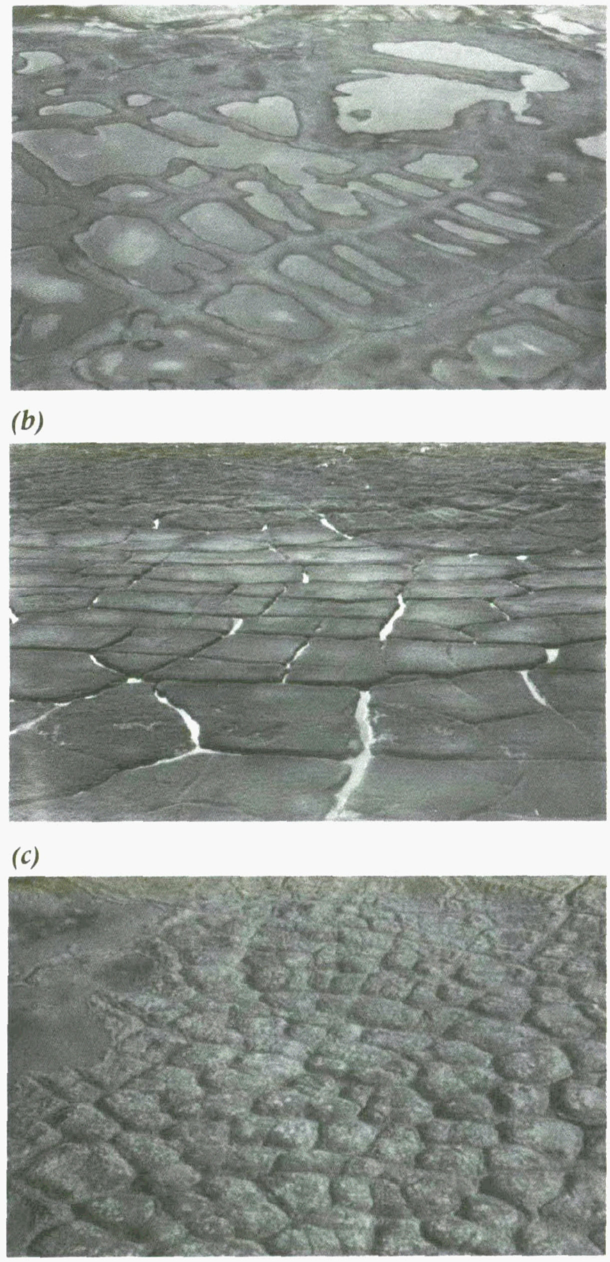


Figure 2–3.
Lowland polygons at various stages of development from low-centre (a) to high-centre (c). Locations: (a) Bathurst Island, (b and c) Mackenzie Delta area.

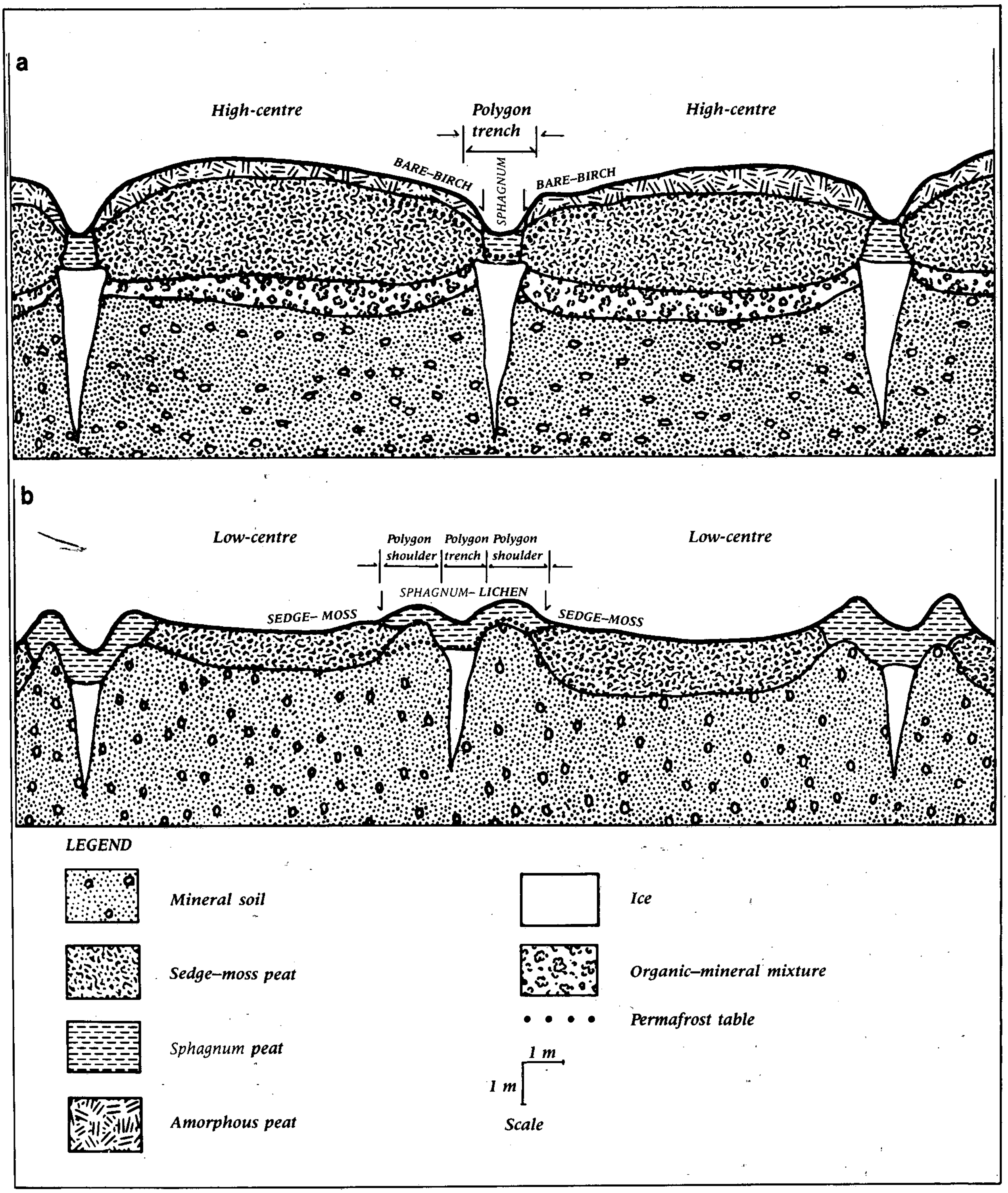


Figure 2–4.
Cross-section of a high-centre lowland polygon (a) and low-centre lowland polygon (b). Locations: (a) Lat. 68°58′ N, Long. 133°48′ W and (b) Lat. 69°56′ N, Long. 131°18′ W.

In many low- and high-centre polygons the peat is underlain by a thick layer of strongly cryoturbated, mixed organic and mineral soil. In the Mackenzie Delta area, according to Zoltai and Tarnocai (1975), such a layer occurred in almost half of the low-centre polygons examined, with an average thickness of 44 cm, and in more than half of the high-centre polygons, with an average thickness of 152 cm. Observation of lowland polygons exposed by shore erosion along the Beaufort Sea coast revealed a pronounced mixing of organic and mineral materials in the lower half of the deposit. In addition to this, bedding planes usually curve up to ice

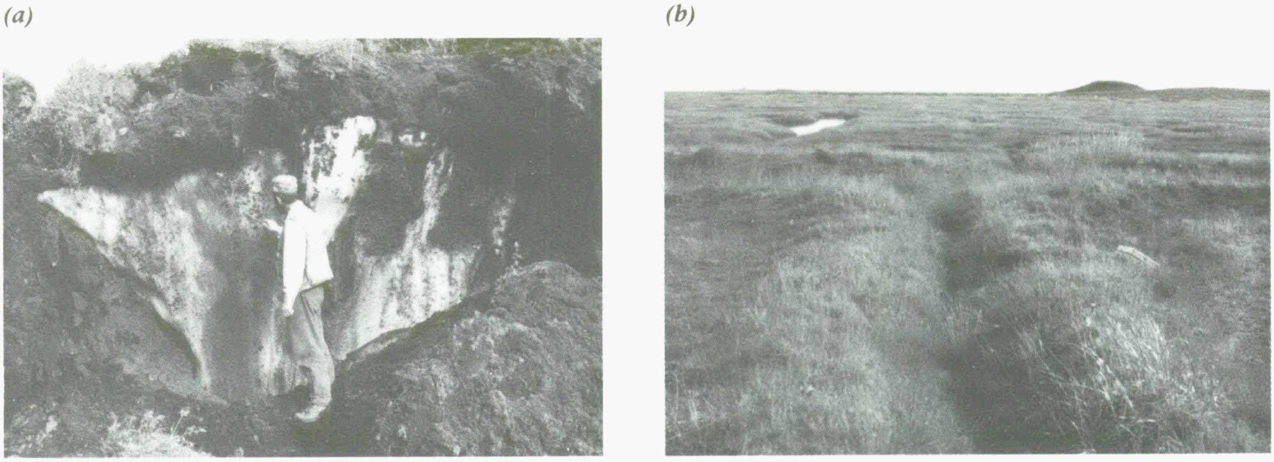


Figure 2–5.
Exposed ice-wedge of a high-centre lowland polygon along the arctic coast near Tuktoyaktuk (a) and a polygonal trench of a low-centre lowland polygon in the Mackenzie Delta area (b).

wedges, and smears and tongues of organic or mineral material intrude into the adjacent strata (Figures 2–5a and 2–6).

Ice Wedges and Ice Content

The widespread occurrence of ice wedges under polygonal trenches is one of the most characteristic features of lowland polygons. The size of these ice wedges varies considerably and depends on the stage of development; the low-centre polygons are generally associated with narrower ice wedges and the high-centre polygons with wider ice wedges (Figure 2–5a). Although the availability of water is also recognized as one of the factors controlling ice-wedge development, it is not a limiting factor in lowland polygons. The majority of the ice wedges associated with lowland polygons are 1–2 m wide near the surface and extend into the ground for 2.5–3 m in the form of a wedge-shaped, or somewhat irregular wedge-shaped, ice body. These wedges develop as the result of a thermally induced contraction in which the wedge growth takes place

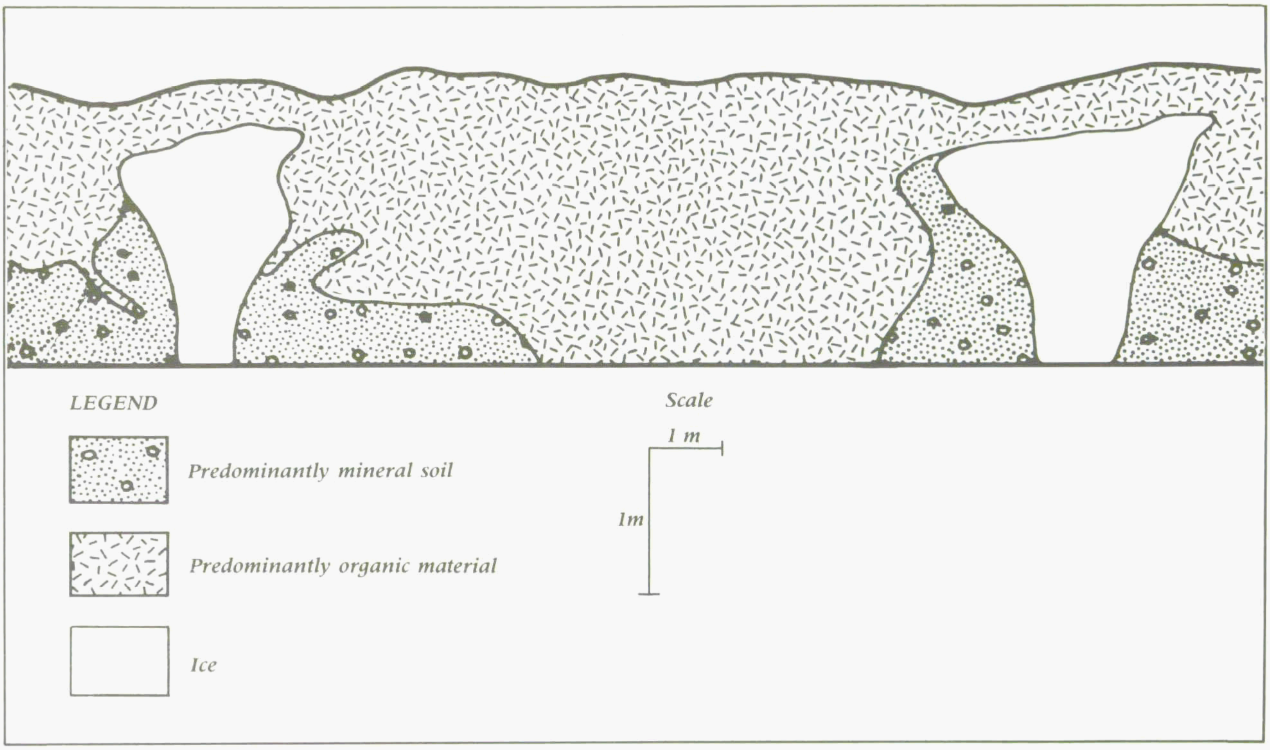


Figure 2–6.
Cross-section of wave-eroded polygons showing contorted mineral soil near the ice wedges. Location: Lat. 69°23′ N, Long. 133°20′ W.

(Black 1976). Cracks develop when the soil is cooled below −15 to −20°C. At this temperature there is a shrinkage in the volume of ice contained within the soil, leading to the development of cracks in the frozen soil. According to the findings of Lachenbruch (1962) and Mackay (1972), a rapid drop in sub-zero temperature is probably the best climatic environment for the development of thermally induced contraction cracks. The optimum conditions for crack development occur in early winter. According to Black (1976), a thermal change of 10°C causes a 10 m long segment of ice to change about 5 mm in length. Black (1952, 1960) measured ice-wedge cracks in Alaska and found that the rate of growth of ice wedges was 0.5–1 mm per year. Mackay (1974) carried out similar studies in the Mackenzie Delta area and found that the maximum annual growth of ice wedges over a six-year period was approximately 2 mm. Most wedges, according to Mackay (1974), grew far less than 1 mm per year because only 40% of the ice wedges under study cracked each year. Mackay (1974) also found that most cracks recur within 5–10 cm of the previous year's crack, that very few cracks are continuous for more than 3–4 m, and that the frequency of cracking is inversely related to depth of snow cover.

The average ice content of perennially frozen peat was found to range between 80 and 90% with some samples as high as 98% (Zoltai and Tarnocai 1975). The ice in perennially frozen peat was found to occur in the form of ice crystals and vein ice. The ice content of the underlying mineral soil was much more variable because this ice occurred in the form of various thicknesses of ice layers and ice lenses, with disseminated ice crystals in the bulk of the mineral soil. In general, the underlying coarse-textured soils had a lower ice content (50–60% on a volume basis) than did fine-textured soils (50–90%). The ice content of a high-centre polygon is shown in Figure 2–7.

The Polygonal Pattern

The average diameter of lowland polygons in the Mackenzie Delta is 8 m, although polygons of much larger diameter also occur. The development of the polygonal pattern associated with ice-wedge polygons has been theoretically examined by Lachenbruch (1962, 1966). He concluded that the angular intersection of the polygonal network of frost cracks will exhibit a preferred tendency towards an orthogonal pattern (an angular intersection of 90°). This conclusion, however, differs from a number of descriptions of polygonal ground (Leffingwell 1919; Black 1952) which indicate a tendency for a hexagonal junction (an angular intersection of 120°). Lachenbruch (1966) classified the polygonal network as a "random orthogonal system", in contrast to an "oriented orthogonal system". The latter system usually develops in the vicinity of large bodies of water.

Associated Peat Materials

Peat materials associated with low-centre polygons are shallow sedge and brown moss peat. As the polygonal peatland develops into a high-centre

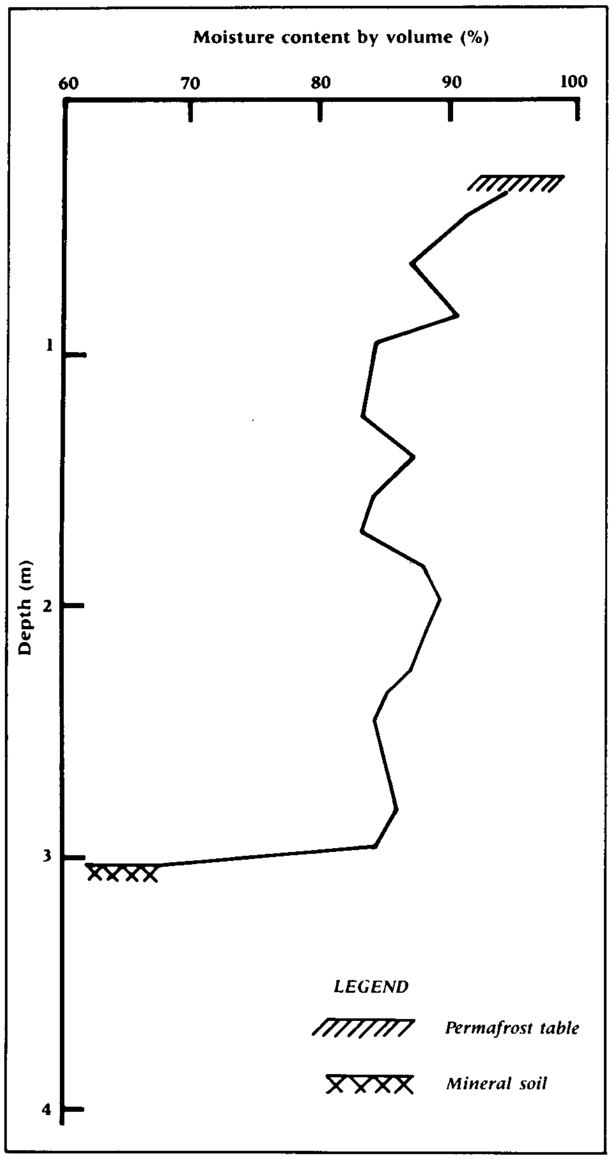


Figure 2–7.
Volumetric moisture content of a high-centre lowland polygon.

form, drainage improves and there is a resulting increase in the number and the cover of shrub species. As a result, woody sedge peat is associated with the upper portion of the peat deposit in these high-centre polygons.

The peat associated with high-centre lowland polygons is generally moderately or well decomposed, with a rubbed fibre content between 6 and 76% and a von Post value of 4 to 7. The peat is generally acid, ranging in pH from 3.4 to 6.9. The chemical and physical composition of peat materials from high-centre polygons in three locations is presented in Table 2–2. The analysis of these peat samples indicates that the carbon (C) content ranges

Vegetation

Low-centre polygons, because of their wetter soil conditions, support entirely different vegetation from that supported by the drier high-centre polygons.

The most commonly occurring species in the central part of low-centre polygons are *Carex rariflora* and *Drepanocladus uncinatus*. Small clumps of willow (*Salix* spp.) are also present, especially in the slightly better-drained locations. On the shoulders, because of their slightly higher position and, thus, better drainage, the vegetation is dominated mainly by grasses (*Poa alpina*), sedges (*Carex* spp.), and some lichens (*Cetraria cucullata*). Shrubs are generally

Table 2–2. Analytical data for peat materials from high-centre lowland polygon bogs

Soil horizon	Depth (cm)	Material	pH ($CaCl_2$)	Total C (%)	Total N (%)	CEC (me/100 g)	Exchangeable cations (me/100 g)				Fibre content		Ash (%)	Bulk density (g/cm^3)	Calorific value (cal/g)
							Ca	Mg	Na	K	Unrubbed (%)	Rubbed (%)			
Location: Lat. 69°26′ N, Long. 133°01′ W															
Oh	0–30	w–s	3.4	36.9	1.4	133.6	13.7	3.2	9.8	0.4	60	6	23.6	0.12	—
Ohz	30–40	w–s	3.5	47.3	1.5	176.8	35.0	7.9	13.5	0.4	52	8	7.6	0.15	—
Omz1	40–150	bm–s	3.9	37.8	1.7	134.2	26.9	9.2	2.7	0.3	78	40	11.3	0.07	—
Omz2	150–215	bm–s	4.0	45.1	1.8	134.2	36.7	11.0	1.3	0.2	76	40	9.7	0.05	—
Wz	215–268	pure ice	—	—	—	—	—	—	—	—	—	—	—	—	—
Cz	268–288	—	7.0	—	—	—	—	—	—	—	—	—	—	—	—
Location: Lat. 69°09′ N, Long. 134°17′ W															
Om	0–7	w	6.3	24.9	1.4	—	79.2	20.9	1.1	1.9	—	20	39.7	—	2 868
Ah	7–20	—	6.2	14.8	0.9	—	63.9	13.0	1.2	0.5	60	20	72.2	—	1 290
Ckgj	20–58	—	7.5	4.5	0.4	—	—	—	—	—	—	—	—	—	—
Ahz	58–65	—	7.4	15.3	1.1	—	—	—	—	—	68	20	72.2	—	1 569
Ckgjz	65–75	—	7.3	3.7	0.3	—	—	—	—	—	—	—	—	—	—
Omz1	75–80	bm	5.2	36.4	2.4	—	98.8	19.6	0.9	0.2	—	16	18.7	—	4 521
Ofz1	80–310	bm	6.7	25.6	1.5	—	83.5	16.4	0.5	0.2	100	76	38.9	—	3 161
Omz2	310–710	bm	5.6	36.2	2.4	—	91.5	16.5	0.3	0.3	60	30	14.8	—	4 644
Ofz2	710–735	s–bm	3.6	27.7	2.8	—	80.4	6.7	—	0.2	80	76	33.6	—	3 598
Ckgz	735+	sand	7.1	7.6	0.7	—	—	—	—	—	—	—	—	—	—
Location: Lat. 75°40′ N, Long. 97°40′ W															
Of	0–25	m	5.7	49.4	0.4	105.0	62.0	14.0	1.1	0.4	80	60	15.0	0.05	—
Ofz	25–78	m	5.9	52.5	0.3	105.0	63.0	19.0	0.9	0.3	72	60	12.0	0.05	—
Omz	78–130	s	6.9	37.8	0.3	75.0	59.0	18.0	0.8	0.4	52	42	28.0	0.08	—
Cz	130–150	sand	—	—	—	—	—	—	—	—	—	—	—	—	—

Peat materials: *w–s, woody–sedge; bm–s, brown moss–sedge; s–bm, sedge–brown moss; m, moss; s, sedge; w, wood.*
Soil horizons: *see Canada Soil Survey Committee (1978).*

between 25 and 52% while the nitrogen (N) content ranges between 0.3 and 2.8%. The ash content of these arctic peat materials, which ranges between 7.6 and 39.7%, is generally higher than that of peat materials in southern Canada. The bulk density is 0.13 g/cm^3 for woody peat and ranges from 0.05 to 0.15 g/cm^3 for other peat materials. Calorific values were determined for a peat profile sampled at latitude 69°09′ N, longitude 134°17′ W (Table 2–2), and ranged between 2 868 and 4 644 cal/g.

more common on the shoulders of these polygons than in the centre. The shrubs are dominated by birch (*Betula glandulosa*), willows, and *Empetrum nigrum*.

The vegetation on the high-centre polygons is dominated by low and high shrubs. The most common species are shrub birch, willows, *Rubus chamaemorus*, *Arctostaphylos rubra*, and *Empetrum nigrum*. Some grasses (*Poa* spp.) and lichens (*Cetraria cucullata*, *Cetraria nivalis*, and *Alectoria* spp.) are also present. Unvegetated surfaces commonly occur on high-centre polygons, resulting from continuous erosion, mainly by wind.

Age

Radiocarbon dates (for basal peat) determined for high-centre polygons give a range of dates between 4 250 and 10 100 years before the present (BP) (Table 2–3). Most of the dates, however, fall between 8 000 and 10 000 years BP, indicating that peat deposition began shortly after deglaciation.

The surfaces of a number of high-centre polygons have been strongly eroded. The age of this surface peat is dated between 1 890 and 8 260 years BP (Table 2–3). These surface dates indicate that this erosion is a long-term process.

Peat Mound Bogs

Peat mound bogs are small, peat-covered mounds, 1–5 m in diameter, that rise up to 1 m above the surface of the surrounding wetland (Figure 2–8, a and b). They usually occur in fens and other poorly drained wetland areas throughout the Arctic. The peat, which is generally 0.5–1.5 m thick, is perennially frozen. The active layer is 25–40 cm deep.

The largest peat mound bog reported by Blake (1974) during his investigation of peat mounds on Bathurst Island was 1.4 m high and 3.7 m in diameter. On August 11, 1963, this mound was frozen below a depth of 40 cm. Other mounds examined by Blake (1974) on July 2, 1963, were frozen below a depth of 21 cm. Peat thicknesses on these mounds

Table 2–3. Radiocarbon age (years before the present—BP) and rate of accumulation of peat deposits from high-centre lowland polygon bogs

Location and source of dates	*Sample location*	*Age (yr BP)*	*Lab. no.*	*Accumulation of peat based on intermittent dates (cm/100 yr)*
69°15′ N, 138°02′ W (Phillips Bay, Yukon)[1]	40 cm* 300 cm (basal)	8 260±110 10 100±130	BGS–196 BGS–197	— 14.13
69°07′ N, 132°56′ W (Eskimo Lakes, NWT)[1]	22 cm 318 cm (basal)	3 150±90 6 020±100	BGS–216 BGS–217	— 10.31
69°06′ N, 133°01′ W (Tuktoyaktuk, NWT)[2]	Surface peat	3 520±90	BGS–319	—
69°09′ N, 134°17′ W (Mackenzie Delta, NWT)[3]	58 cm* 310 cm 735 cm (basal)	1 890±60 4 810±60 8 850±90	Beta–11562 Beta–11564 Beta–11565	— 8.63 10.52
75°50.5′ N, 98°2.5′ W (Bathurst Island, NWT)[4]	Basal peat	9 210±170	GSC–180	—
75°50.5′ N, 98°2.5′ W (Bathurst Island, NWT)[5]	Basal peat	8 420±80	GSC–1887	—
Sherard Valley, (Melville Island, NWT)[6]	Basal peat	9 040±160	GSC–1708	—
75°40′ N, 97°40′ W (Bathurst Island, NWT)[3]	25 cm 78 cm 130 cm	5 070±60 5 830±70 6 160±90	GSC–2326 GSC–2355 GSC–2317	— 6.97 15.75
74°05′ N, 96°09′ W (Cornwallis Island, NWT)[3]	75 cm (basal)	6 590±100	GSC–2532	—
74°23′ N, 94°44′ W (Cornwallis Island, NWT)[3]	110 cm (basal)	4 670±60	GSC–2476	—
73°03′ N, 93°15′ W (Cornwallis Island, NWT)[3]	170 cm (basal)	4 580±80	GSC–2439	—
73°16′ N, 118°50′ W (Banks Island, NWT)[3]	15 cm 178 cm (basal)	2 800±100 4 250±100	BGS–698 BGS–699	— 11.24
71°56′ N, 123°14′ W (Banks Island, NWT)[7]	61 cm 244 cm (basal)	6 940±110 9 820±220	GSC–10 GSC–197	— 6.35

Sources of radiocarbon dates: [1]Zoltai and Tarnocai (1975), [2]Pettapiece *et al.* (1978), [3]this paper, [4]Blake (1964), [5]Lowdon and Blake (1975), [6]Barnett (1973), and [7]Dyck and Fyles (1963).

**Top of peat deposit.*

(a)

(b)

Figure 2–8.
Peat mound bogs (a and b) developed in a fen near Kazan River, Keewatin District, NWT. The auger in photograph (a) is approximately 1 m high.

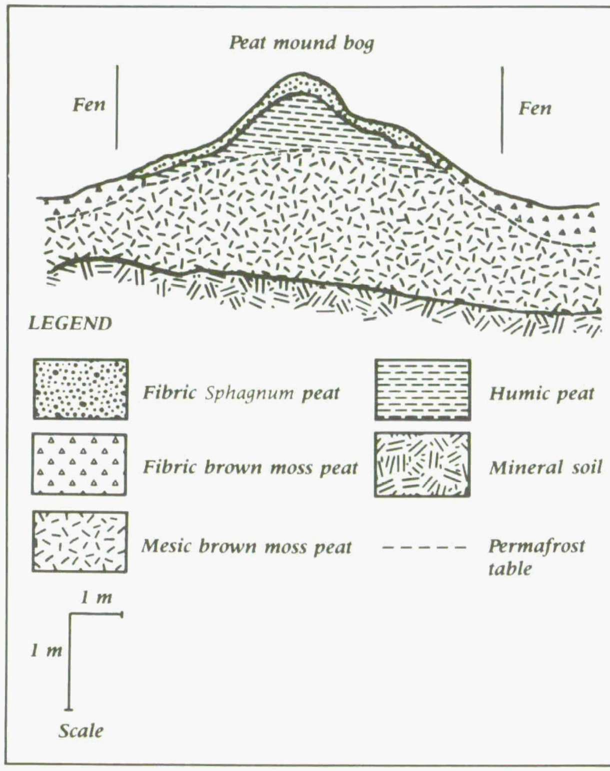


Figure 2–9.
Cross-section of a peat mound bog in a fen near Kazan River, NWT. The position of the permafrost table on July 18, 1976, is showed by a dashed line.

ranged between 2.6 and 3.3 m. Flugel and Mausbacher (1981) described two peat mounds found on Ellesmere Island, the larger one approximately 5.5 m in diameter and 40 cm high. Hodgson (1982) described small ice-cored mounds, 1–5 m in diameter and up to 1 m high, found on Amund Ringnes Island. One of these mounds was cored and found to have an organic-rich active layer 20 cm deep underlain by 60 cm of sand with a high content of ice and 35 cm of pure ice. Below a depth of 115 cm in this mound the ice content dropped to a low level. Washburn (1983a) described peaty mounds found near Resolute on Cornwallis Island. These dome-shaped mounds were up to 60 cm high and 8 m in diameter with an active layer that was approximately 20 cm deep. In addition, Washburn (1983a) reported that mounds of similar height but more irregular form also occur on Cornwallis Island, while others occur as part of low plateau-like rises 1–2 m high and up to 1 600 m^2 in area. His conclusion was that peaty mounds that are 50 cm or more high and 2 m or more in diameter should be regarded as palsas. In a subsequent study, Washburn (1983b) reviewed the term "palsa" as used in the literature and pointed out that a number of authors regard these peat mounds as an arctic variety of palsa.

A peat mound bog in the Kazan River area (67°32′ N, 94°03′ W) was cored (Figures 2–8 and 2–9) and the analytical data obtained from the peat samples are presented in Table 2–4. The uppermost sample shows that at a depth of 35 cm the humic *Sphagnum* peat has a high level of nutrients. Samples from the lower depths also show relatively high levels of nutrients. Although this peat mound is located on the Canadian Shield, it is within the zone of post-glacial marine submergence, and nutrients such as calcium (Ca) and magnesium (Mg) are abundant in the soil. This is reflected in the mineral composition of the peat.

One of the peat mounds examined by Washburn (1983a) on Cornwallis Island had 94.5 cm of peat underlain by pebbly silt. The active layer was found to be 15 cm deep. The ice in the frozen peat layer was predominantly disseminated ice, while the ice in the underlying mineral layer consisted of predominantly clear ice masses.

The elevated peat mounds are better drained than the surrounding wetlands and in the Low Arctic Wetland Region they are dominated by *Sphagnum* mosses, mainly *Sphagnum fuscum*. Other species occurring on these peat mounds are *Rubus chamaemorus, Ledum palustre* var. *decumbens, Andromeda polifolia, Vaccinium uliginosum, Vaccinium vitis-idaea, Betula glandulosa*, and mosses such as *Dicranum elongatum* and *Polytrichum strictum*. The lichen *Ichmadophila ericetorum* also occurs. Peat mounds in the Mid- and High Arctic Wetland Regions are commonly associated with a dense carpet of mosses.

Washburn (1983a) explains the origin and development of peat mounds as follows. The growth of segregated ice, which is responsible for the doming of the mound, begins with the general thinning of a deeper active layer as a result of accumulation of peat on the surface. This thinning of the active layer and the thinner snow cover in winter lead to lower soil temperatures. This causes a greater degree of cooling than occurs in the area adjacent to the mound and triggers the movement of unfrozen water within the perennially frozen part of the mound. As the permafrost table rises locally, ice builds up as a result of water migration into the colder, perennially frozen mound. Some mounds form at the base of slopes, resulting in the development of both injection ice and segregated ice beneath and within the peaty layer (Washburn 1983a).

In summary, the presence of insulating surface peat, the development of segregated ice in the perennially frozen part of the mound, and the lower soil temperatures in the mound are the main factors in the development of a peat mound.

It is generally thought that the development and, especially, the doming of palsas result from ice segregation in the perennially frozen core. According to Washburn (1983a), the development of some palsas is also due to injection ice. As he pointed out (1983a), the development of peat mounds, as it relates to the origin of ice and its mounded form, is very similar to that of palsas and thus peat mounds can be regarded as an arctic variety of palsa.

The basal peat material of the mound is predominantly mesic peat composed mainly of brown mosses (*Drepanocladus* sp.) and sedges. This peat is generally overlain by fibric to mesic moss peat composed mainly of *Sphagnum* and *Dicranum* mosses. The ash content of the brown moss peat is generally high (20–30%). The pH value of the peat is between 5 and 6 while the pH value of the surface of the mound is usually less than 4. The associated soils are Mesic Organic Cryosols.

Table 2–4. Total elemental analysis and other properties of peat from a peat mound bog (Kazan River area, NWT)

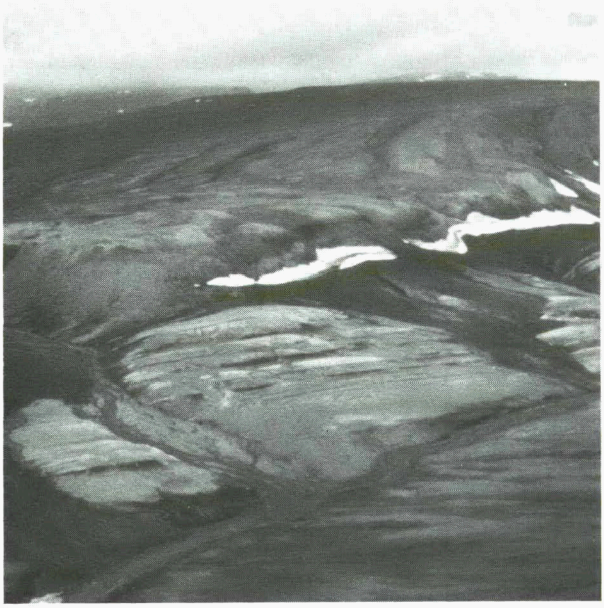
Sample depth (cm)	pH (H_2O)	Material	Decomp. (von Post)	Ash (%)	Ca (mg/kg)	Mg (mg/kg)	K (mg/kg)	Fe (mg/kg)	S (mg/kg)
35	5.0	*Sphagnum*	8	43.5	6 812	1 878	1 278	11 375	3 350
46	5.6	Sedge–moss	5	24.1	9 379	1 557	1 543	12 097	4 032
60	5.7	Sedge–moss	5	25.5	8 818	1 670	1 043	13 081	3 798
77	5.8	Sedge–moss	6	23.1	10 687	1 856	1 090	15 567	4 400
97	5.9	Sedge–moss	6	20.9	12 979	2 188	1 085	12 492	6 433
108	5.8	Sedge–moss	6	37.3	9 962	2 961	1 801	9 525	3 548
119	5.5	Sedge–moss	7	39.4	8 650	2 183	1 270	10 017	3 069
122	—	Mineral soil	—	—	—	—	—	—	—

Snowpatch Fens

In the High Arctic Wetland Region the meagre snowfall is often redistributed by the wind. Some slopes and ridges are blown clear of snow and this snow accumulates below the brows of the hills, on the lee side. This snow, with an annual accumulation of up to 2 m, thaws during the summer and provides a steady source of water for the slopes below. However, in many instances all of the snow does not melt during the summer and the snowpatch becomes a perennial feature. If the slope below the snowpatch is gentle (less than 3%), the meltwaters may not run off in channels but as a broad flowing sheet. Under such circumstances small snowpatch fens become established on the slopes, nourished by the meltwaters that usually contain some wind-borne mineral grains (Figure 2–10, a and b).

The peat in these fens is generally less than 20 cm thick and is composed of fibric to mesic sedge and moss remains. It is underlain by heavily gleyed mineral soil. The main vegetation cover is provided by *Carex aquatilis* var. *stans* and *Eriophorum scheuchzeri*. Other vascular species include *Alopecurus alpinus*, *Carex misandra*, *Juncus biglumis*, *Polygonum viviparum*, *Saxifraga hirculus*, and *Pedicularis arctica*. The main moss species are *Drepanocladus brevifolius*, *Drepanocladus revolvens*, *Campylium arcticum*, and *Bryum* spp.

(a)



(b)

Figure 2–10.
Vegetated areas are snowpatch fens with seepage water fed by the snowbanks (a). A close-up of such a snowpatch fen with the snowbank above it is shown in (b). Both photographs were taken on Axel Heiberg Island, NWT.

Although peat development is usually less than 20 cm thick, this represents near-maximum peat formation in a high arctic environment. Snowpatch fens display a luxuriant growth within a generally bleak environment.

Basin Fens

Basin fens occur in topographic depressions where water inflow is restricted to drainage from the surrounding slopes. Permafrost underlies the entire fen and the active layer is between 40 and 80 cm deep. The peat cover is 50 to 100 cm thick and these basin fens are sometimes associated with peat mounds.

The basal peat material is generally mesic peat composed mainly of brown mosses (*Drepanocladus* sp.) and some sedge remains. Layers of humic aquatic peat may occur within this peat. The brown moss peat usually extends to the surface. The ash content of the brown moss peat is generally high, with values between 20 and 30% being common. Mineral grains and small stones can often be found within this peat, possibly having been worked up by cryoturbation through the peat from the underlying mineral soil. The pH value of the peat is between 5 and 6. The associated soils are Mesic and Humic Organic Cryosols.

The vegetation is dominated by sedges such as *Carex aquatilis* var. *stans*, *Carex chordorrhiza*, *Carex membranacea*, *Eriophorum angustifolium* ssp. *triste*, *Eriophorum vaginatum* var. *spissum*, and mosses such as *Drepanocladus aduncus*, *Drepanocladus fluitans*, and *Scorpidium scorpioides*. They provide nearly complete cover. The only shrub present is the occasional, widely scattered *Salix arctica*. Broad-leaved herbs are rare and inconspicuous; lichens are absent.

Tundra Pool Shallow Waters

Scattered throughout the meadows of the Mid- and High Arctic Wetland Regions there are small pools (usually less than 1 ha in area) with shallow water (less than 50 cm deep). These are usually bordered by peaty shores which drop off steeply into the pools (Figure 2–11, a and b).

The vegetation in the deeper part of the pools (up to a depth of 30 cm) consists mostly of *Hippuris vulgaris*, with *Pleuropogon sabinei* in somewhat shallower water. In the near-shore shallows, *Carex aquatilis* var. *stans* is the dominant plant along with *Eriophorum scheuchzeri*, *Carex saxatilis* var. *rhomalea*, *Ranunculus aquatilis*, and submerged *Drepanocladus*

(a)

(b)

Figure 2–11.
Various sizes of shallow water bodies in a wetland complex in (a) the Tuktoyaktuk area and (b) a tundra pool with vegetated shoreline on Bylot Island, NWT.

revolvens. The peaty mat surrounding the pools consists of mosses (*Tomenthypnum nitens*, *Aulacomnium palustre*, *Hypnum bambergeri*, *Philonotis fontana*, and *Campylium arcticum*) and vascular plants such as *Carex saxatilis*, *Eriophorum scheuchzeri*, *Juncus biglumis*, *Pedicularis arctica*, and *Saxifraga hirculus*.

Floodplain Marshes

Floodplain marshes occur in active floodplains adjacent to channels. Since the water levels are controlled by river water levels, these marshes usually have a high water level during the spring flood period and a low water level during the fall. In river estuaries, especially close to the sea, floodplain marshes are usually affected by tides. In the Mackenzie River Delta, floodplain marshes cover a strip several tens of metres wide along the channels (Figure 2–12, a and b).

Floodplain marshes were examined at a number of locations in the Mackenzie Delta and on the islands on the east side of Kittigazuit Bay. Permafrost was found to be present in all locations. Large portions of the floodplain marshes, especially those occurring on the outer islands, are affected by tides. Although the tide is relatively small, the low-lying parts of the islands are under water during high tides. This water is still fresh, however, because of the large amount of fresh water discharged by the Mackenzie River.

A floodplain marsh on one of the islands in the Kittigazuit Bay area was examined in detail (Figure 2–13). The vegetation associated with this marsh is a grass–*Equisetum* community. Permafrost occurred at a depth of 120–150 cm. Other floodplain marshes with similar vegetation examined on adjacent islands had permafrost at a depth of 50–90 cm. The soil on this wetland is a poorly drained Rego Gleysol with a silt loam texture. Since these floodplain marshes annually receive heavy sedimentation, scarcely any surface build-up of organic matter is associated with these soils.

Floodplain Swamps

Floodplain swamps occur in deltas with open drainage resulting from unrestricted connection to active channels. The water level of these swamps is therefore usually at its highest during the spring breakup, recedes continuously during the summer, and is generally lowest in the fall. Floodplain swamps occur on a number of islands in the Kittigazuit Bay area of the Mackenzie Delta (Figures 2–12 and 2–13). The floodplain swamps found in this lower part of the delta are periodically flooded throughout the summer season as a result of high tides, wind tides, and increases in the water level of the river.

The floodplain swamps are covered with tall willows (2–3 m), mainly *Salix alaxensis*. These willows usually form distinct vegetation communities with sedges, grasses, or *Equisetum* spp.

The thickness of the active layer on the floodplain swamps is between 130 and 150 cm. The soils are predominantly Regosolic Static Cryosols with cumulic alluvial layers, indicating that these soils receive heavy annual sedimentation. As a result of this sedimentation there is very little build-up of organic matter.

(a)

(b)

Figure 2–12.
(a) Marsh-covered islands and (b) the transition from a floodplain marsh at the water's edge (1) to an active delta marsh (2) and then to a willow-covered floodplain swamp (3). East Channel of the Mackenzie River near Kittigazuit Bay, NWT.

Active Delta Marshes

Active delta marshes are usually associated with floodplain swamps. These marshes, however, are located on the higher portion of the delta and are inundated only during spring floods (Figure 2–12b).

Most of the active delta marshes are covered by a low willow community with patches of sedge–grass. The common species in the shrub layer are *Salix lanata* and *Salix alaxensis*, while the most common species in the forb layer are *Carex aquatilis*, *Eriophorum vaginatum*, and *Eriophorum angustifolium* (Reid and Calder 1977). Old, filled-in river channels within this form of marsh are covered with sedge–grass communities. An example of this form of wetland and its association with floodplain marshes and floodplain swamps is shown in Figure 2–13.

The thickness of the active layer on active delta marshes is 90–100 cm. On unvegetated areas, however, the thickness of the active layer is approximately 180 cm. Soils associated with these wetlands are predominantly Regosolic Static Cryosols. Since there is heavy annual sedimentation, scarcely any build-up of organic matter is associated with these soils.

Other Shallow Waters

Shallow water refers to semi-permanent or permanent, standing or flowing water bodies with relatively large and stable expanses of open water. These are known locally as ponds, pools, shallow basins, bays, lagoons, oxbows, or channels. Shallow waters are less than 2 m deep, although this depth may occasionally be exceeded during abnormal floods. During late summer or intertidal periods these shallow water bodies may temporarily dry out (Figure 2–11, a and b).

The margins of shallow waters may be vegetated, especially in the Low Arctic Wetland Region, by submerged and floating aquatic plants. The shallow waters in the Mid- and High Arctic Wetland Regions, however, generally have unvegetated shorelines.

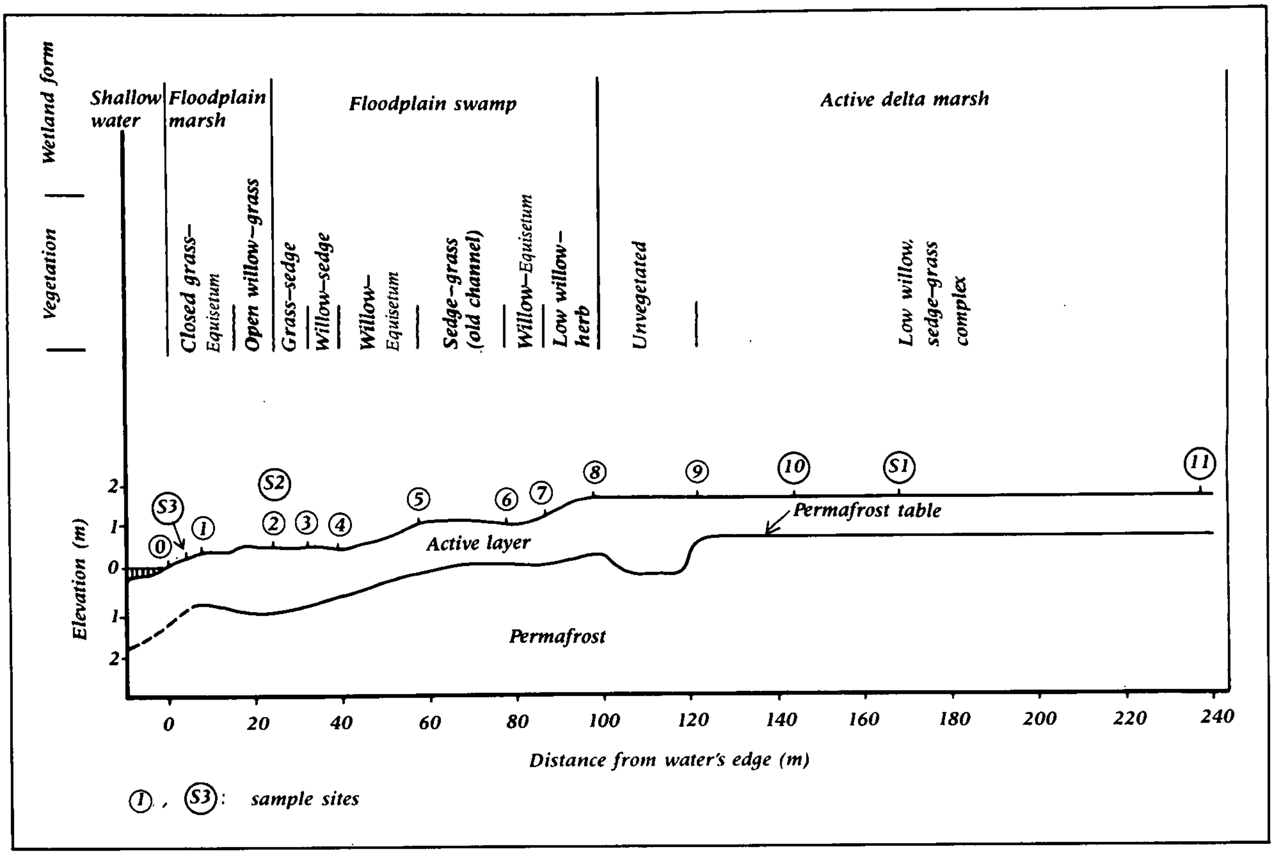


Figure 2–13.
A transect located at Lat. 69°22′ N, Long. 134°02′ W in the Kittigazuit Bay area, Mackenzie Delta, showing various wetlands.

The transect located at Kittigazuit Bay, shown in Figure 2–13, starts from the shallow water. Sample site 0 on this transect marks the shoreward edge of the shallow water. This site also indicates the low tide level at the time the study was carried out. On site 0, permafrost was found at a depth of 130 cm. This and other observations in the Mackenzie Delta area indicate that most of the shallow waters in the Low Arctic Wetland Region are underlain by permafrost. Similar conditions are thought to exist in the Mid- and High Arctic Wetland Regions.

Dynamics of Arctic Wetlands

Formation of Arctic Wetlands

Factors affecting the development of an arctic wetland ecosystem include time, climate, permafrost, hydrology, relief, vegetation, and organisms. The interaction of these factors produces a particular form of wetland. However, the wetland ecosystem may change with time because of changes occurring in some of these factors; these changes result in a new wetland ecosystem. Changes in wetlands, and especially in those wetlands associated with organic deposits, are recorded by the various peat layers. These peat layers differ in botanical composition, indicating a change in vegetation, decomposition (organisms), or nutrient status (hydrology and relief).

Reconstruction of the environment of those arctic wetlands associated with organic deposits (peatlands) suggests that gradual build-up is the most commonly occurring depositional process. There may, for instance, be a thin, mixed organic–mineral layer at the base, covered by brown moss–sedge peat, which is covered in turn by woody peat material derived from shrubby vegetation. This sequence suggests a gradual peat build-up in a poorly drained basin, where the water table was always at the surface and where there was some influx of waters relatively rich in cations, especially calcium. Permafrost is associated with this system from the beginning of its development. Its presence is indicated by the basal mixing at the mineral–organic interface.

The depositional process resulting from infilling of organic materials, commonly found in southern wetlands, is not common in the Arctic. In southern wetlands this process begins with a shallow pond, as shown by basal deposition of organic detritus of marl, gastropods, or sedimentary peat. Occasionally these materials occur in the basal peat of lowland polygons in the Mackenzie Delta area. This has been interpreted, however, as indicating that these basal materials were deposited during the time (approximately 8 000 years ago) when the climate was much warmer than it is at present (Nichols 1969; Ritchie and Hare 1971; Terasmae 1972).

Infilling by mineral sediments is common in delta marshes in the Arctic. Mineral-rich waters are thus a very important factor in maintaining the high productivity of delta marshes such as those occurring in the Mackenzie Delta.

The internal morphology of arctic peatlands (e.g. lowland polygons) suggests that they were deposited in a permafrost environment. Excessive mixing of organic and mineral materials is commonly observed (Zoltai and Tarnocai 1975). Large cobbles can be seen on the surface of lowland polygons, near the polygon trench. These stones were heaved by frost action from the underlying mineral soil to the surface through as much as 2 m of peat. This mixing and the presence of organic or mineral intrusions at the mineral–organic interface suggest that soil movement is common in the active layer above the permafrost. Permafrost now underlies all the components of lowland polygons and all observations suggest that this condition occurred while the polygons were developing, specifically when they were in the low-centre polygon phase.

High-centre polygons have been regarded as an eroding, melting phase in which the ice wedges are inactive (Price 1972). The consistently greater thickness of peat in high-centre polygons, however, suggests that peat formation contributes to the different surface morphology. In the field, a complete range from low-centre to high-centre polygons is observed. It has been found that the polygon shoulders became thicker and the enclosed pools smaller as the peat accumulated, until the surface became level. The development of a domed centre, characteristic of high-centre polygons, may be due to partial melting of the ice wedge during a senescent stage (Price 1972). In some instances, near lake shores or on gentle slopes, the polygonal trenches may be excessively deepened by running water (Péwé 1966).

Arctic wetlands were formed by the particular environmental parameters prevalent in the Arctic. In some cases they may resemble wetlands occurring elsewhere, but closer examination usually reveals some basic differences. Thus, wetlands with low, narrow ridges were found, which resemble the ribbed fens described in the chapters on subarctic and boreal wetlands in this book. Such "string bogs" (Henoch 1960) were found to have a mineral soil core and are believed to be a solifluction phenomenon (Rowe *et al.* 1977). Other low ridges resemble those of ribbed fens, originating as rows of organic debris. They differ from the southern ribbed fens, however, since their height increases through injection of frost-heaved soil and not just by differential peat formation as in the more southern climates (Rowe *et al.* 1977).

Peat Accumulation

Accumulation of peat, based on the radiocarbon dates presented in Table 2–3, was calculated for a number of locations in the arctic wetland regions. Peat accumulation data also presented in Table 2–3 indicate intermittent accumulation within a given section of the deposit. The rate of peat accumulation is based on the peat thickness between dated layers. Variation in the rate of peat deposition was found between the various sections within the peat deposit.

A peat deposit with a thickness of 260 cm associated with a high-centre polygon in the Phillips Bay area, Yukon (Table 2–3), is composed entirely of sedge peat. The peat in this deposit accumulated at a rate of 14.13 cm/100 yr between 8 260 and 10 100 years BP. This peat deposit is capped by a sandy aeolian layer between 0 and 40 cm. This aeolian layer is associated with a well-developed Brunisolic soil. A peat deposit in the Eskimo Lakes area, Northwest Territories, is composed of moss and woody sedge peat. This peat deposit accumulated at a rate of 10.31 cm/100 yr between 3 150 and 6 020 years BP.

Peat materials from depths of 58, 310, and 735 cm at a Mackenzie Delta site (Table 2–3) were dated. The date from the sample obtained at 735 cm represents the age of the basal peat or the beginning of the peat deposition. At depths between 58 and 310 cm (between 1 890 and 4 810 years BP) woody moss peat accumulated at a rate of 8.63 cm/100 yr, and at depths between 310 and 735 cm (between 4 810 and 8 850 years BP) brown moss peat was deposited at a rate of 10.52 cm/100 yr.

A peat deposit on Bathurst Island (Table 2–3) accumulated at a rate of 6.97 cm/100 yr between 5 070 and 5 830 years BP and 15.75 cm/100 yr between 5 830 and 6 160 years BP. Another peat deposit on Banks Island (Table 2–3) occurs in a highly eroded, high-centre polygon composed of fibric brown moss peat (mainly *Drepanocladus* sp.). There is no living vegetation on the surface, which consists of strongly oxidized, reddish peat. The rate of peat accumulation at this site between 2 800 and 4 250 years BP was 11.24 cm/100 yr.

These rates of peat deposition between dated layers are shown on the block diagram in Figure 2–14 and are divided according to occurrence in the Low, Mid-, and High Arctic Wetland Regions. This figure indicates not only that the rate of peat deposition has not been uniform but also that the rate of peat deposition was much higher during the early stage of peat accumulation, between 5 000 and 10 000 years BP. Following this period, the rate of accumulation decreased in both the Low and High Arctic Wetland Regions. When the rates of peat accumulation in the High and Low Arctic Wetland Regions are compared, it can be seen that the high arctic peats accumulated at a greater rate between 5 000 and 10 000 years BP than did the low arctic peats.

These differences in the rate of peat accumulation in various parts of the Arctic were probably due to the effect of climate. The climate, as was mentioned in a previous section, was much warmer for several thousand years (5 000–10 000 years) after deglaciation (Nichols 1969; Ritchie and Hare 1971; Terasmae 1972) and then gradually became cooler. Especially rapid cooling occurred about 4 000–5 000 years BP. After this period the climate further deteriorated in the High Arctic Wetland Region causing peat formation almost to cease. Accumulation did continue, however, in the Low Arctic Wetland Region but at a slower rate. The greater rate of peat accumulation in the High Arctic Wetland Region between 5 000 and 10 000 years BP was probably the result of a climate that was moister than that which now exists in the Low Arctic Wetland Region. This climatic condition contributed to higher biomass production in that region.

These rates of peat accumulation were calculated using depths measured primarily in perennially frozen peat. The moisture (ice) content of the frozen peat was similar to that of the unfrozen wet peat, and thus it was assumed that there was little volume change due to ice build-up in the perennially frozen peat layer.

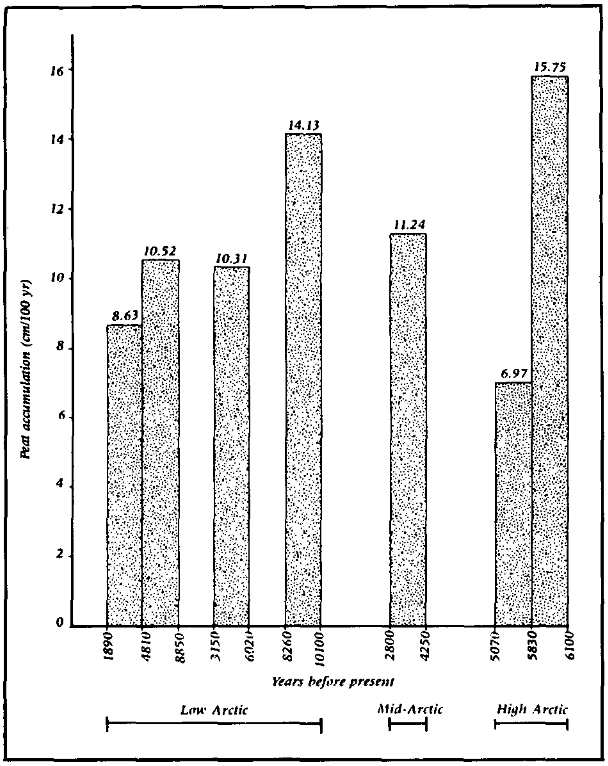


Figure 2–14.
The rate of peat accumulation at various periods in the Low, Mid-, and High Arctic Wetland Regions.

Age of Arctic Peatlands

Radiocarbon dates determined from various peat deposits (Table 2–3) indicate that peat deposition began in arctic Canada shortly before 10 000 years BP. The oldest date, obtained from the north slope of Yukon, was 10 100 ± 130 years BP. This date was from the basal peat of a high-centre lowland polygon. Other basal peat dates ranged between 4 250 and 9 820 years BP (Table 2–3).

These dates indicate that peat development in arctic areas began shortly after deglaciation and, as was suggested by Tarnocai (1978), this probably resulted from favourable climatic conditions in the arctic wetland regions at that time. There is evidence that, after the retreat of glacial ice from the North American continent, there was a relatively warm and dry period lasting several thousand years (Ritchie and Hare 1971; Terasmae 1972; Delorme *et al.* 1977). It is possible that during this period it was generally too warm and dry for optimum peat development in the south. In the arctic areas, however, the climate was assumed to have been cooler and moister (although warmer than at present) after the retreat of glacial ice and, consequently, conditions were favourable for peat development. As the climate became colder, peat development virtually ceased in the High and Mid-Arctic Wetland Regions and slowed in the Low Arctic Wetland Region, with the boreal and subarctic wetland regions becoming established as the areas of optimum peat development.

Stability of Arctic Wetlands

Arctic wetlands, in general, are considered to be very fragile. Damage caused by nature or man is slow to heal. This is partly due to the presence of permafrost and to low biological productivity. Damage done to the surface organic layer changes the thermal regime and initiates melting and subsidence. The slow biological productivity of the vegetation hinders the repairing of this damage. As a result, the effects of disturbance are evident for a long period of time.

Increased human activity in arctic Canada during the past two decades has resulted in greater use of wetlands. The initial lack of knowledge concerning these wetlands resulted in activities that caused considerable damage. Subsequently, studies of wetland use were carried out (Kurfurst 1973; Strang 1973) and, as a result of the experience gained, land use practices and regulations as well as some engineering practices were modified to eliminate, or at least minimize, the damage.

Frozen peatlands in northern Canada have a cyclic nature with developing, mature, over-mature, and eroding stages. When marshes are subjected to sedimentation from rivers, the resulting deposition changes the water regime. If this change in water regime were drastic enough, the wetlands could cease to exist. Wildfires can initiate the thawing and eventual collapse of perennially frozen peatlands in the southern fringes of the boreal wetland regions. In the Arctic, however, the soil temperature is much lower than in boreal regions and the effect of these fires is only minimal (Strang 1973).

Seismic operations carried out during the summer months in the 1960s created a great deal of surface disturbance with subsequent melting and subsidence. However, seismic operations are now carried out during the winter months and this greatly minimizes surface disturbance and thus causes little or no permafrost degradation (Strang 1973).

Arctic Wetland Values and Conservation

In the arid Arctic, wetlands provide oases in which vegetation and animal life abound. The lowland polygons, tundra pools, and associated wet meadows serve as nesting sites and summering areas for countless waterfowl that depend on the water bodies for food and protection and on the adjoining meadows for food.

Geese are especially abundant in arctic wetlands, many of which are internationally significant for waterfowl and migratory birds. Canada Geese (*Branta canadensis*) nest on islets in ponds or lakes (Bellrose 1976) and feed in the adjoining sedge meadows. Brant (*Branta bernicla*) generally nest in coastal meadows. They feed almost exclusively on vegetation, especially on sedges (Barry 1967). Snow Geese (*Anser caerulescens*) are especially abundant in arctic lowlands such as the Great Plain of the Koukdjuak on Baffin Island, nesting in low, grassy tundra, feeding on grasses and sedges (Palmer 1976). About 30–50% of the North American breeding population of Greater Snow Geese (*Anser caerulescens atlanticus*) are found on the lowlands bordering Admiralty Inlet on Baffin Island and on the adjoining Bylot Island (Heyland and Boyd 1970). Greater White-fronted Geese (*Anser albifrons frontalis*), along with Canada Geese and Snow Geese, are concentrated in tundra ponds and sedge-dominated wet areas on the Rasmussen Lowland at the base of the Boothia Peninsula (Allen and Hogg 1978). Up to one million nesting birds concentrate in the wetlands of southwestern Baffin Island each summer.

It is estimated that, in the summer, two-thirds of Canada's Tundra Swan (*Cygnus columbianus*) population, about 20 000 birds, are concentrated on the Mackenzie and Anderson river deltas (Bellrose 1976). They nest adjacent to ponds or on islands in tundra pools, lakes, or sluggish rivers and feed mainly on the tubers and stems of aquatic plants growing in the ponds (Palmer 1976).

Among the mammals, muskoxen are very dependent on wetland habitats (Russell *et al.* 1978). They feed on hydric sedge meadows almost exclusively, although in the summer they also browse on *Salix* spp. in the uplands. The main forage species are *Carex membranacea, Carex aquatilis* var. *stans, Eriophorum triste,* and *Salix arctica.* A wide range of other species is also to some degree dependent on arctic wetland habitats. These species include red fox, arctic hare, wolf, weasel, polar bear, and barren-ground caribou.

Arctic wetlands are not only valued for their waterfowl and wildlife. They are often the most biologically productive component of the arctic ecosystem and are vital to water storage in an environment that is generally water-poor after the first few weeks of the spring melt. In addition, coastal wetlands are essential to the survival and reproduction of many species of freshwater and marine fish as well as shellfish and invertebrates.

Conservation of wetlands and northern ecosystems has recently been identified as a national priority in Canada's response to the World Conservation Strategy (Environment Canada 1986). Northern wetlands are thus a vital component in national conservation efforts. Rubec and Lynch-Stewart (1987) have identified a range of key requirements for the conservation of northern wetlands and have reviewed their values. They note that there is a need for improved wetland inventory in the North, for protection of essential, highly sensitive, and regionally representative wetlands, and for evaluation and research on the response of wetland ecosystems to the impact of such factors as oil spills, acid precipitation, and toxic chemicals.

They estimate that 22% of the 278 000 km² of wetlands in the Northwest Territories and Yukon are now in some way legally protected within national or territorial wildlife areas, migratory bird sanctuaries, reserves, parks, or game sanctuaries. Protected wetland areas in the three arctic wetland regions include those within the Northern Ellesmere, Northern Yukon, and Auyuittuq national park reserves; Polar Bear Pass National Wildlife Area; Kendall Island, Bylot Island, Queen Maud Gulf, Banks Island, Harry Gibbons, East Bay, Anderson Delta, Dewey Soper, and McConnell River national migratory bird sanctuaries; and the Bowman Bay and Thelon territorial game sanctuaries.

Acknowledgements

The authors wish to thank the following individuals for their review comments and suggestions for this text: H. Hirvonen, D. Kelly, W. Glooschenko, E. Oswald, and C. Rubec.

References

ALLEN, D.L., AND T.H. HOGG. 1978. Bird studies in the Keewatin District. Environmental –Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. AI-27. 129 p.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals 1951–1980. Volume 2: Temperature; Volume 3: Precipitation; Volume 4: Degree-days. Environment Canada. Downsview, Ontario.

BARNETT, D.M. 1973. Radiocarbon dates from eastern Melville Island. Report of Activities Part B. Geological Survey of Canada. Paper 73-1B. Ottawa, Ontario. pp. 137–140.

BARRY, T.W. 1967. Geese of the Anderson River Delta, Northwest Territories. Ph.D. thesis, University of Alberta, Edmonton, Alberta. Unpublished. 212 p.

BELLROSE, F.C. 1976. Ducks, geese, and swans of North America. Stackpole Books. Harrisburg, Pennsylvania. 544 p.

BLACK, R.F. 1952. Growth of ice wedge polygons in permafrost near Barrow, Alaska. Geological Society of America Bulletin 63:1235–1236.

BLACK, R.F. 1960. Ice wedges in northern Alaska. Abstract of Paper, 19th International Geographical Congress. Stockholm, Sweden. 26 p.

BLACK, R.F. 1976. Periglacial features indicative of permafrost: ice and soil wedges. Quaternary Research 6:3–26.

BLAKE, W. 1964. Preliminary account of the glacial history of Bathurst Island, Arctic Archipelago. Geological Survey of Canada. Paper 64-30. Ottawa, Ontario. 8 p.

BLAKE, W. 1974. Periglacial features and landscape evolution, central Bathurst Island, District of Franklin. Geological Survey of Canada. Paper 74-1B. Ottawa, Ontario. pp. 235–244.

BLISS, L.C. 1977. Introduction. *In* Truelove Lowland, Devon Island, Canada: a high arctic ecosystem. L.C. Bliss, editor. University of Alberta Press. Edmonton, Alberta. pp. 1–11.

BLISS, L.C. 1979. Arctic heathlands. *In* Ecosystems of the world. 9A. Heathlands and related shrublands: descriptive studies. R.L. Specht, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 415–424.

BLISS, L.C., G.M. COURTIN, D.L. PATTIE, R.R. RIEWE, D.W.A. WHITFIELD, AND P. WIDDEN. 1973. Arctic tundra ecosystems. Annual Review of Ecology and Systematics 4:359–399.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 9–30.

BOTCH, M.S. 1974. Bogs in the tundra zone of Siberia. *In* Bog types of the USSR and principles of their classification. Translation. National Research Council of Canada. Technical Translation No. 1925. Ottawa, Ontario. pp. 146–154.

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication No. 1646. Ottawa, Ontario. 164 p.

DELORME, L.D., S.C. ZOLTAI, AND L.L. KALAS. 1977. Freshwater shelled invertebrate indicators of paleoclimate in northwestern Canada during late glacial times. Canadian Journal of Earth Sciences 14:2029–2046.

DYCK, W., AND J.G. FYLES. 1963. Geological Survey of Canada radiocarbon dates, I and II. Geological Survey of Canada. Paper 63-21. Ottawa, Ontario. 31 p.

EDLUND, S.A. 1986. Vegetation–geology–climate relationships of Western Melville Island, District of Franklin. Geological Survey of Canada. Paper 86-1A. Ottawa, Ontario. pp. 719–726.

ENVIRONMENT CANADA. 1986. World conservation strategy—Canada, a report on achievements in conservation. Report to Conference on Conservation and Development. Ottawa, Ontario. June 1986. 61 p.

FLUGEL, W.-A., AND R. MAUSBACHER. 1981. Beobachtungen zu organischen Kleinformen im Oobloyah Tal, N-Ellesmere Island, NWT, Kanada. *In* Ergebnisse der Heidelberg-Ellesmere Island-Expedition. D. Barsch and L. King, editors. Heidelberger Geographisches Arbeiten 69:559–563.

HENOCH, W.E.S. 1960. String-bogs in the arctic 400 miles north of the tree-line. Geographical Journal 126:335–339.

HEYLAND, J.D., AND H. BOYD. 1970. An aerial reconnaissance of the eastern Canadian Arctic, 20–29 July, 1969, in search of Greater Snow Geese. Canadian Wildlife Service, Environment Canada. Ottawa, Ontario. Unpublished. 29 p.

HODGSON, D.A. 1982. Surficial materials and geomorphological processes, western Sverdrup and adjacent islands, District of Franklin. Geological Survey of Canada. Paper 81-9. Ottawa, Ontario. 46 p.

KURFURST, P.J. 1973. Terrain disturbance susceptibility, Norman Wells area, Mackenzie Valley. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-24. 36 p.

LACHENBRUCH, A.H. 1962. Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost. Geological Society of America. Special Paper No. 70. 69 p.

LACHENBRUCH, A.H. 1966. Contraction theory of ice wedge polygons: a qualitative discussion. Proceedings, 1st International Permafrost Conference. National Academy of Science–National Research Council. Publication No. 1287. Washington, DC. pp. 63–71.

LEFFINGWELL, E. DE K. 1919. The Canning River region, northern Alaska. United States Geological Survey. Professional Paper No. 109. 251 p.

LOWDON, J.A., AND W. BLAKE, JR. 1975. Geological Survey of Canada radiocarbon dates, XV. Geological Survey of Canada. Paper 75-7. Ottawa, Ontario. 32 p.

LYNCH-STEWART, P., R.G. HÉLIE, AND D. OUIMET. 1984. Northern wetlands research project: procedures, results and guidelines. Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 53 p.

MACKAY, J.R. 1972. Some observations on ice-wedges, Garry Island, NWT. *In* Mackenzie Delta area monograph. D.E. Kerfoot, editor. Brock University, St. Catharines, Ontario. pp. 131–139.

MACKAY, J.R. 1974. Ice-wedge cracks, Garry Island, NWT. Canadian Journal of Earth Sciences 11:1366–1383.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NICHOLS, H. 1969. The late Quaternary history of vegetation and climate at Porcupine Mountain and Clearwater Bog, Manitoba. Arctic and Alpine Research 1:155–167.

PALMER, R.S. 1976. Handbook of North American birds. Volume 2: Waterfowl (Part 1). Yale University Press. New Haven and London. 560 p.

PETTAPIECE, W.W., C. TARNOCAI, S.C. ZOLTAI, AND E.T. OSWALD. 1978. Guidebook for a tour of soil, permafrost, and vegetation relationships in the Yukon and Northwest Territories of northwestern Canada. Tour 18, 11th International Congress, Society of Soil Science. Edmonton, Canada. 165 p.

PÉWÉ, T.L. 1966. Ice wedges in Alaska—classification, distribution and climatic significance. Proceedings, 1st International Permafrost Conference, National Academy of Science–National research Council. Publication No. 1287. Washington, DC. pp. 76–81.

PREST, V.K. 1970. Quaternary geology of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 675–764.

PRICE, L.W. 1972. The periglacial environment, permafrost, and man. Committee on College Geography, Association of American Geography. Research Paper No. 14. 88 p.

REID, D.E., AND G.H. CALDER. 1977. The vegetation of the Mackenzie Delta region. Canadian Arctic Gas Study, Ltd. Biological Report Series. Volume 37, Chapter IV. 59 p.

RITCHIE, J.C., AND F.K. HARE. 1971. Late quaternary vegetation and climate near the arctic tree line of northwestern North America. Quaternary Research 1:331–342.

ROWE, J.S., G.R. COCHRANE, AND D.W. ANDERSON. 1977. The tundra landscape near Rankin Inlet, NWT. Musk-Ox 20:66–82.

RUBEC, C.D.A. (personal communication). April 1986. Lands Directorate, Environment Canada. Ottawa, Ontario.

RUBEC, C.D.A., R.G. HÉLIE, AND D. OUIMET. 1983. Terrestrial ecosystems of Coats Island, NWT. Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 1:125 000 map with extended legend.

RUBEC, C.D.A., AND P. LYNCH-STEWART. 1987. Northern wetlands conservation: management and data needs. *In* Proceedings, Wetlands/ Peatlands '87 Symposium. 23–27 August, 1987. Edmonton, Alberta. 9 p.

RUSSELL, R.H., E.J. EDMONDS, AND J. ROLAND. 1978. Caribou and muskoxen habitat studies. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. AI-26. 140 p.

SAVILE, D.B.O. 1972. Arctic adaptations in plants. Research Branch, Canada Department of Agriculture. Monograph No. 6. Ottawa, Ontario. 81 p.

STRANG, R.M. 1973. Studies of vegetation, landforms, and permafrost in the Mackenzie Valley: some case histories of disturbance. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-14. 49 p.

TARNOCAI, C. 1978. Genesis of organic soils in Manitoba and the Northwest Territories. *In* Proceedings, 3rd York University Symposium on Quaternary Research, Geographical Abstracts. Norwich, UK. pp. 453–470.

TARNOCAI, C., A.N. BOYDELL, J.A. NETTERVILLE, AND K.A. DRABINSKY. 1976. Biophysical land classification of Boothia Peninsula and northeastern Keewatin, NWT. Geological Survey of Canada. Open File 390. Ottawa, Ontario.

TERASMAE, J. 1972. Muskeg as a climate-controlled ecosystem. *In* Proceedings, 14th Muskeg Research Conference. 1971. Kingston, Ontario. National Research Council of Canada. Technical Memorandum No. 102. Ottawa, Ontario. pp. 147–158.

WASHBURN, A.L. 1983a. Palsas and continuous permafrost. Proceedings, 4th International Permafrost Conference. National Academy Press. Washington, DC. pp. 1372–1377.

WASHBURN, A.L. 1983b. What is a palsa? *In* Mesoformen des Reliefs im Heutigen Periglazialraum (Bericht über ein Symposium). H. Poser and E. Schunke, editors. Abhandlungen der Akademie der Wissenschaften in Göttingen, Mathematisch-Physikalische Klasse, Dritte Folge 35:34–47.

ZOLTAI, S.C., AND W.W. PETTAPIECE. 1973. Terrain, vegetation, and permafrost relationships in the northern part of the Mackenzie Valley and northern Yukon. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-4. 105 p.

ZOLTAI, S.C., AND F.C. POLLETT. 1983. Wetlands in Canada: their classification, distribution, and use. *In* Mires: swamp, bog, fen and moor. B. Regional Studies. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 245–268.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12:28–43.

3 Wetlands of Subarctic Canada

S.C. Zoltai
C. Tarnocai
G.F. Mills
H. Veldhuis

Wetlands of Subarctic Canada

Subarctic wetland regions extend in a broad belt between the forested Boreal and the treeless Arctic, and cover about 760 000 km² in Canada. This chapter does not include discussion of the Atlantic Subarctic Wetland Region (SA) which is discussed in Chapter 7. Wetlands are common in the Subarctic, constituting about 30% of the land surface, and in some areas they dominate the landscape. Three subarctic wetland regions were delineated on the basis of characteristic wetland development and were divided into High, Low, and Atlantic Subarctic Wetland Regions.

In this chapter the subarctic wetland environments are discussed and the common forms of wetlands described in some detail. Tidal subarctic salt marsh wetlands are considered in Chapter 9.

Environmental Setting

Physiography

The physiography of the subarctic wetland regions varies from nearly level plains to mountainous uplands. Parts of the continental core areas of the Canadian Shield, as well as parts of the Borderlands composed of sedimentary rocks, occur in the Subarctic (Bostock 1970)..

The Shield consists of massive crystalline rocks and some local sedimentary belts. The relief is generally typical of a peneplain: low hills of about 100 m in elevation, without prominent peaks. There are innumerable lakes enclosed in bedrock basins, and the rolling hills are thinly covered by sandy moraine. The physiography of the Shield, although generally uniform in geology and topography, has been divided on the basis of geological structure by Bostock (1970).

The Kazan physiographic region lies to the west of Hudson Bay and consists of massive crystalline rocks, forming uplands and plateaus. The plain in the Thelon River area owes its low relief to flat-lying sandstone bedrock. The Whale Lowland, south of Ungava Bay, occurs within the subarctic wetland regions as a broad, drift-covered area with scattered hills. The James region, east of Hudson Bay, has a typical peneplain surface with thin, discontinuous morainal deposits over crystalline bedrock and countless lakes. The Labrador Hills present prominent relief up to 1 000 m high, consisting of folded Precambrian sedimentary and volcanic rocks.

The Hudson physiographic region is composed of flat-lying Paleozoic bedrock over Precambrian basement rocks. The Hudson Bay Lowland is a generally flat plain, covered by glacial drift and thin marine sediments, that slopes gently towards Hudson Bay. Large, well-entrenched rivers cross this area and drain into the Bay.

The Borderlands have a more varied physiography and geology than the Shield. The northwestern portion of the subarctic wetland regions falls within three physiographic regions: the Cordilleran, the Arctic Coastal Plain, and the Interior Plains (Bostock 1970). In the Cordilleran region, subarctic wetlands occur on plateaus and plains between the northern mountain ranges. The Porcupine Plateau is almost entirely unglaciated and consists of a weathered, undulating hilly surface, with a well-entrenched drainage system. The Old Crow Plain is a generally flat lowland of Pleistocene lacustrine sediments. The Eagle Plain has long, even-topped ridges of gently rounded summits typical of unglaciated areas.

Only a small portion of the Arctic Coastal Plain lies within the subarctic wetland regions. This area, the southern part of the Mackenzie Delta, is characterized by a maze of river channels and ponds in a flat alluvial plain.

The northern part of the Interior Plains physiographic region is within the subarctic wetland regions. The Anderson Plain is a gently rolling area of glacial drift over Cretaceous shales and sandstones. The Peel Plain is a low, featureless area, studded with lakes in the western part, and the Peel Plateau rises in three steps of erosional surfaces from the plains to the Mackenzie Mountains. The Mackenzie Plain is a narrow, gently undulating area underlain by Mesozoic and Paleozoic bedrock, while the Great Bear Plain is composed of a rolling surface underlain by Mesozoic strata. The Great Slave Plain is composed of Paleozoic strata that have little relief. The Colville Hills consist of several ridges of Paleozoic strata rising to sinuous ridges some 400 m above the plains.

The drainage characteristics of various areas are influenced by the physiography and by the composition of the materials. In the areas of the Shield with hard, crystalline rock, drainage is poorly organized: chains of lakes interconnected by short stretches of rapid-filled rivers are the typical water courses. In softer bedrock or in drift-covered areas, the rivers tend to be entrenched and have a well-developed tributary system. In such areas poorly drained interfluves are less prominent. Areas of low relief, especially when underlain by dense, fine-textured soil, are likely to have poor drainage and hence will support extensive wetland areas.

Most of the subarctic wetland regions were subjected to repeated glaciation during the Quaternary period. Continental glaciation, radiating from the Hudson Bay area, and mountain glaciers, originating in the Cordilleran region, covered most of the land surface. Glacial action eroded the existing surfaces, depositing debris directly as morainal materials, or in lakes and rivers as sediments. During the waning stages of glaciation, some 7 000–13 000 years ago, the natural drainage to the sea was blocked by the remnant ice sheet and large glacial lakes were formed. In coastal areas the sea invaded the low-lying areas which were depressed as much as 300 m by the weight of the ice. The lake and marine sediments often formed extensive plains which, if poorly drained, were occupied by wetlands.

The northwestern part of the subarctic wetland regions in northern Yukon has never been glaciated. The area is drained by a well-developed river system with tributaries at regular intervals. Wetlands are scarce in this area, but occur where Pleistocene lacustrine sediments are present.

Subarctic Climate and Wetland Regions

The subarctic wetland regions are characterized by very cold winters and short, warm summers. The Subarctic is where the most frequent encounters between arctic and temperate air masses occur (Dolgin 1970). In the summer the average position of the arctic frontal zone is in the Subarctic (Bryson 1966), allowing the incursion of temperate air masses. The winter position of the arctic frontal zone is well to the south, permitting the domination of arctic air masses in the winter. Precipitation is low in the western part of these regions, but increases twofold in the areas around Hudson Bay and eastwards, possibly reflecting the influence of this water body on atmospheric moisture.

In the High Subarctic Wetland Region (SH) (Figure 3–1), the mean annual temperatures are lower in the west than in the east (Table 3–1), possibly due to low winter temperatures. However, the July temperatures are lower in the east,

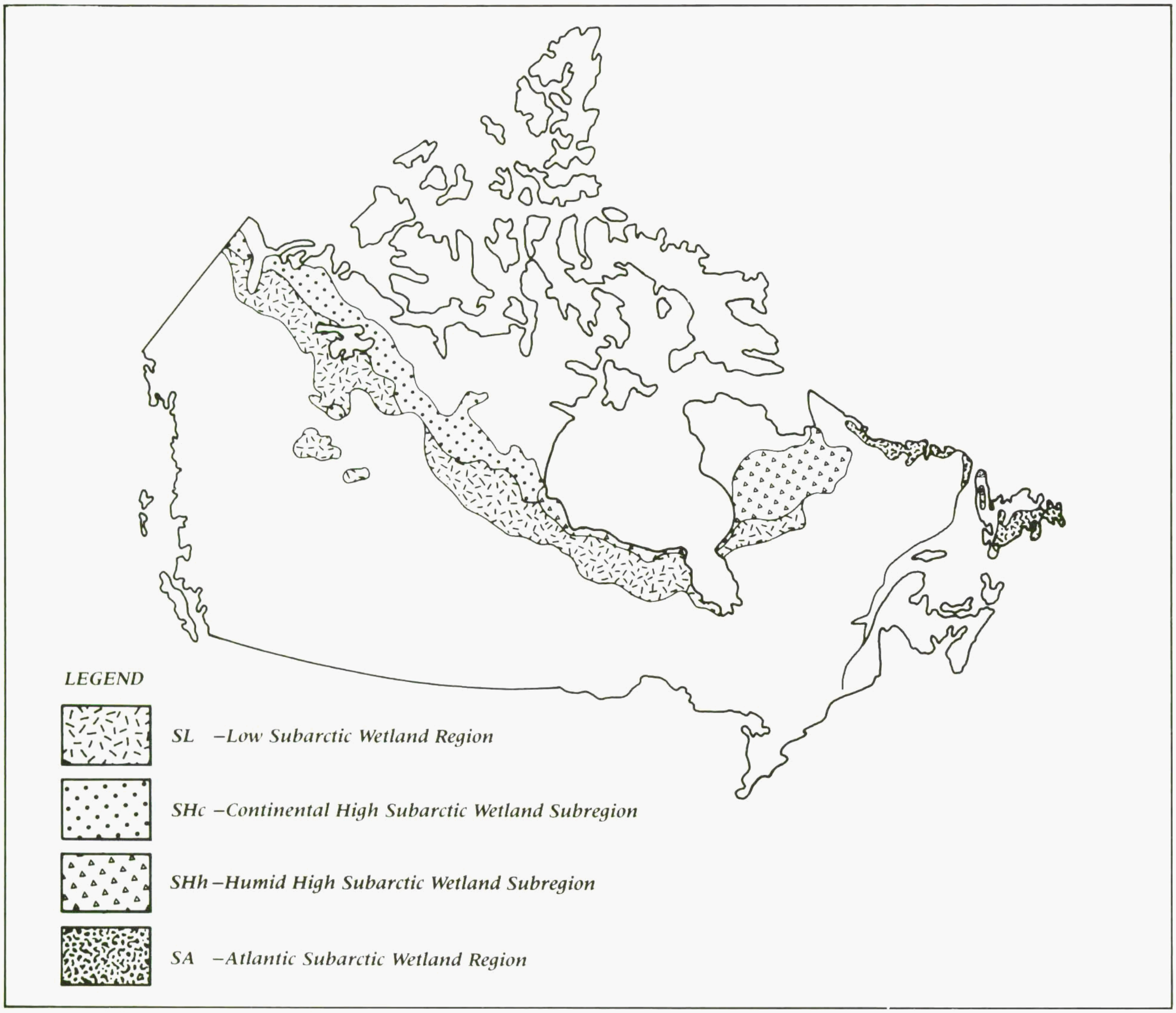


Figure 3–1.
The subarctic wetland regions of Canada.

resulting in lower accumulations of degree-days above 5°C (growing degree-days) in this area. Snowfall and total precipitation are both markedly higher in the east. However, the effects of these climatic differences on wetland development are not pronounced; hence both areas are in the same wetland region, but in different wetland subregions: (i) SHc (Continental) and (ii) SHh (Humid) High Subarctic.

In the Low Subarctic Wetland Region (SL) (Figure 3–1), the mean annual temperature is higher than in the Continental High Subarctic Wetland Subregion (Table 3–1). The mean July temperature is also higher, but the mean January temperatures are virtually the same. This results in a greater number of growing degree-days than in the High Subarctic Wetland Region. Precipitation and snowfall are also somewhat higher in the Low Subarctic Wetland Region.

Table 3–1. Climatic data of the subarctic wetland regions (average values)

Wetland region	No. of stations	Mean annual temp. (°C)	Mean daily July temp. (°C)	Mean daily January temp. (°C)	Mean degree-days above 5°C	Mean annual total precip. (mm)	Mean annual snowfall (cm)
SHh	5	−5.4	11.5	−24.1	559.8	622.9	280.8
SHc	5	−9.1	13.4	−30.1	656.4	239.9	127.9
SL	6	−6.6	15.3	−29.6	938.8	330.1	158.8

Source: Atmospheric Environment Service (1982).

Regional Vegetation and Wetlands

The Subarctic lies between the closed-canopied boreal forest in the south and the treeless arctic tundra in the north. It is characterized by open-canopied coniferous forest or by patches of open-canopied forest and tundra. It is included in the transitional forest–tundra (Rowe 1972) and is similar to the "lesotundra" of the Soviet Union (Norin 1961). Permafrost is widespread in subarctic soils. Distinctive wetland forms are produced by the interaction of excess water and severe climate, manifested in the limited growth of some plants and in the development of permafrost.

The vegetation of the high subarctic uplands is characterized by open stands of black or white spruce (*Picea mariana, Picea glauca*), with a conspicuous ground cover of lichen (*Cladina mitis, Cladina rangiferina, Cladina alpestris*). In poorly drained areas *Larix laricina* may also be present. Open tundra patches occupy increasingly larger areas towards the northern limit of the High Subarctic Wetland Region. Such tundra patches consist of low shrubs (*Betula glandulosa, Dryas integrifolia*), sedges, and lichens.

Most wetlands are affected by permafrost in the Continental High Subarctic Wetland Subregion. The common wetlands are peat plateau and polygonal peat plateau bogs, separated by fens. In the Humid High Subarctic Wetland Subregion, in the Hudson Bay Lowland and east of Hudson Bay, unfrozen fens and permafrost-affected palsa and peat plateau bogs, some with ice-wedge polygons, are the characteristic wetland forms.

The low subarctic upland vegetation consists of a spruce–lichen forest, in which open-canopied black and white spruce dominate. There is a patchy lichen cover, consisting of *Cladina* spp., and a layer of heath shrubs. On some hillsides deciduous trees, such as *Populus tremuloides* or *Betula papyrifera*, may occur, and on river floodplains *Populus balsamifera* can be found mixed with *Picea glauca*.

The common and characteristic wetlands are fen and peat plateau–palsa bog complexes. Northern ribbed fens occupy large areas, with incipient permafrost in some of the ridges.

Subarctic Wetland Forms

In this section those wetlands that are characteristic of or abundant in the subarctic wetland regions are described, although not all forms present are included, as other less prominent wetland forms also occur. The discussion of each wetland form in this section consists of two parts: a generalized account followed by a specific example. The most common forms of wetlands in the Subarctic which are highlighted in this section, in order of prominence of occurrence, are:

—peat plateau bogs
—polygonal peat plateau bogs

—palsa bogs
—northern ribbed fens
—channel fens
—veneer bogs/collapse scar fens
—floodplain marshes
—floodplain swamps
—thermokarst shallow waters

Peat Plateau Bogs

Peat plateau bogs are perennially frozen peatlands elevated about 1 m above the water table of the associated wetlands (Zoltai and Tarnocai 1975). They are generally flat, with only minor surface irregularities (Figure 3–2). In the Subarctic they may reach a size of several square kilometres. They resemble the "flat palsas" of the northern Soviet Union (Botch and Masing 1983) or the "palsa plateaus" of northern Norway (Åhman 1977). In Norway, however, they seldom reach 1 km^2 in size. The vegetation consists of scattered, stunted *Picea mariana* with abundant lichen ground cover in the Low Subarctic Wetland Region. In the High Subarctic Wetland Region there is a very open, stunted, scattered spruce woodland with a ground cover of lichen and low heath shrubs. In the Humid High Subarctic Wetland Subregion both treeless (dominated by *Cetraria nivalis*) and treed types are present. The absence of trees may often be the result of fires (Couillard and Payette 1985).

In the subarctic wetland regions, peat plateau bogs generally occupy large portions of wetlands (Figure 3–3), but are usually associated with open or shrubby fens. The fens are not affected by permafrost in the Low Subarctic Wetland Region and in the Humid High Subarctic Wetland Subregion, but usually contain permafrost in the Continental High Subarctic Wetland Subregion (Zoltai and Tarnocai 1975). At the edges of many peat plateau bogs, newly developing peat plateaus can be seen in which a carpet or cushion of *Sphagnum fuscum* contains relatively thin permafrost that does not reach the mineral soil. Such *Sphagnum* carpets or cushions are somewhat elevated (up to 50 cm) above the fen level. If elevated further by the thickening permafrost, the surface becomes dry enough for the establishment of lichens and this developing peat plateau then merges with the main peat plateau body. *Picea mariana* and *Ledum groenlandicum* usually form the upper vegetation layers in these newly developing peat plateaus.

Figure 3–2.
Flat surface of a peat plateau bog with stunted Picea mariana *and abundant ground lichens at Ft. Good Hope, NWT.*

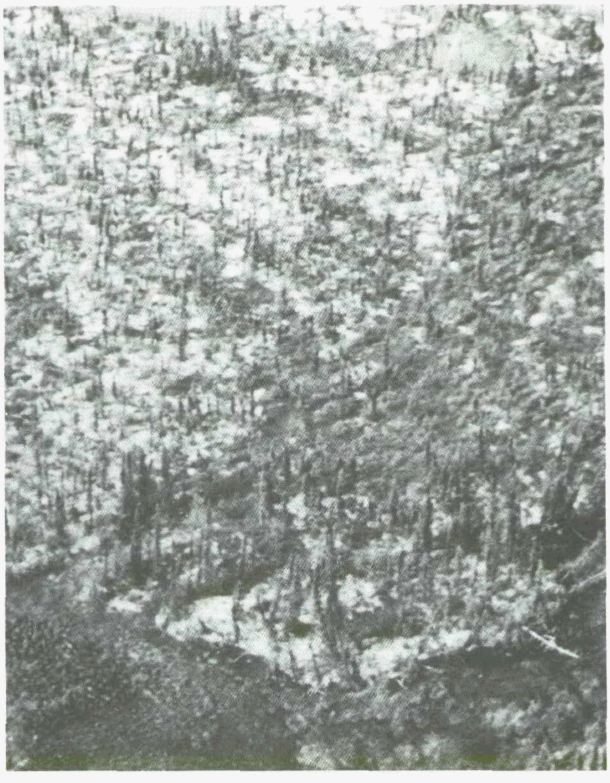


Figure 3–3.
Aerial view of an extensive peat plateau bog with unfrozen fen in foreground near Sans Sault Rapids, NWT.

Although degrading permafrost occurs in the Low Subarctic Wetland Region and in the Humid High Subarctic Wetland Subregion, it is most common in the High Boreal Wetland Region described in the next chapter of this book. If the thermal balance of a portion of a peat plateau bog changes, the permafrost thaws and the surface of the peat plateau subsides into the fen. Such "collapse scar" areas, usually fen wetland forms, are limited in size to a few tens of square metres. They are marked by the presence of dead trees protruding from the fen, and by the bright green colour of *Sphagnum riparium* that grows partially submerged in water in the collapse scar. In the Humid High Subarctic Wetland Subregion *Sphagnum balticum* and *Sphagnum lindbergii* are common in collapse scars (Couillard and Payette 1985).

The thickness of peat deposits is commonly in excess of 2 m and may reach 4 m. In the Mackenzie Valley the peat thickness averaged 217 cm at 83 sites (Zoltai and Tarnocai 1975). Permafrost occurred 30–50 cm below the surface, extending well into the mineral soil (Brown 1970). There is a surface layer (up to 30 cm thick) of moderately to well decomposed forest peat, underlain by *Sphagnum* peat to a depth of 50–60 cm below the surface. Beneath this is moderately decomposed fen peat consisting of sedge and brown moss (mainly *Drepanocladus* spp.) remains. The perennially frozen peat contains ice crystals and small ice veins, but the water content of the peat is about the same as that of unfrozen peat. Ice accumulation may be encountered as 2–10 cm thick layers in the fen peat, or in the upper part of a silty mineral soil.

The vegetation associated with this wetland form is a sparse spruce–lichen woodland, with some shrubs and extensive lichen ground cover. There may be variations in the proportions of these components, but the vegetation is generally uniform. Some variations are caused by fires. In the Humid High Subarctic Wetland Subregion, fires may remove the trees, establishing a seral stage dominated by lichens (*Cetraria nivalis*) and mosses (*Dicranum groenlandicum*). In the Continental High Subarctic Wetland Subregion, the tree cover initially increases and the lichen decreases after a fire, but the open spruce–lichen woodland is re-established within the first generation after a fire. The main shrub species are *Ledum decumbens* in the open woodlands and *Ledum groenlandicum* in the forested areas, as well as *Andromeda polifolia* and *Betula glandulosa*. The distribution and extent of *Vaccinium vitis-idaea* and *Rubus chamaemorus* is sparse but constant. *Sphagnum fuscum* may grow in small, moist depressions, but the main ground cover is provided by *Cladina mitis, Cladina stellaris, Cladina rangiferina*, and *Cladonia amaurocraea*.

A peat plateau bog near Bonnet Plume River, Yukon Territory (65°37′ N, 134°18′ W), was examined in some detail. A peat plateau complex occupies most of a large depression, where the individual peat plateaus are separated by narrow, wet fen drains. A short transect was made from the central part of the peat plateau to the fen to examine the peat at three sites, describe the vegetation, and conduct levelling to describe the topography (Figure 3–4).

On this peat plateau bog, stunted *Picea mariana* trees cover about 5% of the surface and *Betula glandulosa* shrubs cover about 10% of the area. Dwarf shrubs, mainly *Ledum decumbens* and some *Vaccinium vitis-idaea*, constitute the lowest vascular layer. Lichens cover about 95% of the surface, mainly *Cladina stellaris, Cladina rangiferina, Cladonia amaurocraea*, and *Cetraria nivalis*.

Along the somewhat protected margin of the peat plateau bog, trees, *Picea mariana*, and some *Larix laricina* form a 15% cover, with a 40% shrub cover composed mainly of *Ledum decumbens* and *Rubus chamaemorus*. The ground cover is nearly continuous, mainly *Sphagnum fuscum* with a few lichens, including *Cladonia amaurocraea* and *Cetraria cucullata*. In the unfrozen fen, *Sphagnum balticum, Carex* spp., *Eriophorum* sp., and *Drepanocladus* sp. are found.

The peat was cored 14 m from the edge of the peat plateau bog and at the margin, and it was probed in the adjacent fen. On the peat plateau bog the surface stratum consists of fibric to mesic *Sphagnum* peat (Table 3–2), with the permafrost table at 33 cm. This is underlain by mesic to fibric layers of moss peat and sedge–moss peat. A thin layer of well-humified peat occurs above the mineral soil.

Chemical analyses of the peat (Table 3–2) show that the *Sphagnum* cap within the upper 70 cm is low in calcium (Ca) and magnesium (Mg). At greater depths, in the fen deposits, both the Ca and Mg levels are high.

At the margin core the top layer is composed of *Sphagnum* peat (Table 3–3), with the permafrost table at 25 cm. This is underlain by mesic sedge–moss and fibric *Drepanocladus* moss peat, resting

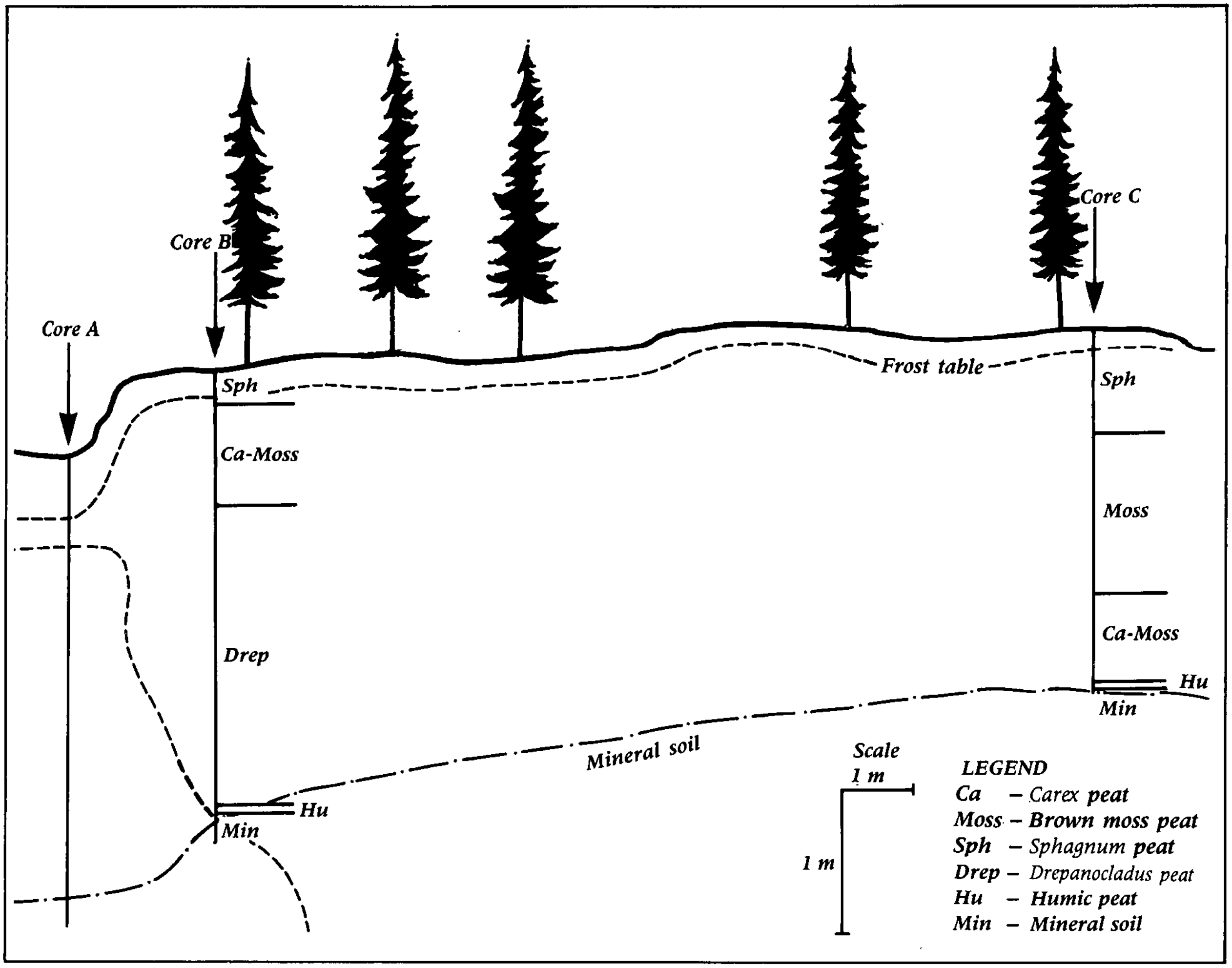


Figure 3–4.
Cross-section showing the stratigraphy at the marginal and central part of a peat plateau bog, Bonnet Plume River, YT.

on a thin layer of aquatic detritus. This is underlain by unfrozen sandy silt.

The analyses (Table 3–3a) show low levels of Ca and Mg in the surface *Sphagnum*, whereas the underlying sedge–moss peat is high in iron (Fe). The Ca and Mg levels are high in the lower fen peat.

In the fen the top 40 cm was unfrozen, composed of fibric *Carex–Sphagnum* peat. Seasonal frost was present (early July) at 40–61 cm in fibric to mesic *Carex–Sphagnum* peat, and beneath this was unfrozen peat. Mineral soil was encountered at 294 cm. The single peat sample from the fen (Table 3–3b) shows moderately high levels of Ca and Mg.

The volumetric water content of the peat and the underlying mineral soil was determined

Table 3–2. Total elemental analysis and other properties of peat from the central part of a peat plateau bog

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	H_2O by volume (%)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)
29	—	*Sphagnum fuscum*	3	3.8	87.9	4 721	518	4 455
41	—	*Sphagnum fuscum*	3	6.0	86.8	3 199	284	7 365
64	—	*Sphagnum fuscum*	5	3.9	71.6	3 141	153	3 914
76	—	Moss	3	4.4	91.1	6 321	435	2 170
99	—	Moss	3	4.1	89.9	9 603	964	1 972
137	—	*Carex*–moss	3	5.9	93.1	6 648	723	1 522
150	—	Moss	5	9.4	94.3	10 074	956	2 180
193	—	*Carex*–moss	5	7.4	91.9	16 854	1 394	3 368
228	6.1	*Carex*–moss	5	14.0	87.6	10 258	1 123	2 637
246	6.1	Mineral	—	77.6	72.5	—	—	—

Table 3–3. Total elemental analysis and other properties of peat from the margin of a peat plateau bog (A) and a fen (B)

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	H_2O by volume (%)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)
A—Peat plateau bog margin								
23	—	*Sphagnum fuscum*	3	2.3	92.2	5 133	564	2 986
31	5.2	*Carex*–moss	5	18.2	70.0	2 259	254	29 714
43	5.2	*Carex*–moss	3	6.9	89.5	4 078	233	10 668
62	5.2	*Carex*–moss	5	7.5	82.9	11 330	377	5 877
86	5.2	*Carex*–moss	5	6.6	82.9	9 196	874	2 204
105	5.2	*Drepanocladus*	3	5.2	94.2	11 393	1 081	2 654
127	6.1	*Drepanocladus*	3	8.2	93.2	13 025	1 139	2 775
149	6.1	*Drepanocladus*	3	6.6	89.6	10 210	892	1 853
183	6.1	*Drepanocladus*	3	4.6	94.4	12 817	1 082	2 537
240	5.8	*Drepanocladus*	3	6.7	95.8	9 263	578	2 152
292	5.8	*Drepanocladus*	3	7.2	93.8	8 563	574	3 523
299	—	Aquatic detritus	7	16.8	59.5	8 815	913	3 516
B—Fen								
45	—	*Sphagnum*	5	20.2	90.4	8 814	1 093	3 571

(Tables 3–2, 3–3). In general, it is found that excess ice is present in the peat samples when the volumetric water content exceeds 93%. In mineral soils, fully saturated clay loam can hold about 45% water by volume (Kohnke 1968). Therefore, moisture values that exceed this limit indicate the presence of excess water occurring as ice. Excess ice occurred at the centre core only in one sample in the peat and in the mineral soil. At the margin site, the lower peat samples had excess ice but the mineral soil showed only slight excess moisture.

The botanical composition of the peat shows that a thin *Sphagnum* cap, composed mainly of *Sphagnum fuscum*, exists over the perennially frozen fen peat of the peat plateau bog. The fibric peat in elevated hummocks is an excellent insulator, delaying thawing during the summer and eventually permitting the development of permafrost. As permafrost develops, the affected area is elevated, and the surface becomes drier, promoting the further development of permafrost. The dry conditions on the surface, however, are not conducive to further *Sphagnum* growth, and peat formation virtually ceases.

The peat is some 60 cm thinner on this peat plateau bog than at the margin or in the fen where peat deposition still continues. This implies that the peat plateau core site was elevated by the permafrost for some time, sufficiently long to allow the addition of 60 cm of peat at the peat plateau margin and in the adjacent fen. Similarly, since the thickness of peat at the margin and in the fen is about the same, the margin was probably affected by permafrost only recently. This is substantiated by the observation that permafrost has not yet reached the mineral soil under the margin (Figure 3–4).

Polygonal Peat Plateau Bogs

These perennially frozen wetland forms resemble peat plateau bogs in many respects: they are elevated about 1 m above the associated fen and their surface lacks relief. The main difference is that they are crisscrossed by trenches that form a polygonal pattern when viewed from above (Zoltai and Tarnocai 1975). Polygonal peat plateau bogs occupy the major portion of the depressions in which they occur, often covering hundreds of hectares. The associated fens are affected by permafrost in the Continental High Subarctic Wetland Subregion, but permafrost may be absent in the Humid High Subarctic Wetland Subregion. The surface of polygonal peat plateau bogs is usually treeless, with dwarf shrubs and a prominent ground lichen layer (Figure 3–5). These plateaus occur chiefly in the Continental High Subarctic Wetland Subregion, although a few have been noted in the Low Subarctic Wetland Region, especially in particularly exposed, windswept localities.

The polygons consist of cells of various sizes and shapes. The average diameter is about 15 m and the shape may vary from rectangles to eight-sided polygons. The pattern is formed by a lineal depression, the trench, flanked on both sides by a slight rise, the shoulders (Figure 3–6). The trench is generally 10–30 cm deeper than the local ground surface, and the shoulders are seldom more than

30 cm higher than the surface. The polygons may, therefore, be slightly concave in cross-section. Examination of eroded peat banks and corings indicates that there is an ice wedge under each polygon trench, extending downwards for 2–4 m. The ice of the wedges is clear, without inclusions, and it often contains bubble trains rising towards the surface in a slightly outward-curving arc (Tarnocai 1973). The peat is cut by the ice wedge, and contorted peat layers have been noted only near the surface where the ice wedge is the widest. The shoulders appear to consist of peat displaced by the developing ice wedges.

The average thickness of peat in polygonal peat plateau bogs is about 2 m (Zoltai and Tarnocai 1975; Dredge 1979). The peat consists of materials deposited in bogs and fens, without any indication of distorted, cryoturbated layers and without any frost-heaved mineral soil inclusions. There are few ice lenses or layers in the peat; when present they are less than 10 cm thick. There may be an ice layer 2–10 cm thick at the peat–mineral soil interface. The thickness of the annually thawed active layer is 25–35 cm, considerably lower than that in adjacent mineral soil (Dredge 1979).

The vegetation of polygonal peat plateau bogs is dominated by the lichen ground cover. *Cladina mitis*, *Cladina rangiferina*, *Cetraria cucullata*, *Cetraria nivalis*, and *Alectoria ochroleuca* are the main species. *Sphagnum fuscum* occurs in some of the wetter trenches. Low shrubs of *Betula glandulosa* and *Ledum decumbens* can also be found in

Figure 3–5.
Aerial view of a polygonal peat plateau bog, showing a variety of polygon sizes and shapes, Richardson Mountains, YT.

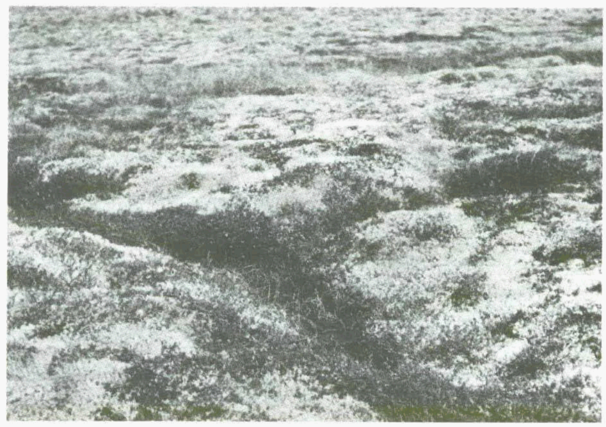


Figure 3–6.
Junction of three polygon trenches on a polygonal peat plateau bog, Richardson Mountains, YT.

Table 3–4. Total elemental analysis and other properties of peat from the shoulder of a peat polygon trough

Depth of sample (cm)	Decomposition (von Post)	Material	Ash (%)	H_2O by volume (%)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	S (mg/kg)
24	3	*Sphagnum*	1.6	71.2	2 156	555	1 332	515
40	3	*Sphagnum*	1.3	94.9	1 925	377	615	445
53	4	*Sphagnum*	6.8	73.5	2 225	342	1 085	808
80	4	*Sphagnum*	2.4	93.2	2 062	419	1 131	529
92	4	*Sphagnum*	3.0	90.8	1 945	392	1 112	737
115	3	*Sphagnum*	1.8	92.8	1 812	356	1 195	528
128	3	*Sphagnum*	1.5	90.8	1 725	400	1 170	410
160	4	*Sphagnum*	2.2	92.0	4 975	480	1 535	349
170	3	*Sphagnum*	3.5	90.1	6 400	552	1 890	456
182	3	*Sphagnum*	3.4	90.7	7 828	549	2 010	620
201	5	*Carex*–moss–wood	8.2	90.1	6 738	309	2 296	1 330
214	5	*Carex*–moss–wood	6.7	87.9	11 375	425	3 938	2 380
225	5	*Carex*–moss–wood	8.9	88.4	19 197	701	6 733	7 020
250	5	*Carex*–moss–wood	8.6	89.0	23 203	830	5 953	12 187
272	5	*Carex*–moss–wood	11.5	88.1	23 250	1 050	4 400	12 525
291	3	*Carex*–moss	8.1	92.1	15 025	850	2 670	9 150
313	3	*Carex*–moss	8.0	76.2	17 187	1 074	3 281	11 925
334	7	*Carex*–aquatic	24.6	76.9	68 000	1 735	4 381	20 100
351	7	*Carex*–aquatic	27.1	85.1	73 750	1 945	4 194	22 500
365	—	Organic–mineral	53.2	69.2	1 992	2 820	6 250	24 000

the trenches. There may be individual *Picea mariana* present as low, wind-blasted krumholz.

The ice wedges in polygonal peat plateau bogs appear to be identical to the ice wedges that develop in mineral soil. Ice wedges form as thermal contraction cracks are filled with snow, hoarfrost, or water that later turns to ice (Leffingwell 1915). The cracking is caused by low temperatures and rapid cooling (Lachenbruch 1962), and can extend 3 m or more into the ground (Mackay 1974). The cracks cut through the vegetation mat with a sharp, clean cleavage. Examination of ice wedges in polygonal peat plateau bogs has shown that such sharp cuts extended through the peat and initiated the growth of ice wedges in them.

Peat stratigraphy shows that the peat was initially deposited in a non-permafrost environment, in bogs and fens. The macrofossils in a polygonal peat plateau bog in Yukon show a sequence from pond to marsh, then to fen and finally to bog (Ovenden 1982). The peat was later affected by permafrost, as in the peat plateau bogs. In northern areas where winter snowfall is low, or where wind removes much of the snow, the peat surface is subject to cracking by frost. Under such conditions ice wedges have developed, forming polygonal patterns.

A polygonal peat plateau bog at Tundra Lake, Northwest Territories (67°39′ N, 133°38′ W), was investigated. The peatland occupies the lowlands around a large lake and its surface is about 2 m above the level of the lake. The wave action of the lake is eroding the peat, exposing freshly cut banks. The sampling site is located 100 m from the lake where a short transect was run. The vegetation, surface morphology, and depth of thaw were noted along this transect and the peat was cored at three locations: at the centre of a polygon, on the shoulder, and in the middle of a polygon trough (Figure 3–7).

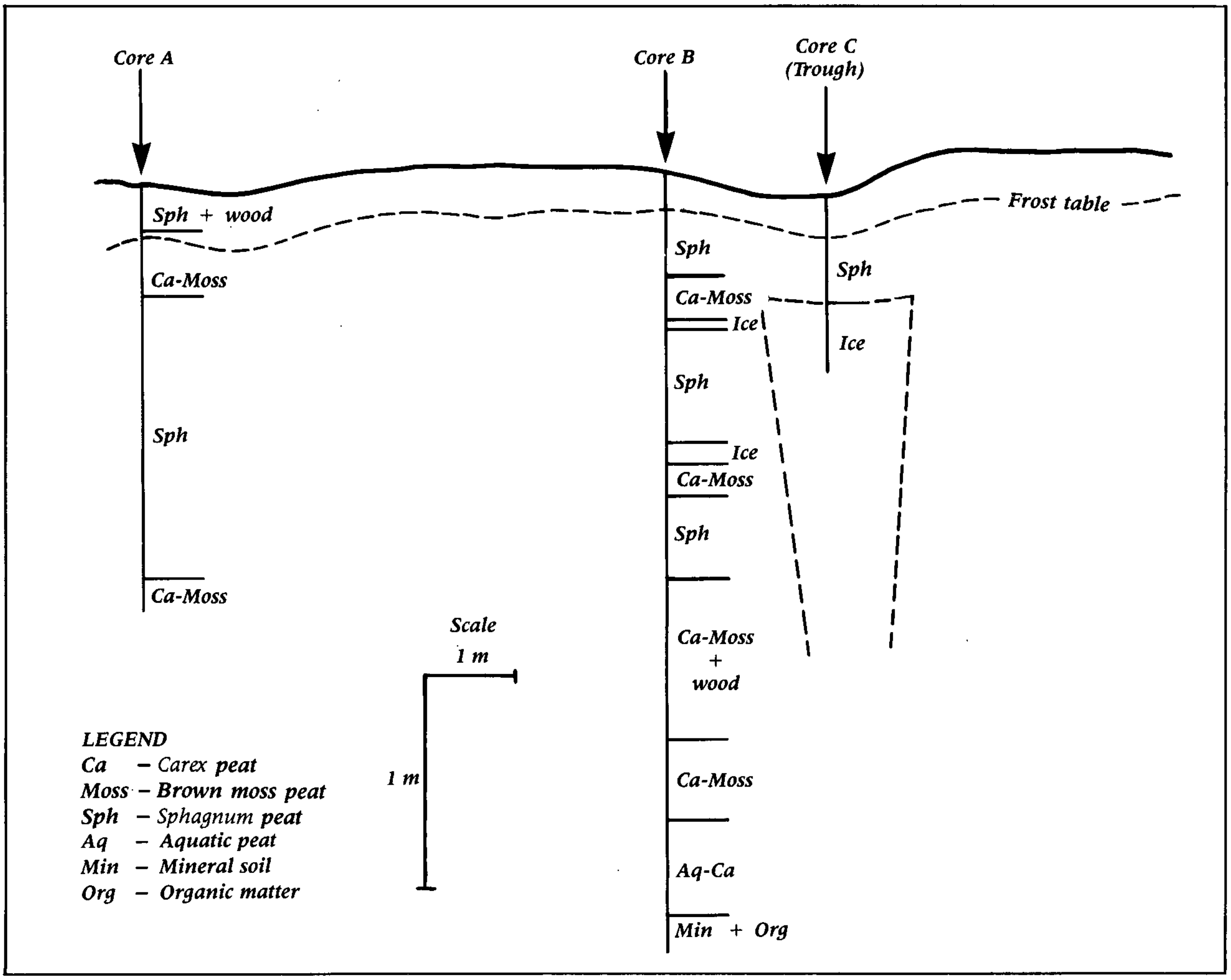


Figure 3–7.
Cross-section along a transect in a polygonal peat plateau bog near Tundra Lake, NWT.

Table 3–5. Total elemental analysis and other properties of peat from the centre of a polygonal peat plateau bog (A) and a polygon trough in a polygonal peat plateau bog (B)

Depth of sample (cm)	Decomposition (von Post)	Material	Ash (%)	H_2O by volume (%)	Ca (mg/kg)	Mg (mg/kg)	Fe (mg/kg)	S (mg/kg)
A—Centre								
28	4	*Carex*–moss	5.4	82.3	1 775	352	3 037	945
43	5	*Carex*–moss	8.1	83.8	1 185	131	767	325
53	5	*Carex*–moss	4.9	87.2	1 425	207	1 142	532
62	3	*Sphagnum*	1.3	88.2	1 787	335	910	560
76	3	*Sphagnum*	1.6	88.8	1 669	349	712	460
87	3	*Sphagnum*	1.4	94.3	1 875	387	496	414
97	3	*Sphagnum*	2.0	91.6	1 675	295	490	429
110	3	*Sphagnum*	2.5	91.9	1 800	272	525	537
123	4	*Sphagnum*	2.0	89.3	2 475	320	600	486
135	4	*Sphagnum*	2.4	95.7	2 406	310	1 031	667
149	4	*Sphagnum*	2.8	95.5	2 662	315	692	600
160	5	*Sphagnum*	4.5	91.0	5 400	500	1 265	720
170	5	*Sphagnum*	2.5	91.1	5 000	499	1 245	540
183	5	*Sphagnum*	3.3	95.6	5 062	455	1 519	675
196	5	*Carex*–moss	5.4	88.2	7 375	565	1 612	840
B—Trough								
18	2	*Sphagnum*	2.1	90.4	1 992	318	1 947	1 500
27	2	*Sphagnum*	1.9	90.7	1 960	256	1 412	1 331
39	3	*Sphagnum*	2.2	91.0	2 015	364	1 006	787
48	3	*Sphagnum*	1.9	92.9	1 815	432	900	520

Lichen covers about 95% of the surface and is composed of *Cetraria nivalis*, *Cetraria cucullata*, *Cladina mitis*, *Cladina alpestris*, *Cladina rangiferina*, and *Alectoria ochroleuca*. Low *Ledum decumbens* and *Rubus chamaemorus* are occasionally present in the troughs and on shoulders. *Sphagnum fuscum* is present in the troughs.

The peat was cored on the shoulder of a polygon down to the mineral soil, reaching permafrost at 23 cm. The surface material is fibric to mesic *Sphagnum* peat, mostly *Sphagnum fuscum* (Table 3–4). Two narrow (3 and 7 cm thick) ice lenses were encountered. Below this layer, fen peat materials occur over a layer of mixed organic–aquatic detritus and *Carex*. The core ends in a mixture of well-humified organic material and mineral soil.

The chemical analyses (Table 3–4) show that the *Sphagnum* peat is very low in nutrients, especially in Ca and Mg, to a depth of 160 cm. There is a sudden increase in most nutrients in the woody fen peat at 214 cm, while the peat between 160 and 214 cm shows intermediate nutrient levels. The Ca content reaches very high levels, especially in the aquatic detritus, but decreases sharply in the mineral soil. Sulphur (S) levels show a sudden increase in the fen peat (at 201 cm) and continue to increase steadily to high levels at the base. The moisture content of the peat does not show any excessively high levels.

In the polygon trough there is a 60 cm thick *Sphagnum fuscum* peat layer above clear ice (Table 3–5). The ice was penetrated for some 40 cm and then the hole was abandoned. This ice probably represented the ice wedge. The chemical analyses show low values of all nutrients, except for high amounts of sulphur at the surface.

At the centre of the polygon the surface consists of *Sphagnum fuscum* peat that contains twigs. Beneath this is mesic *Carex*–moss (*Drepanocladus*) peat (Table 3–5), which is underlain by *Sphagnum* peat, followed by *Carex*–moss (*Drepanocladus*) peat. The hole was abandoned at 204 cm.

The analyses (Table 3–5, centre) show that the nutrient levels are low until the *Carex*–moss fen peat is reached at 192 cm, where the Ca, Fe, and S levels show a substantial increase. The *Sphagnum* peat immediately above the fen peat (160–192 cm) has somewhat elevated Ca and Fe concentrations. The moisture content of the peat was generally similar to non-permafrost materials, but some excess ice was present in four samples where the water content was higher than 93% by volume. The peat from the trough shows low levels of Ca and Mg (Table 3–5, trough), but high amounts of Fe and S.

An examination of the peat materials shows that, initially, shallow lacustrine and marsh conditions prevailed at the site. These were replaced by an open sedge fen which was later invaded by shrubs, depositing woody sedge–moss peat. The fen was then replaced by a *Sphagnum* bog, depositing nearly 2 m of peat. Permafrost was probably formed in the peat at this time, elevating the peatland into a peat plateau. The development of polygons came later, as the ice wedges cut across both the bog and fen peat.

Palsa Bogs

Palsa bogs are mounds of peat with a permafrost core. They rise 1–7 m above the surrounding wetland and they have a diameter of less than 100 m (Zoltai and Tarnocai 1975). They occur as islands in very wet, unfrozen fens or ponds, or as peninsulas extending into these non-permafrost, wet areas (Figure 3–8). Palsa bogs can occur singly or in groups of several mounds of different sizes (Hamelin and Cailleux 1969). In some wetlands they may coalesce, forming contorted ridges and swales of peat, occupying several hundred hectares.

Small palsa bogs, apparently recently emerged, may occur in the same wetlands as large, deeply fissured peat mounds. Palsa bogs often deteriorate through the thawing of the permafrost core, especially when the core is exposed by cracking of the palsa surface. In such areas permafrost degradation can progress as a result of the collapse and subsidence of the palsa bogs beginning at the margins, and of the thawing of permafrost from below (Kershaw and Gill 1979). In the Subarctic, collapsing palsa bogs occur mainly where the surrounding wetland has become flooded. Aggrading permafrost is frequently encountered, forming a peat plateau margin around the palsa bog, isolating it from the unfrozen wetlands (Figure 3–9).

The internal structure of palsa bogs generally consists of a surface layer of *Sphagnum* peat up to 50 cm thick. The active layer is 30–50 cm thick. The *Sphagnum* cap is underlain by fen peat composed of sedge and brown moss remains. The basal peat may be humified organic matter or aquatic detritus. Permafrost extends well into the

Figure 3–8.
This 3.75 m high palsa bog occurs as a peninsula into a wet fen (foreground), Norman Wells, NWT.

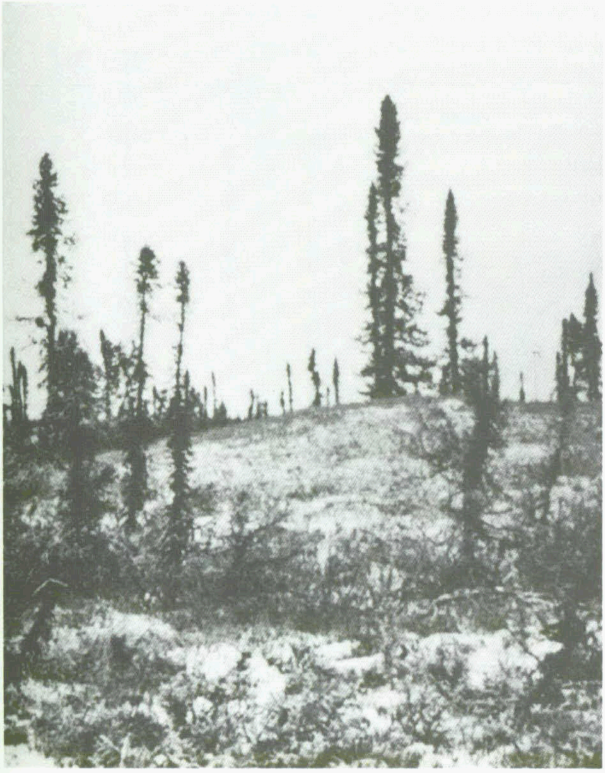


Figure 3–9.
A 2 m high palsa occurring in the centre of a peat plateau bog, Peel River, YT.

mineral soil. Thin (up to 10 cm thick) ice lenses may be encountered in the frozen peat, but large ice accumulations are usually found at the peat–mineral soil interface, especially in the upper mineral soil. The peat in the palsa bogs, as in the peat plateau bogs, is not distorted by cryoturbation, implying that frost has penetrated into the peat from the surface downwards (Seppälä 1980).

The thickness of the peat in palsa bogs is variable. In the Subarctic an average of 267 cm (140–442 cm) has been reported (Zoltai and Tarnocai 1975), but there are also reports of very thin peat cover over palsa bogs: 7 cm in northern British Columbia (Seppälä 1980) and 8–18 cm in the Rocky Mountain foothills in Alberta (Brown 1980).

The vegetation of palsa bogs in the Subarctic resembles that of the peat plateau bogs as described earlier in this chapter. Lichens dominate the ground surface, composed mainly of *Cetraria nivalis, Cetraria cucullata, Cladina rangiferina, Cladina alpestris*, and *Cladina mitis*. Dwarf shrubs of *Ledum decumbens* and *Rubus chamaemorus* may cover up to 20% of the surface. There is a very open *Picea mariana* tree cover, composed of low (less than 5 m tall) trees.

A palsa bog at Eagle River, Yukon Territory (67°07′ N, 137°13′ W), was investigated in some detail. The palsa bog is situated at the edge of a large peat plateau bog, surrounded on three sides by a wet, unfrozen fen. A short transect was run from the fen, across the palsa bog to the peat plateau bog (Figure 3–10). The surface morphology was surveyed by levelling, and the depth of thaw and the vegetation were determined along the transect line.

Trees of low *Picea mariana* form a 5% cover, with an equally sparse shrub layer of *Betula glandulosa*. Dwarf shrubs cover about 70% of the surface, composed mainly of *Ledum decumbens* and some *Rubus chamaemorus* and *Vaccinium vitis-idaea*. Lichens (*Cladina mitis, Cladina alpestris, Cetraria nivalis*) cover about 35% of the surface.

The peat core at the summit of the palsa shows 12 cm of well-decomposed sylvic peat at the surface, made up of humified peat, roots, and needles. This is underlain by mesic *Sphagnum* peat to a depth of 72 cm (Table 3–6). The permafrost table was within this material at 47 cm. The *Sphagnum* layer is underlain by mesic moss peat (*Drepanocladus* sp.) and by peat composed of sedge and moss remains, including layers containing small twigs and wood chips. The mineral soil was reached at 285 cm. The basal peat below 256 cm and the mineral soil contain large amounts of excess ice, as shown by field observations and by the high amounts of volumetric moisture content of these samples. The dominant soil types associated with such palsa bogs are Mesic Organic Cryosols.

The chemical analyses (Table 3–6) show that the surface *Sphagnum* layer is low in nutrients, but the nutrient levels increase in the moss and sedge–moss layers. A sudden increase in all measured nutrient levels takes place at the 183 cm level and thereafter increases with depth.

A second core was taken near the edge of the palsa bog, 3 m from the unfrozen fen. The peat sequence is similar to that at the palsa bog summit (Table 3–7): a 10 cm surface layer of well-decomposed sylvic peat is underlain by a mesic *Sphagnum* peat layer to a depth of 44 cm. The permafrost table was encountered at 36 cm. A fibric moss peat, composed of *Drepanocladus* sp., and a mesic sedge–moss peat occur to a depth of 139 cm where the mineral soil was encountered. Both the peat below a depth of 116 cm and the underlying mineral soil contain large amounts of segregated ice.

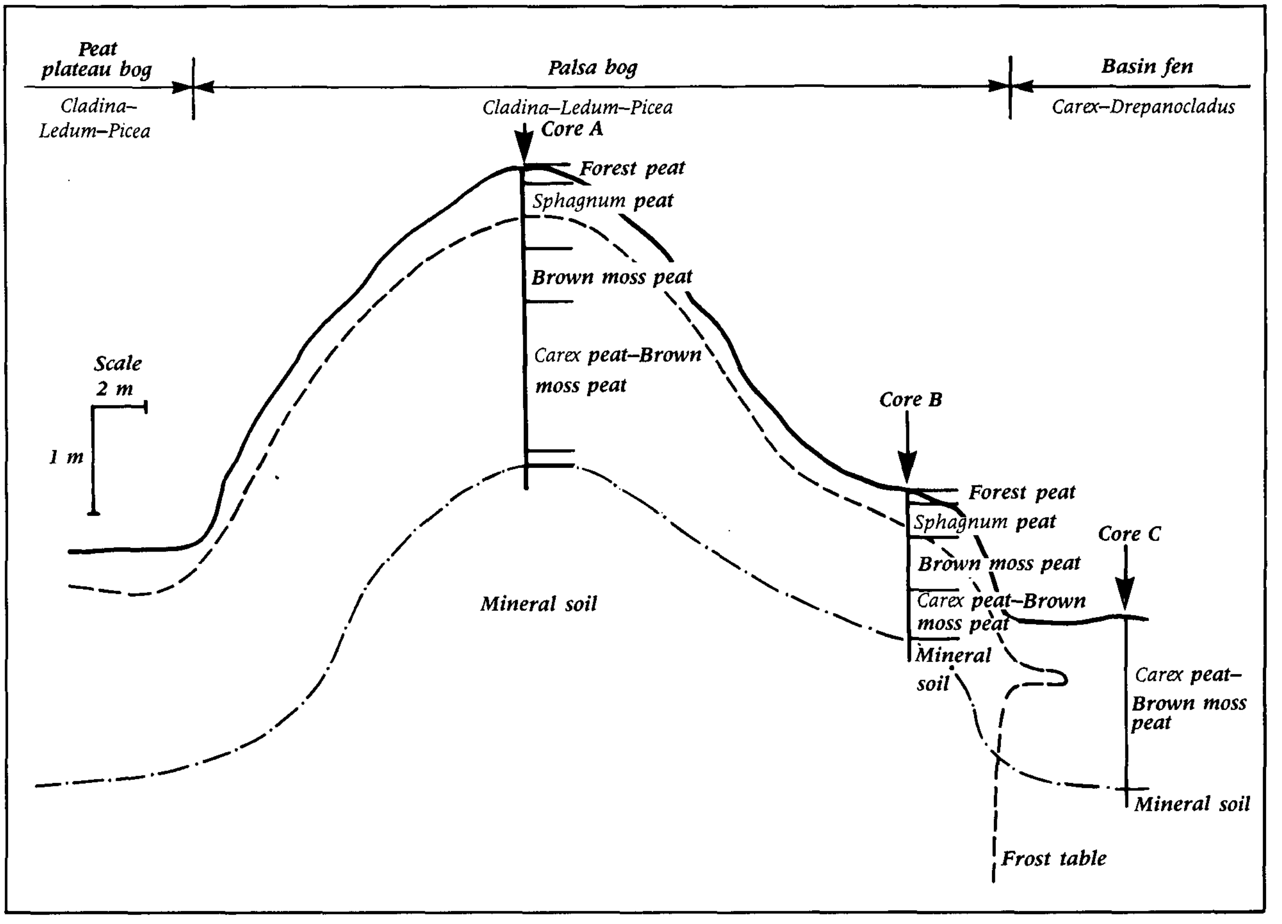


Figure 3–10.
Cross-section showing the internal structure of a palsa bog at Eagle River, YT.

The chemical analyses (Table 3–7) indicate that the surface *Sphagnum* peat is low in all measured nutrients. The nutrient levels, especially magnesium, increase in the moss layer and remain high throughout the rest of the peat profile. The volumetric moisture levels indicate that excess ice was present only in the basal peat and in the mineral soil.

The unfrozen fen was probed about 2.5 m from the edge of the palsa bog. The depth of peat was 163 cm and no permafrost was encountered.

The internal structure of the palsa bog is consistent with that of other permafrost peatlands: a thin *Sphagnum* peat cap covers peat that was deposited in a fen. The general sequence shows an initial deposition of peat in a fen dominated by sedge and moss species (*Drepanocladus;* possibly also *Campylium* sp., *Hypnum* sp.). The fen was later covered by *Sphagnum* spp., mainly *Sphagnum fuscum* or *Sphagnum balticum*. This initiated permafrost development by insulating the surface in the summer. The freezing of water in the peat elevated the surface of the peatland, creating better-drained conditions that effectively terminated *Sphagnum* growth. Lichens and dwarf shrubs became dominant, as shown by the surface sylvic peat. As the permafrost reached the mineral soil, excessive moisture penetrated into the peatland mainly along the peat–mineral soil interface from the fen that surrounds the palsa bog on three sides. As excess ice accumulated in the basal peat and in the mineral soil, the palsa bog was elevated some 3.5 m above the adjoining peat plateau bog and 4.25 m above the fen level.

Northern Ribbed Fens

These wetlands are characterized by low, narrow peat ridges that cut across the fens at right angles to the direction of water movement. The ridges (often called "strings") are spaced from five to several tens of metres apart, forming gentle arcs across the fens. The areas between these ridges are usually very poorly drained in contrast to the ridges, which are somewhat better drained. Although the gradient of the fens is almost always

Table 3–6. ***Total elemental analysis and other properties of peat from the centre of a palsa***

Depth of sample (cm)	*Decomposition (von Post)*	*Material*	*Ash (%)*	*H_2O by volume (%)*	*Ca (mg/kg)*	*Mg (mg/kg)*	*Fe (mg/kg)*
45	4	*Sphagnum*	5.4	58.7	4 646	259	3 423
61	4	*Sphagnum*	3.0	89.2	4 936	533	3 128
72	3	Moss	5.2	88.8	5 499	530	3 282
96	3	Moss	5.1	90.6	6 886	576	3 418
112	4	Moss	4.8	93.6	6 758	564	3 890
132	4	*Carex*–moss	5.5	83.4	7 118	530	3 877
146	5	*Carex*–moss	4.8	90.4	9 324	658	5 272
166	5	*Carex*–moss	5.8	91.0	9 675	639	5 443
183	5	*Carex*–moss	5.8	91.6	14 885	920	7 945
200	6	*Carex*–moss–wood	6.6	97.0	16 515	1 645	9 629
209	6	*Carex*–moss	8.1	92.5	15 942	970	9 437
219	7	*Carex*–moss–wood	12.4	88.9	16 505	1 132	10 001
248	7	*Carex*–moss–wood	10.6	85.9	19 436	1 033	11 541
255	7	*Carex*–moss	8.4	94.5	20 587	1 190	11 554
273	8	Humus–mineral soil	58.7	89.4	—	—	—
285	—	Mineral soil	83.1	74.0	—	—	—

Table 3–7. ***Total elemental analysis and other properties of peat from the margin of a palsa***

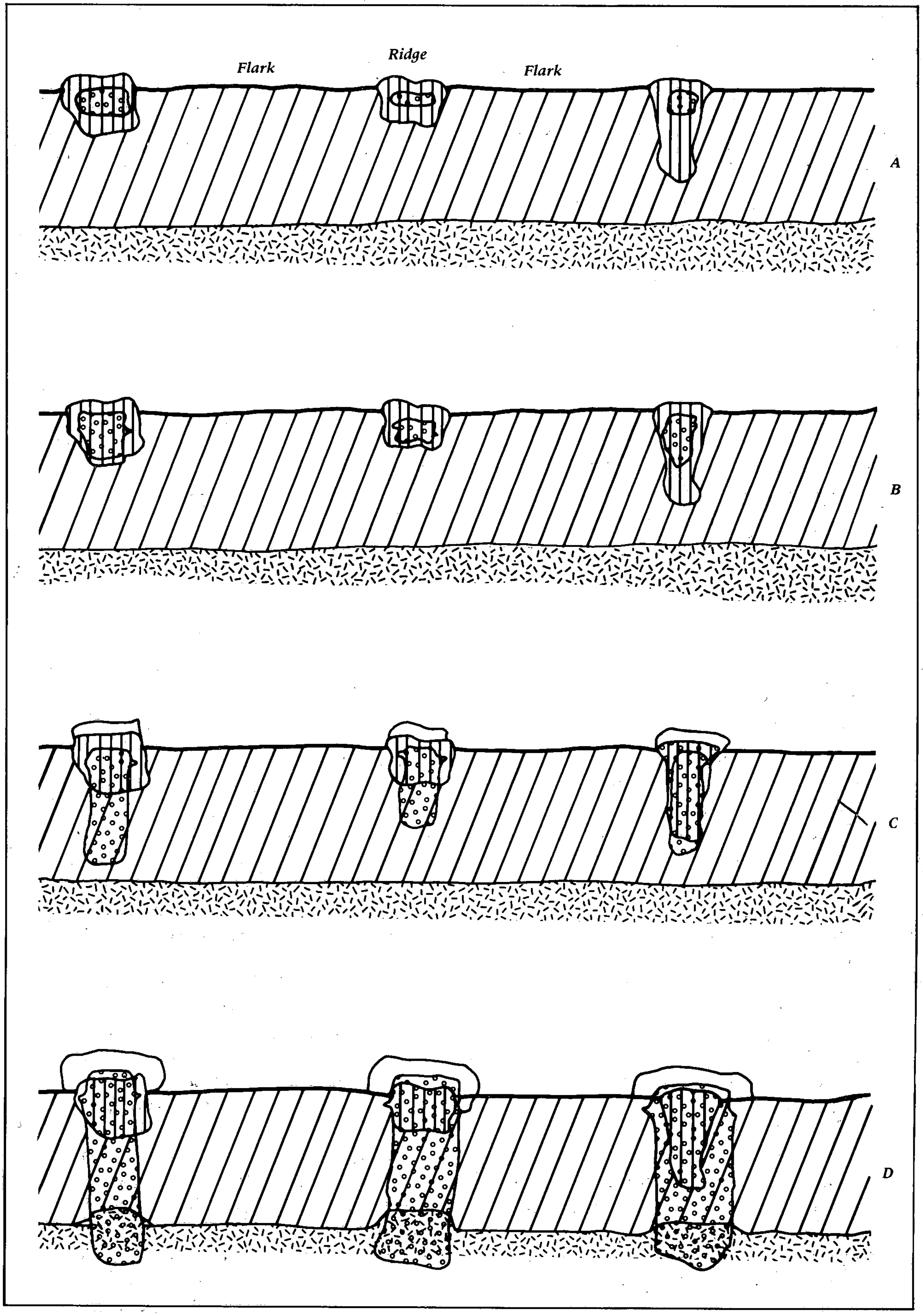
Depth of sample (cm)	*Decomposition (von Post)*	*Material*	*Ash (%)*	*H_2O by volume (%)*	*Ca (mg/kg)*	*Mg (mg/kg)*	*Fe (mg/kg)*
39	3	*Sphagnum*	2.8	90.6	4 498	416	171
77	3	Moss	4.2	88.5	5 162	1 405	2 672
88	3	Moss	4.4	88.2	6 056	773	3 388
96	4	Moss	4.1	87.1	7 507	863	4 731
111	5	*Carex*–moss	6.0	92.8	9 780	885	5 693
120	5	*Carex*–moss	6.1	94.2	11 751	826	7 835
141	—	Mineral	92.4	78.8	—	—	—

less than 1°, the ridges appear to be more closely spaced in fens with higher gradients. Where the gradient is very low, the ridges are not only widely spaced but become more sinuous and interconnected in a net-like pattern. The height of the ridges varies between 10 and 30 cm, and reaches 70 cm or more if affected by permafrost. Northern ribbed fens are common in the Low Subarctic and High Boreal Wetland Regions. The main regional difference is that, in the Low Subarctic Wetland Region, permafrost is often present in the ridges, affecting their morphology and interfering with drainage.

The ridges consist of peat that is somewhat denser and is elevated above the peat in the intervening depressions; these are called "flarks" (Andersson and Hesselman 1907). The flarks may contain wet peat or shallow, peat-bottomed pools, depending on the hydrology of the fen. The ridges act as dams impeding the seepage of water, as shown by the generally wetter conditions on the upslope sides of the ridges. Careful levelling measurements reveal a slight (less than 10 cm) difference in the elevation of the surface of successive flarks.

The ridges present a somewhat drier environment than the main body of the fen. Being slightly higher and periodically drier, the peat acts as an insulator and in the subarctic wetland regions may eventually prevent the complete thawing of seasonal frost. As water is changed into ice, it expands by about 10% of its volume (Pounder 1965), further elevating the surface of the peat. This induces even drier surfaces with better insulating qualities, resulting in the acceleration of permafrost development. This in turn results in the development of small peat plateau bogs on the ridges.

A series of observations in the Low Subarctic Wetland Region revealed a sequence that begins with late-thawing seasonal frost and ends with peat plateau bogs that cover the entire fen (Figure 3–11). Late-thawing frost in the ridges persists long after the seasonal frost has thawed in the fen, but disappears by the end of the summer (Figure 3–11a). However, because frost is present during most of the summer, it impedes the surface



Ridge
Flark
Flark
A
B
C
D

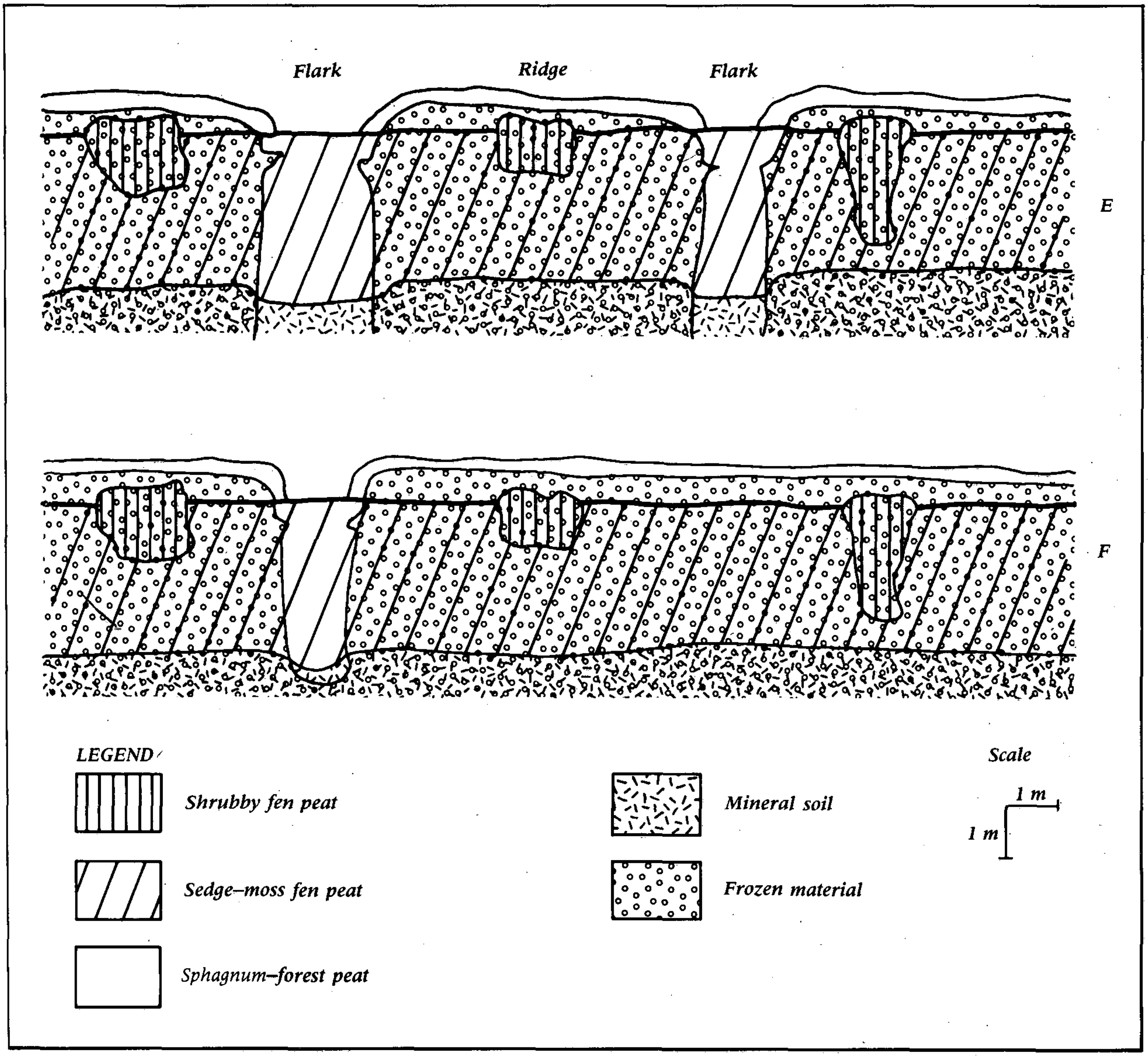


Figure 3–11.

Progress of permafrost development in a northern ribbed fen.
A – Persistent seasonal frost under ridges in mid-summer
B – Small permafrost lenses in peat
C – Large permafrost lenses in peat
D – Permafrost lenses reach mineral soil
E – Permafrost expands
F – Permafrost affects nearly all of the wetland

flow and near-surface water seepage in the fen. Persistent seasonal frost may lead to the establishment of permafrost, where frozen peat remains throughout the year in the upper portion of the ridges (Figure 3–11b); it eventually increases and extends downwards (Figure 3–11c). In many cases such permafrost cores develop first at the nodes where two or more ridges join (Figure 3–12). As the permafrost is blocking only the surface or near-surface water movements, water seepage through the fen is still possible. In time, however, the permafrost lenses may reach the mineral soil (Figure 3–11d), establishing a series of dams across the fen. Observations show that at this stage small creeks are formed on the surface of the fen and provide channels for water flow (Figure 3–13). Consequently, the water quality of the wetland changes, since mineralized water no longer reaches the surface of the wetland. The ridges begin to thicken as permafrost expands into the former flarks (Figure 3–11e). Eventually the flarks disappear, although small, wet depressions may mark their former location (Figure 3–11f). At this stage, permafrost is present under all but the wettest depressions, and the conversion of the patterned fen to a peat plateau bog is completed.

The vegetation of northern ribbed fens is influenced to a large extent by the degree of permafrost development. In those northern ribbed fens where no permafrost is present in the ridges, the vegetation of the flarks consists mainly of *Carex* spp. and *Eriophorum vaginatum*, with mosses such as *Drepanocladus* sp., *Scorpidium* sp. (depending on wetness and nutrient status), *Campylium* sp., and *Pohlia* sp. The ridges usually support shrub vegetation (*Betula glandulosa*, *Ledum groenlandicum*, *Chamaedaphne calyculata*) and mosses, such as *Sphagnum fuscum* and *Sphagnum magellanicum*.

In northern ribbed fens where permafrost is already present in the ridges but does not extend to the mineral soil, the vegetation of the flarks is dominated by *Carex* spp. and *Eriophorum vaginatum*. However, *Sphagnum* lawns, composed of *Sphagnum balticum* and *Sphagnum compactum*, may appear on the flark margins. The ridges, if well elevated, support a vegetation of *Ledum decumbens* and lichens (*Cladina mitis*, *Cladina rangiferina*). Lower ridges tend to have more shrubs (*Betula glandulosa*, *Kalmia polifolia*) and sedges. When permafrost blocks the drainage in the fen, the *Sphagnum* carpet and *Eriophorum vaginatum* content increase in the flarks. The vegetation of the broad ridges resembles that of peat plateau bogs: scattered *Picea mariana* and *Betula glandulosa* in a dominant lichen ground cover.

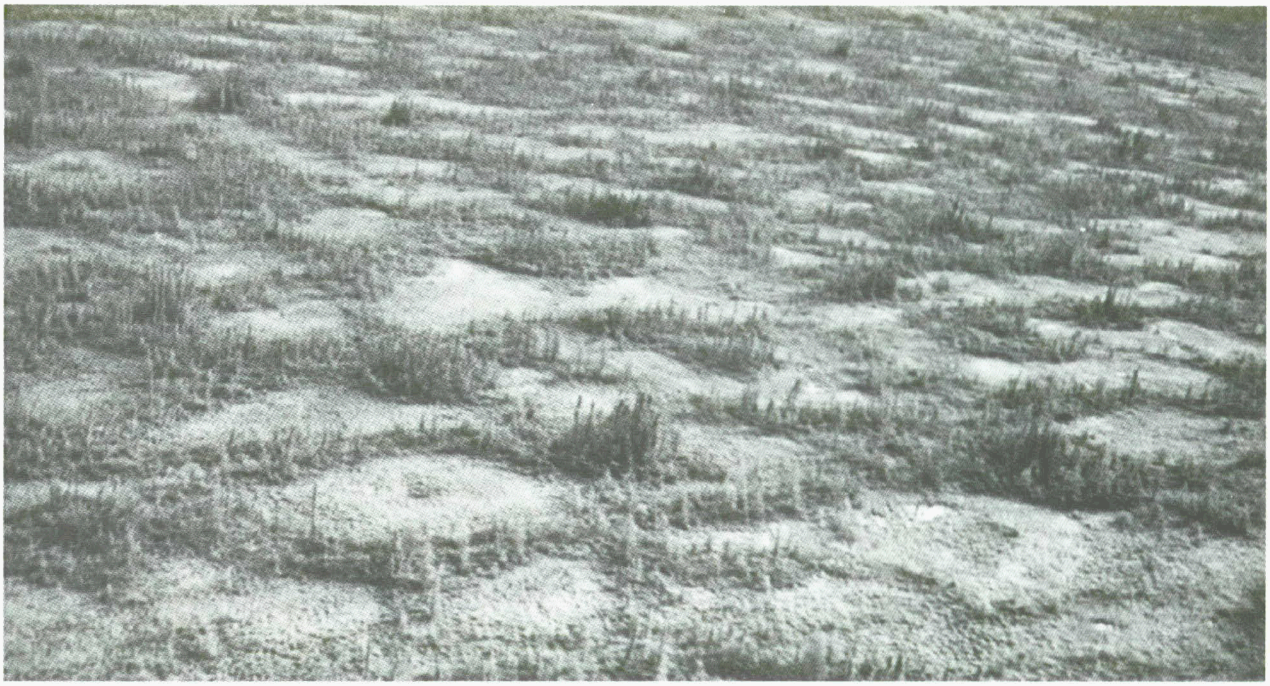


Figure 3–12.
Northern ribbed fen where permafrost has developed at some ridge nodes, marked by clumps of taller trees, Arctic Red River, NWT.

Northern ribbed fens in the Subarctic are identical to those in the High Boreal Wetland Region, except for a tendency to develop permafrost in the ridges. The origin of a ridge pattern in fens is subject to debate, as numerous theories have been advanced (Moore 1982). This subject is reviewed more fully in Chapter 4 on the wetlands of the boreal areas of Canada. The only theory that involves permafrost was advanced by Schenk

Figure 3–13.
Extensive permafrost development on former ridges blocked drainage through this fen; drainage now takes place through a series of small creeks, Rengleng River, NWT.

(1963) and was based on observations of permafrost in some ridges in northern Europe and North America. He believed that when a peat-covered permafrost area collapses as a result of thawing from below, the buckled and broken peat blocks form ribs and ditches. However, observations described here indicate that permafrost develops in already existing ridges and there is no evidence of massive collapse under the ribbed fens. Thus, these observations cast doubt on the sequence of events proposed by Schenk (1963).

A northern ribbed fen near Snake River, Yukon Territory (66°55′ N, 133°00′ W), was investigated in some detail. The fen is situated in a broad depression near a major watershed divide. The central part of the fen has a ribbed pattern, but peat plateau bogs occur near the margin of the fen. The ridges are narrow and uneven in height, ranging between 30 and 75 cm even on the same ridge. A short transect was run across two ridges and the intervening flark (Figure 3–14), chosen to intersect a high point on one ridge and the low point on

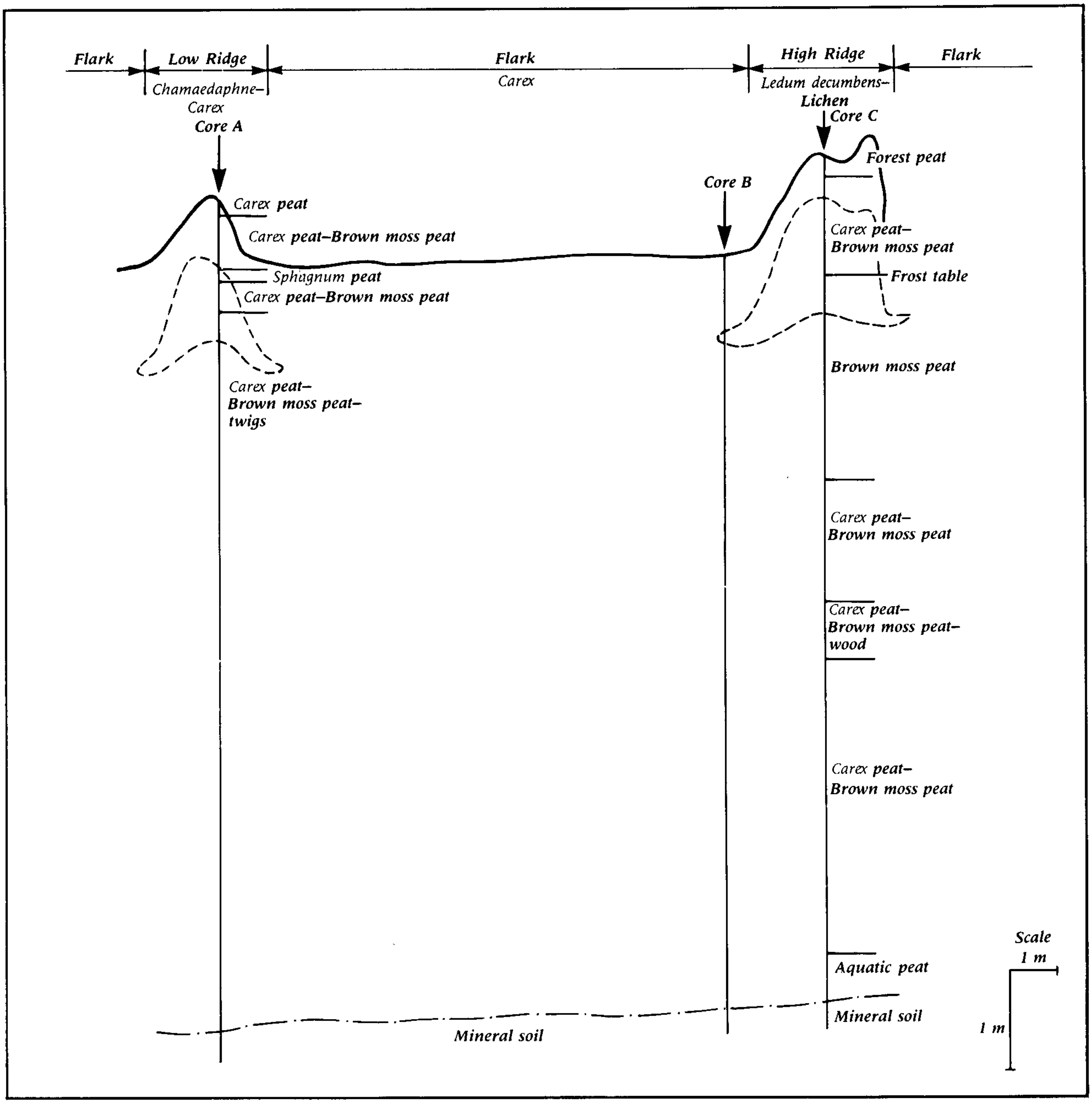


Figure 3–14.
Cross-section with three cores of a northern ribbed fen, with permafrost lenses under the ridges. Permafrost lenses are outlined with broken lines. Snake River, YT.

the neighbouring ridge. Vegetation, depth of thaw, and topography were measured along this transect.

The vegetation on the higher ridge consists of a few low *Picea mariana* trees, forming approximately 10% of the ground cover and associated with some *Ledum groenlandicum*. In the treeless parts, dwarf shrubs (*Ledum decumbens*, *Vaccinium vitis-idaea*, *Rubus chamaemorus*) form about 30% of the ground cover. In the moss layer *Sphagnum fuscum* is dominant, covering about 50% of the surface, and lichens are represented by small patches of *Cladonia sulphurina* and *Cladonia cornuta*. About 20% of the ground is bare of any vegetation.

On the low ridge there are a few *Betula glandulosa* shrubs (5% cover) and some low ericaceous shrubs. The main cover (75%) is provided by various *Carex* spp., but mosses (*Sphagnum warnstorfii*, *Sphagnum magellanicum*) are sparse. The flark is dominated by *Carex* spp. and *Eriophorum vaginatum*, along with *Drepanocladus* mosses.

On the higher ridge the surface layer (0–8 cm) consists of moderately decomposed forest peat made up of root, moss, and lichen remains. This is underlain by fibric woody *Sphagnum* peat (8–28 cm) and by mesic *Carex*–moss (*Drepanocladus*) peat (28–47 cm) (Table 3–8, high ridge). The top of the frost table was in this layer at 22 cm. The underlying peat is composed mainly of fibric *Drepanocladus* moss (47–146 cm), and the base of the frozen lens was reached at 65 cm. Beneath this layer is fibric to mesic *Carex*–moss peat which is underlain by detrital aquatic peat (336–356 cm). The mineral soil was reached at 356 cm.

The chemical analyses (Table 3–8, high ridge) show that the nutrient levels in the upper part of the section are low, generally consistent with nutrient values found in bogs and poor fens. Nutrient levels increase with depth in the unfrozen fen.

On the low ridge (Table 3–8, low ridge) the surface peat (0–8 cm) consists of fibrous *Carex* peat, under which is mesic *Carex*–moss peat (8–24 cm). The frost table occurred at the base of this layer. It is underlain by mesic *Sphagnum*–moss peat (24–36 cm) and by a fibric to mesic *Drepanocladus* and *Carex*–moss peat that contains small twig fragments. This is underlain by unfrozen peat to a depth of 357 cm.

Chemical analyses (Table 3–8, low ridge) show low concentrations of nutrients (especially calcium) in the top part of the section. Nutrient levels generally increase with increasing depth. The single sample from the seasonally frozen fen near the higher peat ridge (Table 3–8, fen) is also low in nutrients, falling within the range of poor fens (Sjörs 1950).

The low levels of nutrients in the top layers of both ridges indicate that they are elevated above the influence of fen waters. Nutrient levels are low

Table 3–8. Total elemental analysis and other properties of peat from three locations on a northern ribbed fen

Depth of sample (cm)	*Frozen (F) or non-frozen (NF)*	*Decomposition (von Post)*	*Material*	*Ash (%)*	*H_2O by volume (%)*	*Ca (mg/kg)*	*Mg (mg/kg)*	*Fe (mg/kg)*
A—High peat ridge								
29	F	5	*Carex*–moss	5.2	85.6	—	—	—
50	F	3	Moss	4.7	88.5	3 548	234	2 412
62	F	3	Moss	6.0	84.4	3 797	271	1 862
117	NF	3	Moss	8.3	87.7	4 583	286	4 557
135	NF	5	Moss	10.3	83.0	6 216	350	5 448
160	NF	3	*Carex*–moss	6.0	87.0	5 960	340	5 516
173	NF	3	*Carex*–moss	5.0	90.4	6 911	394	6 568
208	NF	6	*Carex*–moss–twiglets	10.4	84.9	9 720	486	8 159
258	NF	4	*Carex*–moss	9.3	91.1	10 124	524	10 033
300	NF	4	*Carex*–moss	12.8	86.9	11 327	534	9 101
345	NF	—	Aquatic detritus	72.2	75.8	—	—	—
358	NF	—	Mineral soil	46.0	93.1	—	—	—
B—Low peat ridge								
27	F	4	*Sphagnum*	4.2	87.5	3 585	350	2 028
49	F	3	Moss	5.6	94.2	4 548	391	3 599
59	F	5	*Carex*–moss–twiglets	6.1	88.5	5 967	376	3 256
C—Seasonally frozen fen								
31	F	3	Moss	7.1	91.5	4 892	367	2 667

even in the fen, indicating that the fen, located near a watershed divide, does not receive large amounts of nutrients from its surroundings.

Thin frozen lenses were encountered under both peat ridges. The time of sampling (mid-August) suggests that these may not thaw completely during the summer and therefore could persist as thin, incipient permafrost bodies.

The peat sections in the ridges show the presence of a shrub fen (*Carex*–moss–small twig peat), indicating a somewhat drier habitat than that in the flark. This may mark the initial formation of the ridges. Under the present conditions in this area, however, permafrost is not expected to occur in shrub fens. Thus the incipient permafrost lenses began to form relatively recently, after the ridges were elevated above the fen level.

Channel Fens

These minerotrophic wetland forms have a generally flat and featureless surface that slopes gently in the direction of drainage. They are confined to narrow, well-defined channels formed by mineral soil uplands, bedrock, or frozen organic landforms. The vegetation is usually uniform, with herbaceous, shrub, and tree species characteristic of nutrient-rich sites fed by minerotrophic waters from the surrounding mineral terrain and from headwater sources. The underlying peat deposit is moderately to well decomposed and ranges in thickness from 40 cm to an average of over 3 m. This wetland form occurs throughout the Subarctic in areas of suitable physiography.

In the Low Subarctic Wetland Region many channel fens occur in complex association with peat plateau and palsa bogs affected by permafrost. The fens are unfrozen and are characterized by flat relief resulting in predominantly poor surface drainage. The associated peat plateau and palsa bog landforms provide local relief within the fens and modify the surface drainage patterns. The boundary between an unfrozen fen and adjacent peat plateau bogs or uplands is strikingly abrupt (Figure 3–15). In the Continental High Subarctic Wetland Subregion the peat in channel fens is often affected by permafrost, without elevating them to peat plateau bogs, and is usually less than 2 m thick.

The structure and composition of the vegetation cover reflect the drainage conditions in the fen: open, stunted forest with poor drainage changes to fen species growing under the wettest conditions. Treed fens are characterized by an open-canopied forest in which *Larix laricina* is the most common species. Shrubs, usually *Betula glandulosa* (*Betula pumila* in the east), may dominate portions of the fen. In the Continental High Subarctic Wetland Subregion most channel fens are dominated by sedges, and shrubs and trees are usually absent. Shrubs (*Betula glandulosa*) may occur along the margins of the channels where drainage is slightly better.

Figure 3–15.
A channel fen with a peaty "island", showing some ridge development, Hume River, NWT.

Open fens with no trees and few shrubs may occupy large portions of the area, usually in association with small pools of water (Sims *et al.* 1982). The dominant vegetation consists of graminoid species (*Scirpus hudsonianus, Scheuchzeria palustris, Rhynchospora alba, Carex limosa*). A few shrubs (*Salix pedicellaris, Myrica gale, Betula pumila*) may be present but are not dominant. They are usually associated with small moss cushions of *Sphagnum fuscum, Tomenthypnum nitens*, and *Pleurozium schreberi*.

The surface 30–60 cm of the peat is usually fibric and scarcely decomposed, consisting of mosses and root masses. This is underlain by moderately to well decomposed peat in which wood chips from trees and shrubs may be present. The basal peat deposits are usually well decomposed. These soils are predominantly Fibric Mesisols.

The waters affecting these fens have been in contact with the mineral soil and have been enriched by the nutrients leached from them. In the James Bay Lowland the pH value of water in graminoid, shrubby, and treed fens averaged between 6 and 6.6. The conductivity averaged 0.091–0.200 mS/cm and the calcium content averaged 16.5–21.9 mg/L (Sims *et al.* 1982).

A treed channel fen in the Hudson Bay Lowland near Pennycutaway River, Manitoba (56°39′ N, 93°03′ W), was investigated in some detail. The fen occupies a relatively narrow (0.3–0.8 km wide) drainage-way extending for some 9 km across the extensive level to depressional landscape of the Lowland, which was formerly affected by marine submergence. The shape of the wetland is largely determined by the peat plateau complexes along the sides of the drainage-way.

The vegetation and peat stratigraphy was examined about 50 m from the edge of the channel fen in the upper reaches of the drainage-way. The treed portion of the fen has a sparse cover of low (3–6 m) *Larix laricina*. Shrubs provide a nearly closed ground cover, dominated by *Betula glandulosa* and *Andromeda polifolia*. The herb layer is composed of *Carex limosa*. A nearly complete moss cover is composed of *Sphagnum warnstorfii* in low ridges and cushions.

Tree cover is absent in more poorly drained areas where the shrubs *Betula glandulosa* and *Andromeda polifolia* are dominant. The herb layer consists mainly of *Carex limosa*, with the common occurrence of *Menyanthes trifoliata*. The moss layer in these wetter sites is dominated by *Aulacomnium palustre* and *Drepanocladus* spp.

The peat thickness was 185 cm, with the water table varying from the surface to 15 cm. The core shows that the surface 45 cm consists of *Sphagnum* peat, grading into mixed *Sphagnum* and sedge peat typical of peat formed under wet, forested conditions. The scarcity of woody inclusions reflects the open and poor quality of the forest cover. Beneath this layer is more decomposed fen peat composed of *Carex* spp., *Drepanocladus* spp., and occasional small twigs (45–120 cm). This is underlain by a mixture of sedge and moss peat grading into a thin layer of well-decomposed peat above the mineral soil. The most common soils associated with channel fens are Typic Mesisols and sphagnic phases of Mesisols.

The chemical analyses (Table 3–9) show that nutrient levels, especially calcium, are high throughout the peat section and increase with depth. The low pH in the upper part of the peat section may reflect a reduced minerotrophy due to the development of permafrost in the headwater area and in the surrounding organic terrain, restricting contact between groundwater and mineral soil.

The stratigraphic sequence observed in the core samples suggests that the wetland was initially a shallow marsh that later became a fen. This was superseded by a shrubby fen with scattered coniferous trees, a wetland that persisted for a long time. During the later stages the *Sphagnum* layer and the tree component increased to form the treed fen that exists at present. Downslope portions of this wetland still have shrub fens and fens with open pools of water, present-day analogues to the suggested early stages at the core site.

Veneer Bogs and Collapse Scar Fens

Veneer bogs are characterized by thin, peaty surface layers on a gently sloping terrain, and by the patchy occurrence of permafrost. The peat varies

Table 3–9. Chemical and physical properties of peat from a horizontal fen

Sampled layer (cm)	pH ($CaCl_2$)	Fibre content (%)		Material	Ash (%)	Organic C (%)	Total N (%)	Exchangeable cations* (me/100 g)				
		Rubbed	Unrubbed					Ca	Mg	Na	K	H
0–45	4.9	56	64	*Sphagnum magellanicum–Carex*	5.0	56.8	2.4	45.9	9.6	1.0	0.6	60.9
45–120	5.0	24	52	Feathermoss–*Sphagnum–Carex*	5.0	57.9	2.6	59.1	11.1	2.6	0.1	59.0
120–185	5.8	20	36	*Carex–Drepanocladus*	7.0	57.3	2.4	86.4	7.6	4.9	0.1	52.5
185+	7.6	—	—	Mineral (silty loam)	—	0.8	—	—	—	—	—	—

*Ammonium acetate extractable bases.

in thickness from about 0.3 to 1.5 m, with the depth of peat usually increasing towards the lower slopes of the bog. Veneer bogs are common on lower and mid-slope positions of gently sloping terrain throughout the northern part of the High Boreal Wetland Region and the southern part of the Low Subarctic Wetland Region. When viewed from the air, these slopes are characterized by distinctive patterns of parallel lineations. These lineations or "runnels" vary in spacing, but they are always oriented downslope, suggesting drainage patterns (Zoltai and Pettapiece 1973). Although the topography associated with runnels is often poorly expressed, differences in vegetation between the runnel and interrunnel areas help to locate them on the ground (Figure 3–16). The border of each runnel is marked by taller trees (up to 10 m high), compared with tree heights of 3–7 m between runnels (Mills *et al.* 1978). In addition, species variety in the vegetation is much greater in the runnels. Mixtures of *Picea mariana*, *Larix laricina*, and occasional *Betula papyrifera* occur with shrubs (*Betula glandulosa*, *Alnus rugosa* or *Alnus crispa*, and *Salix* spp.), sedges, and some mosses. In the boreal wetland regions, small upland shrubs and herbs, such as *Cornus canadensis* and *Fragaria vesca*, also occur. The enhanced tree growth and rich assemblage of minor species along the runnels reflect the flow of drainage waters, which create swamp-like conditions.

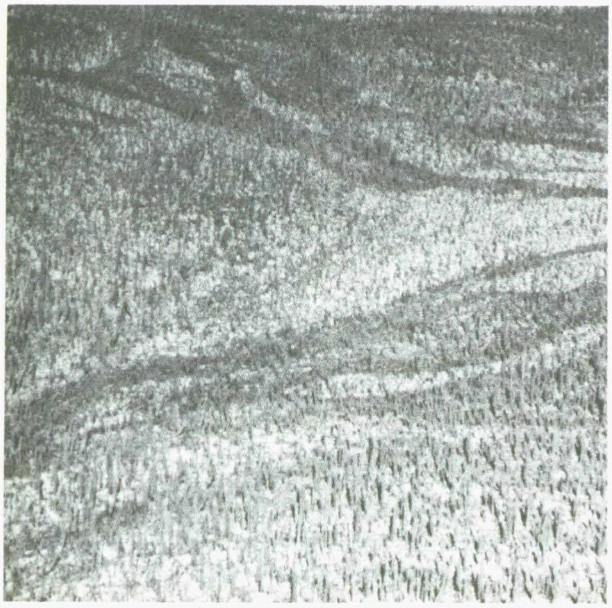


Figure 3–16.
Veneer bog with darker runnels, sloping from right to left, Horn Plateau, NWT.

In the boreal wetland regions the areas between runnels are characterized, depending on the thickness of the peat, by forest cover typical of poorly drained organic soils developed from forest or *Sphagnum* peat and imperfectly drained mineral soils. Therefore, the forest cover varies from patchy, closed stands of black spruce to fairly open forests of black spruce. In the Low Subarctic Wetland Region, the forest cover primarily consists of open stands of stunted black spruce regardless of the depth of peat. The shrub layer consists predominantly of *Ledum groenlandicum* (*Ledum decumbens* in the Subarctic), with lesser amounts of *Chamaedaphne calyculata*, *Rubus chamaemorus*, and shrub-sized *Picea mariana*. Other low shrubs and herbs include *Vaccinium myrtilloides*, *Vaccinium vitis-idaea*, *Oxycoccus microcarpus*, *Eriophorum* spp., and *Carex* spp. The shrub layer is sparse or absent in the more densely treed areas. Ground cover consists of feathermosses, such as *Pleurozium schreberi* and *Hylocomium splendens*, interspersed with large hummocks of *Sphagnum fuscum*. Lichens (mainly *Cladina* spp.) occur in patches on locally drier feathermoss sites. The lichen ground cover is more abundant in the subarctic wetland regions where the tree cover is much more sparse.

The permafrost in veneer bogs is discontinuous; its occurrence is more widespread in the subarctic than in the boreal wetland regions. Variations in active layer thickness range from 60 cm to more than 150 cm, but the variations decrease in the subarctic and northern portions of the boreal wetland regions.

Veneer bogs are often the dominant wetland component in gently undulating, rolling, or ridged terrain and may extend continuously over areas of several square kilometres. The boundaries of veneer bogs are not well defined, merging gradually to well-drained uplands along the upper slopes and to fens or peat plateau complexes along the lower slopes.

A veneer bog with collapse scar fens (Figure 3–17) near Thompson, Manitoba (55°55′ N, 97°43′ W), was studied in detail (Mills *et al.* 1985). It occupies the very gently sloping middle and lower north-facing slopes on a lacustrine clay deposit. Several transects were made downslope across the veneer bog, and topography, vegetation, soil types, thickness of peat veneer, and depth to permafrost table were noted.

The elevation difference of the bog surface is 2.5 m over a distance of 175 m from the upland to

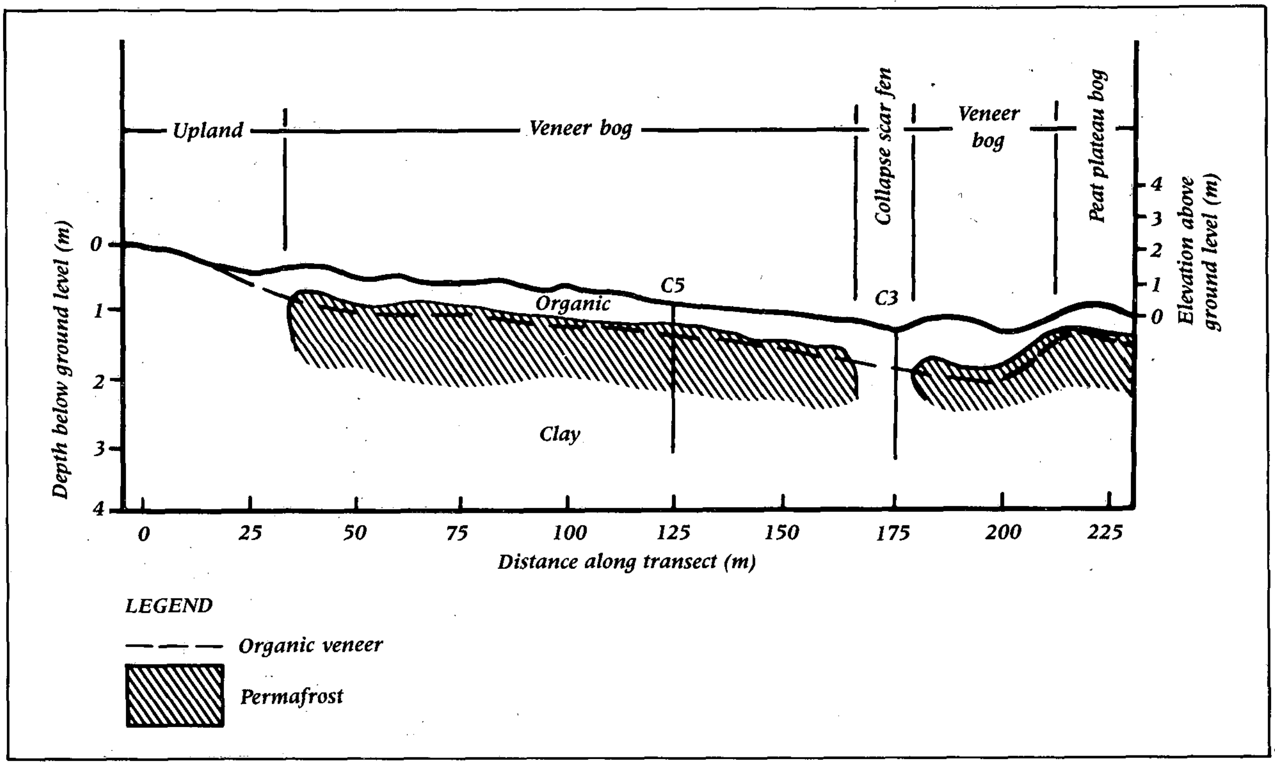


Figure 3–17.
Cross-section of a veneer bog on a gently sloping, deep lacustrine clay deposit near Thompson, Manitoba.

a peat plateau bog at the toe of the slope. The surface of the bog is microhummocky with gently sloping drainage-ways and level to depressional collapse areas.

The veneer bog is treed with unevenly aged black spruce forest typical of northern portions of the boreal wetland regions. The trees cover about 40% of the surface, growing in fairly open stands with frequent small openings. The trees vary from 3 to 5 m in height, with shrub-sized spruce (less than 1 m high) growing in association with *Ledum groenlandicum* and *Vaccinium myrtilloides* in open areas. A herb layer consisting of species such as *Vaccinium vitis-idaea* and *Rubus chamaemorus* is common in openings. Under more dense spruce the feathermosses *Pleurozium schreberi* and *Hylocomium splendens* form a hummocky surface. Lichens (*Cladina* spp.) occupy the apices of drier hummocks. *Sphagnum* spp. form both carpets and hummocks or cushions in association with mixed feathermosses and cover about 75% of the surface in broad drainage-ways and wetter depressions.

The bog is characterized by shallow Organic Cryosols associated with Brunisolic Static Cryosols and Gleyed Brunisols where the organic veneer is thin. Permafrost usually occurs within 2 m of the surface, but runnels may have a deeper active layer or permafrost may be lacking. Collapse scar fen areas occur in the veneer bog where the permafrost has thawed; the soils there are Terric Fibrisol or Rego Gleysols (peaty phase).

The organic layer on the veneer bog varies from 27 to 70 cm in thickness and averages 46 cm. Two sites were cored and sampled in detail (C5 and C3 in Figure 3–17). Site C5 is located at approximately the mid-point in the veneer bog and is characterized by an organic layer 72 cm thick. It is composed of 58 cm of fibric *Sphagnum* peat underlain by 12 cm of humic sedge–reed peat with woody inclusions. The underlying mineral soil is clay with a weakly developed Bm horizon occurring above the frost table. The active layer ranged from 85 to 120 cm thick at the time of sampling and the thickness of organic veneer varied from 30 to 75 cm. The soil is classified as a Terric Fibric Organic Cryosol.

The upper 30 cm of the peat is low in available nutrients and extremely acid (Table 3–10). Nutrient levels increase slightly in the next layer and are highest in the humified basal layer. These analyses indicate that the living moss vegetation is largely dependent on rainfall for nutrients, but some of the deeper-rooted vegetation on the bog may obtain nutrients from the well-decomposed peat and the upper layers of the mineral soil.

Site C3 (Figure 3–17) was cored in a small, irregularly shaped collapse scar fen ranging in diameter from 25 to 75 m and located 50 m downslope from site C5. This collapse scar fen is on the lower slope of the veneer bog and hence receives both surface runoff and seepage from the upper slopes of the bog. The collapse scar fen is very poorly drained and treeless. In the centre the dominant vegetation is *Carex* spp. and *Drepanocladus* spp. The slightly better-drained edges of the collapse scar fen also support low shrubs, such as *Salix* spp., *Chamaedaphne calyculata, Betula glandulosa, Vaccinium myrtilloides,* and a few scattered shrub-sized *Picea mariana*. The ground cover under the shrubs consists of *Carex* spp. and *Drepanocladus* spp., with patches of *Sphagnum* spp. and feathermosses.

The peat thickness at this site was 55 cm. The peat sequence indicates a relatively uniform accumulation of fibric *Carex–Drepanocladus* peat. This shallow organic soil is classified as a Terric Fibrisol. The chemical analyses (Table 3–10) show that the nutrient levels of the peat are very similar to those from the treed portion of the veneer bog, differing mainly in pH and exchangeable hydrogen (H) concentration. The surface peat of the treed portions of the veneer bog is thus not as strongly influenced by groundwater as that in the collapse scar fen.

The thickness of the active layer at the same locations across the veneer bog varied between 60 and 150 cm over a five-year period. Such fluctuation in the depth of the active layer from year to year and from site to site is an indication of the condition of fragile equilibrium in which frost persists in these wetlands. Indications are that particular sequences of weather conditions can increase or decrease the extent of permafrost and the thickness of the active layer. Warm summers, cold winters, lack of snow, or unusually thick snow can induce substantial annual variations. Fire in dry seasons may completely remove the organic veneer, usually resulting in the complete degradation of the permafrost.

The drainage of the veneer bog also influences wetland development and the distribution of permafrost. The morphology of the runnels indicates that they serve as runoff channels which carry the largest amounts of water in the spring and seepage flow during the rest of the thermal season as the seasonal frost melts. Probings show that the active layer is deeper or that the permafrost is absent under the runnels and seepage channels, whereas in the better-drained portions (between runnels or under slightly raised ridges along the sides of runnels) the depth of annual thaw is usually less. The channeling of most runoff waters improves the surface drainage in the interrunnel areas and results in the persistence of permafrost on the veneer bog.

Table 3–10. Chemical and physical properties of soils from two sites in a veneer bog

Soil horizon	*Sampled layer (cm)*	*pH ($CaCl_2$)*	*Fibre content (%)*		*Material*	*Ash (%)*	*Organic C (%)*	*Total N (%)*	*Exchangeable cations* (me/100 g)*				
			Rubbed	*Unrubbed*					*Ca*	*Mg*	*Na*	*K*	*H*
A—Veneer bog													
Of1	0–30	3.6	86	96	*Sphagnum*	6.2	56.5	0.7	24.9	8.8	3.4	3.9	79.6
Of2	30–58	5.2	64	88	*Sphagnum*	7.6	56.3	1.1	64.5	15.1	0.7	1.5	49.1
Oh	58–70	5.6	8	16	*Carex*–wood	50.4	27.7	1.0	74.9	18.0	2.9	1.3	41.4
Ah	70–73	5.9	—	—	Silty loam	—	7.4	0.3	31.0	6.9	0.2	0.5	12.6
AB	73–80	6.0	—	—	Clay	—	2.5	—	21.8	6.0	0.2	0.6	6.7
Bm	80–95	7.3	—	—	Clay	—	0.5	—	22.9	5.1	0.2	0.6	4.1
BC	95–115	7.5	—	—	Clay	—	0.4	—	31.8	1.6	0.2	0.6	—
Ck**	115–120	7.5	—	—	Clay	—	—	—	32.2	4.7	0.2	0.7	—
Ckz	120–150	7.5	—	—	Clay	—	—	—	33.2	5.4	0.2	0.7	—
B—Collapse scar fen													
Of1	0–30	5.3	—	78	*Carex–Drepanocladus*	13.8	50.8	1.6	20.4	9.0	0.4	2.5	47.4
Of2	30–55	5.1	—	76	*Carex–Drepanocladus*	19.9	48.2	1.3	30.3	10.8	1.6	1.3	54.4
Ahg	55–70	5.1	—	—	Silty clay	—	11.3	0.4	29.1	3.1	1.3	0.1	35.1
ACg	70–80	5.3	—	—	Clay	—	4.7	0.2	21.3	1.0	0.4	0.3	15.6
Cg1	80–100	5.5	—	—	Clay	—	—	—	17.2	0.3	0.2	0.3	9.0
Cg2	100–150	6.2	—	—	Clay	—	—	—	19.2	7.5	0.1	0.6	7.5
Ckg1	150–200	7.3	—	—	Clay	—	—	—	31.8	6.8	0.1	0.5	—

**Ammonium acetate extractable bases.*
***Frost table at 120 cm.*

Figure 3–18.
Abrupt boundary between floodplain marsh (left) and floodplain swamp (right), Mackenzie Delta, NWT.

Peat stratigraphy, vegetation, drainage, and permafrost relationships associated with veneer bogs indicate a possible path of development. Peat macrofossils from the lower slopes of the veneer bog show that this portion of the bog probably evolved from a wet moss–sedge–shrub meadow, developing gradually into a *Sphagnum*–feathermoss–black spruce forest. On the moderately well-drained mid-slope positions, upland forests dominated by *Pinus banksiana*, *Picea glauca*, and *Populus tremuloides* developed on Brunisolic soils. However, such slopes were gradually paludified as spruce forest, dominated by a mixed moss ground cover, advanced up the slope. In the subarctic wetland regions the open black spruce–lichen forest growing on mid-slope positions was gradually altered as mosses became more prevalent through the encroachment of the mixed moss cover.

As the peaty surface advanced up the slopes, it retained much of the moisture falling on the area and also intercepted much of the runoff from upslope positions. Expansion of the peat veneer combined with the insulation provided by the peat and the shade provided by the associated forest to initiate permafrost development. The distribution of permafrost was initially sporadic, but it became more widespread as the peat veneer advanced and peat depths increased.

Floodplain Marshes and Swamps

Most larger rivers have an active floodplain that becomes flooded during high-water stages in the spring. A distinctive vegetation zonation occurs, reflecting the ground surface levels below flood levels, the duration of flooding, and the frequency of flooding (Gill 1971). In the Mackenzie Delta, the vegetation zone nearest the river channel consists of an *Equisetum* community, followed by *Salix–Equisetum*, *Populus*, decadent *Populus*, and finally by *Picea* communities farthest from the river (Gill 1973). Of these communities the *Equisetum* community is a marsh, as it is annually submerged for a long period (Figure 3–18). The somewhat less frequently flooded *Salix–Equisetum* community represents a floodplain swamp, but the treed communities (*Populus* sp., *Picea* sp.), which are flooded very infrequently, have a water table below the rooting zone and are not wetlands. A similar zonation is found along some of the floodplains associated with the Big Spruce and Seal rivers in northern Manitoba (Ritchie 1959).

In the floodplain marsh the dominant vegetation consists of *Equisetum fluviatile* with some *Salix alaxensis* and the moss *Leptobryum pyriforme* (Gill 1971, 1973). The soil shows no profile development and is classed as a Rego Gleysol (Veldhuis 1980). In the summer the water table is slightly above the water level in the nearby river channel. Permafrost is usually absent (Figure 3–19) (Heginbottom and Tarnocai 1983).

(Veldhuis 1980). A Gleyed Cumulic Regosol underlies the leading edge of the willows in a strip parallel to the channel. In this area the accumulation of drifted snow is usually the deepest and its insulating effect the strongest, possibly preventing the formation of permafrost. The soil in the remainder of the willow zone is a Gleyed Cumulic Regosol, cryic phase, and contains permafrost at a depth of about 100–120 cm.

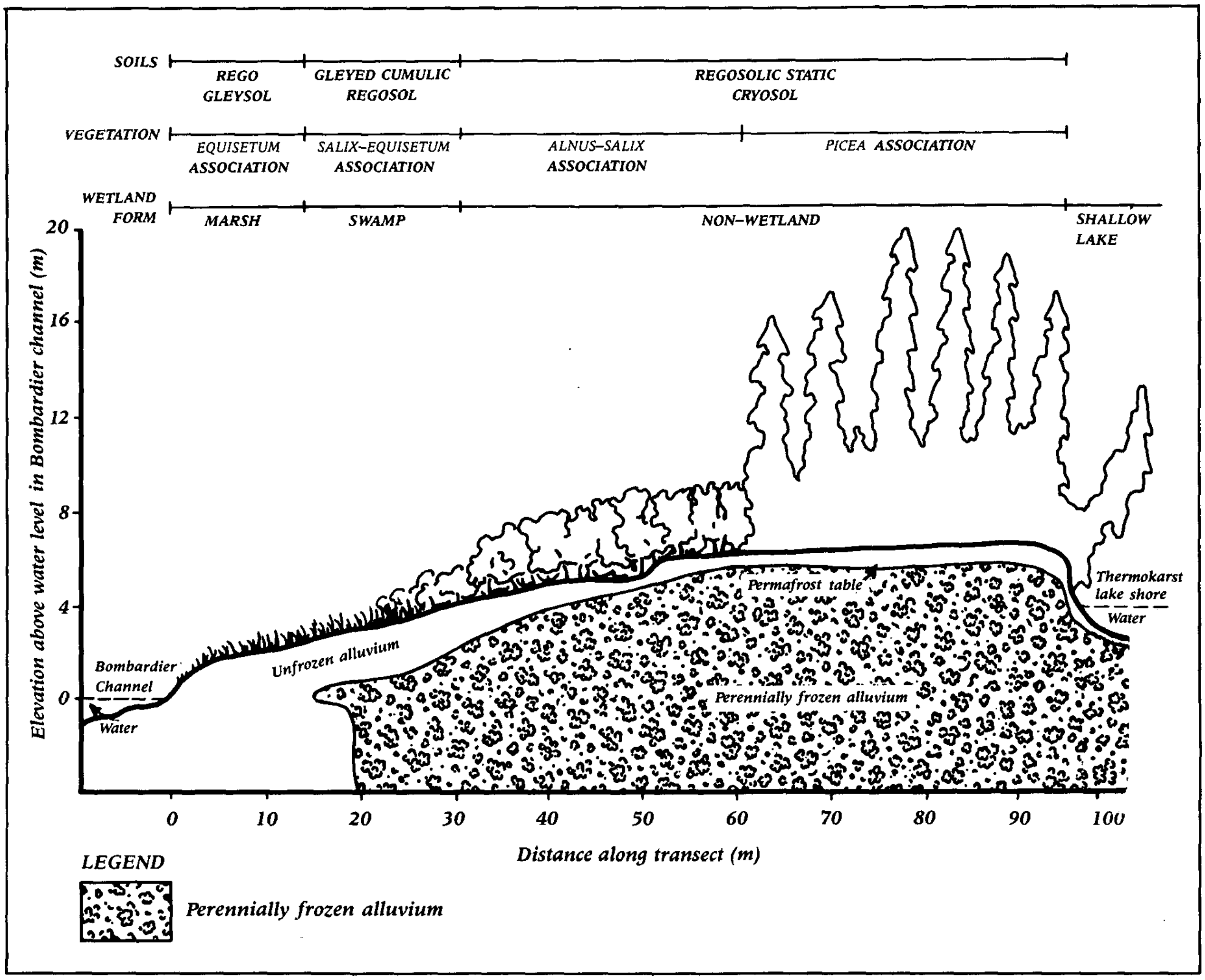


Figure 3–19.
Cross-section showing vegetation, soil, and permafrost conditions on a floodplain, Mackenzie Delta, NWT.

The next level of the vegetation zone is a swamp, consisting of *Salix alaxensis* growing to a height of 3–4 m, and a nearly complete ground cover of *Equisetum arvense*. Other species include *Hedysarum alpinum, Aster sibiricus, Campylium stellatum,* and *Leptobryum pyriforme* (Gill 1971). The soils in the willow (*Salix* sp.) zone are of two kinds

Thermokarst Shallow Waters

Lakes situated in shallow basins on ice-rich soils have unstable shorelines. Thermal and wave erosion cut into the shorelines, constantly thawing and eroding them. The basin under the newly submerged shore deepens as the ice in the degrading permafrost thaws and the ground subsides (thermokarst process). In some instances this process can erode the outlet of a lake, resulting in the partial or complete drainage of the lake (Figure 3–20). Permafrost develops on the exposed lakebed, elevating it as the groundwater freezes. Second-generation lakes are often formed in the lower parts of the old lakebed, renewing the cycle of lake formation and erosion.

Large subarctic concentrations of such shallow lakes occur on the older part of the modern Mackenzie Delta, on the peat-covered lacustrine basin

Figure 3–20.
Shallow lakes and lakebeds recently exposed by drainage of the lakes, Old Crow Flats, YT.

at Old Crow, and on the peaty marine sediments on the coastal Hudson Bay Lowland. They are also a prominent feature on the Great Plain of the Koukdjuak on Baffin Island.

In the Hudson Bay Lowland, thermokarst lakes are common in peatland environments characterized by high- and low-centre polygons. The lakes are elongated (longer than 1 km) but fairly shallow (less than 3 m in depth) and flat-bottomed. One hypothesis for the development of these lakes is based on predicted change in the thermal characteristics of the peat with changing moisture content (Dredge and Nixon 1979). These shallow water bodies appear to be part of the development sequence of low- and high-centre polygons. Initially, small pools develop as some polygon troughs deepen. The pools may expand and coalesce into larger thermokarst lakes which, if drained, may begin peatland development again.

The lakes vary in size from a few to several hundred hectares. Many are without outlets, but others may be interconnected by small streams. The average depth of 11 lakes on the Old Crow Flats was 1.4 m (Ruttan 1974a). Similarly, the maximum depth in an experimental lake in the Mackenzie Delta was 2.25 m (Snow and Rosenberg 1975a). The mean ice thickness during March ranged between 75 and 90 cm in the Old Crow Flats (Ruttan 1974a), leaving unfrozen water in the deeper parts of the lakes.

The pH values in two shallow lakes in the Mackenzie Delta ranged from 7.2 to 8.75, and the specific conductivity was 0.15–0.31 mS/cm (Snow and Rosenberg 1975b). In general, lakes that have inlet channels or are periodically flooded by river overflow have higher nutrient levels than lakes without inflow.

Macrophyte distribution is influenced by the depth of water. In stable shoreline shallows *Carex aquatilis* and *Juncus* spp. are common. The floating plant *Lemna trisulca* often occurs in large numbers in these areas. In shallow waters *Equisetum fluviatile, Menyanthes trifoliata, Hippuris vulgaris, Potamogeton foliosus,* and *Myriophyllum* sp. occur. In deep water (approximately 0.9–1.8 m), *Potamogeton foliosus* and *Potamogeton richardsonii* are found, along with *Nuphar polysepalum* (Ruttan 1974a).

It was found that, among the phytoplankton in the Mackenzie Delta area, *Chrysophyta* completely dominated a turbid lake. They were also very common in clear lakes, but diatoms such as *Chlorophyta* spp., *Pyrrhophyta* spp., and *Cryptophyta* spp. were also present in significant amounts (Snow and Rosenberg 1975a, 1975b).

Regional Wetland Development

Nutrient Status

The nutrient status of wetlands is influenced by the chemical composition of the associated groundwater and the atmospheric moisture that falls on the area. Elemental contaminants deposited from the atmosphere are generally similar in various parts of northern Canada and, indeed, in northern Europe (Glooschenko and Capobianco 1978). The main differences in nutrient status among subarctic wetlands can be attributed to the quality of groundwater that has been in contact with mineral soil and has been enriched by it. However, regional differences in geology and geochemistry influence the amounts of nutrients contained in the groundwater. Thus, fen peat from carbonate-rich regions (Silcox site, Table 3–11) has a much higher pH value and Ca content than fen peat from low carbonate regions (sites 27C, 35A, and 28A in Table 3–11).

Wetlands in which the surface is not affected by groundwater are nourished by atmospheric enrichment only (and are called "ombrotrophic"); hence they are lower in pH and nutrients than fens. Tarnocai (1973) found that the electrical conductivity of groundwater from fens ranged between 0.20 and 0.55 mS/cm and in bog water it averaged 0.05 mS/cm. The Ca content in the water from fens was 18.6–83.8 mg/kg and the Mg was 2.8–28.8 mg/kg. In bog water the Ca content was 1.4–2.8 mg/kg and the Mg 0.12–0.73 mg/kg. In a generally nutrient-poor area the electrical conductivity was higher in the mineral-enriched groundwaters (0.04–0.06 mS/cm) than in the ombrotrophic bog waters (0.02–0.03 mS/cm) (Jasieniuk and Johnson 1982).

Nutrient levels are far lower in surface *Sphagnum* peat of the active layer of bogs than in underlying perennially frozen fen peat (Table 3–10). Levels of Ca are more than 10 times higher in fen peat, and Mg shows a consistent, but less pronounced, increase. The pH increases and hydrogen ion (H) concentration decreases in fen peat.

Perennially frozen peats are able to take up Ca selectively by exchanging H (Tarnocai 1972). Thus perennially frozen *Sphagnum* peat contains more Ca and less H than the covering unfrozen *Sphagnum* peat (Table 3–11). This tends to increase the

Table 3–11. Chemical analyses from active layer, perennially frozen Sphagnum *cap, and fen peat from permafrost bogs*

Bog form and site no.	pH*			Ca**			Mg			H		
	Active layer peat	Frozen Sphagnum cap peat	Frozen fen peat	Active layer peat	Frozen Sphagnum cap peat	Frozen fen peat	Active layer peat	Frozen Sphagnum cap peat	Frozen fen peat	Active layer peat	Frozen Sphagnum cap peat	Frozen fen peat
Polygonal peat plateau												
Site 27C (Tarnocai 1973)	2.5	3.6	4.7	8.08	30.80	73.73	3.03	3.66	11.86	85.95	71.50	44.50
Site 35A (Tarnocai 1973)	2.7	3.6	4.4	5.05	34.59	56.30	4.04	4.80	10.35	73.35	60.38	43.65
Peat plateau												
Site 28A (Tarnocai 1973)	2.5	3.3	4.4	4.04	32.06	69.94	5.05	8.83	9.85	83.92	71.55	47.25
Silcox site (Tarnocai 1972)	3.0	4.0	6.3	8.65	35.60	98.90	8.44	12.40	22.90	103.5	44.7	5.1

*pH in KCl.
**Nutrients as me/100 g of ammonium acetate extractable bases.

nutrient (mainly Ca) content of the perennially frozen *Sphagnum* cap that covers the fen peat in many permafrost peatlands. In a comparison of the total elemental composition of the perennially frozen *Sphagnum* cap with that of the frozen fen peat, it was found that in 14 out of 26 permafrost-affected peatlands the Ca and Mg content of the *Sphagnum* cap was as high or higher than that in the fen peat below. At 11 of the 26 sites Fe was higher in the frozen *Sphagnum* peat than in the frozen fen peat, while S was higher at only 3 of the 11 measured sites. This shows that translocation of elements in the perennially frozen peats tends to equalize the mineral constituents in peats of different origin, regardless of the nutrient content at the time of deposition. The exception is sulphur, which appears to increase with depth.

Wetland Dynamics

In the Subarctic, wetlands develop in depressional areas, generally going through a series of developmental stages from fens to bogs to permafrost forms. A wetland may originate as a pond which is gradually filled in with lacustrine organic debris and then invaded by fen species ("hydrosere"). Equally important is the "primary mire formation" process (Sjörs 1980) in which wetland development begins on moist soil where the water table is close to the surface. "Paludification", a process of wetland development in previously upland environments, occurs in the Subarctic as the water table rises in an accreting peatland, expanding its margins onto the adjacent lower slopes.

In the Subarctic the basal deposit in most wetlands is a thin (1–15 cm), well-humified peat that may be mixed with mineral soil. Such deposits currently occur under some wet meadows, dominated by *Carex* spp. and *Eriophorum* spp. Next to the basal layer is fen peat, with various proportions of *Carex* spp., *Drepanocladus* spp., and the remains of associated fen species. In some cases the fen peat rests on detrital, organic lacustrine deposits, indicating the infilling of a pond and a subsequent invasion by a fen. The fens may proceed to a shrub and treed stage, but repeated reversions to open fens are sometimes indicated by the peat stratigraphy. In fens of low nutrient regime a carpet of *Sphagnum* moss may become established.

The development of a peat plateau bog complex in northern Quebec has been documented by the examination of peat macrofossils and by radiocarbon dating (Couillard and Payette 1985). It was found that at first a minerotrophic herbaceous vegetation had colonized the depression, but peat plateau bogs began forming about 1 000 years after the establishment of the wetland. In many cases treed fens and sedge fens preceded the peat plateau bogs which are invariably found in an ombrotrophic environment, dominated by *Sphagnum nemoreum*, *Sphagnum fuscum*, and *Sphagnum russowii*, as well as *Picea mariana*. Peat plateau bogs expanded as ombrotrophic conditions developed, although several fires swept over them. Palsa bogs appeared only relatively recently, within about the last 700 years.

The internal structure of perennially frozen peatlands suggests that permafrost developed in them at a later stage. The majority of such wetland forms (peat plateau, palsa, and polygonal peat plateau bogs) shows at least a thin *Sphagnum fuscum* cap covering the fen peat. In the Mackenzie Valley it was found that in 96 out of 116 cored peatlands the *Sphagnum* cap averaged 33–42 cm in thickness (Table 3–12). Thick *Sphagnum* peat (thicker than 1 m) was present at 8 sites, and *Sphagnum* peat was absent at only 12 sites. The surface peat was strongly oxidized at many of the 12 sites and the recognizable macrofossils at a depth of 20–30 cm were those of fen species. Fen species were also identified in the surface peat materials of two palsas.

Permafrost is formed when heat loss (cooling) exceeds heat influx (warming) on a perennial basis. It has been shown that dry peat has low thermal conductivity (about 0.00017 g cal/sec/cm^2/°C), but that it greatly increases when saturated (0.0011 g cal/sec/cm^2/°C) (Brown 1966). Dry *Sphagnum* peat also has low thermal conductivity (Tikhomirov 1952). It has been found that in central Saskatchewan seasonal frost thaws much later (57 days) in *Sphagnum* hummocks than in fens (FitzGibbon 1981).

The presence of a thin *Sphagnum fuscum* cap indicates that *Sphagnum* spp. play a role in the establishment of permafrost in many peatlands. This may take the form of small *Sphagnum fuscum* cushions occurring randomly in fens, or as somewhat elevated ridges in patterned fens. In the summer the dry surface *Sphagnum* moss insulates the underlying seasonal frost, and in the fall the wet *Sphagnum* allows heat loss from the peat (Railton and Sparling 1973). This results in late-thawing,

Table 3–12. ***Thickness of Sphagnum fuscum cap over fen peat in permafrost bogs in the Mackenzie Valley***

Bog form	*Sphagnum fuscum* cap				Thick *Sphagnum*	Sites where *Sphagnum* not present
		Thickness (cm)				
	No. of sites	Mean	Maximum	Minimum	No. of sites	No. of sites
Peat plateau	63	41.4	80	18	6	8
Palsa	11	33.4	68	15	0	2
Polygonal peat plateau	22	42.4	87	12	2	2

seasonal frost that may eventually become a small permafrost lens. The freezing of water in the peat elevates the mound, encouraging further *Sphagnum* growth and more permafrost development. Small *Picea mariana* trees may become established on the mounds, decreasing the depth of snow there, and thus reducing insulation still more in the winter (Zoltai and Tarnocai 1971). Eventually the small mounds may coalesce to form large peat plateau bogs. Such a developmental sequence has been observed in various parts of the Subarctic (Zoltai and Tarnocai 1975; Payette *et al.* 1976).

If plentiful moisture is available, the mounds may become palsa bogs. As most palsa bogs occur as islands or peninsulas in wet fens, abundant moisture is available along most of their periphery. As moisture moves from the warm side (fen) to the cold side (palsa) (Hoekstra 1966), ice accumulation takes place in the palsa bog, mostly at the mineral–peat interface which is often more permeable by water. In peat plateau bogs only a small portion of their area is close to the periphery, and the influx of water into the frozen peat is limited to the fen margin.

Another form of permafrost development has been observed in areas of thin fen peat or shallow ponds. Here low mounds of peat are created by intensive frost action in the winter (Brown 1970). In some cases the exposed peat may dry out, especially if swept free of snow by the wind, and may provide sufficient insulation to prevent its thawing during the summer. Once initiated, mosses, lichens, and trees will colonize the small permafrost mound, and it can develop into a peat plateau or palsa bog.

In the High Subarctic Wetland Region and in exposed areas in the Low Subarctic Wetland Region, the intense winter cold creates cracks in the frozen peat and ice-wedge development takes place. Nevertheless, in polygonal peat plateau bogs, as in peat plateau and palsa bogs, frost penetration takes place from above, that is, permafrost is established in peat deposited in a non-permafrost environment. This contrasts with the development of lowland polygons (both low- and high-centre) in the Arctic which develop under permafrost conditions.

The time of permafrost development in peatlands is not known in sufficient detail to relate it to climatic events or changes. However, in northern Quebec the expansion of peat plateau bogs in a minerotrophic fen has been related to cooling periods 2 700, 1 400, 1 100, 700, and 150 years before the present (BP) (Couillard and Payette 1985). This interpretation is based on nine radiocarbon dates taken at the ombrotrophic–minerotrophic contact and thus relates the change to ombrotrophic conditions. Development of permafrost probably followed some time after that.

In the continental climate of the Subarctic, peat accumulation virtually ceases after permafrost elevates the peatland, which consequently becomes dry at the surface. Available dates from such peatlands show a great age for near-surface peat. Peat from a level of 5.5–8.5 cm in a polygonal peat plateau bog was dated 1 145 ± 65 years BP (Ovenden 1982), and peat from a level of 35 cm in another polygonal peat plateau bog was dated 2 710 ± 60 years BP (Zoltai and Tarnocai 1975). The age of peat from a depth of 30 cm at Natla River, Northwest Territories, was 3 000 ± 50 years BP (MacDonald 1983). However, these samples give only minimum dates for permafrost development in these peatlands.

In the absence of information one can only speculate on the time of permafrost formation in the peatlands. Some permafrost peatlands may be several thousand years old, as suggested by the humified upper soil horizon; others are still in the process of formation. Virtually all initial peat deposition was in unfrozen fens and often several metres of fen peat were formed before permafrost affected the peat. It is possible that widespread permafrost formation took place after a general cooling of the climate some 5 000 years ago (Ritchie *et al.* 1983).

The surface of elevated permafrost wetland forms is dry, except for small moist depressions. Under such conditions peat-forming vegetation does not grow and therefore these wetland forms are no longer functioning as wetlands. Although the peat is saturated with water beneath the active layer, the water is present in a relatively inert, frozen form and this too throws their wetland status into question. However, as a result of severe disturbance the permafrost may thaw in these peatlands and they may collapse into the fen. Similarly, new peat plateau and palsa bogs are currently forming under *Sphagnum* hummocks. Because of the occurrence of these potential and actual changes, and because of the development of these wetland forms from a saturated environment, they may be regarded as wetlands.

The development of wetlands in the Subarctic is dictated by the hydrology and climate of the area as manifested by permafrost dynamics (Sjörs 1980). The evolution of wetlands is from a fen (established on pond deposits, wet meadows, or paludified lowlands) to a fen with an ombrotrophic cap, and finally to peat plateau and palsa bogs (Figure 3–21). This succession proceeds at a different pace at different locations, due to such factors as hydrology, water quality, history, and local climate. In some areas it may stall for a long time; in other areas setbacks may occur due to short-term environmental changes. In addition, some of the earlier stages in the developmental sequence may remain in equilibrium with environmental factors, such as physiography and hydrology, and may not always proceed to the next stage in the succession. The completion of the developmental sequence appears to be the development of peat plateau bogs. However, because the time that has elapsed since glaciation and the establishment of wetlands is relatively short, this apparent final point may not represent the true end in the development of wetlands.

Stability of Wetlands

Wetlands are dynamic ecosystems that are subject to long-term developmental changes and to short-term changes in response to catastrophic events such as drought, fire, or flood, or to anthropogenic activities. Given the slow rate of change because of the developmental process, wetlands are relatively stable and tend to recover from catastrophic events.

Fires are frequent on peat plateaus with their open-canopied *Picea mariana*, erect woody shrub, and dry lichen cover. Fire kills only the dry surface vegetation but does not destroy the peat to any depth (Jasieniuk and Johnson 1982). Many rhizomes, rhizoids, and gemmae remain alive and regenerate rapidly after a fire. Other species are slow in reoccupying the burned surface, but the original vegetation once again becomes prevalent within about 100 years after a fire.

Permafrost occurring in veneer bogs is particularly susceptible to disturbance by fire. Fire often sweeps across veneer bogs, starting from the adjacent better-drained mineral soils. Removal of the vegetation cover and the thin peat veneer by fire often alters the thermal regime of the veneer bog sufficiently to induce the complete degradation of permafrost. Permafrost often remains absent from a recently burned veneer bog until the moss cover encroaches up the slope from adjacent poorly drained terrain. The resulting cooler and wetter conditions permit the regeneration of permafrost.

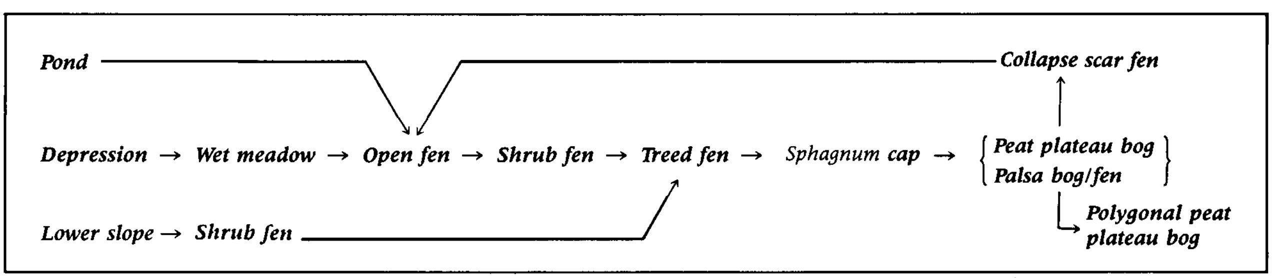


Figure 3–21.
Developmental trends of wetlands in the subarctic wetland regions.

Permafrost peatlands are also subject to degradation through thawing of the permafrost. When such thawing occurs, the peatland surface subsides to the level of the surrounding fen and fen vegetation invades the collapse scar fens. Dead trees and bright green *Sphagnum riparium* patches mark the recently collapsed permafrost margins. In some cases new permafrost development has been observed in such collapse scar fens (Tarnocai 1973).

When palsa bogs reach a senescent stage, they are subject to erosion by rain and runoff, and large blocks can be detached ("calved") from them (Railton and Sparling 1973). Ultimately the palsas may disappear completely (Kershaw and Gill 1979). The cracking of palsas may be due to their expansion as ice accumulates in their core. It has been noted that palsas which are sealed off from the wet fen stage by peat plateau development do not show intensive crack development, possibly because they are no longer growing.

Thermal degradation has been observed on polygonal peat plateau bogs in the Hudson Bay area (Dredge and Nixon 1979). Here some ice wedges may begin to thaw, becoming water-filled depressions. The accumulated water may saturate the surface peat in the centres of the polygons, causing deeper summer thaw. This may create shallow pools in the polygons. Once the depth of water exceeds 25 cm, the pools become heat sinks and thawing is accelerated, eventually resulting in expansion of the pools to form shallow lakes.

In the Subarctic, thermal degradation of permafrost peatlands does not occur on a large scale. Disturbances such as fires rarely set off extensive thawing except in areas where the peat is so thin that fires can completely consume it. Most collapses are triggered by persistent raising of the water table caused by linear construction activity, such as the building of roads or pipelines. Direct damage to the frozen peat surface caused by activities such as bulldozing or deep rutting can also initiate thermal subsidence.

Rate of Peat Accumulation

Peat is composed of the preserved remnants of plants that grew on a peatland. Peat accumulation takes place at the surface where the remnants of plants (both above and below the surface portions) are preserved. Decay and decomposition tend to reduce the volume of plant materials and only the surplus remains as peat. The thickness of peat can be further reduced by compaction, and can be increased by freezing as water changes to ice. Thus the rate of peat accumulation is only a very crude approximation of the productivity of a wetland.

The rate of peat accumulation near the surface of a number of sites in the Mackenzie Valley was indicated by the thickness of peat over a thin but widespread layer of volcanic ash. This ash, the White River ash, was deposited about 1 250 years BP by a volcanic eruption west of the area (Lerbekmo *et al.* 1975). The thickness of peat deposited in various environments, as determined by Tarnocai (1973), is shown in Table 3–13. A few additional measurements are included.

It is evident that the least peat accumulation took place in the lichen–forest environment, found on peat plateaus and palsas. This can be attributed to the generally dry conditions that persist on these well-elevated landforms where more decomposition than deposition of peat takes place. Lichen contains no fibres and leaves little residue. The *Picea*–ericaceous shrub forest is

Table 3–13. Peat accumulation in different environments, as indicated by peat thickness above White River volcanic ash layer in the Mackenzie Valley

Peat material	No. of sites	Range of depth to ash (cm)	Mean depth (cm)	Accumulation (cm/100 yr)
Cladina forest peat	3	2–5	3.6	0.29
Feathermoss forest peat	10	23–40	36.6	2.93
Ericaceous–woody forest peat	1	—	13.0	1.04
Sphagnum fuscum peat	9	20–61	38.8	3.10
Sphagnum riparium peat	1	—	104.0	8.32
Carex fen peat	8	19–67	33.2	2.66

Source: Tarnocai (1973).

somewhat higher in peat production, but still much below other wetland environments. The feathermoss forests, the wet *Sphagnum* bogs, and the sedge fens produced peat at about the same average rate. The fastest rate of peat development was found on level sites with wet *Sphagnum* spp.

Longer-term average accumulation rates can be obtained from radiocarbon-dated peat sections (Table 3–14). All four sections show at least one period of a high rate of accumulation occurring in their lower halves. All peatlands display a marked reduction in the accumulation rate at the top of the peat sections. The accumulation rates are similar to the very low rates found in the lichen–forest environment occurring on peatlands in the Mackenzie Valley that are currently affected by permafrost. The onset of the very slow rate of accumulation may well signal the establishment of surface-dry peatlands elevated by permafrost.

Table 3–14. ***Peat accumulation in radiocarbon-dated peat sections from subarctic wetland regions***

Depth of sample (cm)	*Radiocarbon age (yr BP)*	*Radiocarbon lab. no.*	*Rate of peat accumulation (cm/100 yr)*
A—Ennadai Lake (61°10′ N, 100°55′ W) (Nichols 1967)			
4	630±70	WIS–133	0.63*
20	1 510±80	WIS–88	1.82
55	2 670±105	WIS–93	3.02
72	3 140±105	WIS–139	3.62
90	3 650±100	WIS–80	3.53
110	4 800±90	WIS–166	1.74
132	5 570±100	—	2.86
150	5 780±110	WIS–67	8.57
B—Colville Lake (67°06′ N, 125°47′ W) (Nichols 1974)			
35	1 810±60	WIS–297	1.93*
44	3 160±65	WIS–314	0.67
69	3 980±65	WIS–295	3.05
90	4 130±55	WIS–294	14.00
124	5 730±75	WIS–296	2.12
174	6 630±85	WIS–299	5.56
206	6 790±75	WIS–275	20.00
C—Old Crow (67°49′ N, 139°50′ W) (Ovenden 1982)			
7	1 145±65	S–1864	0.61*
23	3 025±85	S–1865	0.85
27	3 250±85	S–1866	1.78
39	3 865±80	S–1867	1.95
66	5 285±115	S–1868	1.87
90	5 750±130	S–1869	5.16
122	7 575±170	S–1870	1.75
146	7 975±110	S–1778	6.00
150	8 200±180	S–1906	1.78
176	10 080±340	S–1871	1.44
215	11 435±270	S–1779	2.88
D—Natla River (63°00′ N, 129°05′ W) (MacDonald 1983)			
10	1 250	White River ash	0.80*
30	3 000±50	GSC–3176	1.14
90	5 460±70	GSC–3171	2.44
150	7 750±90	GSC–3169	2.69
220	8 420±80	GSC–3383	10.45
230	8 640±160	GSC–3097	4.54

**Accumulation rate based on assuming present date for the surface (0 cm).*

Long-term average peat accumulation rates of between 2.15 and 5.08 cm/100 yr were obtained for peatlands where at least two radiocarbon dates were available (Table 3–15). These permafrost peatlands also show a severe reduction in peat accumulation rates near the surface.

A number of radiocarbon dates are available from basal peat samples (Table 3–16). The peat accumulation rates were calculated on the assumption that they were uniform until the present. However, in the permafrost peatlands these rates are probably somewhat low because of the slow accumulation rates near the surface, as found in other permafrost peatlands. The data in Table 3–16 confirm this; the accumulation rates in non-frozen peatlands are higher than those in frozen peatlands.

Age of Wetlands

The ultimate determinant of the age of the wetlands in the Subarctic is the time of deglaciation and the disappearance of glacial lakes. Most of the Subarctic was glaciated during the Wisconsin glaciation with the exception of northwestern Yukon Territory, parts of which were never glaciated. Eventually, as the glaciers waned, the land was exposed, beginning about 13 000 years BP in the west, with the ice completely disappearing from the area by about 7 000 years BP (Prest 1970). In the unglaciated area, large areas such as Old Crow, Bell, and Whitefish basins were occupied by lakes fed by glacial meltwaters; hence they too were available for wetland development only after the glaciers disappeared.

The ages of basal peat samples (Table 3–16) indicate that peat started accumulating at least 1 000–2 000 years after glaciers vacated the land, and in some areas development began considerably later. Radiocarbon dates of organic lacustrine sediments overlain by peat are available mainly from the unglaciated–glaciated boundary in Yukon Territory (Table 3–17). The dates show that deposition of organic debris in small ponds began almost immediately after the disappearance of glacial ice. The dates from the Northwest Territories show the usual delay of 1 000–2 000 years after glaciation.

Table 3–15. Radiocarbon dates of surface and deeper peat deposits in subarctic wetland regions

Location	Bog wetland form	Depth of sample (cm)	Radiocarbon age (yr BP)	Radiocarbon lab. no.	Source	Rate of peat accumulation (cm/100 yr)
58°13′ N, 71°59′ W, Que.	Peat plateau	7	1 040±80	QU–977	Couillard and Payette (1985)	0.67*
	Peat plateau	95	3 640±100	QU–790	Couillard and Payette (1985)	3.38
63°00′ N, 129°05′ W, NWT	Peat plateau	30	3 000±50	GSC–3176	MacDonald (1983)	1.00*
	Peat plateau	230	8 640±160	GSC–3097	MacDonald (1983)	3.55
61°10′ N, 100°55′ W, NWT	Peat plateau**	4	630±70	WIS–133	Nichols (1967)	0.63*
	Peat plateau**	150	5 780±110	WIS–67	Nichols (1967)	2.83
67°06′ N, 125°47′ W, NWT	Peat plateau**	34	1 810±60	WIS–297	Nichols (1974)	1.88*
	Peat plateau**	206	6 790±75	WIS–275	Nichols (1974)	3.45
67°41′ N, 132°05′ W, NWT	Polygonal peat plateau	35	2 710±60	BGS–147	Zoltai and Tarnocai (1975)	1.29*
	Polygonal peat plateau	229	7 200±60	BGS–149	Zoltai and Tarnocai (1975)	4.32
67°49′ N, 139°50′ W, YT	Polygonal peat plateau	23	3 025±85	S–1865	Ovenden (1982)	0.76*
	Polygonal peat plateau	175	10 080±340	S–1871	Ovenden (1982)	2.15
55°34′ N, 84°38′ W, Ont.	Palsa	5	243±55	BGS–5	Railton and Sparling (1973)	2.06*
	Palsa	89	1 897±63	BGS–6	Railton and Sparling (1973)	5.08

**Accumulation rate based on assuming present date for the surface (0 cm).*
***Inferred, wetland form not precisely identified in original reference.*

Table 3–16. Radiocarbon dates of basal peat deposits from subarctic wetland regions

Location	Depth of sample (cm)	Frozen (F) or non-frozen (NF)	Radiocarbon age (yr BP)	Radiocarbon lab. no.	Source	Rate of peat accumulation (cm/100 yr)
68°22′ N, 132°44′ W, NWT	366	F	8 200±300	GSC–25	Dyck and Fyles (1963)	4.46
69°12′ N, 132°27′ W, NWT	213	F	7 400±200	GSC–16	Dyck and Fyles (1963)	2.88
64°52′ N, 138°19′ W, YT	162	F	9 620±150	GSC–310	Dyck *et al.* (1966)	1.68
68°04′ N, 139°50′ W, YT	183	F	6 430±140	GSC–372	Dyck *et al.* (1966)	2.85
68°45′ N, 133°16′ W, YT	213	F	7 120±140	GSC–371	Dyck *et al.* (1966)	2.99
64°36′ N, 138°20′ W, YT	162	F	6 840±150	GSC–415	Lowdon and Blake (1968)	2.37
64°36′ N, 138°22′ W, YT	140	F	3 100±130	GSC–416	Lowdon and Blake (1968)	4.52
64°36′ N, 138°22′ W, YT	126	F	3 180±130	GSC–469	Lowdon and Blake (1968)	3.96
68°22′ N, 133°44′ W, YT	330	F	11 500±160	GSC–1514	Lowdon and Blake (1973)	2.87
56°52′ N, 95°47′ W, Man.	170	F	6 490±170	GSC–1738	Lowdon *et al.* (1977)	2.62
65°34′ N, 135°30′ W, YT	300	F	8 980±90	GSC–2341	Hughes *et al.* (1981)	3.34
65°15′ N, 126°42′ W, NWT	170	F	3 960±50	—	Korpijaakko *et al.* (1972)	4.29
65°59′ N, 135°03′ W, YT	372	F	10 470±80	BGS–144	Zoltai and Tarnocai (1975)	3.55
66°10′ N, 134°18′ W, YT	255	F	5 910±60	BGS–140	Zoltai and Tarnocai (1975)	4.31
67°08′ N, 137°25′ W, YT	438	F	9 530±170	GSC–1829	Lowdon *et al.* (1977)	4.60
54°34′ N, 84°40′ W, Ont.	290	NF	5 580±150	GSC–247	Dyck *et al.* (1965)	5.20
55°00′ N, 82°20′ W, Ont.	122	NF	1 210±130	GSC–231	Dyck *et al.* (1965)	10.01

Table 3–17. Radiocarbon dates of organic lacustrine sediments overlain by peat in subarctic wetland regions

Location	Radiocarbon age (yr BP)	Radiocarbon lab. no.	Source
64°34′ N, 138°15′ W, YT	7 510±100	GSC–50	Dyck and Fyles (1963)
67°28′ N, 139°54′ W, YT	10 740±180	GSC–121	Dyck and Fyles (1964)
65°28′ N, 139°42′ W, YT	12 550±190	GSC–128	Dyck and Fyles (1964)
63°30′ N, 135°24′ W, YT	10 840±150	GSC–150	Dyck *et al.* (1966)
64°52′ N, 138°19′ W, YT	13 870±180	GSC–296	Dyck *et al.* (1966)
64°38′ N, 138°24′ W, YT	13 740±190	GSC–515	Lowdon and Blake (1968)
65°29′ N, 126°34′ W, NWT	8 880±150	GSC–1099	Lowdon *et al.* (1971)
67°54′ N, 139°26′ W, YT	6 020±140	GSC–2225	Lowdon *et al.* (1977)
68°19′ N, 133°25′ W, NWT	7 230±130	Beta–6600	This paper

Some indication of the sequence and time involved in wetland development is given by a study of the present Hudson Bay shoreline. At present this shoreline is receding about 6 cm a year in the York Factory area of northern Manitoba, as a result of post-glacial crustal rebound and sedimentation (Tarnocai 1982). This permits the study of wetland development as the land emerges from the sea and slowly becomes elevated. The initial low tidal marshes give way to high marshes that emerged from the sea 500–700 years ago. Some peat development begins during this stage about 600 years after emergence. These marshes are succeeded by horizontal fens with small palsas, inundated periodically by flood waters that maintain their minerotrophic character. Peat is actively formed during this fen phase. The land finally rises sufficiently to elevate it above even the highest floods; bogs with peat plateaus and palsas develop, beginning about 2 000 years after emergence from the sea. In areas not subject to flooding, ombrotrophic conditions are reached much earlier, some 1 000 years after emergence.

This sequence shows that under climatic conditions favourable for peat formation, peat deposition began some 600 years after the establishment of wetlands. The greater delay (over 2 000 years) in many wetlands, indicated by radiocarbon dating, implies that conditions were not optimal for peat formation immediately after glaciation. Conditions such as combinations of climate, plant migration, or other environmental factors may account for the delay in peat development.

Subarctic Wetland Values

Wetlands occupy the most moisture-rich habitats that constitute the landscape, contributing to the biotic diversity of any area. The intrinsic value of wetlands in an undisturbed landscape has already been determined by their invaluable contribution to the organisms that occupy them. Therefore the value of wetlands is best considered from a human-centred viewpoint.

Wetlands can be regarded both as places of biological production and as suppliers of resources. Although some uses may be totally non-consumptive and non-disruptive (such as viewing), most uses involve the removal of some wetland products (such as pelts or peat). These different intensities of use cause variations in the magnitude of disruptions resulting from human use.

Wetlands possess exploitable values, including production of waterfowl, fur-bearers, and ungulates, and a potential for peat harvesting and for land development for uses such as agriculture and water management. However, the remoteness of most subarctic wetlands makes the use of some of these resources unprofitable at present. This does not reduce the intrinsic value of the wetlands; their use is a matter of accessibility and economics.

There are enormous peat resources in the Subarctic. The estimated amount of peat in the Northwest Territories is 577 553 million m^3 (Tarnocai 1984). However, as most of the peat occurs in the Subarctic, a large portion is perennially frozen and development for uses such as mining would be dependent on special extraction techniques.

The biologically most active wetlands are the marsh–shallow lake complexes where both waterfowl and fur-bearing animals abound. Such areas are common in the Mackenzie Delta, in the Old Crow Flats, and the coastal areas of Hudson Bay, characterized by flat, poorly drained terrain with abundant peatlands and many shallow thermokarst lakes. In the Old Crow Flats ducks are common, although they are scarce everywhere else in the region (Schweinsburg 1974). Nine spe cies were found, with the American Widgeon (*Anas americana*) and White-winged Scoter (*Melanitta fusca*) being the most common. Furthermore, the Old Crow Flats and the Mackenzie Delta are extremely important as staging areas during the migration of geese, ducks, and swans (Schweinsburg 1974), as is the Hudson Bay coastal zone (Wellein and Lumsden 1964).

Both the Old Crow Flats and the Mackenzie Delta are very important for muskrat (*Ondatra zibethicus*) breeding and, in the Old Crow Flats, the shallow lakes and their marshy margins provide excellent habitat for muskrat (Ruttan 1974a). Muskrat are trapped in great numbers, with annual harvests averaging 14 800 pelts (Stager 1974). Muskrat meat is an important food resource for the trapper families. In 1973, 10% of the meat harvested by the Old Crow community was muskrat (Stager 1973).

Beaver (*Castor canadensis*) are basically aquatic animals that derive most of their food from the neighbouring lands. They are common in small lakes and streams in flat, boggy areas (Wooley 1974). Their main food sources are the stems and branches of various *Salix* spp., abundant in such areas.

Moose (*Alces alces*) are heavily concentrated during the summer in the Old Crow Flats and in the southern Mackenzie Delta (Ruttan 1974b). Wetland complexes, composed of flat, marshy areas with ponds, provide very important moose habitats (Watson *et al.* 1973), especially if there is a significant deciduous shrub component. These areas are especially important for the winter survival of moose.

Caribou, both woodland (*Rangifer tarandus caribou*) and barren-ground subspecies (*Rangifer tarandus tarandus*), winter in the widespread subarctic *Picea mariana*–lichen woodlands (Jakimchuk *et al.* 1974), including the treed peat plateau bogs. It has been found that areas without significant *Picea mariana*–lichen components are avoided by wintering caribou (Watson *et al.* 1973).

The most important value of wetlands at present appears to be their utilization for waterfowl and other wildlife production. The most important wetlands in this respect are the shallow lake–marsh–fen complexes. Peatlands (bogs and fens) are far less important for wildlife, with the exception of caribou. However, peatlands do represent a potential resource for peat production for various commercial uses.

At present, the remoteness of subarctic wetlands offers some measure of protection from intensive exploitation and disruption. However, pressure on these wetlands is already evident. Increased accessibility by new roads affects the wetlands and their use. Pipeline routings may avoid highly concentrated wetland areas, but they will have an impact on smaller wetlands. Nevertheless, there is still time to plan for the protection and conservation of both unique and representative wetlands throughout the Subarctic to ensure their continued existence.

Acknowledgements

Comments and reviews by the following individuals have been most useful in preparing this chapter: G. Adams, R. Hebda, H. Hirvonen, J. Johnson, E. Oswald, J. Pojar, and C. Rubec.

References

ÅHMAN, R. 1977. Palsar i Nordnorge. The Royal University of Lund, Sweden. Department of Geography Series. Avhandlingar No. 78. 165 p.

ANDERSSON, G., AND H. HESSELMAN. 1907. Vegetation och flora i Hamra kronopark. (Vegetation and flora in the state forest of "Hamra Kronopark".) Meddelelser Statens Skogsförsöksanst. 4:35–102.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals, 1951–1980. Volume 2: Temperature; Volume 3: Precipitation; Volume 4: Degree-days. Environment Canada. Downsview, Ontario.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 9–30.

BOTCH, M.S., AND V.V. MASING. 1983. Mire ecosystems in the USSR. *In* Ecosystems of the world. Volume 4B. Mires: swamp, bog, fen and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 95–152.

BROWN, G. 1980. Palsas and other permafrost features in the lower Rock Creek valley, west–central Alberta. Arctic and Alpine Research 12:31–40.

BROWN, R.J.E. 1966. Influence of vegetation on permafrost. *In* Proceedings, 1st International Permafrost Conference. National Academy of Science–National Research Council. Publication No. 1287. Washington, DC. pp. 20–25.

BROWN, R.J.E. 1970. Occurrence of permafrost in Canadian peatlands. *In* Proceedings, 3rd International Peat Congress. National Research Council of Canada. pp. 174–181.

BRYSON, R.A. 1966. Air masses, streamlines, and the boreal forest. Geographical Bulletin 8:228–269.

COUILLARD, L., AND S. PAYETTE. 1985. Evolution holocène d'une tourbière à pérgélisol (Québec nordique). Canadian Journal of Botany 63:1104–1121.

DOLGIN, I.M. 1970. Subarctic meteorology. *In* Ecology of the subarctic regions. Ecology and Conservation, UNESCO. Report No. 1. pp. 41–61.

DREDGE, L.A. 1979. Thaw depths and permafrost in polygonal peat terrain, Hudson Bay Lowland, Manitoba. Geological Survey of Canada. Paper 79-1C. Ottawa, Ontario. pp. 27–30.

DREDGE, L.A., AND F.M. NIXON. 1979. Thermal sensitivity and the development of tundra ponds and thermokarst lakes in the Manitoba portion of the Hudson Bay Lowland. Geological Survey of Canada. Paper 79-1C. Ottawa, Ontario. pp. 23–26.

DYCK, W., AND J.G. FYLES. 1963. Geological Survey of Canada radiocarbon dates, I and II. Geological Survey of Canada. Paper 63-21. Ottawa, Ontario. 31 p.

DYCK, W., AND J.G. FYLES. 1964. Geological Survey of Canada radiocarbon dates, III. Geological Survey of Canada. Paper 64-40. Ottawa, Ontario. 15 p.

DYCK, W., J.G. FYLES, AND W. BLAKE, JR. 1965. Geological Survey of Canada radiocarbon dates, IV. Geological Survey of Canada. Paper 65-4. Ottawa, Ontario. 23 p.

DYCK, W., J.A. LOWDON, J.G. FYLES, AND W. BLAKE, JR. 1966. Geological Survey of Canada radiocarbon dates, V. Geological Survey of Canada. Paper 66-48. Ottawa, Ontario. 32 p.

FITZGIBBON, J.E. 1981. Thawing of seasonally frozen ground in organic terrain in central Saskatchewan. Canadian Journal of Earth Sciences 18:1492–1496.

GILL, D. 1971. Vegetation and environment in the Mackenzie River Delta, Northwest Territories—a study in subarctic ecology. Ph.D. thesis, Department of Geography, University of British Columbia, Vancouver, British Columbia. 694 p.

GILL, D. 1973. Floristics of a plant succession sequence in the Mackenzie Delta, Northwest Territories. Polarforschung 43:55–65.

GLOOSCHENKO, W.A., AND J.A. CAPOBIANCO. 1978. Metal content of *Sphagnum* mosses from two northern Canadian bog ecosystems. Water, Air and Soil Pollution 10:215–220.

HAMELIN, L.E., AND A. CAILLEUX. 1969. Les palses dans le bassin de la Grande Rivière de la Baleine. Revue géographique de Montréal 23:329–337.

HEGINBOTTOM, J.A., AND C. TARNOCAI. 1983. Mackenzie Delta and Inuvik. *In* Northern Yukon Territory and Mackenzie Delta, Canada. H.M. French and J.A. Heginbottom, editors. Guidebook to Permafrost and Related Features. International Conference on Permafrost, Guidebook No. 3. pp. 113–146.

HOEKSTRA, P. 1966. Moisture movements in soils under temperature gradients with the cold-side temperature below freezing. Water Resources Research 2:241–250.

HUGHES, O.L., C.R. HARINGTON, J.A. JANSSENS, J.V. MATTHEWS, JR., R.E. MORLAN, N.R. RUTTER, AND C.E. SCHWEGER. 1981. Upper Pleistocene stratigraphy, paleoecology, and archaeology of the northern Yukon interior, Eastern Beringia. I. Bonnet Plume Basin. Arctic 34:329–365.

JAKIMCHUK, R.D., E.A. DEBOCK, H.J. RUSSELL, AND G.P. SEMENCHUK. 1974. A study of the Porcupine Caribou Herd, 1971. Canadian Arctic Gas Study Ltd. Biological Report Series. Volume 4, Chapter 1. 111 p.

JASIENIUK, M.A., AND E.A. JOHNSON. 1982. Peatland vegetation organization and dynamics in the western subarctic, Northwest Territories, Canada. Canadian Journal of Botany 60:2581–2593.

KERSHAW, G.P., AND D. GILL. 1979. Growth and decay of palsas and peat plateaus in the Macmillan Pass–Tsichu River area, Northwest Territories, Canada. Canadian Journal of Earth Sciences 16:1362–1374.

KOHNKE, H. 1968. Soil physics. McGraw-Hill Book Company. New York, New York. 224 p.

KORPIJAAKKO, M., M.L. KORPIJAAKKO, AND N.W. RADFORTH. 1972. Ice-biotic relationship in frozen peat. *In* Proceedings, 14th Muskeg Research Conference. 1971. Associate Committee on Geotechnical Research, National Research Council of Canada. Technical Memorandum No. 102. pp. 111–120.

LACHENBRUCH, A.H. 1962. Mechanics of thermal contraction cracks and ice-wedge polygons in permafrost. Geological Society of America. Special Paper No. 70. 69 p.

LEFFINGWELL, E. DE K. 1915. Ground-ice wedges: the dominant form of ground-ice on the north coast of Alaska. Journal of Geology 23:635–654.

LERBEKMO, J.F., J.A. WESTGATE, D.G.W. SMITH, AND G.H. DENTON. 1975. New data on the character and history of the White River volcanic eruption, Alaska. *In* Quaternary Studies. R.P. Suggate and M.M. Cresswell, editors. Royal Society of New Zealand. Wellington, New Zealand. pp. 203–209.

LOWDON, J.A., AND W. BLAKE, JR. 1968. Geological Survey of Canada radiocarbon dates, VII. Geological Survey of Canada. Paper 68-2, Part B. Ottawa, Ontario. pp. 207–245.

LOWDON, J.A., AND W. BLAKE, JR. 1973. Geological Survey of Canada radiocarbon dates, XIII. Geological Survey of Canada. Paper 73-7. Ottawa, Ontario. 61 p.

LOWDON, J.A., I.M. ROBERTSON, AND W. BLAKE, JR. 1971. Geological Survey of Canada radiocarbon dates, XI. Geological Survey of Canada. Paper 71-1. Ottawa, Ontario. pp. 255–324.

LOWDON, J.A., I.M. ROBERTSON, AND W. BLAKE, JR. 1977. Geological Survey of Canada radiocarbon dates, XVII. Geological Survey of Canada. Paper 77-7. Ottawa, Ontario. 25 p.

MACDONALD, G.M. 1983. Holocene vegetation history of the upper Natla River area, Northwest Territories, Canada. Arctic and Alpine Research 15:169–180.

MACKAY, J.R. 1974. Ice-wedge cracks, Garry Island, Northwest Territories. Canadian Journal of Earth Sciences 11:1366–1383.

MILLS, G.F., D.B. FORRESTER, AND H. VELDHUIS. 1978. A guide to biophysical land classification, Knee Lake, 53M. Manitoba Department of Renewable Resources and Transportation Services. Technical Report No. 78-2. Winnipeg, Manitoba.

MILLS, G.F., H. VELDHUIS, AND R.G. EILERS. 1985. Preliminary results of soil climate and hydrology studies in the discontinuous permafrost zone near Thompson, Manitoba. *In* 28th Annual Meeting, Canadian Society of Soil Science. January 9 and 10, 1985. Winnipeg, Manitoba. pp. 179–200.

MOORE, P.D. 1982. Pool and ridge patterns in peat mires. Nature 300:110.

NICHOLS, H. 1967. The post-glacial history of vegetation and climate at Ennadai Lake, Keewatin, and Lynn Lake, Manitoba, Canada. Eiszeitalter und Gegenwart 18:176–197.

NICHOLS, H. 1974. Arctic North American palaeoecology: the recent history of vegetation and climate deduced from pollen analysis. *In* Arctic and alpine environments. J.D. Ives and R.G. Barry, editors. Methuen and Company, Ltd. London, UK. pp. 637–667.

NORIN, B.N. 1961. Chto takoe lesotundra? (What is the lesotundra?) Botanicheskij Zhurnal 46(1).

OVENDEN, L. 1982. Vegetation history of a polygonal peatland, northern Yukon (Canada). Boreas 11:209–224.

PAYETTE, S., H. SAMSON, AND D. LAGAREC. 1976. The evolution of permafrost in the taiga and in the forest-tundra, western Quebec-Labrador Peninsula. Canadian Journal of Forest Research 6:203–220.

POUNDER, E.R. 1965. The physics of ice. Pergamon Press. Oxford, UK.

PREST, V.K. 1970. Quaternary geology of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 675–764.

RAILTON, J.B., AND J.H. SPARLING. 1973. Preliminary studies on the ecology of palsa mounds in northern Ontario. Canadian Journal of Botany 51:1037–1044.

RITCHIE, J.C. 1959. The vegetation of northern Manitoba. III. Studies in the Subarctic. Arctic Institute of North America. Technical Paper No. 3. 56 p.

RITCHIE, J.C., L.C. CWYNAR, AND R.W. SPEAR. 1983. Evidence from north–west Canada for an early Holocene Milankovitch thermal maximum. Nature 305:126–128.

ROWE, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Environment Canada. Publication No. 1300. Ottawa, Ontario. 172 p.

RUTTAN, R.A. 1974a. Muskrat studies on Old Crow Flats, Yukon Territory, 1972. Chapter IV. *In* Studies of furbearers associated with proposed pipeline routes in the Yukon and Northwest Territories. R.A. Ruttan and D.R. Wooley, editors. Canadian Arctic Gas Study Ltd. Biological Report Series. Volume 9. 104 p.

RUTTAN, R.A. 1974b. Observations of moose in the northern Yukon Territory and Mackenzie River valley, 1972. Chapter VI. *In* Studies of furbearers associated with proposed pipeline routes in the Yukon and Northwest Territories. R.A. Ruttan and D.R. Wooley, editors. Canadian Arctic Gas Study Ltd. Biological Report Series. Volume 9. 45 p.

SCHENK, E. 1963. Origin of string bogs. *In* Proceedings, 1st International Permafrost Conference. National Academy of Science–National Research Council. Publication No. 1287. Washington, DC. pp. 155–159.

SCHWEINSBURG, R.E. 1974. An ornithological study of proposed gas pipeline routes in Alaska, Yukon Territory, and the Northwest Territories, 1971. Canadian Arctic Gas Study Ltd. Biological Report Series. Volume 10. 215 p.

SEPPÄLÄ, M. 1980. Stratigraphy of a silt-cored palsa, Atlin region, British Columbia, Canada. Arctic 33:357–365.

SIMS, R.A., D.W. COWELL, AND G.M. WICKWARE. 1982. Classification of fens near southern James Bay, Ontario, using vegetational physiognomy. Canadian Journal of Botany 60:2608–2623.

SJÖRS, H. 1950. On the relation between vegetation and electrolytes in north Swedish mire waters. Oikos 2:241–258.

SJÖRS, H. 1980. An arrangement of changes along gradients, with examples from successions in boreal peatland. Vegetatio 43:1–4.

SNOW, N.B., AND D.M. ROSENBERG. 1975a. Experimental oil spills on Mackenzie Delta lakes. I. Effect of Norman Wells crude oil on Lake 4. Fisheries and Marine Service, Environment Canada. Technical Report No. 548. 44 p.

SNOW, N.B., AND D.M. ROSENBERG. 1975b. Experimental oil spills on Mackenzie Delta lakes. II. Effect of two types of crude oil on Lakes 4C and 8. Fisheries and Marine Service, Environment Canada. Technical Report No. 549. 19 p.

STAGER, J.K. 1974. Old Crow, YT, and the proposed northern gas pipeline. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 74-21. 233 p.

TARNOCAI, C. 1972. Some characteristics of cryic organic soils in northern Manitoba. Canadian Journal of Soil Science 52:485–496.

TARNOCAI, C. 1973. Soils of the Mackenzie River area. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-26. 136 p.

TARNOCAI, C. 1982. Soil and terrain development on the York Factory Peninsula, Hudson Bay Lowland. Naturaliste canadien 109:511–522.

TARNOCAI, C. 1984. Peat resources of Canada. National Research Council of Canada. Publication No. 24140. Ottawa, Ontario. 17 p.

TIKHOMIROV, B.A. 1952. The importance of moss cover in the vegetation of the far north. Botanicheskiy Zhur. Sept. 629–638.

VELDHUIS, H. 1980. Soil and vegetation sequences in the Mackenzie Delta, NWT. *In* 24th Annual Meeting, Canadian Society of Soil Science. Winnipeg, Manitoba. pp. 12–21.

WATSON, G.H., W.H. PRESCOTT, E.A. DE BOCK, J.W. NOLAN, M.C. DENNINGTON, H.J. POSTON, AND I.G. STIRLING. 1973. An inventory of wildlife habitat of the Mackenzie Valley and the northern Yukon. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-27. 152 p.

WELLEIN, E.G., AND H.G. LUMSDEN. 1964. Northern forests and tundra. *In* Waterfowl tomorrow. J.P. Linduska, editor. Bureau of Sport Fishing and Wildlife, Fish and Wildlife Service, United States Department of the Interior. pp. 67–76.

WOOLEY, D.R. 1974. Beaver (*Castor canadensis*) studies in the Mackenzie Valley, 1972. Chapter II. *In* Studies of furbearers associated with proposed pipeline routes in the Yukon and Northwest Territories. R.A. Ruttan and D.R. Wooley, editors. Canadian Arctic Gas Study Ltd. Biological Report Series. Volume 9. 52 p.

ZOLTAI, S.C., AND W.W. PETTAPIECE. 1973. Terrain, vegetation, and permafrost relationships in the northern part of the Mackenzie Valley and northern Yukon. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-4. 105 p.

ZOLTAI, S.C., AND C. TARNOCAI. 1971. Properties of a wooded palsa in northern Manitoba. Arctic and Alpine Research 3:115–129.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12:28–43.

4 Wetlands of Boreal Canada

S.C. Zoltai
S. Taylor
J.K. Jeglum
G.F. Mills
J.D. Johnson

Wetlands of Boreal Canada

Boreal wetland regions extend across Canada at mid-latitudes, are characterized by the widespread occurrence of coniferous forest, and cover about 3 034 000 km². Exclusive of the Atlantic Boreal Wetland Region (BA) and mountains, these regions constitute about one-third of the area of Canada. Wetlands cover approximately 20% of the land surface within these regions and, where the physiography permits, they dominate the landscape.

In this chapter, the common and characteristic boreal wetland forms are discussed with the exception of salt marshes, which are considered separately in Chapter 9, and those boreal wetlands lying in the Atlantic Boreal Wetland Region, which are discussed in Chapter 7.

Environmental Setting

Physiography

The physiography of such a large area as that covered by the boreal wetland regions is representative of the entire country. It includes large parts of the core area of old, massive Precambrian crystalline rock which forms the Canadian Shield, and a surrounding crescent of younger, mainly sedimentary rock in the borderlands (Bostock 1970). The common features of the Shield are those of a peneplain, with a generally even skyline composed of rounded hills with a local relief of less than 100 m and covered by a thin, discontinuous mantle of glacial moraine. Countless lakes dot the landscape. Despite the general uniformity of the terrain, geological structure and evidence of tectonic activities provide a basis for subdivision. Boreal wetland regions coincide with parts of the Kazan, Hudson, James, and Laurentian physiographic regions defined by Bostock (1970). These can be further characterized as plains or lowlands, hills, plateaus, or uplands. All but the Hudson physiographic region show the typical peneplain features of the Shield. The Hudson region is a flat, featureless plain, underlain by flat-lying, unmetamorphosed Paleozoic and Proterozoic sedimentary rocks, now mantled by glacial moraine and marine sediments and covered by extensive peatlands.

The Borderlands present a physiography of much greater contrast. Boreal wetland regions occur within parts of the Cordilleran, Interior Plains, and St. Lawrence Lowlands physiographic regions. The Cordilleran region is composed of three parallel mountain systems—the eastern, the interior, and the western (Bostock 1970). The eastern system is composed almost entirely of folded sedimentary strata. The western system, in contrast, is composed mainly of crystalline plutonic rocks, and the interior system consists of folded sedimentary and volcanic strata. These three great systems are further divided into mountains, plateaus, and basins.

The Interior Plains are underlain by flat-lying late-Proterozoic to Tertiary strata and can be subdivided on the basis of geology and the elevation of plateau levels. The Alberta Plateau occurs at elevations 750 m above sea level (ASL), presenting a gently undulating surface over Cretaceous sedimentary bedrock. A continuation of this Plateau, the Alberta High Plain, is similar but underlain by Mesozoic sediments. The Saskatchewan Plain is separated from the Alberta High Plain by The Missouri Coteau and is about 200 m lower. The Saskatchewan Plain has a gently rolling surface over Mesozoic sediments. The Manitoba Plain is another 200–300 m lower than the Saskatchewan Plain and is separated from it by the Manitoba Escarpment. The surface is flat over flat-bedded Paleozoic bedrock and Pleistocene lacustrine sediments.

Part of the St. Lawrence Lowlands occurs within the boreal wetland regions. The western part is underlain by Paleozoic bedrock. The surface relief varies according to the character of the underlying bedrock; the Niagara Escarpment separates the generally low, gently rolling eastern part from the occasionally hilly western portion.

To a large extent, physiography defines the drainage characteristics of the various boreal wetland regions. In the massive, crystalline bedrock of the Shield, water courses are poorly defined and may consist of chains of lakes. Most depressions are occupied by lakes, many of which have been filled in by wetlands. In mountainous areas, rivers occupy the valleys, draining the surrounding uplands, and wetlands are restricted to small segments of the valleys. In the gently rolling interior plains, the main rivers are well entrenched in the soft bedrock and glacial drift and have a well-developed tributary system. The general flatness of the terrain, however, permits the development of large, poorly drained basins, now occupied by wetlands.

Soil parent materials comprising the surface vary with the geology of the bedrock and with the origin of the surficial materials. In the Shield areas, this material is derived from granitic bedrock: it is very low in nutrients and has a coarse texture. Soil materials derived from volcanic rocks tend to have more nutrients: the Limerick glacial deposits, derived from volcanic rocks, have 2.6 times more available calcium (Ca) and five times more available magnesium (Mg) than the granitic Sherbourne glacial deposits, although they are still very low at 0.44 me/100 g Ca and 0.20 me/100 g Mg (Pierpoint 1962). Pockets of glacio-lacustrine or marine clay and silt, derived from distant sources, may occur in many areas of the Shield. These sediments contain high nutrient levels, with calcium carbonate ($CaCO_3$) contents of up to 26% (Zoltai 1965). Portions of the Shield southwest of the Hudson Bay Lowland have glacial moraine with $CaCO_3$ contents of up to 40%.

The surficial materials of the Interior Plains are generally fine-grained and contain high levels of nutrients, but regional variations do exist, according to different bedrock types. In the Manitoba Lowland, materials derived from Paleozoic bedrock can have very high $CaCO_3$ contents (60%, Smith *et al.* 1975). On moraine derived from Mesozoic bedrock, the $CaCO_3$ content is lower (9%, Rostad and Ellis 1972), and on moraine derived from shale it is even lower (2%, Kjearsgaard 1972).

Climate

Boreal wetland regions are characterized by cold winters and short, warm summers. They occur within a broad belt bounded in the north by the average summer position of the arctic frontal zone and in the south by the winter position of the arctic frontal zone (Bryson 1966). The boreal wetland regions are therefore dominated by polar and arctic air masses during the winter and by Pacific and tropical air in the summer. Within these areas, there is a north–south gradient in temperature, colder in the north and warmer in the south. A further difference is evident in the distribution of precipitation: low amounts in the west, but becoming increasingly humid in the east. The portion lying approximately west of Lake Winnipeg has a dry climate, but eastwards it passes from a moist subhumid to a perhumid climate on the basis of the relationship between water deficiency and water excess (Sanderson 1948).

Climatic zonation within the boreal wetland regions is reflected by the occurrence and development of different kinds of wetlands. Although the boreal wetland regions and their subregions are defined by the development of characteristic wetlands, the climatic data indicate that many differences in these wetlands are related to climate.

The mean annual temperature within the various boreal wetland regions ranges from about −4 to 3°C (Table 4–1). Summer temperatures are remarkably uniform, but winter temperatures show much more diversity. In the northerly High Boreal Wetland Region (BH), the mean annual temperatures are consistently below 0°C and the winters are very cold. Incoming energy that can be utilized by vegetation may be estimated from the degree-days above 5°C. In the western portions of this wetland region there are about 1 100 degree-days above 5°C, but the number is much lower to the east in the Humid High Boreal Wetland Subregion (BHh) (Table 4–1). In the Mid-Boreal Wetland Region (BM), the mean annual temperatures are slightly above 0°C, but the winters are still cold. The degree-days above 5°C are in the range of 1 250–1 300, but rise to 1 470 along the southern margin in the Transitional Mid-Boreal Wetland Subregion (BMt). In the south, in the Low Boreal Wetland Region (BL), all average temperatures are higher and the number of degree-days above 5°C exceeds 1 600.

Some wetland subregions reflect differences in atmospheric moisture. The Continental High Boreal Wetland Subregion (BHc) receives about half the precipitation and snowfall that occur in the Humid High Boreal Wetland Subregion (Table 4–1). The same pattern is evident in the Continental Mid-Boreal and Humid Mid-Boreal Wetland Subregions (BMc; BMh). The Low Boreal Wetland Region receives precipitation amounts that are similar to those of the more humid wetland regions.

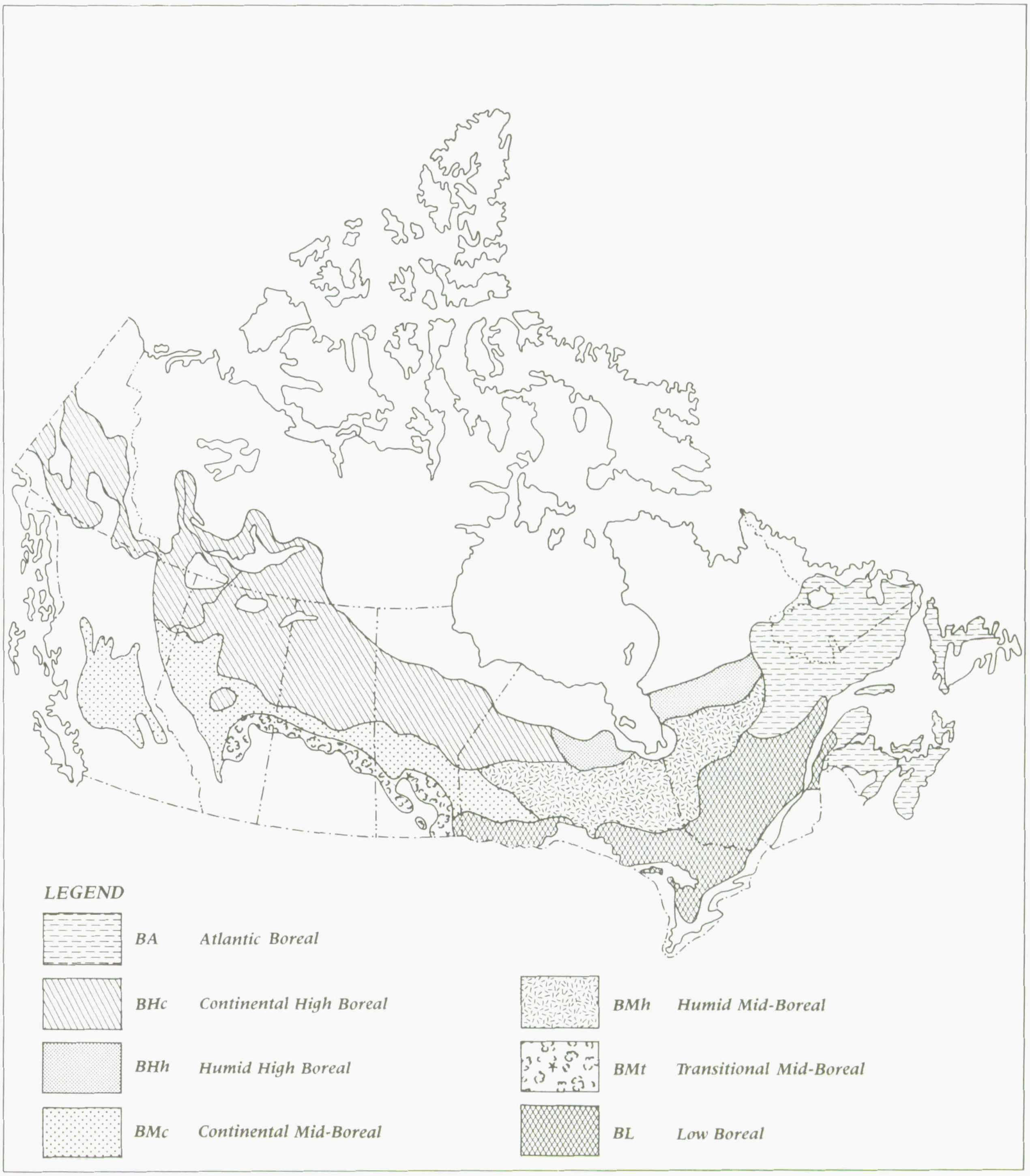
Boreal Wetland Regions and their Vegetation

Across Canada there are four boreal wetland regions (Figure 4–1): the High Boreal, the Mid-

Table 4–1. Climatic data for the boreal wetland subregions (average values)

Wetland region or subregion	*No. of stations*	*Mean annual temperature (°C)*	*Mean daily July temp. (°C)*	*Mean daily January temp. (°C)*	*Mean no. of degree-days above 5°C*	*Mean annual total precip. (mm)*	*Mean annual snowfall (cm)*
BHc	36	−2.7	15.9	−25.1	1 096.0	404.6	162.3
BHh	2	−3.8	13.0	−23.2	706.8	705.8	259.4
BMc	45	1.7	16.1	−17.4	1 274.0	496.0	167.5
BMh	21	0.8	16.4	−18.6	1 261.3	823.8	273.8
BMt	19	1.2	17.5	−19.6	1 470.0	460.2	121.3
BL	53	3.0	18.1	−14.5	1 604.3	836.4	235.0

Source: Atmospheric Environment Service (1982).



Source: Modified from National Wetlands Working Group (1986).

Figure 4–1.
The boreal wetland regions and subregions of Canada.

Boreal, the Low Boreal, and the Atlantic Boreal. As indicated earlier, discussion of the Atlantic Boreal Wetland Region and its various subregions is presented separately in Chapter 7. The High Boreal and Mid-Boreal Wetland Regions are further divided into the Continental, Humid, and Transitional Wetland Subregions. No subregions of the Low Boreal Wetland Region are, as yet, recognized. These various regions are presented in Figure 4–1 and are based on the definitions prepared by the National Wetlands Working Group (1986).

The vegetation of the boreal wetland regions is characterized by closed-canopied forests, predominantly composed of coniferous species. This applies to the boreal forest region and the Great

Lakes–St. Lawrence forest region defined by Rowe (1972). Climatic differences in temperature and precipitation are reflected both in the vegetation of uplands and in the development of wetlands.

A universal feature of the boreal forest is the frequent occurrence of forest fires. This results in the growth of even-aged, pioneer vegetation following fires. Very few areas escape forest fires during the life span of a forest; consequently there are few stands over 200 years old. In contrast, boreal wetlands are often spared when a fire sweeps across an area, as many are usually too wet to support fires. Old, uneven-aged forests, stunted in growth by excessive moisture, are common in some forms of wetlands. However, charred horizons, evidence of past fires, are common in some of the drier wetlands.

High Boreal Wetland Region

The vegetation of drier uplands in this region is characterized by black and white spruce (*Picea glauca* and *Picea mariana*) in pure stands or in mixtures with balsam fir (*Abies balsamea*), trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*). On sandy soils or after fires, jack pine (*Pinus banksiana*) or, in the west, lodgepole pine (*Pinus contorta*) grow in even-aged stands, sometimes mixed with white birch (*Betula papyrifera*).

The most widespread wetlands are fens and bogs. Swamps are usually restricted to areas bordering streams or to the periphery of bogs. Marshes are relatively rare, occurring mainly on inland deltas or along lake shores. Among the common wetland forms that are characteristic of the region are northern ribbed fens, which have narrow peat ridges extending across the direction of water movement, relatively featureless horizontal fens that occupy poorly defined depressions, and basin fens. Heavily treed peat plateau and palsa bogs occur as small islands in fens, accompanied by collapse scar fens. Flat bogs occur in the Continental High Boreal Wetland Subregion. Basin bogs are common in areas of moderate relief.

Mid-Boreal Wetland Region

The vegetation of drier uplands in this wetland region is characterized by mixed-wood forests of white spruce, balsam fir (or subalpine fir [*Abies lasiocarpa*] in the west), and aspen, with black spruce restricted to areas of poor drainage. Jack pine, and lodgepole pine in the west, are established after fires and on sandy soils. In the Humid Mid-Boreal Wetland Subregion, black spruce often invades the gentle lower slopes, with consequent accumulation of shallow peat.

The most common wetlands are bogs and fens. Coniferous swamps may be common locally on gently sloping areas that are covered by shallow peat. Marshes are generally restricted to lacustrine or riverine environments. Domed bogs are common in the Humid Mid-Boreal Wetland Subregion, where precipitation is sufficiently high to nourish them. In the Continental Mid-Boreal Wetland Subregion, the equivalent wetland form is the peat plateau bog, characterized by an even bog surface that is elevated only slightly above associated fens. Flat bogs and basin bogs are also common. Common fens include northern ribbed fens, horizontal fens, and basin fens. Spring fens may occur in areas of groundwater discharge. Delta and shore marshes develop in suitable locations throughout this wetland region.

Low Boreal Wetland Region

The vegetation of drier uplands in the Low Boreal Wetland Region is characterized by forests of tolerant hardwoods such as sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*), often mixed with eastern hemlock (*Tsuga canadensis*) and white pine (*Pinus strobus*). West of the Great Lakes these species play a minor role. On dry sites or after fires, jack pine, red pine (*Pinus resinosa*), or red oak (*Quercus rubra*) are common.

The most commonly occurring bog forms are domed bogs and basin bogs. Fens include basin fens and shore fens, but patterned fens are rare. Swamps may be the coniferous type (with white spruce–*Picea mariana* or eastern white cedar [*Thuja occidentalis*]) or the hardwood type (with black ash [*Fraxinus nigra*]).

Boreal Wetland Forms

This section presents descriptions of selected wetland forms of the boreal wetland regions. Some of these wetland forms may occur in other regions as well, but they will differ in some respects. The forms described are not necessarily definitive of boreal wetland regions; variations, especially in vegetation, are certain to occur. Consequently, the following is not intended as a comprehensive description of all wetlands in the boreal areas of Canada. Rather, it presents both a generalized and a specific account of selected wetland forms that are common to or characteristic of particular boreal wetland subregions. Other less common wetland forms occur but are omitted here.

The wetland forms described in this chapter, with specific examples from study sites in boreal wetland regions, are:

(1) domed bogs;
(2) northern plateau bogs;
(3) flat bogs;
(4) basin bogs;
(5) peat plateau bogs and palsa bogs with collapse scar fens;
(6) horizontal fens;
(7) basin fens;
(8) spring fens;
(9) northern ribbed fens;
(10) feather fens;
(11) delta marshes;
(12) shore marshes; and
(13) floodplain swamps.

Domed Bogs

Domed bogs are characterized by thick, dome-shaped accumulations of peat in which the groundwater is at a higher elevation than in the surrounding areas. Both the surface and groundwater contours display a concentric pattern. As the centre of the domed bog is higher than the edges, surface drainage can develop, radiating from the centre. In some cases, longer sustained slopes develop in one direction, resulting in an off-centre (eccentric) domed bog. Several forms of domed bog have been found (Glaser and Janssens 1986). Some have a relatively well-drained crest, while others have shallow pools. The pools may be randomly distributed on the central part of the bog or may occur as crescent-shaped pools whose long axis is on the contour. Some of these domed bog forms are restricted to the maritime climates of the Atlantic Boreal Wetland Region and will not be discussed in this chapter. Two domed bog forms occur in the Humid Mid-Boreal Wetland Subregion and in the Low Boreal Wetland Region: one has a distinct, forested crest and the other has a linear crest that grades into a convex ridge (Glaser and Janssens 1986). The surface of the linear-crested domed bog is reasonably well drained, as shown by the absence of pools. On the linear–convex-crested domed bogs the linear ridge often displays the drainage lines characteristic of the crested domed bogs. On the convex part of the crest the surface is poorly drained, showing a pattern of linear peat ridges separated by wet hollows and even shallow pools, arranged in an elliptical pattern around the crest (Glaser and Janssens 1986).

Peat accumulation on domed bogs typically exceeds 3 m. The surface layers usually consist of fibric *Sphagnum* peat, underlain by mesic *Sphagnum* peat with variable amounts of wood. The basal layers are usually composed of fen peat which may be underlain by aquatic peat. The groundwater and upper peat layers are very low in nutrients and highly acid. The vegetation of domed bogs is usually dominated by stunted black spruce, ericaceous shrubs, and *Sphagnum* mosses.

Raised bogs are common in the Humid Mid-Boreal Wetland Subregion and the Low Boreal Wetland Region (Grondin and Ouzilleau 1980; Glaser and Janssens 1986). They do not occur in the subhumid climate of the continental boreal wetland subregions, where they appear to be replaced by slightly elevated, flat-topped peat plateau bogs; these are discussed in a subsequent section.

Following are two examples of domed bogs, both from the Humid Mid-Boreal Wetland Subregion. Each is situated in a basin with a fen on one or more sides and swamps on the margins of the basin.

Domed bog (with linear–convex crest)

A domed bog near Cochrane, Ontario (49°02′ N, 81°00′ W), represents this wetland form (Figure 4–2). The bog is almost completely surrounded by a minerotrophic swamp, but on one side it borders an open fen. A transect was made from the swamp to the centre of the domed bog.

In this bog, the black spruce becomes shorter and more shrub-like towards the centre, occurring mainly on linear ridges composed of peat hummocks arranged concentrically around the bog centre at right angles to the direction of drainage. In this particular bog, there is a slightly stronger seepage in the direction of the fen. This is indicated by a sharper development of treed bog ridges and also of bog pools ("flarks") between the ridges.

The treed portion of domed bogs is usually dominated by black spruce and tamarack (*Larix laricina*). There are low shrubs in the field layer, such as *Chamaedaphne calyculata*, *Ledum groenlandicum*, and *Kalmia polifolia*. The main surface mosses are *Sphagnum nemoreum*, *Sphagnum fuscum*, and *Pleurozium*

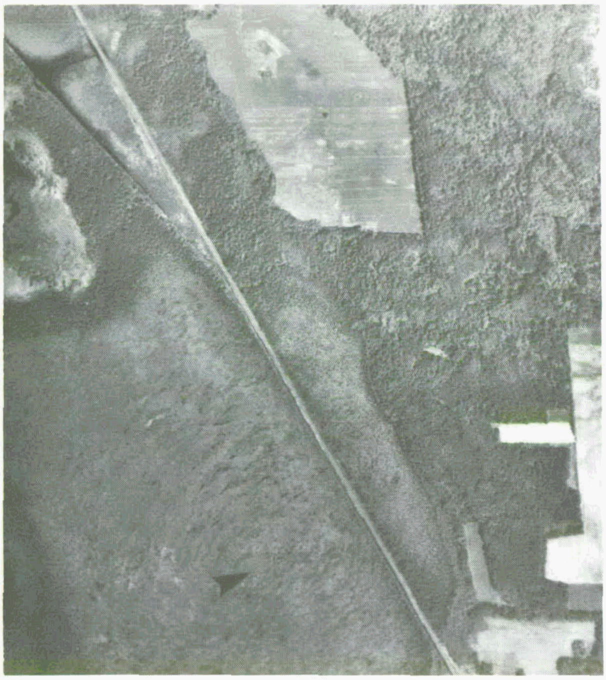


Figure 4–2.
Aerial photograph of a domed bog with wet centre near Cochrane, Ontario. The bog is mainly open, with small crescent-shaped pools and treed ridges. Arrowhead points to the approximate centre of the bog.

schreberi. In some wet hollows *Sphagnum angustifolium* and *Sphagnum magellanicum* are found.

The open portion of domed bogs is generally characterized either by the predominance of dense *Eriophorum vaginatum* ssp. *spissum* or by a poorly developed layer of dense cottongrass and the aforementioned ericaceous shrubs. The important mosses are often *Sphagnum rubellum* and *Sphagnum nemoreum*. From the air, the red colour of these two species is conspicuous, and bogs such as this are often called "red bogs".

In such bogs, elongated wet pools (flarks) commonly occur adjacent to some treed ridges (Figure 4–2). Some pools are quite deep (up to 50 cm) with bottoms consisting of flocculent muddy organic material or algal mats. Others are in the process of being invaded by or are completely covered with submerged or floating *Sphagnum* spp. *Sphagnum cuspidatum* tends to occur as submerged or slightly floating mats; *Sphagnum majus* occurs in somewhat more consolidated mats elevated slightly above water level. At the edges of these mat-covered pools there is often some development of *Carex limosa* and *Scheuchzeria palustris*.

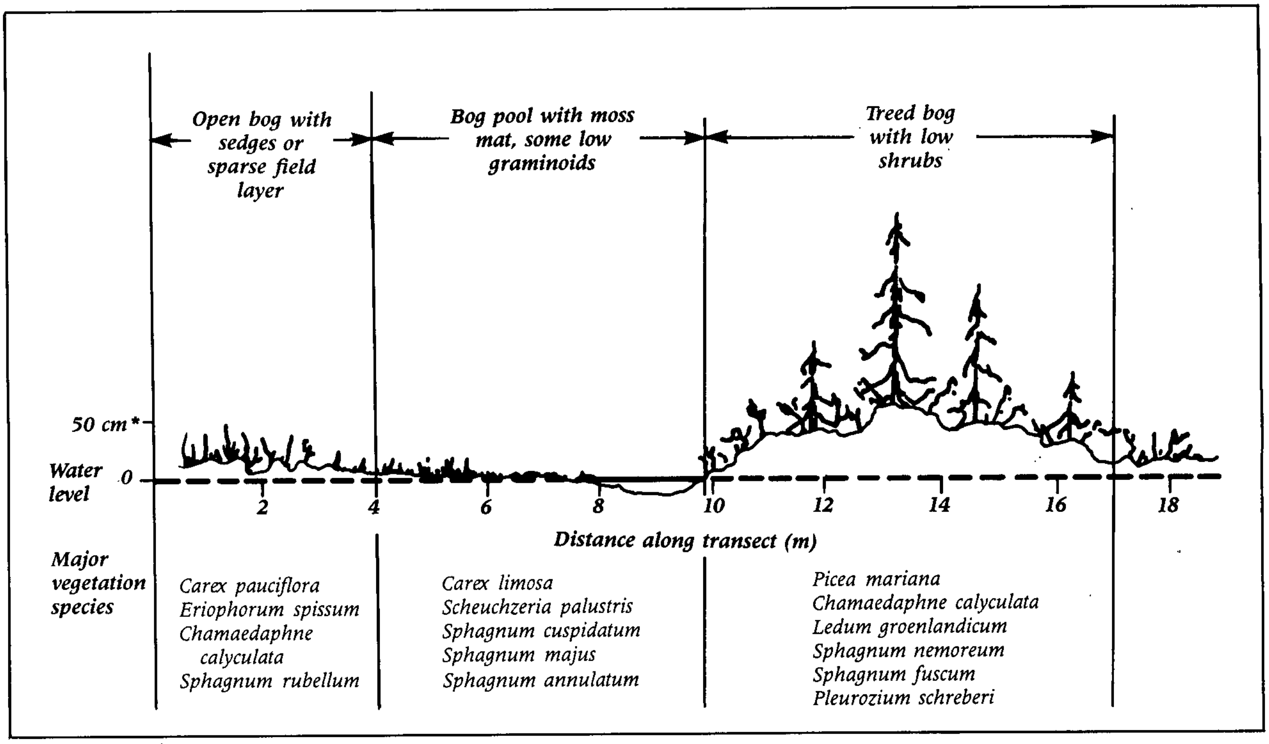
A cross-section of a treed ridge, a bog pool with moss cover, and a consolidated open domed bog at the Cochrane, Ontario, study site is presented to demonstrate that bog pools occur closest to the side of the ridges in the direction from which the water is moving (Figure 4–3), suggesting that the ridges impede the movement of water, damming the water on their upslope sides.

Chemical data for the surface water and peat (Table 4–2) indicate the change from minerotrophic swamp to ombrotrophic bog on one side, and from fen to bog on the other side of this site. Ash content and chemical analyses are presented for selected depths of sample collection for swamp, bog, and fen points on the transect. The swamp peat has the highest content of ash, nitrogen (N), and Ca in the uppermost horizons. Fen peat has intermediate values and bog peat has the lowest.

There is considerable variation in the chemical content of the peat profiles, some increasing with depth, others decreasing. This variation relates to the botanical composition and the nutrient content of groundwater at the time of deposition. Furthermore, there has undoubtedly been some translocation of nutrients in the profiles to modify their initial amounts. Calcium seems to be the key indicator of the trophic status of peat (Table 4–3); it increases with depth. In the bog profile, it reaches 6 100 mg/kg at a depth of 310–350 cm. Calcium content is highest in the swamp peat, both at the surface and at the base.

This domed bog developed in a well-defined basin with the central part of the bog situated over the lowest part of the basin (Figure 4–2). A rise in the topography of the underlying mineral terrain between the bog basin and the main fen basin is noted. This ridge may have influenced the development of the bog (Figure 4–4), as the steeply sloping bog margin adjacent to the fen is positioned over this subsurface mineral soil ridge.

The developmental history of this domed bog is indicated by its peat stratigraphy (Figure 4–4). The central part of the peat body is dominated by sedge peat, with *Sphagnum* peat as a secondary constituent in places. At the centre of the bog, brown moss is found at some depth, suggesting an earlier fen phase. Initially a fen filled this entire basin, with a swamp around the edges of the open fen, producing conditions similar to those in the adjacent basin fen at present. The fen, isolated from the main basin by the mineral ridge, became progressively more oligotrophic and the central portion gradually became an open bog. The bog groundwater surface became slightly elevated concurrently with the rise in the peat surface. At this stage, excess water began to drain radially outwards from the bog centre.



** Vegetation above ground surface not to scale.*

Figure 4–3.
Topography and vegetation along a transect in a domed bog near Cochrane, Ontario.

Domed bog (with linear crest and swamp margin)

Another domed bog, which occupies part of a large treed fen complex north of Timmins, Ontario (48°55′ N, 82°06′ W), has been examined in some detail. A transect, made from the mineral terrain to the centre of the domed bog, indicated that there is a swamp margin at the edge of the mineral terrain, with an adjoining sparsely treed, nutrient-poor fen, and a treed domed bog at the centre (Figures 4–5 and 4–6).

A swamp with shrubs and trees, located around the edge of this wetland complex, has many deep pools with water derived from both the adjacent mineral soil and the domed bog at the centre. The peat is shallow (less than 1 m) over the mineral soil. The subsurface peat from this swamp has the highest amounts of phosphorus (P), potassium (K), Mg, iron (Fe), manganese (Mn), and sodium (Na) of any of the samples from this wetland complex (Table 4–4). Nitrogen content is higher at the surface than at any other site, suggesting greater biological activity. Although speckled alder (*Alnus rugosa*) is the dominant species, black spruce can grow to a considerable size on these sites; however, because these trees root in shallow organic soil, they are susceptible to blowdown.

Vegetation composition in such swamps is often complex because of the great variety of microhabitats and their relatively high degree of minerotrophy. Species characteristic of drier upland sites (e.g. *Cornus canadensis, Anemone quinquefolia, Mitella nuda, Trientalis borealis, Coptis trifolia,* and *Pleurozium schreberi*) occur on the tops of hummocks. *Sphagnum girgensohnii, Sphagnum magellanicum,* and a variety of *Carex* species appear on the sides of hummocks. *Mnium* spp. and liverworts can be found in the pools. Speckled alder dominates the shrub layer, but *Salix discolor, Ledum groenlandicum,* and *Kalmia angustifolia* may also occur. A variety of sizes of black spruce and occasionally balsam fir and balsam poplar can be found.

Towards the bog centre, the upland species, the taller spruce, the alder, fir, and poplar, *Sphagnum girgensohnii,* and some of the *Carex* species on the sides of hummocks, disappear. Pools are still present, but high hummocks (over 50 cm) no longer occur, eliminating the drier habitats. A more uniform depth in the water table decreases microhabitat diversity, and a species-poor community develops. The depth of peat to mineral soil also increases (1–3 m) and concentrations of many nutrients in the rooting zone decrease (Table 4–4). Although the nutrient levels are low, the vegetation is best described as typical of a fen. Tamarack are scattered among the black spruce, but most trees are less than 5 m tall. Among the shrubs, species common to fens (*Betula pumila* and *Salix pedicellaris*) can be found, along with *Andromeda glaucophylla, Chamaedaphne calyculata, Kalmia polifolia,* and *Ledum groenlandicum,* the last being common in the most nutrient-poor areas. *Carex chordorrhiza* and *Carex limosa* are present in the graminoid area, and *Sphagnum angustifolium* and *Sphagnum magellanicum* dominate the moss stratum. Low areas support *Calliergon stramineum, Drepanocladus fluitans,* and *Drepanocladus exannulatus,* along with a variety of liverworts (*Cladopodiella fluitans, Mylia anomala, Scapania irrigua*). Carnivorous plants, most noticeably *Sarracenia purpurea* and *Drosera rotundifolia,* appear from this point to the bog centre.

A number of additional fen-indicator species may be present at this kind of site, especially if there is a greater water flow from the bog and a larger input from the mineral soil. At the site described here, there is moisture influence both from the ombrotrophic bog centre and from the underlying mineral soil, resulting in intermediate levels of nutrients.

At the centre of the bog, the depth of peat exceeds 3 m (Figure 4–6). The dominant ombrotrophic conditions are reflected in the low amounts of K, Ca, Mg, Fe, and Na (Table 4–4). The ash content is also low, suggesting that the peat contains very little inorganic material.

The bog centre is somewhat elevated above the surrounding fen, possibly as a result of a more rapid accumulation of peat. Numerous high (50–75 cm) hummocks of *Sphagnum fuscum* support black spruce, which can attain heights in excess of 10 m. Reproduction of black spruce occurs mainly through layering of the branch tips into the moss. There is no tamarack at the bog centre. *Sphagnum nemoreum* forms patches on some of the hummocks and, on their dry tops, *Pleurozium schreberi, Cladina rangiferina,* and *Cladina mitis* are present. Hummock species include *Ledum groenlandicum, Oxycoccus microcarpus,* and *Gaultheria hispidula.* The areas between hummocks are dry, as they are aligned parallel to the water flow. *Sphagnum angustifolium* is common between the hummocks, and the most common vascular plants include *Rubus chamaemorus* and several carnivorous plants. *Carex*

Table 4–2. Chemical and other properties of peat and water from a transect across a linear-convex crested domed bog near Cochrane, Ontario

		Hardwood	Deciduous	Treeless	Treed	Wet	Hummock	Treeless	Hummock	Treed	Open
Site description		***Swamp***					***Bog***				***Fen***
Moisture regime											
Depth to water table (cm)		5	15	20	15	10	15	20	25	5	−2
Water cover (%)		10	2	2	0	1	1	1	0	10	50
Water table											
pH		6.0	5.7	3.9	3.6	3.8	3.6	4.0	3.9	3.5	4.0
Ca		11.40	6.50	2.90	6.90	2.20	2.00	3.80	2.60	4.50	3.10
Mg		2.29	1.52	0.32	0.47	0.31	0.23	0.31	0.21	0.64	0.25
Mn		0.58	*	*	*	*	*	*	*	*	*
Fe	***Exchangeable***	*	*	*	*	*	*	*	*	*	*
Cu	***cations***	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.03	0.02	0.02
Pb	***(mg/L)***	*	*	*	*	*	*	*	*	*	*
Zn		0.02	0.02	0.04	0.04	0.02	0.03	0.04	0.01	0.04	0.01
Al		0.67	0.70	0.54	0.71	0.55	0.74	0.68	0.63	0.91	0.49
P		1.38	1.19	0.37	*	*	*	*	0.50	*	*
Peat											
Ca		—	21 600	1 700	800	1 200	1 100	1 200	1 900	9 300	2 400
Mg		—	1 310	210	130	190	2 220	320	270	330	390
Mn	***Total cations***	—	110	110	110	160	70	50	60	110	120
Fe	***(mg/kg)***	—	2 230	990	390	320	390	590	72	1 280	1 410
Na	***in upper***	—	100	100	100	120	60	120	70	60	130
N	***10–20 cm***	—	16 300	12 100	13 200	13 500	10 300	12 900	21 500	17 100	14 800
P		—	430	580	490	570	230	620	510	300	700
K		—	430	760	220	170	170	530	370	220	570
Ash content (%)		—	7.9	3.4	2.0	4.0	2.0	3.4	2.8	4.7	3.9
Depth to mineral soil (m)		0.1	2.2	5.5	5.8	6.2	6.0	4.5	3.2	3.4	3.4

**Below detection limit.*

Table 4–3. Total elemental analysis and other properties of peat from a boreal bog, a fen, and a swamp near Cochrane, Ontario

Depth of sample (cm)	Decomposition (von Post)	Material	Ash (%)	Total elements (mg/kg)					
				Ca	Mg	Fe	N	P	K
Boreal bog									
0–50	2	*Sphagnum–Carex*	1.8	1 200	200	300	13 500	600	200
50–100	4	*Carex–Sphagnum*	1.1	2 000	300	400	8 100	300	100
150–200	6	*Carex–Sphagnum*	1.5	3 600	100	400	9 800	20	100
310–350	2	*Drepanocladus*	2.2	6 100	2 100	900	17 700	400	100
Boreal fen									
0–20	2	*Sphagnum–Carex*	3.3	2 400	400	1 400	14 800	700	600
70–100	7	No data	9.0	8 400	400	3 300	25 900	600	800
135–175	5–6	No data	6.0	11 100	400	3 000	23 600	400	600
Boreal swamp									
0–50	3	*Sphagnum*–wood–*Pleurozium*	7.9	21 600	1 300	2 200	16 300	400	400
205–215	4	*Sphagnum*–wood–*Pleurozium*	7.2	24 200	4 100	13 100	11 300	500	7 800

pauciflora and *Eriophorum vaginatum* are present in patches.

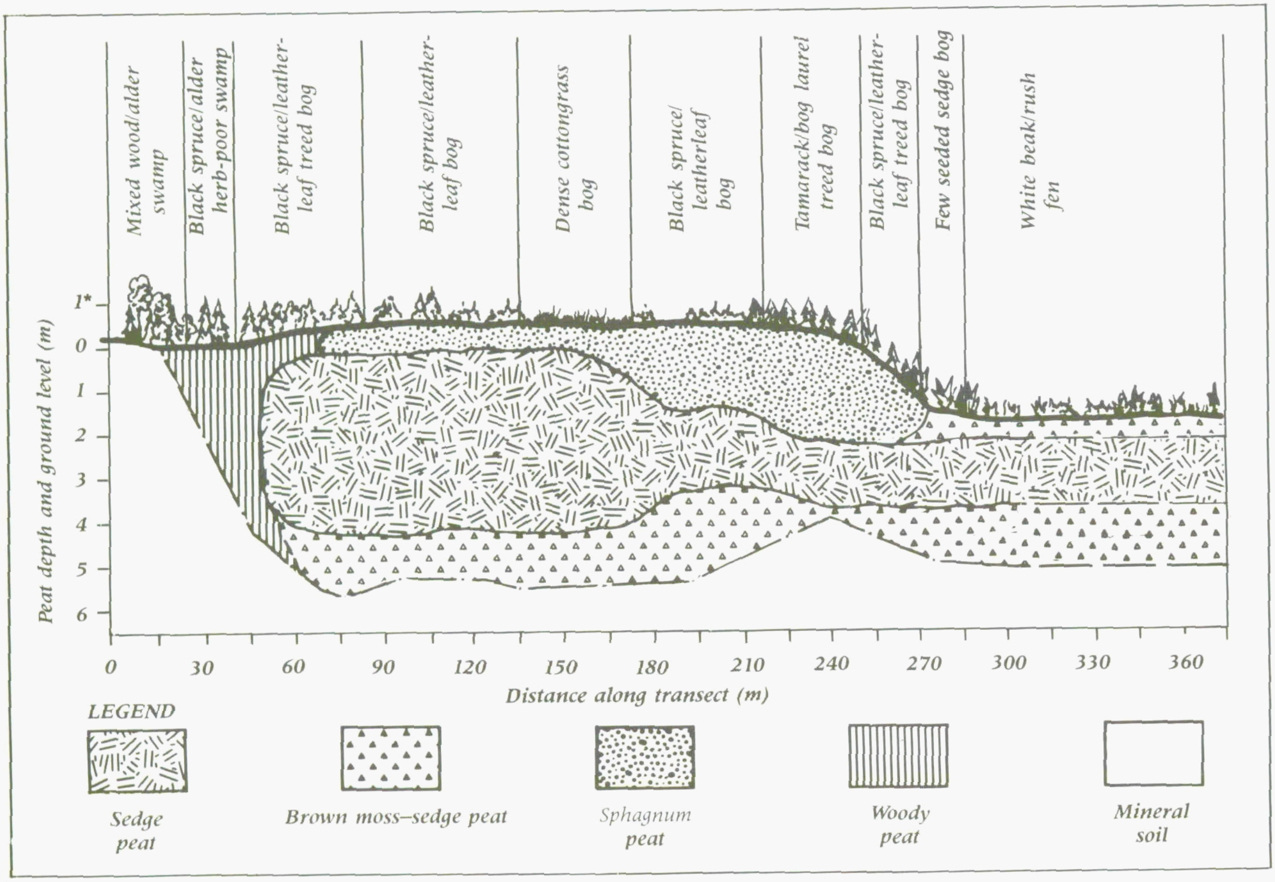
This domed bog is one of several large and varied wetland complexes within an area of about 1 000 km^2 around Timmins, Ontario. Together they retain large quantities of water that often falls within a short period of time and then they discharge it slowly into rivers. Although these wetlands are not used extensively by many species of wildlife, Sandhill Crane (*Grus canadensis*) with young inhabit the fens of the area and have been observed to frequent the bogs.

Northern Plateau Bogs

This ombrotrophic wetland form has a flat surface, elevated between 0.5 and 1 m above the surrounding fen. The surface is usually level, with a subdued hummocky microrelief. The elevation of a northern plateau bog is the result of greater vertical peat accumulation than in the surrounding fen. Because of this greater elevation, the surface peat is isolated from the local water table. Therefore, most of the water available to the vegetation on the bog surface is from precipitation. Northern plateau bogs vary from several hectares to several square kilometres in size and they are often teardrop-shaped when observed from above. This wetland form appears to be similar to the "black spruce island" defined by Heinselman (1963) and to the "ovoid island" of Glaser *et al.* (1981). It often develops in those parts of large basin fens which appear to be out of the main water seepage stream—in embayments or near the edges (Figure 4–7). Northern plateau bogs are usually treed, but may be treeless and covered with ericaceous shrubs. This wetland form is common in the Continental High Boreal Wetland Subregion in areas of moderate relief, and it may be the equivalent of domed bogs occurring in subhumid climates.

The thickness of the peat deposit is commonly in excess of 2 m, but is seldom greater than 5 m. There are generally three layers of peat. The surface layer (50–90 cm thick) consists of fibric *Sphagnum* remains and ericaceous leaves. The middle layer ranges in thickness between 1 and 2 m, and is composed of moderately decomposed mixed *Sphagnum* and forest (sylvic) peat, or fen peat, or both. Basal peat layers may be moderately to well decomposed woody forest peat or, more commonly, well-decomposed fen and aquatic peat.

The soils found on northern plateau bogs are Fibric Mesisols and Mesic Fibrisols where the surface *Sphagnum* peat is thin (60–135 cm), and Typic Fibrisols where the fibric *Sphagnum* peat extends below a depth of 135 cm. The surface peat is usually extremely acid (pH less than 4.5), becoming less acid with increasing depth. The ash content of the peat is low, in the range of 5–10%, and usually increases with depth. The mineral nutrient status of the peat is also low, but increases with depth. The surface *Sphagnum* peat layer usually contains the lowest amounts of both total and available nutrients. Peat materials at lower depths in this wetland form have commonly originated under more nutrient-rich conditions and are characterized by a higher nutrient status.



* Vegetation above ground surface not to scale.

Figure 4–4.
Cross-section of a domed bog with linear-convex crest showing vegetation, surface topography, and broad peat stratigraphy, near Cochrane, Ontario.

The vegetation associated with this wetland form is relatively uniform throughout all the boreal wetland regions, although the abundance of different species may vary. Semi-open to closed stands of stunted *Picea mariana* form the dominant tree cover. A poorly to well developed ericaceous, low shrub cover commonly occurs on a hummocky surface formed by *Sphagnum* spp. The shrub layer is characterized by *Ledum groenlandicum*, with lesser occurrences of *Chamaedaphne calyculata*, *Kalmia angustifolia*, *Rubus chamaemorus*, and shrubby *Picea mariana*. On *Sphagnum* hummocks, *Vaccinium vitis-idaea* and *Vaccinium oxycoccus* are common. This shrub layer becomes sparse or absent under more densely treed portions of the northern plateau bogs.

The hummocky surface of these bogs is caused by the formation of cushions of *Sphagnum fuscum*. The drier apices and sides often have characteristic lichen growth, such as *Cladina rangiferina*. Other *Sphagnum* species occur in hollows and low places between the hummocks where the water table is closer to the surface. In such areas, *Eriophorum* spp. and *Sarracenia purpurea* may occur.

An example of this wetland form occurs near Riverton, Manitoba (51°05′ N, 97°00′ W), where

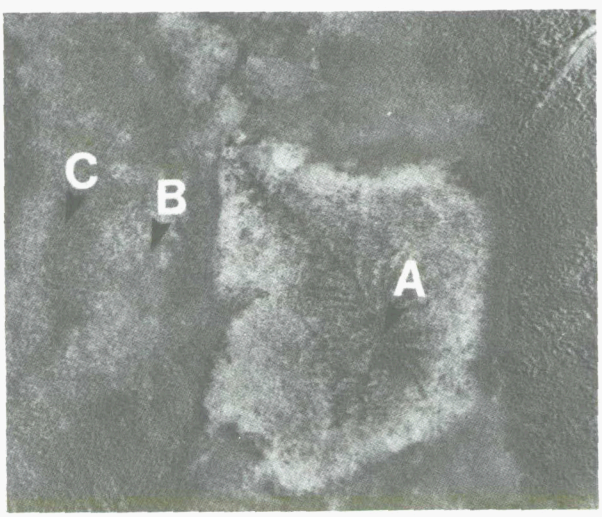


Figure 4–5.
Aerial photograph of a domed bog with dry centre near Cochrane, Ontario, with drainage lines radiating from the centre (A). The bog is surrounded by a treed fen (B), with an alder swamp at its outer fringe (C).

four northern plateau bogs have developed within a small (150 ha) basin fen. A transect was made from one northern plateau bog to a fen channel between this and another northern plateau bog.

This northern plateau bog is sparsely treed with *Picea mariana* that reach a height of 10 m. There is a dense, low shrub layer of *Ledum groenlandicum* and *Chamaedaphne calyculata*. The herb layer is very sparse, consisting of *Vaccinium vitis-idaea* and *Oxycoccus quadripetalus*. Moss covers nearly 75% of the surface, with *Sphagnum fuscum* in the open areas and *Pleurozium schreberi* and *Hylocomium splendens* in the more heavily wooded areas. Lichens are sparse, mainly *Cladina mitis* and *Cladina rangiferina*, with several species of *Cladonia*.

The bog surface drops abruptly some 40 cm to the fen level. The fen is mainly a shrub fen with some open patches. The shrub layer is dominated by *Myrica gale*, with abundant taller shrubs of *Betula pumila* and *Salix lucida*. The herb layer covers about 60% of the surface and is composed mainly of *Carex lasiocarpa* and *Carex aquatilis*, with some *Calamagrostis inexpansa*. Mosses are rather sparse, covering about 20% of the surface and consisting mainly of *Campylium stellatum*, *Drepanocladus aduncus*, and *Hypnum pratense*.

The measured peat profile is 166 cm deep under this northern plateau bog, with the water table observed at 70 cm. In the fen the peat is 110 cm deep, and the water table, when studied, was 13 cm below the surface. The peat stratigraphy in the bog consists of fibric *Sphagnum fuscum* peat (0–95 cm), with an abrupt change to mesic fen peat composed of *Carex* spp. and *Menyanthes trifoliata* remains (95–159 cm) (Figure 4–8). Underlying this is a thin, mixed organic–mineral layer (159–166 cm) and a silty clay mineral soil. The total nutrient content of the peat is low in the *Sphagnum* layer, al-

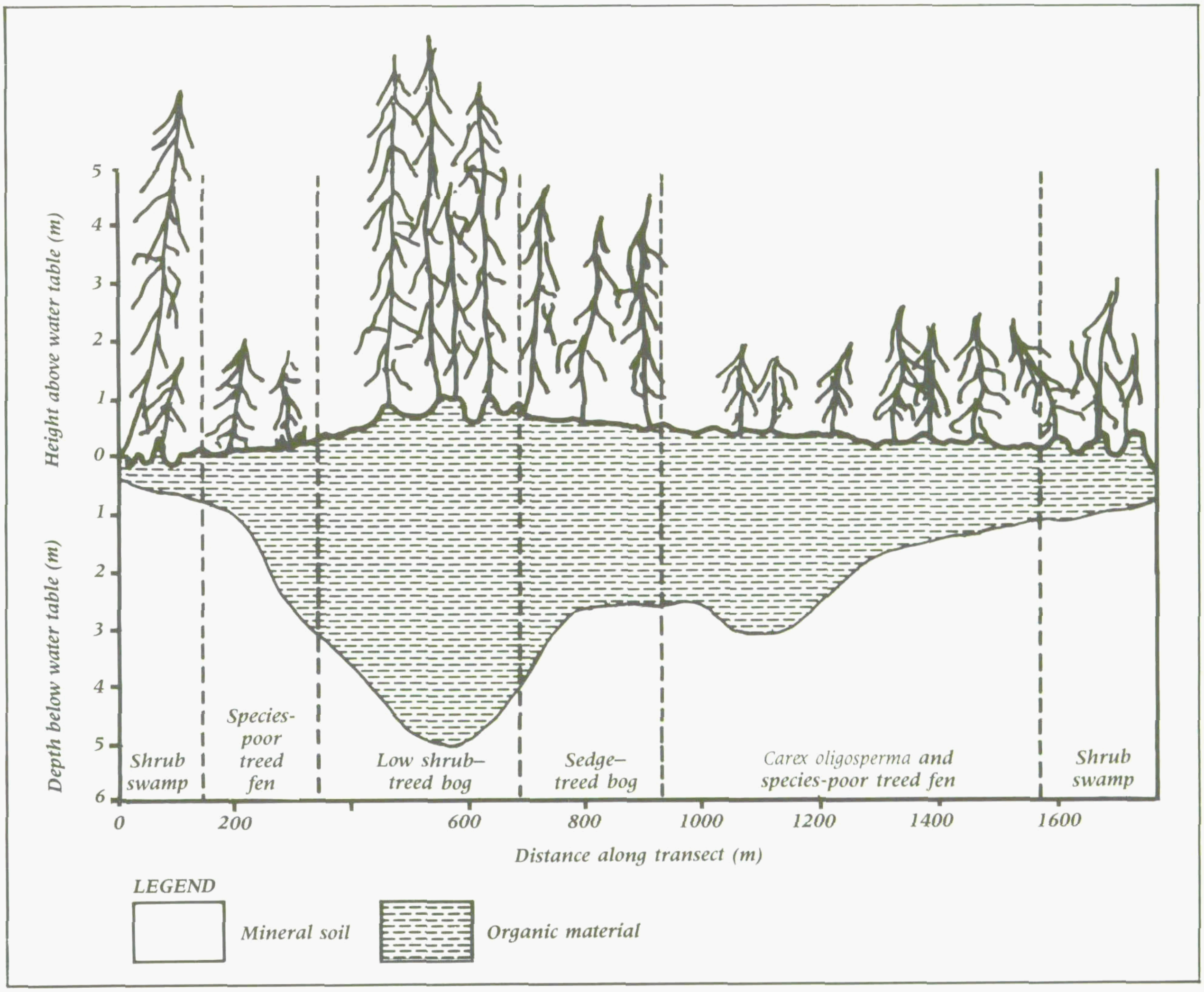


Figure 4–6.
Transect through a domed bog with linear crest and swamp margin near Cochrane, Ontario.

Table 4–4. ***Total elemental analysis and other properties of*** *Sphagnum* ***peat and water from three sites in a boreal domed bog with a linear crest near Timmins, Ontario***

Sampling site	Sample depth (cm)	pH	Decom-position (von Post)	Ash (%)	Total elements (mg/kg) Ca	Mg	Mn	Fe	Na	N	P	K
Peat												
Shrub swamp	0–30	—	3	9.0	24 100	1 720	101	1 850	91	13 940	30	420
	75–85	—	6	44.8	29 100	6 200	360	15 410	367	9 350	940	8 070
Nutrient-poor fen	0–40	—	2	3.3	5 420	530	30	480	142	8 110	690	650
	60–100	—	4	10.7	33 010	1 570	63	1 970	67	9 920	380	240
Low shrub treed bog	0–20	—	3	2.6	1 890	210	62	450	114	10 500	380	390
	50–100	—	5	2.0	2 690	250	51	310	121	10 370	250	140
Water												
Shrub swamp	—	4.9	—	—	0.94	*	*	*	—	—	—	—
Nutrient-poor fen	—	4.4	—	—	2.17	0.51	*	*	—	—	—	—
Low shrub treed bog	—	4.0	—	—	1.32	0.18	*	*	—	—	—	—

*Below detection limit.

though the high amounts of Ca show possible contamination from road dust (Table 4–5). The lower part of the *Sphagnum* sequence (55–95 cm) is higher in nutrients than the surface layer. The fen peat in the lower part of the sequence shows a substantial increase in all nutrients.

In the fen, peat stratigraphy begins with a fibric fen peat, composed mainly of *Carex* remains. Mesic fen peat is encountered at a greater depth and is also composed of *Carex* spp. and *Menyanthes trifoliata*, with some twigs from various shrubs. The basal layer is a 10 cm thick humified layer resting on the mineral soil. The nutrient levels are higher than those at the bog surface and they increase with depth (Table 4–6). Disregarding the bog materials which lie above the fen level (0–47 cm, four samples), the chemical properties of the fen and the lower bog are comparable.

Figure 4–7.
Aerial view of a cluster of northern plateau bogs occurring in an embayment of a large fen, separated by fen drains which join the main fen at right.

The developmental history, as indicated by peat stratigraphy, appears to begin with a wet, marsh-dominated depression where peat deposition was initiated. An open fen with shrubby patches developed in the basin, but later bog development started abruptly in parts of the basin. Peat accumulated faster in the bog, raising its surface above the fen and maintaining it there. The development of northern plateau bogs often includes some lateral expansion over the surface of adjacent open or shrub fens. The bog surface waters have oligotrophic attributes, but the waters at 70 cm are less acid and are associated with the fen environment. Thus, it appears that the portion of peat under the bog surface which lies at or below the level of the fen may be affected by the more nutrient-rich fen waters.

Flat Bogs

This ombrotrophic wetland form presents a flat, featureless surface (Reid and Morrow 1974) and occurs in broad, poorly defined depressions. The vegetation of flat bogs consists mostly of stunted trees and ericaceous shrubs. The depth of peat deposited in such bogs is generally uniform, ranging from 2 to 4 m. This wetland form is common in the High Boreal Wetland Region, in areas of low relief such as the James Bay and Hudson Bay lowlands.

Vegetation appears to be uniform throughout the High Boreal Wetland Region (Figure 4–9), but the

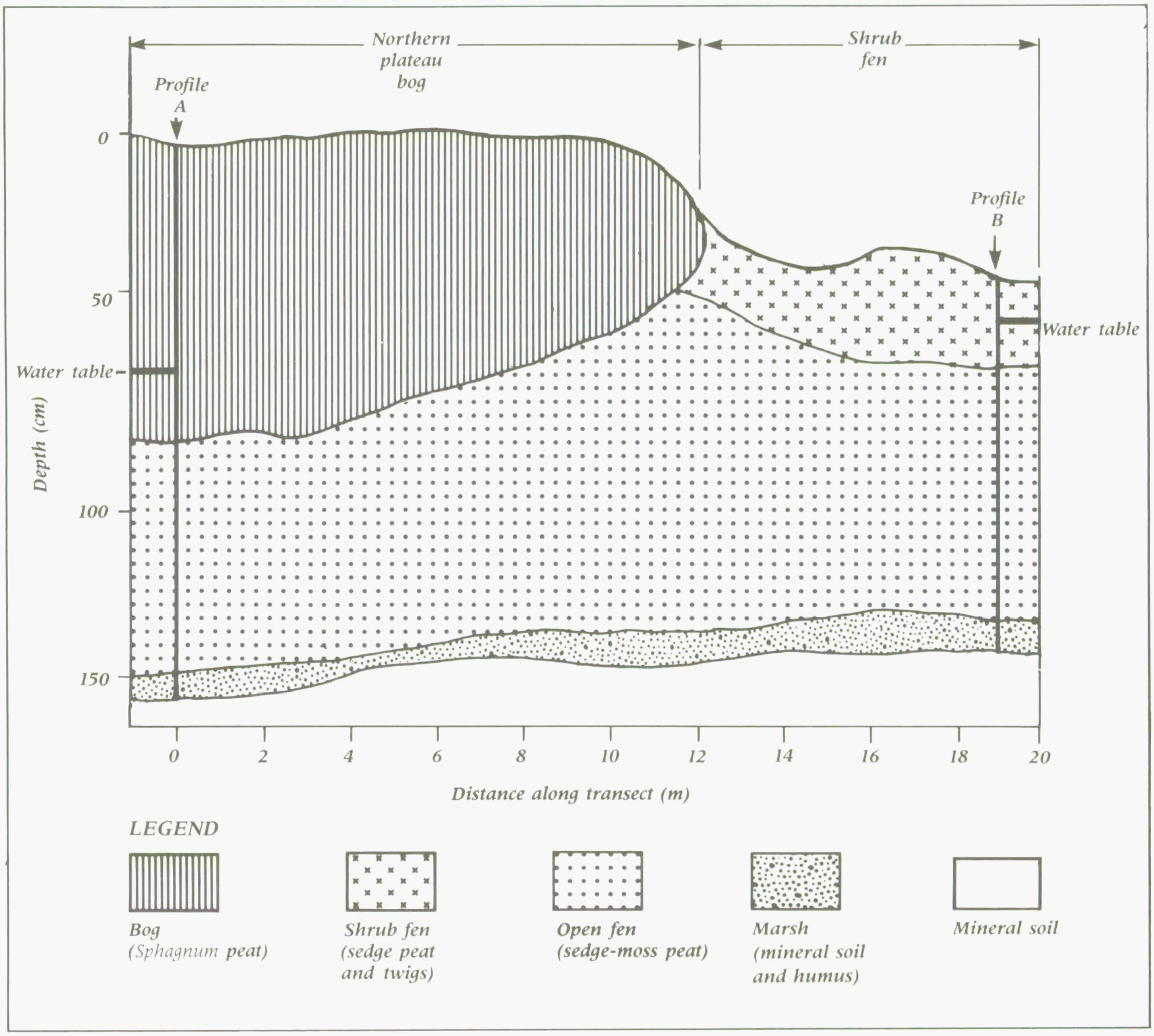


Figure 4–8.
Cross-section of a northern plateau bog near Riverton, Manitoba, indicating wetland environments during deposition.

composition and abundance of some species may vary regionally. *Picea mariana* is generally the only tree species occurring on flat bogs. In the Continental High Boreal Wetland Subregion, black spruce are found throughout flat bogs, occurring individually, stunted and scattered. In the Humid High Boreal Wetland Subregion of the east, trees are restricted to the vicinity of the margins of these bogs. Under the trees and in openings, a dense shrub layer of *Chamaedaphne calyculata*, *Kalmia angustifolia* in the east (*Kalmia polifolia* in the west), and *Ledum groenlandicum* is present, with some *Rubus chamaemorus*. The herb *Smilacina trifolia* is common. In the Humid High Boreal Wetland Subregion, trees are usually absent from the central parts of flat bogs or, if present, they reach only shrub size. Ericaceous shrubs grow on slightly raised moss hummocks. The moss layer is largely composed of *Sphagnum fuscum*, with *Sphagnum fallax* or *Sphagnum angustifolium*. On drier moss hummocks, lichens such as *Cladina rangiferina* and *Cladina stellaris* may be present. In small, wet depressions, *Carex oligosperma* is the dominant vegetation, with some *Sarracenia purpurea* and *Andromeda glaucophylla* (*Andromeda polifolia* in the west).

The underlying peat in flat bogs is generally divided into three layers, the most important being the middle, mesic layer. The surface consists of fibric mosses and ericaceous leaves in the upper 30–60 cm. The middle layer is composed of similar, moderately decomposed materials, the thickness of which may reach 3 m. The basal layer is well decomposed, consisting of residues of sedges and tree wood.

Table 4–5. Total elemental analysis and other properties of peat and water in a northern plateau bog near Riverton, Manitoba

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–2	4.1	*Sphagnum*	1	3.8	6 253	1 724	1 019	918	620
14–17	4.4	*Sphagnum*	2	3.7	1 737	1 146	1 369	619	433
30–32	4.6	*Sphagnum*	2	4.5	1 769	1 722	1 326	566	217
45–47	4.6	*Sphagnum*	2	1.4	2 029	3 449	761	609	183
60–62	4.7	*Sphagnum*	2	2.3	5 351	4 619	445	820	200
75–80	5.1	*Sphagnum*	2	4.3	6 769	4 311	435	2 478	367
97–102	5.3	Fen	5	5.2	9 765	4 610	629	6 905	418
117–122	5.6	Fen	5	9.6	17 459	6 928	1 403	11 197	442
130–135	5.9	Fen	5	9.9	20 849	7 585	2 732	13 065	348
140–145	6.0	Fen	5	10.3	21 205	7 388	2 939	13 118	364
150–155	6.1	Fen	5	11.7	21 531	7 361	6 018	16 377	405
160–165	6.2	Mineral humus	—	90.9	6 029	13 351	35 405	1 900	437
170–175	6.8	Mineral	—	93.8	6 495	13 278	35 378	1 086	489
Water									
70	4.7	—	—	—	2.2	1.9	0.2	1.2	0.2

An example of this wetland form occurs at Washow Bay, Manitoba (51°25′ N, 96°53′ W), on Lake Winnipeg. It is situated in a broad depression only a few metres above the water level of Lake Winnipeg. Trees cover about 70% of the flat bog and most are less than 5 m in height. There is a nearly continuous ericaceous shrub cover of *Chamaedaphne calyculata*, *Ledum groenlandicum*, and *Kalmia polifolia*. The herb layer is sparse, mainly consisting of *Vaccinium vitis-idaea*, *Oxycoccus quadripetalus*, and some *Rubus chamaemorus*. Mosses cover the entire bog surface, mainly with *Sphagnum fuscum*, *Pleurozium schreberi*, and minor *Dicranum polysetum* and *Dicranum undulatum*. Lichens are sparse and are mainly *Cladina rangiferina* and *Cladina mitis*.

This bog was cored near its centre, where a thickness of 469 cm of peat was encountered. The peat sequence (Table 4–7) shows a thick accumulation of *Sphagnum fuscum* peat (0–325 cm), followed by a mixture of *Sphagnum teres–Menyanthes* peat (325–385 cm) and, finally, a *Carex–Menyanthes* peat (385–469 cm) above a silty clay that has some humic organic inclusions. Chemical analyses indicate that oligotrophic conditions prevail from 0 to 270 cm and that much higher nutrient levels occur below the 320 cm level. These analyses demonstrate that only the lowermost *Sphagnum fuscum* layers (270–330 cm) are affected by nutrient-rich groundwaters. This implies that only low amounts of minerotrophic waters reach the basin in which the bog is situated.

The depositional sequence suggests that the wetland was initiated as a wet meadow, possibly a marsh. This was followed by open fen conditions. A radiocarbon date of 4 340±155 years before the present (BP) from the basal peat suggests that peat deposition began about 4 300 years ago. The open fen was followed by a treed fen, depositing 70 cm of peat (330–400 cm), and then a bog dominated by *Sphagnum fuscum* became established (peat deposition upwards of 330 cm). This bog has occupied the site to the present.

Basin Bogs

These ombrotrophic wetland forms develop in basins of essentially closed drainage (Figure 4–10),

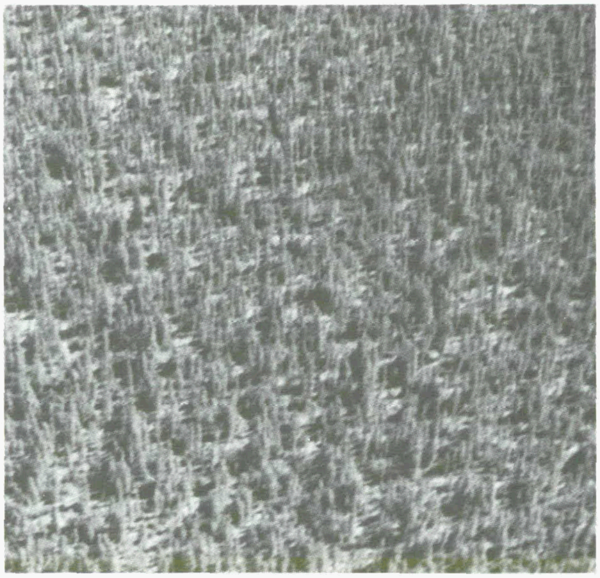


Figure 4–9.
Aerial view of a featureless flat bog with an open Picea mariana*-lichen cover near Kimiwan Lake, Alberta.*

receiving their water from precipitation and runoff from the immediate surroundings. They have a flat surface often covering more than 3 m of peat that fills the topographic basin. They are usually treed with black spruce, but treeless shrub basin bogs are also encountered. They are often ringed with tall shrub or coniferous treed swamp margins. In such cases, the basin bogs appear bowl-shaped, lower in the centre than on the edges, but this impression is created only by the tall trees at the margin, decreasing in height towards the centre. In other basins, there may be a narrow fen (less than 15 m wide) along the edge of the basin, influenced by minerotrophic runoff from the upland. The bog surface rises slightly (25–40 cm) towards the centre of the basin, creating ombrotrophic surface conditions. In either case, minerotrophic water does not affect the surface of the bog, although such mineral-rich water may be present at shallow depths under the ombrotrophic surface.

The thickness of peat usually increases towards the centre of the basin bog, but it may be variable, depending on the configuration of the basin surface. The surface peat tier usually consists of shallow (40–60 cm) fibric peat of *Sphagnum* moss and ericaceous shrub origin. This is generally underlain by mesic *Sphagnum* peat or by *Carex*–moss fen peat. In many basin bogs these sequences rest on aquatic peats which in turn grade into lacustrine sediments. In other instances, the middle peat tier is underlain by well-decomposed peat over mineral soil. The upper tier is generally acid (pH below 4.5) with low levels of nutrients. These oligotrophic conditions may persist well into the middle peat tier; however, in the lower part of the peat, minerotrophic conditions generally prevail.

The vegetation associated with basin bogs is similar to that of other bogs in the boreal wetland regions. Treed basin bogs have an open (10–50%) cover of *Picea mariana* that seldom exceed 5 m in height. Ericaceous shrubs, such as *Ledum groenlandicum*, *Chamaedaphne calyculata*, and *Kalmia polifolia* (*Kalmia angustifolia* in the east), cover large parts of these bogs and are even more extensive in the treeless bogs. *Eriophorum vaginatum*, *Smilacina trifolia*, and *Rubus chamaemorus* occur on wetter sites. *Sphagnum fuscum*, *Sphagnum magellanicum*, and *Sphagnum fallax* are the common peat-forming mosses.

Basin bogs are common throughout all the boreal wetland regions, especially in areas of moderate to high relief where poorly drained basins abound. Following is an example of a basin bog from the Low Boreal Wetland Region.

Basin bog (with swamp margin)

A treed basin bog with a coniferous treed swamp margin near Pointe du Bois, Manitoba (50°20′ N, 95°39′ W), has been studied. This bog is located in a basin formed by Precambrian bedrock. There is no inflow of water other than from the surrounding slopes, but there is outflow through seepage at the northwest margin of the bog.

This wetland has a swamp margin, about 50 m wide, of tall *Picea mariana* trees, merging fairly abruptly into a basin bog towards the centre where stunted, sparse tree cover occurs. In the swamp margin, the trees are dense, up to 14.5 m high, and consist mostly of black spruce, with a few tamarack in small openings. There is sparse cover in the shrub layer, except in openings where *Ledum groenlandicum* and *Chamaedaphne calyculata* are found. The herb layer is equally sparse, with a few individual specimens of *Vaccinium vitis-idaea* and *Smilacina trifolia*. There is a nearly continuous carpet of feathermosses, with *Pleurozium schreberi*, *Hylocomium splen-*

Table 4–6. Total elemental analysis and other properties of peat and water from a boreal fen near Riverton, Manitoba

Depth of sample (cm)	*pH*	*Material*	*Decomposition (von Post)*	*Ash (%)*	*Total elements (mg/kg)*				
					Ca	*Mg*	*Fe*	*S*	*P*
Peat									
0–2	4.6	Fen	1	9.8	6 939	4 265	2 044	1 701	1 736
15–17	4.7	Fen	2	18.7	4 749	2 617	1 812	2 271	1 181
30–32	5.0	Fen	2	5.4	7 170	3 825	749	5 601	534
45–47	5.9	Fen	2	5.0	8 641	4 980	582	7 120	564
60–65	6.2	Fen	5	11.5	15 598	8 038	2 117	12 775	500
75–80	6.5	Fen	5	11.5	18 074	8 255	2 472	13 650	384
89–94	6.8	Fen	5	10.6	17 624	7 773	3 640	14 312	435
101–106	6.0	Humic	8	43.4	16 631	9 494	13 303	12 524	434
Water									
13	4.7	—	—	—	7.5	8.5	0.4	3.7	0.1

dens, and *Ptilium crista-castrensis* in decreasing order of dominance. There are also various other mosses occurring in varied microhabitats, such as wet sinkholes and drier mounds.

A peat core was taken from the swamp margin about halfway between the surrounding mineral upland and the basin bog. Water was also sampled from the water table in the peat at 66 cm, and from a small sinkhole pool 42 cm below ground level. In the peat sequence, the top 20 cm is a woody feathermoss peat, also called "forest" or "sylvic" peat. This is underlain by *Sphagnum fuscum* peat (20–93 cm) containing several charcoal layers, in turn underlain by thin (93–110 cm) *Carex* peat with twigs, and then by woody forest peat. Silty clay mineral soil is encountered at 165 cm.

later reverted to the coniferous treed swamp of the present time.

Towards the central part of the basin, black spruce become more widely spaced and shorter (less than 5 m in height). There is a nearly continuous cover of *Chamaedaphne calyculata*, *Ledum groenlandicum*, and *Kalmia polifolia* in the shrub layer. The herb layer has sparse cover, represented by *Oxycoccus quadripetalus*, *Smilacina trifolia*, and *Eriophorum vaginatum*. Moss cover is also almost continuous, with *Sphagnum fuscum* predominating, followed by *Sphagnum angustifolium*, *Sphagnum magellanicum*, *Pleurozium schreberi*, and *Polytrichum strictum*.

In a second core from the associated basin bog, peat is 195 cm thick above the mineral soil, with the water table observed at 61 cm. The peat consists of

Table 4–7. Total elemental analysis and other properties of peat and water from a flat bog at Washow Bay, Manitoba

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
15–17	4.2	*Sphagnum fuscum*	2	3.6	2 962	1 034	1 026	493	358
44–46	4.1	*Sphagnum fuscum*	2	2.7	1 213	629	1 581	342	451
73–75	4.4	*Sphagnum fuscum*	3	1.5	1 528	789	717	390	278
103–108	4.7	*Sphagnum fuscum*	2	1.4	1 706	639	717	272	123
133–138	4.7	*Sphagnum fuscum*	2	2.0	1 667	710	558	355	166
163–168	4.7	*Sphagnum fuscum*	2	1.5	1 996	1 225	603	293	123
193–198	4.8	*Sphagnum fuscum*	2	1.4	2 242	1 690	549	339	115
223–228	4.8	*Sphagnum magellanicum*	3	2.1	2 772	2 004	493	543	264
255–260	4.9	*Sphagnum magellanicum*	4	2.2	2 960	1 950	436	527	207
285–290	5.0	*Sphagnum fuscum*	5	3.8	7 756	4 373	625	789	220
320–325	5.0	*Sphagnum fuscum*	5	5.2	10 129	4 146	901	3 502	216
350–355	5.0	*Sphagnum teres*	6	5.0	12 197	4 302	1 472	3 056	269
380–385	5.0	*Sphagnum teres*	6	5.1	12 012	3 360	2 393	4 323	451
415–420	5.6	*Carex–Menyanthes*	6	5.7	13 173	3 095	3 352	3 390	456
445–450	5.9	*Carex–Menyanthes*	6	8.9	18 449	3 901	5 778	4 246	521
473–478	6.1	Mineral	—	90.5	6 320	10 532	25 773	560	533
Water									
73	4.2	—	—	—	0.7	0.2	0.2	0.8	0.1

Chemical analyses (Table 4–8) indicate that the surface is enriched with Ca, but the peat immediately below is low in nutrients. Enrichment by surface runoff from the mineral upland is suspected, as sinkhole water at shallow depths on this site has levels of Ca, Mg, and sulphur (S) about twice those in the water from the water table at somewhat greater depths. Generally minerotrophic conditions are reached at a depth of 50 cm, with increasing amounts of nutrients at greater depths.

The wetland development at this swamp margin site, as indicated by plant remains in the peat sequence, began with a treed wetland, perhaps a coniferous swamp. This was invaded by the bog, but

Sphagnum fuscum peat 103 cm thick, underlain by a woody *Sphagnum magellanicum* peat (103–160 cm). There is a sedge–*Menyanthes*–twig layer just above the mineral soil (177–191 cm), underlain by a 4 cm humic layer above silty clay mineral soil at 195 cm. Chemical analyses of the peat and water (Table 4–9) indicate that the surface peat and the water at the water table are poor in nutrients, but the concentration of most elements increases with depth.

Plant macrofossils in the peat sequence indicate that, initially, a shrub fen occupied the site, followed by a treed bog which was in turn replaced by a bog with scattered trees. When both the bog centre and

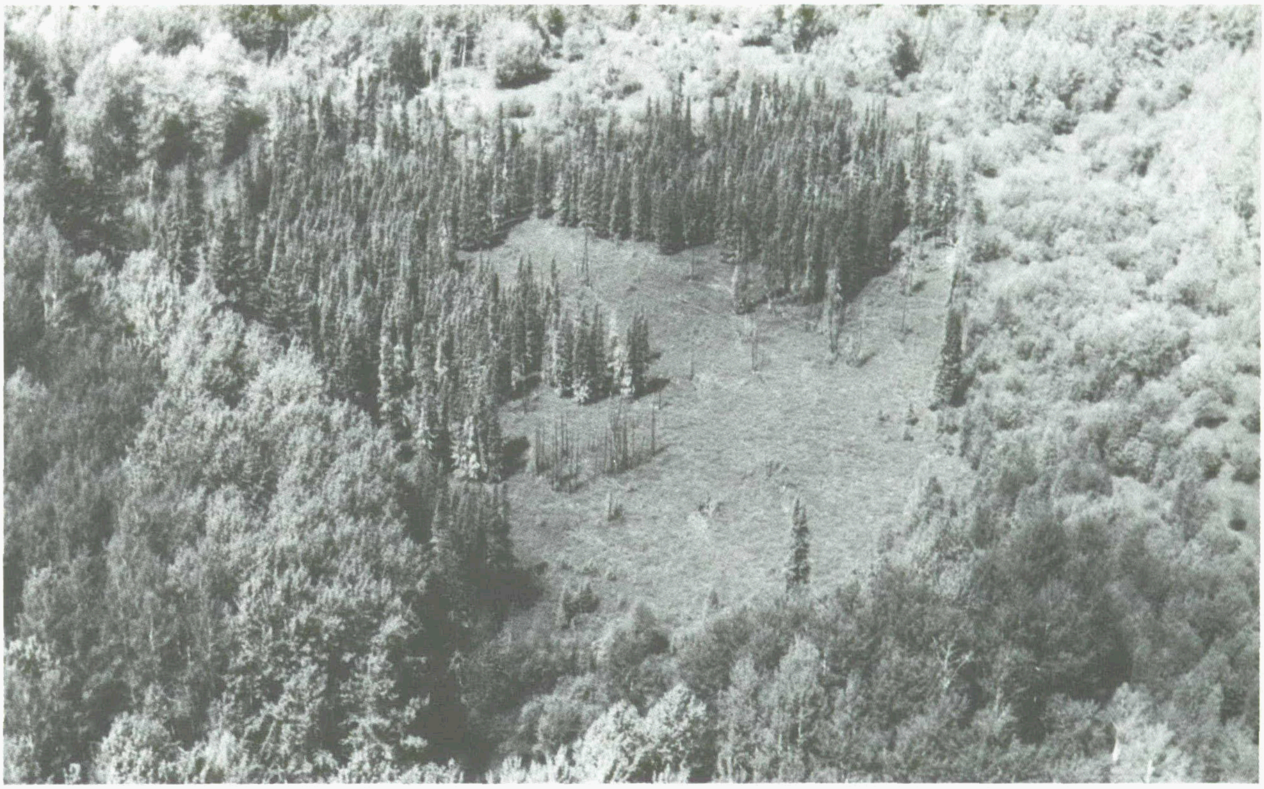


Figure 4–10.
A small basin bog near Lac la Biche, Alberta. The treeless portion failed to regenerate to spruce after a fire.

the swamp margin of this wetland are considered, it can be observed that a periodic expansion of the swamp towards the centre and an expansion of the bog from the centre have occurred, but that the swamp has never reached the central site.

Peat Plateau Bogs and Palsa Bogs with Collapse Scar Fens

Peat plateau bogs are wetland forms with perennially frozen organic layers which commonly occur as treed islands raised about 1–2 m above the adjacent non-frozen fens. Their appearance varies from isolated, near-circular islands (Figure 4–11) to complex networks of coalescing plateaus with only minor areas of fens (Figure 4–12). Peat plateau bogs often extend over several square kilometres (Reid 1974) and occur as various stages of development ranging from youthful to mature to over-mature or old (Zoltai 1972). The occurrence of permafrost and the presence of ice, usually at the base of the peat and in the underlying materials, combine with the vertical accumulation of peat to cause the elevation of these peat plateaus. Peat plateau bogs are characterized by varying rates of growth as well as rates of degradation or decay of the permafrost, as evidenced by collapse scar fens within these wetlands or along their outer edges. The relative rate of growth and decay changes with latitude; rates of collapse decrease with the decreasing air temperatures of higher latitudes. The elevated surface of the peat plateau bog effectively isolates the bog from the local water table in the surrounding fen. The peat plateau surface is relatively flat with a microhummocky appearance caused by the different growth rates of various mosses on the plateau surface. The characteristic vegetation of peat plateau bogs is an open-canopied to dense, closed-canopied woodland of *Picea mariana* with a prominent ground cover of feathermoss and lichens, and a sparse covering layer of ericaceous shrubs.

Palsas are circular to elongated mounds of peat that have a permafrost core. They may reach 4 m in height, but their diameter is less than 100 m (Zoltai and Tarnocai 1975). They occur as islands or peninsulas in non-frozen wet fens, rising abruptly above the surface. Their morphology and origin are similar to those in the subarctic wetland regions, discussed in Chapter 3, but differ mainly in vegetation. Palsas are most commonly a bog form but also, rarely, can be considered a fen form.

Palsa and peat plateau bogs generally occur in the High Boreal Wetland Region north of the 0°C mean annual temperature isotherm (Zoltai 1971; Dionne 1984). In Norway, palsa bogs occur where the mean annual temperature is lower than 0 to − 1°C and mean annual precipitation is less than 400 mm, with less than 100 mm during the winter months (December–March) (Åhman 1977). Palsa bogs are generally treeless in the east (Dionne 1984) and in the mountains (Seppälä 1980; Brown 1980), sparsely treed in the northern part (Railton and Sparling 1973), and densely treed with *Picea mariana* in the southern part of the High Boreal Wetland Region (Zoltai and Tarnocai 1971).

The thickness of peat deposits in peat plateau bogs is commonly in excess of 2 m, but seldom exceeds 5 m. There are generally three layers of peat (Figure 4–13). The surface peat layer, about 30–60 cm in thickness, consists of moderately well-decomposed forest peat layered with thin bands of less-decomposed fibric *Sphagnum* peat. The middle layer ranges in thickness from 1 to 2 m and is predominantly composed of mesic forest

Table 4–8. Total elemental analysis and other properties of peat and water from a coniferous swamp margin near Pointe du Bois, Manitoba

Depth of sample (cm)	*pH*	*Material*	*Decomposition (von Post)*	*Ash (%)*	*Total elements (mg/kg)*				
					Ca	*Mg*	*Fe*	*S*	*P*
Peat									
0–2	4.8	Feathermoss	1	9.7	14 045	1 680	1 735	754	809
15–17	3.8	Feathermoss–wood	4	15.5	5 365	1 654	3 816	660	616
24–26	4.3	*Sphagnum fuscum*	3	3.1	5 871	1 552	1 741	707	537
38–40	4.4	*Sphagnum fuscum*	4	3.6	4 009	963	738	665	420
53–55	4.4	*Sphagnum fuscum*	5	4.6	5 603	1 026	1 576	634	335
68–73	4.4	*Sphagnum fuscum*	5	3.6	6 113	992	1 733	716	240
83–88	4.7	*Sphagnum fuscum*	5	4.1	9 288	1 592	2 728	689	197
98–103	4.7	*Carex*–twigs	5	5.5	9 790	1 456	3 319	1 726	336
113–118	5.0	Wood–feathermoss	5	5.1	12 535	1 802	5 245	2 165	244
128–133	5.0	Wood–feathermoss	5	9.5	14 369	2 198	8 659	3 795	429
140–145	5.0	Wood–feathermoss	6	9.4	19 540	2 822	12 700	4 902	289
150–155	5.2	Wood–feathermoss	6	12.5	17 644	2 735	12 147	5 580	474
Water									
Sinkhole (42 cm)	4.7	—	—	—	8.0	3.5	1.1	4.2	0.1
Water table (66 cm)	4.4	—	—	—	4.0	1.6	0.8	1.5	0.2

Table 4–9. Total elemental analysis and other properties of peat and water from the centre of a basin bog near Pointe du Bois, Manitoba

Depth of sample (cm)	*pH*	*Material*	*Decomposition (von Post)*	*Ash (%)*	*Total elements (mg/kg)*				
					Ca	*Mg*	*Fe*	*S*	*P*
Peat									
0–2	3.8	*Sphagnum fuscum*	1	3.0	3 649	1 079	429	764	825
15–17	4.1	*Sphagnum fuscum*	2	3.0	1 593	708	859	310	313
30–32	4.4	*Sphagnum fuscum*	2	3.5	1 694	732	1 059	310	263
48–50	4.6	*Sphagnum fuscum*	2	3.8	3 188	937	1 351	500	357
60–62	4.7	*Sphagnum fuscum*	2	9.0	4 890	1 272	2 516	655	462
75–80	4.7	*Sphagnum fuscum*	2	3.8	5 340	1 041	1 035	748	624
91–96	4.7	*Sphagnum fuscum*	5	10.6	6 780	1 014	1 278	699	413
105–110	4.8	*Sphagnum magellanicum*	5	5.9	10 579	1 478	1 850	924	506
120–125	5.3	*Sphagnum magellanicum*	6	7.4	14 832	2 120	3 214	1 088	401
135–140	5.3	*Sphagnum magellanicum*	5	10.7	17 655	2 490	5 131	1 108	358
150–155	5.3	*Sphagnum magellanicum*	5	7.8	19 966	2 726	7 030	1 464	265
165–170	5.3	*Sphagnum fuscum*	5	8.3	20 230	2 574	8 188	2 289	315
180–185	5.6	*Carex–Menyanthes*	5	10.1	19 354	2 550	8 952	2 914	456
197–202	6.2	Mineral	—	93.4	5 979	7 842	23 252	396	383
Water									
61	4.4	—	—	—	3.8	1.6	0.8	1.5	0.2

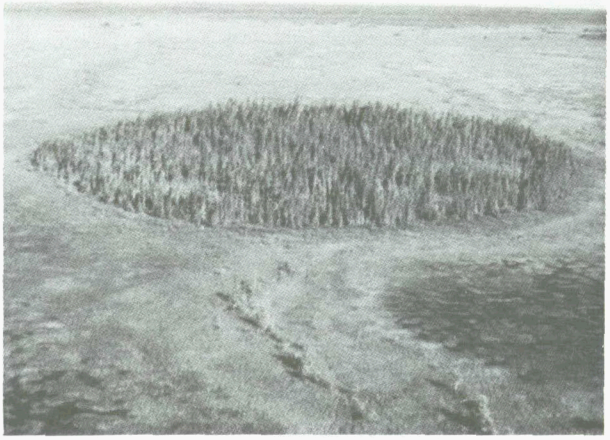


Figure 4–11.
A treed peat plateau bog in a large fen near Amisk Lake, Saskatchewan.

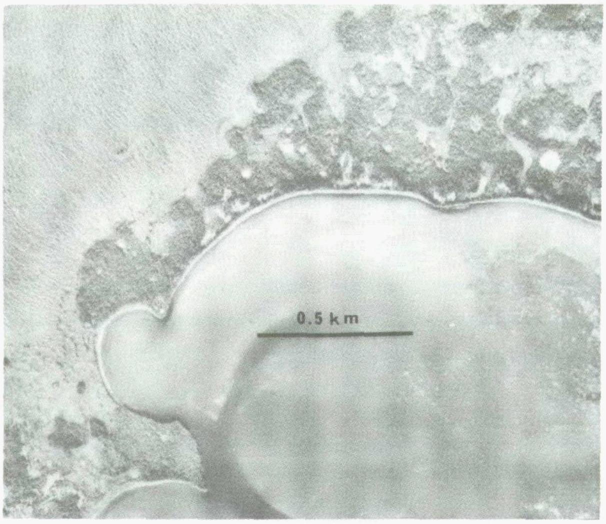


Figure 4–12.
Aerial photograph showing a peat plateau bog complex near Playgreen Lake, Manitoba, that developed between a lake and a ribbed fen. Circular collapse scar fens occur in the densely forested peat plateau bogs. The peat plateau bogs to the left of the small bay have completely collapsed, as marked by treeless, circular scars.

peat, sedge peat, or sedge–brown moss fen peat. The basal peat layer is usually well-decomposed fen and/or aquatic peat above the underlying mineral soil. Permafrost is present only in the peat at the southern fringe of the High Boreal Wetland Region (Zoltai 1972), but extends well into mineral soils further north.

The soils found on treed peat plateau bogs are Mesic Organic Cryosols and Fibric Organic Cryosols. The Mesic Organic Cryosols are dominant, supporting mesic forest peat composed of tree remains (needles, branches, and trunks), shrubs, and feathermosses. The properties of the surface peat vary according to the vegetation cover. On densely forested *Picea*–feathermoss, the surface peat is well decomposed and contains high levels of nutrients. In the more open-canopied spruce forests, the surface material is fibric, composed of *Sphagnum* peat, and contains soils (Fibric Organic Cryosols) with low levels of nutrients. The surface layer is generally underlain by fen peat with high levels of nutrients. The active layer (depth of annual thaw) extends to a depth of 55–80 cm (Reid 1974). The ice content of the perennially frozen peat is approximately the same as the water content of the non-frozen peat. Ice content generally increases to 85–95% by volume close to the mineral-soil contact. The ice content of the perennially frozen clay mineral substrate is greatest immediately below its contact with organic materials, where segregated ice lenses 5–10 cm in thickness are common. Ice lenses are most abundant in silty mineral soils (Zoltai 1972).

The vegetation associated with this wetland form varies mostly in the density and abundance of plants, rather than in floristic composition. Treed peat plateau and palsa bogs near the southern limit of their distribution in the central portions of the boreal wetland regions are characterized by fairly dense *Picea mariana* forests with low productivity. Occasionally, *Betula papyrifera* becomes established on peat plateau bogs after a forest fire. Towards the northern limit of the High Boreal Wetland Region, where the peatlands are frozen, *Picea* cover is more open and stunted. The shrub layer consists predominantly of *Ledum groenlandicum* with a few *Chamaedaphne calyculata*, *Kalmia polifolia*, *Rubus chamaemorus*, and shrub-sized *Picea mariana*. *Salix* spp. may occur in localized clumps. Other small shrubs and herbs usually include *Vaccinium vitis-idaea*, *Eriophorum* spp., and *Carex* spp. The shrub layer becomes sparse or absent under more densely treed portions of peat plateau bogs. Ground cover consists of feathermosses, such as *Pleurozium schreberi* and *Hylocomium splendens*, with cushions and hummocks of *Sphagnum* moss. Lichens (predominantly *Cladina* spp.) occur in patches on locally drier hummocks.

Peat sections taken throughout treed peat plateau bogs suggest three general sequences of development. The initial stages of peat accumulation occur in shallow ponds or poorly drained peaty basins where the water table is always at the surface. Basal organic layers above the mineral

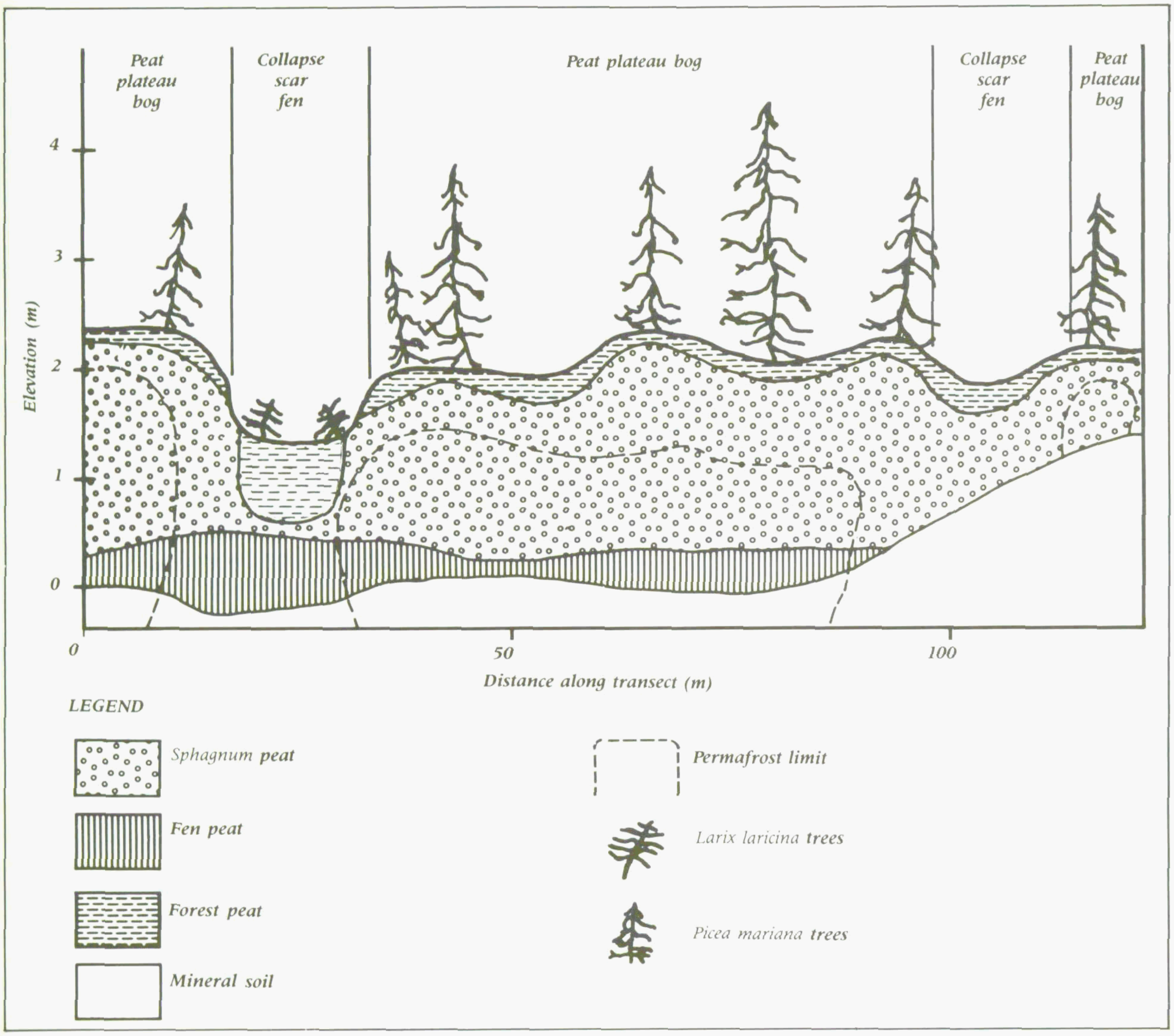


Figure 4–13.
Cross-section of a peat plateau bog complex with collapse scar fen near Knee Lake, Manitoba.

subsoil may consist of aquatic peat (organic detritus of algae, sponges, and marl or gastropods), or brown sedge–moss peat with or without woody shrub remains. These peat layers are capped by *Sphagnum* peat showing a transition to a somewhat elevated bog, or by woody forest peat suggesting sufficient elevation of the surface above the water table to allow the invasion of trees. A third sequence, usually of minor extent, involves thick deposits of *Sphagnum* peat accumulated over either aquatic or moss–sedge peat. The extent to which *Sphagnum* peat accumulates indicates a significant change in the vegetation, which results in the development of an insulating peat layer and the growth of trees. These slightly raised sites are characterized by decreased snow cover in winter and increased insulation in summer which allow the seasonal frost to persist during the summer and hence become permafrost. Once initiated, permafrost forms rapidly as the frozen area is further elevated by the expansion caused by the freezing of water in the peat. In this way small peat plateau and palsa bogs expand horizontally, often merging into extensive complexes of larger peat plateau and palsa bogs.

Peat plateau and palsa bogs are believed to be morphological variations of the same process (Brown 1970). The ratio of perimeter to area in palsa bogs is much higher than in peat plateau bogs; therefore, a larger proportion of the palsa bog is in contact with wet fens. Water migrates into the frozen peat because of a temperature gradient mainly along the mineral-soil–peat interface (Hoekstra 1966) and accumulates as ice. This process is especially pronounced if the mineral-soil substrate is silt (Zoltai 1972). The different rates of ice accumulation cause the morphological differences in palsa and peat plateau bogs.

The morphological character of treed peat plateau and palsa bogs varies with climate and the age of the developed landform. Perennially frozen organic landforms have a cyclic nature, with youthful, mature, overmature, and collapsing stages (Brown 1970; Zoltai 1972). Youthful stages usually show only minimal amounts of collapse, whereas mature and overmature peat plateau and palsa bogs are characterized by increasing rates of collapse or by thawing of the permafrost both within the peat plateau bog and along its edges. Collapsing in peat plateau bogs is more common near the southern limit of their distribution than in the north.

Collapse scars occur where the ice held in the peat or in veins thaws, resulting in the subsidence of the peat plateau or palsa bog surface to the level of the water table in the surrounding fen. Such subsidence may be initiated by the destruction of the insulating qualities of the surface peat by fire (Thie 1974), by windthrow of large trees, by a rise in water level, or by man-made activities. Collapse scars are usually circular in outline (Figure 4–14), but several may merge into a linked ring-like pattern. They usually contain dead trees partially submerged in the fen. If the collapse scar is connected with the surrounding fen, sedges and, later, shrubs occupy it, creating a *collapse scar fen*. Carpets of *Sphagnum riparium*, almost submerged in water, are characteristic of the actively collapsing peat plateau edges. If the collapse scar is surrounded by an intact peat plateau bog on all sides, it is isolated from the fen, and the presence of bog species, such as *Sphagnum magellanicum* and *Eriophorum chamissonis*, creates a *collapse scar bog*. In some instances, small permafrost bodies may be found in the collapse scars, indicating a recurrence of the peat plateau bog–collapse scar cycle over a period of time.

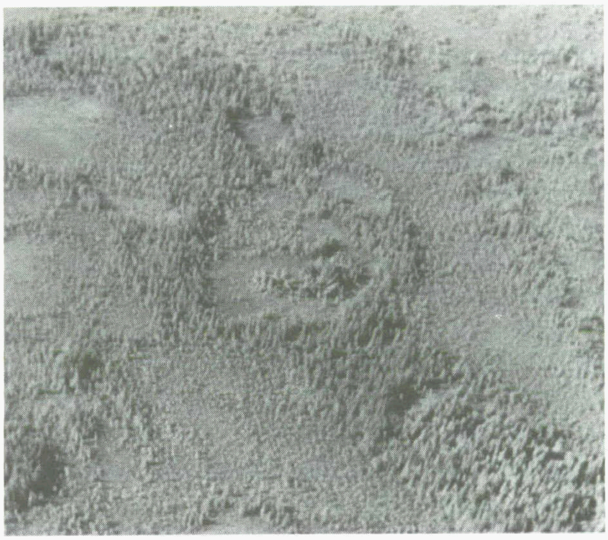


Figure 4–14.
A pattern of collapse scars with living or dead trees at their centre near Wabowden, Manitoba.

The thickness of peat in collapse scar fens is usually the same as the thickness of frozen peat in the nearby peat plateau bogs or only slightly greater (Reid and Morrow 1974). The stratigraphy of the peat reflects the local conditions that prevailed during the thawing of a portion of the peat plateau bog. If a simple subsidence took place, the peat plateau surface became submerged in water and fen peat was deposited on the submerged surface. If the thawing produced steep peat banks, blocks of peat could tumble into the collapse scar, resulting in a mixing of peat plateau materials with subsequent fen peat.

A treed peat plateau bog near Kississing Lake, Manitoba (54°58′ N, 101°28′ W), has been investigated in some detail. This peat plateau bog occupies a small portion of a large treed fen. A short transect was made from the peat plateau bog to a nearby collapse scar fen, with consequent noting of the vegetation and topography.

On the treed peat plateau bog, *Picea mariana* covers about 30% of the surface, growing in dense stands but with extensive openings. The trees are uniformly 10 m tall. In the openings, *Ledum groenlandicum* and *Vaccinium myrtilloides* grow. The herb layer is formed by *Vaccinium vitis-idaea*, *Oxycoccus quadripetalus*, and *Lycopodium annotinum*, in decreasing order of abundance. Under the dense black spruce, *Pleurozium schreberi* and *Hylocomium splendens* form a continuous carpet. In the openings, *Sphagnum nemoreum* and *Sphagnum fuscum* cover about 30% of the surface. Lichens cover about 10% of the surface, mostly in the openings, and consist mainly of *Cladina mitis* and *Cladonia cornuta*.

The peat of this peat plateau bog has been cored and sampled. The thickness of peat is 199 cm, with the permafrost table at 26 cm in mid-July. The peat sequence shows that the top 46 cm consists of woody forest peat, containing remains of *Ledum groenlandicum*, *Pleurozium schreberi*, and *Picea mariana*. Underneath is a woody layer (46–82 cm) with *Larix* cones and needles. The next underlying stratum is a mixture of *Carex–Menyanthes* peat remnants with twigs, followed by *Carex*–

Drepanocladus peat (129–158 cm) with some twiglets. The basal layer consists of humified *Carex* peat (158–199 cm).

The fibric top 10 cm portion of the surface is low in nutrients, but most of the forest peat is rich in most nutrients (Table 4–10), as is the underlying fen peat. This indicates that, although the living moss vegetation is largely dependent on rain for nutrients, the trees are rooted in the nutrient-rich, well-decomposed forest peat more typical of coniferous treed swamps than of ombrotrophic bogs.

A small collapse scar fen (approximately 15 m in diameter) is located within 5 m of the core site on the peat plateau bog. This collapse scar is contained almost entirely within the peat plateau bog, as it is connected to the main fen body only by a channel 1 m wide. The dominant vascular vegetation consists of *Calla palustris, Carex canescens*, and *Calamagrostis canadensis*. The mosses are mainly *Drepanocladus fluitans, Drepanocladus aduncus*, and *Calliergon cordifolium*, covering about 50% of the surface. A few strands of *Sphagnum squarrosum, Sphagnum angustifolium*, and *Sphagnum teres* are also found.

A core in the collapse scar fen shows a peat thickness of 184 cm. The peat sequence indicates that the surface layer (0–13 cm) consists of *Drepanocladus–Carex* peat. This is underlain by woody peat at 13–87 cm, which is composed of *Picea* wood and needles and some well-preserved *Lycopodium annotinum*. This is then underlain at 87–102 cm by another woody layer with *Larix* twigs and needles and then by a basal layer of *Carex–Drepanocladus* peat (151–190 cm). Chemical analyses (Table 4–11) indicate that nutrient levels are high throughout the peat profile.

Peat macrofossils indicate that both the peat plateau bog and the collapse scar fen began as a wet meadow, developing into a shrub fen. This fen was then invaded by tamarack. In a portion of this treed fen, a dense *Picea* forest was established which coincided with the development of permafrost. The frozen peat was elevated above the fen surface as a peat plateau bog. A part of this peat plateau bog later thawed, forming a collapse scar in which a fen has been established.

Horizontal Fens

This minerotrophic wetland form has a generally flat and featureless surface that slopes gently in the direction of drainage. It is usually uniformly vegetated by herb, shrub, and tree species characteristic of nutrient-rich sites fed by minerotrophic waters from surrounding mineral soils and headwater sources. Horizontal fens represent a relatively dry form of fen (Reid and Morrow 1974). Underlying peat deposits are moderately to well decomposed and range in thickness from a few centimetres to an average of over 3 m.

Because of the flat relief of the surrounding areas, the exact boundaries of horizontal fens are difficult to determine. The structure and composition of upland forests gradually change to reflect increasingly poor drainage, until fen species dominate. Fen conditions are indicated by an open-canopied forest in which *Larix laricina* is the most common tree species (Figure 4–15) (Sims *et al.* 1982). Shrubs, usually *Betula pumila*, may domi-

Table 4–10. ***Total elemental analysis and other properties of peat from a peat plateau bog near Kississing Lake, Manitoba***

Depth of sample (cm)	*pH*	*Material*	*Decomposition (von Post)*	*Ash (%)*	*Total elements (mg/kg)*				
					Ca	*Mg*	*Fe*	*S*	*P*
0–3	4.7	*Pleurozium schreberi*	1	12.9	6 354	1 755	2 756	930	1 130
7–10	4.7	*Pleurozium schreberi–Ledum*	2	5.7	2 960	755	1 566	789	937
16–20	4.7	*Pleurozium schreberi–Ledum*	8	9.4	18 453	752	6 178	1 968	932
23–26*	5.2	Wood	8	11.9	31 073	1 345	10 746	2 766	1 432
56–60	5.1	Wood–*Larix*	8	10.2	27 936	3 050	5 750	3 179	490
70–80	5.1	Wood–*Larix*	6	9.6	26 931	2 959	5 359	3 116	412
85–95	5.1	*Carex*–twigs	6	9.0	26 653	2 887	5 196	3 319	300
100–110	5.3	*Carex*–twigs	6	6.7	18 543	2 075	4 194	3 442	426
115–125	5.3	*Carex*–twigs	6	6.2	15 254	1 629	3 655	3 664	383
135–145	5.3	*Carex–Drepanocladus*	6	8.9	16 406	1 746	3 855	4 901	491
145–155	5.3	*Carex–Drepanocladus*	6	15.7	14 244	2 000	4 603	5 629	578
160–170	5.4	*Carex*	9	26.3	12 562	2 884	7 242	5 906	500
175–184	5.6	*Carex*	9	32.8	12 018	3 747	9 719	6 326	483
190–199	5.6	*Carex*	9	31.9	12 493	3 742	10 219	6 330	505
199–210	5.6	Mineral–humus	—	59.3	7 677	6 135	19 290	6 458	433

**Frost table is at a depth of 26 cm.*

Table 4–11. Total elemental analysis and other properties of peat and water from a collapse scar fen in peat plateau bog near Kississing Lake, Manitoba

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–5	5.9	*Drepanocladus–Carex*	1	17.3	14 667	3 567	16 836	2 769	4 379
10–13	6.0	*Carex–Drepanocladus*	5	14.3	10 762	1 802	7 032	2 708	1 418
26–30	6.0	*Picea* wood–*Lycopodium annotinum*	8	14.1	24 083	1 648	17 014	3 299	1 484
35–75	—	Water	—	—	—	—	—	—	—
70–75	6.0	*Picea* wood	6	11.1	29 092	1 792	8 778	3 628	871
91–96	6.1	Wood–*Larix*	6	10.5	28 256	1 908	8 282	3 584	822
106–111	6.2	*Carex*–twigs	6	10.4	29 112	2 948	5 862	3 241	608
122–127	6.4	*Carex*–twigs	6	8.0	22 028	2 824	5 465	3 011	405
140–145	6.3	*Carex*–twigs	6	8.8	19 561	2 408	5 421	4 556	526
155–160	6.5	*Carex–Drepanocladus*	8	25.4	13 837	3 159	7 167	6 115	508
169–174	6.5	*Carex–Drepanocladus*	8	46.1	9 878	5 015	16 412	7 503	417
184–190	6.3	Mineral	—	98.1	3 215	9 547	22 332	254	511
Water									
5	6.0	—	—	—	22.0	6.3	0.2	5.2	3.1

nate portions of the fen. *Rhamnus alnifolia* is a common shrub species east of Manitoba. Herbs, such as *Scirpus caespitosus, Scirpus hudsonianus,* and *Equisetum fluviatile,* are components of treed or shrub horizontal fens. Mosses, such as *Sphagnum teres, Sphagnum warnstorfii,* and *Sphagnum fallax,* are present in low hummocks or in wet carpets.

In the wetter parts of the fen, other shrub species such as *Myrica gale* are present, along with *Carex exilis, Carex lasiocarpa, Scirpus caespitosus, Eriophorum viridicarinatum, Habenaria dilatata,* and *Menyanthes trifoliata.* Mosses, such as *Campylium stellatum, Drepanocladus revolvens,* and *Scorpidium scorpioides* in particularly rich fens, are common.

The somewhat drier and wetter portions of the fen often impart a pattern of darker and lighter streaks visible from the air or on aerial photographs. The streaks are broad, without sharp boundaries, and are elongated in the direction of drainage. In some areas, such as in the southern James Bay area, vast expanses of horizontal fens are dominated by *Larix laricina* and *Sphagnum warnstorfii* in which small, streamlined "islands" of black spruce occur (Grondin and Ouzilleau 1980).

The surface 30–60 cm of the peat is usually fibrous and poorly decomposed, consisting of mosses and root masses (Mills *et al.* 1977). This is underlain by moderately to well decomposed peat in which wood chips of trees and shrubs are usually present. The basal peat deposits are well humified. The peat thickness in horizontal fens in southeastern Manitoba has been observed to range from 185 to 270 cm (Mills *et al.* 1977).

Horizontal fens commonly occur throughout the boreal wetland regions in areas of low relief, such as the Hudson Bay and James Bay lowlands and northern Manitoba and Alberta.

A treed horizontal fen near Peace River, Alberta (56°10′ N, 116°58′ W), has been investigated in some detail. The fen occupies about 1 100 ha in a broad, flat landscape within the basin of a former glacial lake. The wetland is located near a local height-of-land; therefore all incoming water is from the adjoining uplands.

Vegetation was examined about 1 500 m from the edge of the fen, with a short transect made to examine a treed and a shrub condition. The treed fen has a 15% cover of low (10 m high) *Larix laricina,* with a few scattered *Picea mariana.* Shrubs completely cover the ground, dominated by *Betula pumila, Myrica gale,* and *Salix candida,* with *Ledum groenlandicum* on low peat hummocks. The herb layer covers about 50% of the ground and is composed mainly of *Carex disperma, Carex paupercula, Carex tenuiflora,* and *Carex aquatilis.* An almost continuous moss cover consists of *Sphagnum angustifolium, Sphagnum warnstorfii,* and *Sphagnum fuscum,* with *Tomenthypnum nitens* and *Aulacomnium palustre* occurring about equally.

The shrub portion of this wetland is dominated by *Betula pumila, Myrica gale,* and *Ledum groenlandicum,* in decreasing order of importance. The herb layer is sparse and consists of *Oxycoccus quadripetalus, Smilacina trifolia,* and *Carex aquatilis.* The moss layer offers nearly continuous cover and is dominated by *Sphagnum angustifolium, Sphagnum*

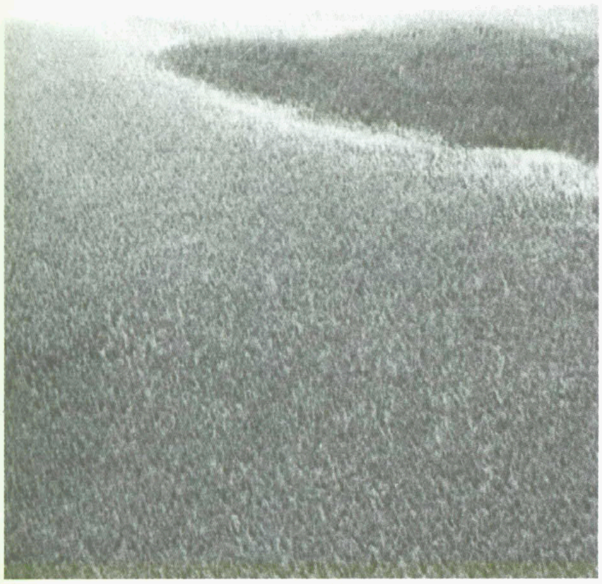


Figure 4–15.
Portion of a large horizontal fen, with tamarack trees at Emmeline Lake, Saskatchewan.

warnstorfii, *Sphagnum fuscum*, and *Aulacomnium palustre*.

A peat core was taken from the treed portion of this horizontal fen. The peat thickness is 140 cm, with the water table observed at 17 cm. The core shows that the surface 25 cm consists of woody *Sphagnum* peat and root masses, characteristic of forest peat. Underlying this is fen peat composed of *Carex* spp., *Drepanocladus* spp., and twigs, along with minor amounts of *Larix* and *Picea* cones and needles (25–119 cm). This is underlain by a peat layer rich in *Salix* wood fragments and by a well-decomposed basal layer above the mineral soil.

Chemical analyses (Table 4–12) indicate that nutrient levels, especially Ca and S, are high throughout the peat profile. High levels of S, especially in the lower part of peat profiles, are common in Alberta and possibly can be related to the mineralogy of the underlying mineral soils which have been derived mainly from shales.

Peat macrofossils in the depositional sequence suggest that this wetland was initially a grassy meadow that later became a shrub–treed swamp. This was followed by a shrub fen with scattered coniferous trees, a wetland that persisted for an extended period. During the later stages, the tree component increased to form the treed horizontal fen that exists at present.

Basin Fens

Basin fens are minerotrophic wetland forms that receive nutrient-enriched waters from their surrounding area, but they are not part of a major regional drainage system. The waters reaching a basin fen are, therefore, locally derived, except for the possibility of enrichment from distant sources. The chemistry of basin fens is often markedly different from that of other fens in their vicinity which receive regional drainage water. The surface of a basin fen is usually level or slightly concave, with the underlying peat being moderately to well decomposed and ranging in thickness from 1 m to more than 6 m. Basin fens are common throughout the boreal wetland regions wherever the topography allows the development of very

Table 4–12. Total elemental analysis and other properties of peat and water from a horizontal fen near Peace River, Alberta

Depth of sample (cm)	*pH*	*Material*	*Decomposition (von Post)*	*Ash (%)*	*Total elements (mg/kg)*				
					Ca	*Mg*	*Fe*	*S*	*P*
Peat									
0–3	4.7	*Sphagnum angustifolium*	1	14.3	9 927	5 954	2 727	1 814	1 508
12–15	5.0	*Sphagnum*–wood	5	10.8	24 871	7 304	1 598	4 539	1 546
20–23	5.0	*Sphagnum*–wood	4	9.5	28 605	6 285	1 076	8 203	972
31–34	5.2	*Drepanocladus–Carex*–twigs	3	8.2	24 967	5 209	631	10 838	689
40–45	5.4	*Carex*–twigs	5	10.0	29 857	5 271	1 036	14 084	650
56–61	5.4	*Drepanocladus–Carex*–twigs	5	9.6	29 434	5 525	991	15 430	740
71–76	5.4	*Drepanocladus–Carex*–twigs	5	8.2	22 932	4 748	990	13 431	618
87–92	5.7	*Drepanocladus–Carex*–twigs	6	11.1	28 933	5 623	2 477	20 805	688
110–115	6.1	*Drepanocladus–Carex*–twigs	6	15.1	35 602	5 711	7 657	22 936	700
122–127	6.0	*Salix* wood	6	18.5	36 984	5 965	13 702	27 998	478
136–140	6.1	Unknown	10	49.2	27 193	4 477	14 874	13 354	681
142–147	6.2	Mineral	—	88.9	9 307	4 204	15 184	3 767	959
Water									
17	5.4	—	—	—	18.5	12.9	0.1	6.6	0.2

poorly drained, isolated basins supplied with minerotrophic water.

The boundaries of basin fens are usually well defined by the topography of the surrounding terrain. Depending on the quality and quantity of water reaching the fen from the surrounding slopes, there may be a narrow marsh fringe with *Scirpus* spp. or *Typha* spp. In some areas, the fringe may consist of a shrub swamp with *Salix* spp. and *Calamagrostis canadensis*. The vegetation on such fens varies with the nutrient levels of the waters reaching them. However, the nutrient levels are generally in the intermediate range. *Larix laricina* may be present, usually with *Betula pumila* shrubs which may cover large parts of the fen. Herbs are represented by sedges, such as *Carex aquatilis* and *Carex lasiocarpa*. Mosses are common, usually consisting of *Drepanocladus exannulatus*, *Drepanocladus revolvens*, *Campylium stellatum*, *Calliergon giganteum*, and *Calliergon richardsonii*. In the treed portions, loose cushions of *Sphagnum angustifolium* may be present. In the wetter parts of basin fens, the sedge and bryophyte components of the vegetation become dominant.

The surface 25–50 cm of the peat in these wetlands is fibrous, composed of a tangle of sedge roots and mosses. At greater depths, the peat is moderately decomposed, usually underlain by a humified basal layer. In many basin fens, however, the peat rests on some form of lacustrine sediment, such as sedimentary peat, marl, or mineral material, indicating that basin fens originated through the infilling of ponds.

A small basin fen (approximately 1 500 ha) near Jan Lake, Saskatchewan (54°53′ N, 102°46′ W), has been investigated. The basin was formed by Precambrian bedrock ridges that are covered by thin, sandy glacial moraine. Although the area is within the former basin of Glacial Lake Agassiz, no glacio-lacustrine sediments were noted in the area. The basin is presently occupied by a treed basin fen, with a small pond in the centre.

The fen is sparsely treed (10% coverage of the surface) with low (up to 6.5 m high) *Larix laricina* and some scattered *Picea mariana*. Shrubs cover about 35% of the surface and consist almost exclusively of *Betula pumila*. In the low shrub layer, covering about 40% of the surface, *Chamaedaphne calyculata* and *Andromeda polifolia* are dominant, with some *Salix pedicellaris* and *Ledum groenlandicum*. The herb layer has sparse cover, represented by *Smilacina trifolia*, *Carex chordorrhiza*, and *Carex aquatilis*. Mosses cover about 80% of the surface and are composed of *Sphagnum fuscum*, *Sphagnum warnstorfii*, *Sphagnum angustifolium*, *Tomenthypnum falcifolium*, and *Aulacomnium palustre* in decreasing order of dominance.

The peat in this treed basin fen has been studied about 500 m towards the centre from the edge of the fen. The depth of peat is 291 cm, with the water table observed at 20 cm. The peat is underlain by 152 cm of detrital aquatic peat, giving a combined thickness of 443 cm of peat above the mineral soil. The peat sequence shows that the surface layer (0–23 cm) consists of a fibrous peat deposited in a treed fen, underlain by more decomposed material of the same composition (23–127 cm). Below this, the shrub twig content increases, but *Larix* needles are still present (127–279 cm). A thin layer of fen peat lacking any twigs follows (279–291 cm), resting on a detrital aquatic peat which extends to the mineral soil (291–443 cm).

Chemical analyses of this peat (Table 4–13) indicate that nutrient levels are moderately high throughout the main peat section, but that the water at the water table and the surface peat are low in nutrients. Sulphur levels increase with depth, although the underlying soil has low levels. This indicates an influx and retention of this element in the peat.

Macrofossils indicate a relatively simple sequence of development. The wetland began as a pond where detrital organic material was deposited. This was followed by a brief period of open fen, perhaps in the form of a floating mat. This open fen was soon invaded by shrubs and tamarack trees, vegetation that has been maintained until the present with only small variation in the proportions of shrub and tamarack.

Spring Fens

Spring fens are minerotrophic wetland forms that are fed predominantly by groundwater discharge sources such as springs. The surface of a spring fen is gently sloping, although there may be a series of pools dammed by peaty ridges (Figure 4–16). Spring fens may be located immediately below upland recharge areas or may be several tens of kilometres from the associated uplands, depending on the hydrology of the aquifer formations. Spring fens are characteristically long and narrow, originating from a point source. Small "islands" may develop on them in those parts of the fen that

Table 4–13. Total elemental analysis and other properties of peat and water from a basin fen near Jan Lake, Saskatchewan

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–3	3.8	*Sphagnum angustifolium–Tomenthypnum falcifolium–Larix*	1	6.4	7 796	2 067	1 154	914	789
15–18	5.1	*Sphagnum angustifolium–Tomenthypnum falcifolium–Larix*	2	6.3	10 045	2 714	2 172	707	449
25–28	5.0	*Sphagnum angustifolium–Tomenthypnum falcifolium–Larix*	4	11.1	15 256	2 966	11 084	1 372	795
40–43	5.0	*Carex*–twigs–*Larix*	4	10.9	13 892	2 723	4 084	2 695	1 166
53–56	5.0	*Carex*–twigs–*Larix*	4	6.2	14 757	2 799	1 894	1 725	636
88–93	5.3	*Carex*–twigs–*Larix*	4	7.2	16 199	2 298	2 570	1 825	746
105–110	5.3	*Sphagnum–Larix*	5	7.3	18 280	2 313	1 976	1 949	562
135–140	5.3	*Sphagnum–Larix*	6	8.0	20 674	2 473	1 974	2 108	492
165–170	5.4	*Carex–Larix*	6	7.1	19 835	2 347	1 651	1 789	382
195–200	5.4	Twigs–*Larix*	6	7.3	21 575	2 366	1 720	2 114	380
225–230	5.4	*Carex–Menyanthes trifoliata–Larix*	6	5.8	14 122	1 667	1 418	1 993	440
270–275	5.9	*Carex–Menyanthes trifoliata–Larix*	6	5.9	12 529	1 475	1 528	1 915	472
300–305	6.2	Detritus	—	21.5	12 272	1 968	3 729	3 210	471
330–335	6.5	Detritus	—	28.0	13 642	2 713	6 029	4 576	435
360–365	6.8	Detritus	—	29.5	14 095	2 911	7 857	6 763	416
390–395	6.8	Detritus	—	39.2	13 076	4 508	16 062	10 042	528
435–440	7.1	Detritus	—	84.4	25 434	12 402	31 174	5 171	392
455–460	7.1	Mineral	—	98.2	6 919	13 764	26 208	402	428
Water									
20	5.0	—	—	—	3.7	1.7	1.1	0.9	0.1

receive less spring water and, therefore, develop a less minerotrophic vegetation with trees and shrubs. This results in a pattern of treed islands in these generally sedge-dominated wetlands. Such fens can be highly minerotrophic if the spring water contains large amounts of dissolved minerals; in such cases, marl deposits may be encountered. Saline springs are noted for a lack of vegetation in the vicinity of the spring.

Spring fens are characterized by fairly open stands of sedges (*Carex lasiocarpa, Carex interior, Carex limosa*), *Scirpus caespitosus*, and *Eleocharis quinqueflora*. Mosses, which cover about 50% of the surface of spring fens, usually include *Scorpidium scorpioides, Drepanocladus revolvens*, and *Campylium stellatum*.

The surface peat of spring fens is usually fibrous in the upper 50 cm, consisting of a tough mat of roots and mosses. In small pools, marl is often deposited. At greater depths, the peat is more decomposed, but may alternate with layers of marl. The thickness of the peat is variable, ranging between 1 and 2.5 m.

A spring fen near Spruce Grove, Alberta (53°34′ N, 113°50′ W), locally called the "Wagner Bog", has been investigated. This wetland occurs on a lower slope of a gently rolling upland. The discharge points are occupied by shallow, marl-filled pools, with narrow sedge fens extending downslope from the springs. These narrow fens cut through dense coniferous treed swamps.

On this site, a 25 m transect was made from a minerotrophic spring fen to the adjacent coniferous treed swamp. In the fen there are a few scattered *Larix laricina* trees and some low shrubs (*Betula pumila, Andromeda polifolia, Salix pedicellaris*). The herb layer consists of *Muhlenbergia glomerata, Eleocharis quinqueflora, Carex diandra, Carex aquatilis*, and *Scirpus validus*. There are bladderworts (*Utricularia intermedia* and *Utricularia minor*) in the small pools, along with *Chara* sp. The moss layer has nearly continuous cover and consists of *Tomenthypnum nitens, Campylium stellatum, Drepanocladus revolvens*, and *Scorpidium scorpioides*, depending on the height of the water table.

The peat in this spring fen was cored and sampled. The mineral soil was reached at 224 cm, with the groundwater table observed at 5 cm below the surface. The surficial peat layer (0–35 cm) is composed of marl and moss remains, underlain by a thin (35–50 cm) layer of *Carex–Drepanocladus* fen peat (Figure 4–17). This is then underlain by a woody *Sphagnum fuscum* peat (50–177 cm), with a basal layer (177–224 cm) of humic marl peat containing wood fragments.

Chemical analyses of the peat (Table 4–14) reflect the high amounts of Ca, Mg, Na, and S found in the groundwater. Calcium levels are very high in the peat throughout the profile, with peaks in the marl layers at 10–35 cm and at 177–189 cm. The high levels of Ca and the high ash content even in the *Sphagnum* peat imply that the peat lying between the marl layers has been enriched by a downward migration of marl. The initially high levels of Na do not change substantially through the profile, indicating that Na is not accumulated in the peat. However, S displays a pattern of amounts increasing with depth.

The macrofossils in the cores from the spring fen and the coniferous treed swamp indicate an intricate development predicated by the presence of minerotrophic fen waters. The basal layers comprise well-decomposed materials that contain some woody plant remains, indicating a marshy condition with some shrubs (Figure 4–17). On the low-lying part of the wetland (the present spring fen), small pools developed where marl was deposited. However, the small pools were overwhelmed by bog conditions, indicated by *Sphagnum fuscum* peat, possibly as a result of a shift in the fen drainage system. As peat filled in the lower part of the wetland, the more elevated part (the present swamp) became wetter and small pools developed on it. Later, bog conditions were prevalent at both core sites, but minerotrophic spring water inundated the lower part of the wetland, initiating a highly minerotrophic fen which still prevails there. On the higher part of the wetland, bog conditions were maintained until recently, when the minerotrophic groundwater rose sufficiently to come within the reach of plant roots, allowing the initiation of minerotrophic swamp development.

Northern Ribbed Fens

This minerotrophic wetland form is characterized by the development of narrow (1–5 m wide), low (5–75 cm high) peaty ridges (also called "strings")

Figure 4–16.
A spring fen with shallow, marl-bottomed pools near Grand Rapids, Manitoba.

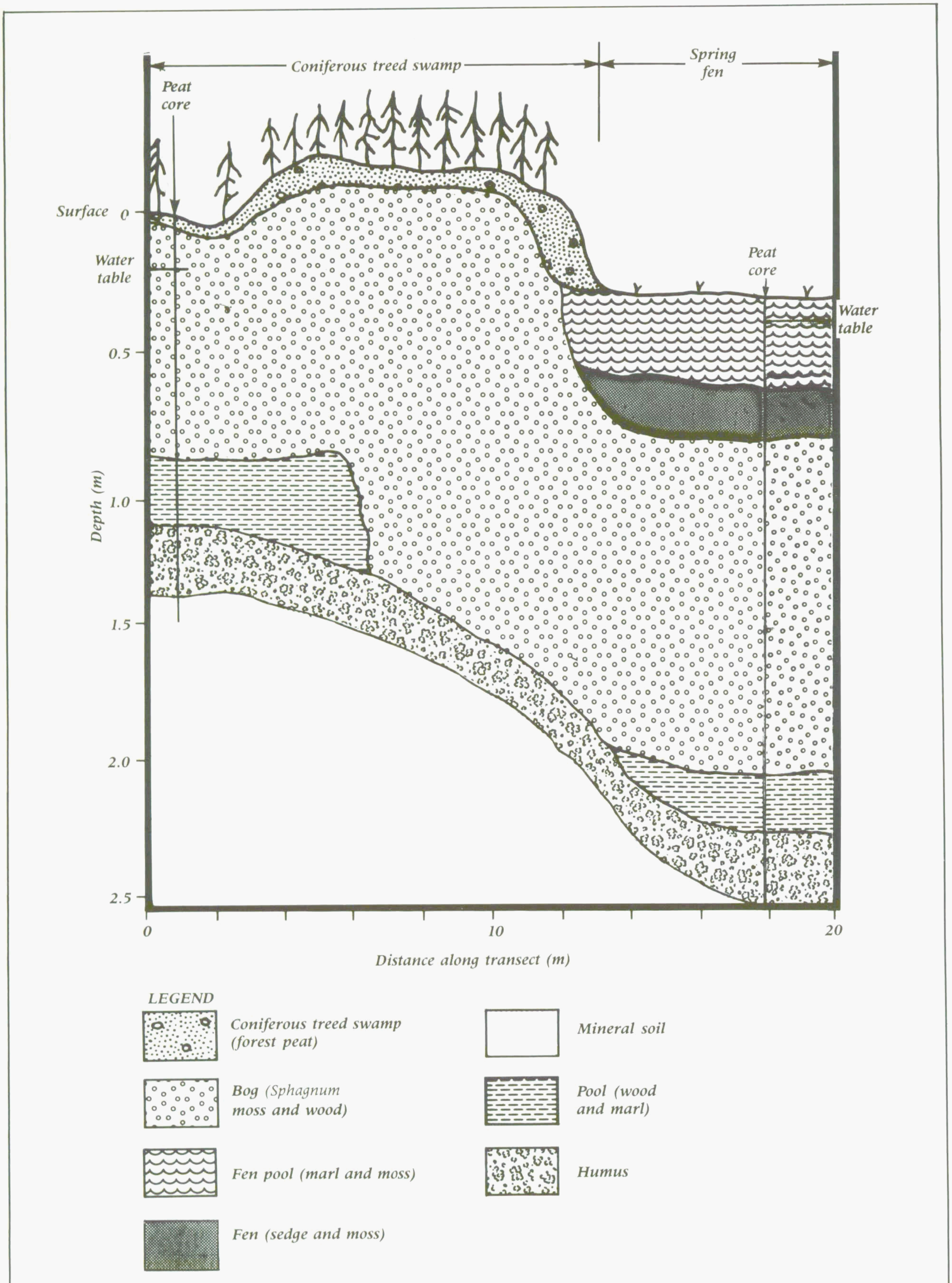


Figure 4–17.
Cross-section of a spring fen and adjacent coniferous treed swamp, indicating wetland environments during deposition, in the Wagner Bog, Spruce Grove, Alberta.

Table 4–14. Total elemental analysis and other properties of peat and groundwater from a spring fen, the "Wagner Bog", near Spruce Grove, Alberta

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg) Ca	Mg	Na	Fe	S
Peat									
0–3	6.2	*Drepanocladus–Bryum*	1	25.9	55 273	5 265	849	1 716	3 458
10–13	6.2	Marl–moss	—	45.3	141 540	4 472	462	1 814	4 913
25–28	6.2	Marl–moss	—	47.7	145 492	4 181	418	1 404	8 826
45–48	6.2	*Carex–Drepanocladus*	6	20.7	68 071	3 915	426	321	13 103
60–63	6.2	*Sphagnum*–wood	6	26.2	76 947	4 770	445	652	14 414
94–99	6.2	Wood–*Sphagnum*	6	33.4	113 352	4 860	402	1 116	17 833
110–115	6.2	*Sphagnum fuscum*–wood	4	23.7	76 979	5 042	491	590	14 764
135–140	6.2	*Sphagnum fuscum*–wood	4	24.0	76 451	5 637	588	3 828	21 471
150–155	6.5	*Sphagnum*–wood	6	31.0	107 474	4 864	701	4 053	23 880
168–173	6.4	Wood–*Sphagnum*	6	23.5	67 550	5 333	897	8 027	23 497
182–187	6.5	Marl–wood	6	50.2	118 096	4 757	948	10 362	25 431
200–205	6.5	Humic	10	88.8	27 746	5 566	583	15 333	9 248
225–230	6.5	Mineral	—	96.6	41 382	7 237	436	12 511	2 746
Groundwater									
5	6.2	—	—	—	137.1	37.8	33.7	0.1	84.8

oriented at right angles to the direction of water movement. These ridges may stretch across the fen in a smooth arc or in sinuous arcs that may divide and rejoin (Figure 4–18). Wet peaty depressions, called "flarks" by Andersson and Hesselman (1907), occur between the ridges. Northern ribbed fens have a slightly sloping surface (0.1–1.0% slope). The ridges act as dams by impeding surface water movement, resulting in increased wetness in the flarks on the upslope side. Careful levelling reveals that the consecutive flarks are some centimetres lower than the preceding ones; hence, there is a slight stepwise drop in the elevation of the surface from flark to flark. The magnitude of this drop in elevation varies with basin configuration, but it seldom exceeds 10 cm. It has been noted that the ridges are closer together on steeper gradients. On lower gradients they are not only farther apart, but they also tend to become more sinuous and branching. On fens with very slight gradients, the ridges tend to lose their orientation across the direction of drainage and become polygonal in outline, with equal lengths on all sides. Northern ribbed fens are distinguished from other

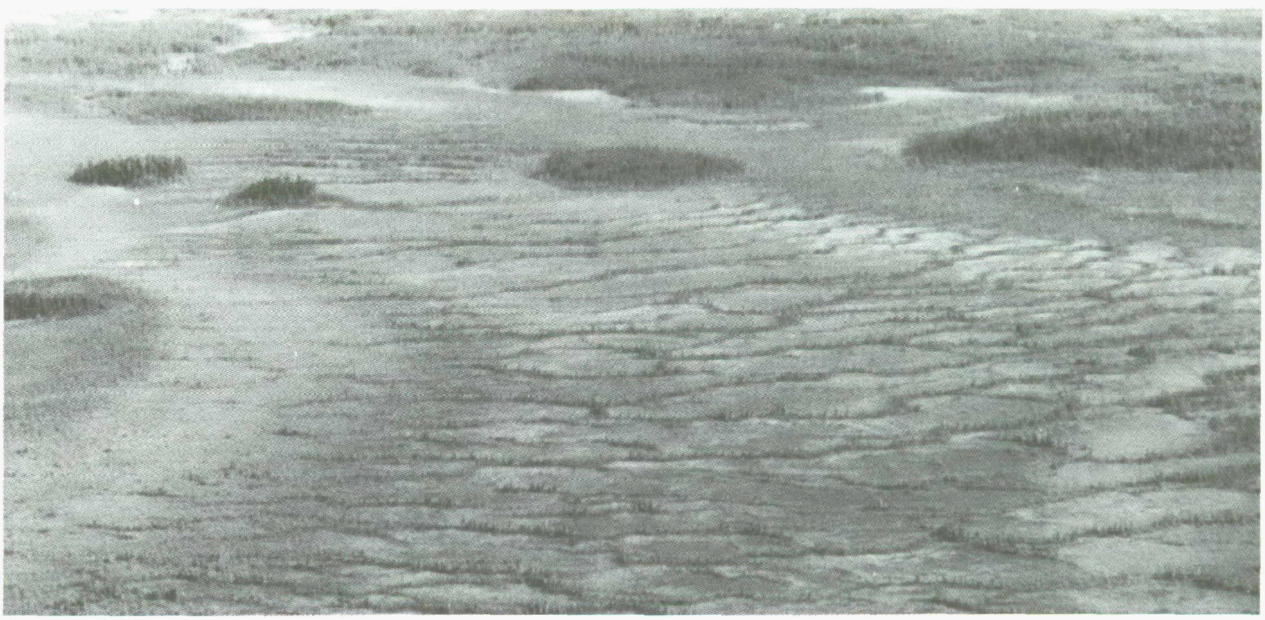


Figure 4–18.
A northern ribbed fen near Besnard Lake, Saskatchewan, with drainage towards the viewer.

patterned fens by the presence of sharply defined, narrow ridges separated by narrow flarks.

Northern ribbed fens are very common in the Mid-Boreal and High Boreal Wetland Regions, as well as in the Low Subarctic Wetland Region (SL). Some regional differences are evident, as both ridges and flarks tend to be narrower and the flarks wetter in the eastern portions of the boreal wetland regions than in the less humid western areas. The few northern ribbed fens in the Low Boreal Wetland Region tend to be diffuse, with poorly defined ridges.

The vegetation on flarks is distinctly different from that on ridges (Slack *et al.* 1980). The flarks are usually wet and are dominated by sedges and mosses, as the water is seldom deep enough to prevent the growth of these peat-forming plants. The dominant species are *Carex chordorrhiza*, *Carex lasiocarpa*, and *Carex limosa*, with *Menyanthes trifoliata*, *Utricularia intermedia*, and *Utricularia minor*. On particularly minerotrophic flarks, *Triglochin maritima* is present. The mosses generally consist of *Scorpidium scorpioides*, *Drepanocladus revolvens*, *Meesia triquetra*, and *Cinclidium stygium*.

The vegetation on the ridges depends on their height above the flarks and, hence, on their elevation above the water table. On the wettest ridges, shrub species dominate, among them *Betula pumila*, *Salix candida*, *Salix pedicellaris*, and *Andromeda polifolia* (*Andromeda glaucophylla* in the east). East of Manitoba, *Lonicera villosa* and *Rhamnus alnifolia* are usually present. A number of *Carex* species may be present, but *Carex diandra* is most characteristic. The moss layer consists of *Tomenthypnum nitens*, *Campylium stellatum*, and *Sphagnum warnstorfii*.

On somewhat higher and drier ridges, the vegetation is dominated by *Larix laricina* and *Betula pumila*. Other shrubs include *Ledum groenlandicum* and *Andromeda polifolia*. The mosses consist mainly of *Tomenthypnum nitens* and *Sphagnum warnstorfii*, with some cushions of *Sphagnum fuscum*.

On ridges where the surface is elevated 25 cm or more above the water table, *Picea mariana* is the dominant tree species, together with some *Larix laricina*. The trees may attain a height of 15 m. Shrubs, such as *Betula pumila*, *Ledum groenlandicum*, and *Chamaedaphne calyculata*, may be present. *Carex disperma* may grow among the mosses. The moss layer is almost continuous and consists of *Sphagnum fuscum*, *Sphagnum magellanicum*, *Pleurozium schreberi*, and *Dicranum undulatum*. Where the tree cover is less dense, lichens, such as *Cladina mitis* and *Cladina rangiferina*, may be present.

Under certain conditions, northern ribbed fens may contain plant species usually characteristic of bogs. In areas where the incoming water is acid and low in nutrients, some *Sphagnum* species, such as *Sphagnum jensenii*, may become abundant in the flarks, and *Picea mariana* may dominate the ridges with *Sphagnum fuscum* and *Sphagnum magellanicum* (Vitt *et al.* 1975). Such fens of low nutrient status have been described by Sjörs (1963) as "poor fens".

Northern ribbed fens are usually underlain by peat that is in excess of 1 m in thickness. In the flarks, the upper 30–40 cm consists of a mat of tough, fibrous roots and mosses, underlain by more decomposed sedge–moss peat. Occasionally the surface mat is "floating" on peat that has a very high water content (95–99% water by volume). This liquid layer, 1.0–1.5 m thick, is usually underlain by moderately decomposed peat. On the ridges, the surface peat is generally fibrous, underlain by more decomposed peat, but liquid layers are not encountered under the ridges. Under the highest and driest of ridges, late-thawing seasonal frost may persist into late summer. This frost is restricted to within 1 m of the surface, but it can further impede the movement of water through the fen.

Examination of peat stratigraphy in 62 different northern ribbed fens in central Canada has shown that the peat under the ridges was formed in drier conditions than that under the flarks. Thus, while the vegetation of the flark reflects open fen conditions at a certain depth, the vegetation under the ridge at the corresponding depth indicates shrub or treed fen conditions. This indicates that the position of both the flarks and ridges is stable, and that they do not move laterally. The initiation of the drier ridge conditions could happen at any time in the development of the fen. In some cases, peat macrofossils indicate that the ridge was initiated in the basal peat and has been maintained until the present. However, in most cases, the drier ridges were initiated about halfway through the peat development sequence and in few instances is ridge development evident only in the surface peat. Thus, while the ridges can be initiated at any time from the inception of a fen, once they have been initiated they seem to be stable, persistent features.

The origin of northern ribbed fens has been the subject of much speculation. The earliest observers noted their relation to frost (Svenonius 1904), attributing their formation to interaction between the movements of water and frozen ground. Auer (1920) suggested that they are formed by ice-thrusting. Schenk (1963) believed that they are formed by collapsing permafrost. Others suggested that solifluction, a slow mass movement downslope, may be a causative agent (Cajander 1913). Most research has focused on the importance of biological processes (Ruuhijärvi 1960). Foster *et al.* (1983) have attributed ridge and pool formation to different growth rates in plants, culminating in the cessation of peat development in the pools. Sjörs (1961) stressed the importance of water flow, in combination with different rates of peat accumulation in flarks and in ridges.

Lundqvist (1962) suggested that water running through a loose vegetation cover on a frozen substrate can form a festoon-like rib pattern. Thom (1972) observed the formation of "debris dams". Thom noted that sheet flow of meltwater over a still-frozen fen causes accumulations of organic debris at right angles to the path of water movement, forming a drier substrate for plant growth. A similar theory was advanced by Sakaguchi (1980), who noted that plant detritus, carried by floodwater, can accumulate in lines across the direction of drainage. Conditions leading to the formation of such lines are: (1) gently sloping surface; (2) availability of suitable elongated plant remains; (3) sheet flooding; and (4) presence of uniformly scattered obstacles on which the debris can be caught. Debris dams could provide the base on which vegetation of somewhat drier habitats can be established. Seppälä and Koutaniemi (1985) accepted this model for the initiation of ridges. In their view, subsequent development is due to peat accumulation on the ridges and peat degradation in the pools. Careful measurements have shown that frost action, ice expansion, and solifluction play only minor roles in the dynamics of ridge development. It should be noted that, in Canadian northern ribbed fens, flarks seldom have deep water that would prohibit the growth of peat-forming vegetation, and peat formation continues in the flarks at a slightly slower rate than on the ridges.

The foregoing illustrates that there is an abundance of theories. However, parameters that are common to all northern ribbed fens include:

(1) sloping surface with non-channelized water movement;
(2) peaty ridges at right angles to water movement;
(3) peaty ridges which are stable in space and time;
(4) differential peat development on ridges and flarks; and
(5) severe winter climate, but no permafrost.

In developing a scenario for the origin and maintenance of northern ribbed fens, all these and possibly other features must be accommodated. The model that fits all parameters should then be tested in the field by careful examination of a variety of ribbed fens, and in the laboratory by testing hydrological models.

A northern ribbed fen near Smith, Alberta (55°08′ N, 114°01′ W), has been investigated in some detail. This wetland is situated in a gently undulating morainal plain, where a depression is occupied by a small lake (about 500 ha), with a 65 ha northern ribbed fen at its northern end. The fen has a slight (less than 1%) slope towards the lake.

The vegetation in a flark at this site is that of an open fen, with only a few low and scattered *Salix pedicellaris* shrubs. The herb layer covers about 60% of the surface and is composed mainly of *Carex lasiocarpa*, *Carex diandra*, *Carex limosa*, *Menyanthes trifoliata*, and *Triglochin maritima*. The moss cover, continuous even in small, shallow pools, is composed almost entirely of *Scorpidium scorpioides*, with minor amounts of *Meesia triquetra*.

The ridges on this site have a 50% surface cover of tall (10–15 m high) *Picea mariana* and *Larix laricina* trees. There is a sparse cover of *Betula pumila* in the shrub layer. Herbs, covering about 60% of the surface, are composed mainly of *Carex interior*, *Carex leptalea*, *Carex lasiocarpa*, *Menyanthes trifoliata*, and *Equisetum fluviatile*. Mosses cover about 75% of the surface and are composed mainly of *Aulacomnium palustre* and *Tomenthypnum nitens*.

A transect was made in the central part of this northern ribbed fen at right angles across two flarks and an intervening ridge. The elevation of the flark upslope of the ridge is about 10 cm higher than that of the flark below the ridge (Figure 4–19). This represents a slope of 1.25% (1:80). The ridge is 10–15 cm above the level of the upslope flark.

A core was taken from the downslope flark and from the ridge. On the flark, the water table was

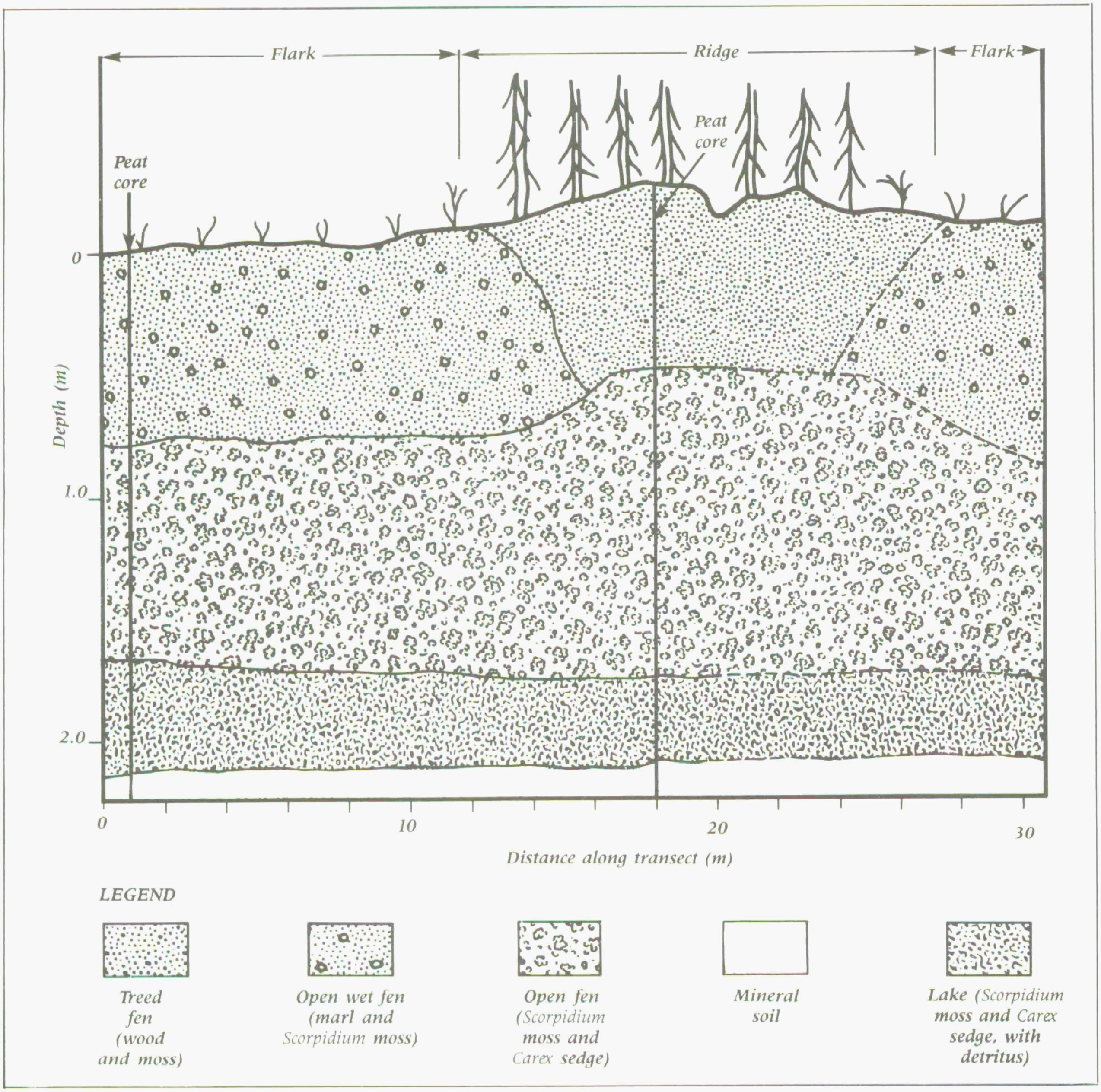


Figure 4–19.
Cross-section of a northern ribbed fen, indicating wetland environments during deposition, near Smith, Alberta.

observed at the surface, and there were a few pools of water 5–10 cm deep. The peat is 215 m deep, with the surface 15 cm consisting of marl and aquatic mollusc shells, with some fibrous *Scorpidium* moss peat. Similar material, but with mesic moss peat, extends to a depth of 78 cm. Underneath this is mesic *Scorpidium–Carex* peat (78–168 cm), underlain by a thin layer (168–187 cm) of similar peat that contains aquatic snail shells. The basal peat (187–215 cm) consists of an amorphous, humified material which may represent a detrital, lacustrine peat deposit.

On the ridge, the water table was observed at a depth of 18 cm, and the total peat depth is 238 cm. Beneath the living moss layer (0–8 cm), there is a humified layer of sylvic peat (8–76 cm), consisting of *Sphagnum* sp., shrub wood chips, *Larix* needles, and rootlets. Below this there is a layer of *Scorpidium–Carex* peat (76–203 cm), underlain by well-humified basal peat, possibly of aquatic origin (203–238 cm).

Chemical analyses of peat from the downslope flark (Table 4–15) indicate very high amounts of nutrients, especially Ca, in the surface marl peat. The Ca content is also fairly high in the rest of the peat, but becomes much lower in the mineral soil.

Table 4–15. ***Total elemental analysis and other properties of peat and water from the flark of a northern ribbed fen near Smith, Alberta***

Depth of sample (cm)	pH	Material	Decom-position (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–3	6.7	Marl–shells–*Scorpidium scorpioides*	—	39.0	130 218	3 257	14 533	2 219	412
18–21	6.5	Marl–shells–*Scorpidium scorpioides*	—	52.3	189 322	3 150	6 667	2 320	546
32–35	6.5	Marl–shells–*Scorpidium scorpioides*	—	45.8	162 730	2 246	6 792	2 222	413
45–50	6.5	Marl–shells–*Scorpidium scorpioides*	—	54.3	194 384	2 770	4 197	2 292	341
60–65	6.5	Marl–shells–*Scorpidium scorpioides*	—	35.8	128 558	1 874	5 331	2 154	570
80–85	6.5	*Scorpidium scorpioides–Carex*	6	20.6	70 953	1 758	5 656	2 113	491
100–105	6.4	*Scorpidium scorpioides*	5	12.2	28 992	1 445	4 179	1 641	437
115–120	6.4	*Scorpidium scorpioides*	5	10.1	29 719	1 896	5 491	2 250	369
140–145	6.5	*Scorpidium scorpioides–Carex*	5	10.4	30 605	2 126	6 005	3 873	420
170–175	6.5	Shells–*Carex–Scorpidium scorpioides*	6	12.0	37 341	2 199	5 671	4 875	420
190–195	6.4	Humic	8	19.2	35 438	3 081	8 029	8 729	697
205–210	6.4	Humic	10	30.0	39 331	3 241	8 124	8 349	736
217–222	6.4	Mineral	—	96.9	5 810	2 960	4 429	425	329
Water									
0	6.5	—	—	—	76.2	16.5	0.2	1.7	0.1

Similarly, the S content is much higher in the peat than in the mineral soil.

In the peat from the ridge, only the surface sample is somewhat low in nutrients; the nutrient content of all other samples resembles that of the flark (Table 4–16). The surface sample is low in Fe and S, but has higher levels of Ca and Mg than ombrotrophic peats, indicating that even the surface is affected by minerotrophic waters. The mineral composition of the water table at 18 cm in the ridge is indistinguishable from that of the water of the flark.

Two radiocarbon dates were obtained from the peat beneath the ridge in order to understand better the development of this wetland. One peat sample (BGS-788), from 32–38 cm within the forest peat, yielded an age of 700±130 yr, while the second sample (BGS-789), from 224–230 cm in the basal aquatic peat, indicated an age of 6 800±150 yr. This suggests a rate of peat accumulation of 5 cm/100 yr in the forest peat from 700 years ago to the present, and a rate of 3.1 cm/100 yr in the fen peat between 700 and 6 800 years BP.

Table 4–16. ***Total elemental analysis and other properties of peat and water from the ridge of a northern ribbed fen near Smith, Alberta***

Depth of sample (cm)	pH	Material	Decom-position (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–3	5.3	Moss–twigs–*Carex*	1	6.0	11 669	2 639	324	610	500
18–21	6.2	Moss–twigs–*Carex*	8	22.4	59 903	3 097	26 315	2 757	1 537
45–50	6.2	Moss–twigs–*Carex*	7	14.4	44 369	2 963	9 193	2 617	1 156
60–65	6.1	Moss–twigs–*Carex*	7	11.2	37 472	2 589	7 468	2 925	1 157
81–86	6.2	*Scorpidium scorpioides–Carex*	5	10.9	28 630	2 121	6 769	2 188	838
96–100	6.0	*Scorpidium scorpioides–Carex*	6	8.0	21 133	1 597	5 188	1 599	568
130–135	6.1	*Scorpidium scorpioides–Carex*	6	10.0	24 908	1 955	5 150	1 948	555
165–170	6.3	*Scorpidium scorpioides–Carex*	5	9.7	26 554	2 090	6 183	4 373	433
195–200	6.2	*Scorpidium scorpioides–Carex*	5	8.9	23 006	1 918	5 966	4 763	346
244–250	6.2	Mineral	—	97.9	4 742	3 024	3 895	283	298
Water									
18	6.2	—	—	—	90.0	19.0	0.2	2.1	0.2

Macrofossils suggest that the entire wetland originated within a lake (Figure 4–19). This changed to an open *Scorpidium–Carex* fen at both sampling sites. In time, the flark site became wetter, as shown by marl deposits, but the ridge site remained the same until a treed fen was established about 2 000 years BP. No change was detected in the conditions on either the flark or on the ridge during the time that has elapsed since the initiation of the ridge.

Feather Fens

This wetland form is located within a pattern of ombrotrophic and minerotrophic peatland elements. The feather fen is composed of long, low, narrow ridges with ombrotrophic bog conditions on the ridge tops. Frequent, narrow drainage-ways originate on the ridges, extending downslope. Here, minerotrophic conditions prevail (Grondin and Ouzilleau 1980). This pattern of bog and fen gives a feathery appearance to the wetland complex when viewed from the air: the ombrotrophic ridge top is the shaft of the feather, and the subparallel minerotrophic drainage-ways, separated by ombrotrophic patches, are the barbs of the feather (Figure 4–20). These wetlands are 0.75–2.25 km wide and up to 10 km long, separated by small creeks. Usually, several of them occur parallel to one another, forming a distinctive pattern.

The surface of a feather fen is convex, as it conforms to the slope of the underlying, usually clay-textured soil. The thickness of the peat is relatively uniform on the ombrotrophic ridges and in the minerotrophic drainage-ways, with an average thickness of 2 m. The pH value of the surface peat is almost 4 on the ombrotrophic areas and nearly 5 on the minerotrophic sites. Although feather fens bear some resemblance to the veneer bogs of the subarctic wetland regions (see Chapter 3), they do not contain permafrost and are, thus, fundamentally different.

Ombrotrophic bogs develop on the ridge tops above feather fens and may extend downslope in narrow patches. The vegetation is composed of bog species, dominated by shrubs such as *Chamaedaphne calyculata*, with stunted *Picea mariana* and ombrotrophic *Sphagnum* species. The vegetation is more diverse on the minerotrophic drainage-ways, dominated by a number of *Carex* species and *Sphagnum warnstorfii*. *Larix laricina* is also common. At the base of the slopes where the water is collected by small streams that run parallel to the ridges, a narrow zone of coniferous treed stream swamps develops, dominated by *Picea mariana*.

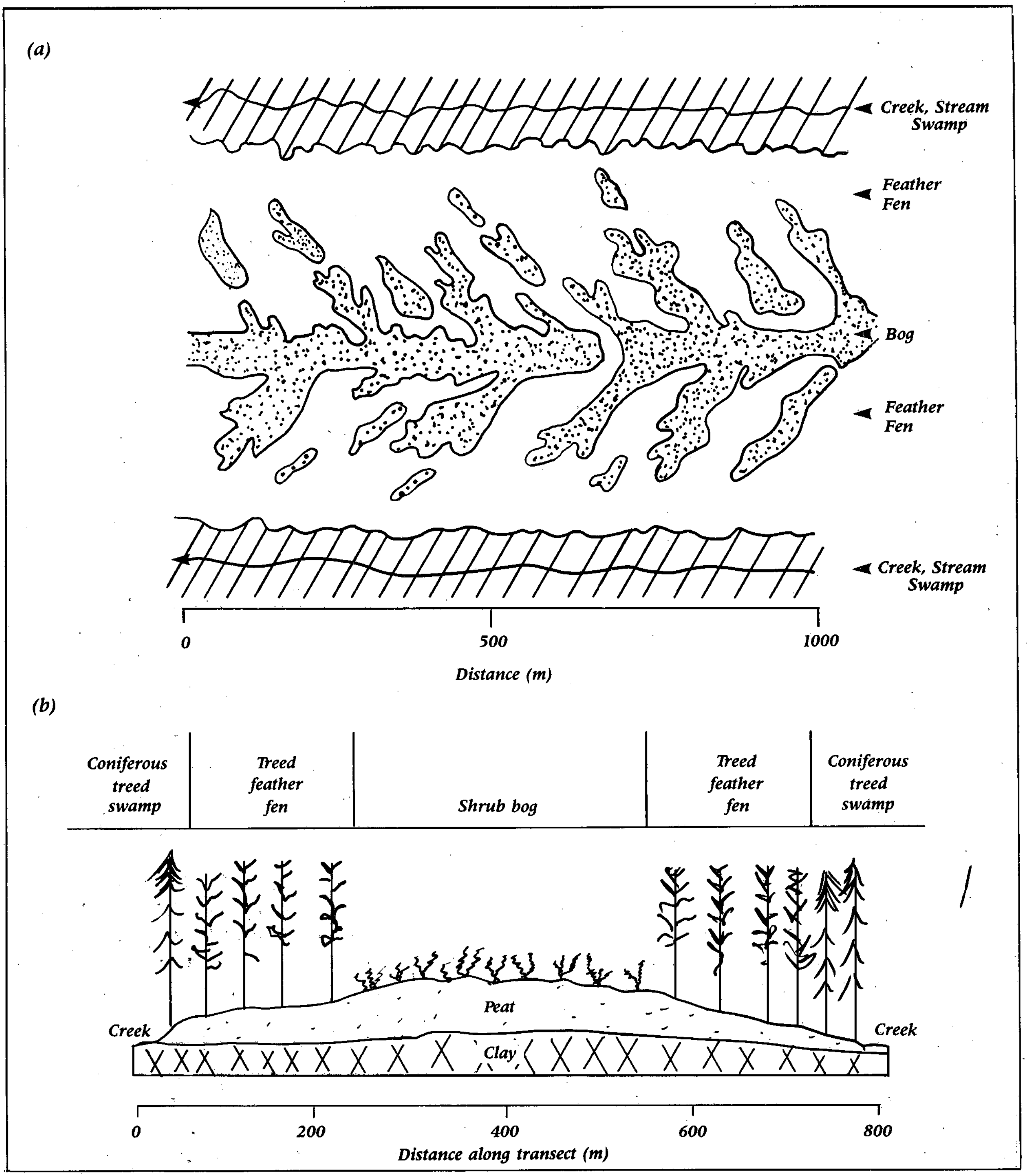
These fens occur in the southern James Bay area of Quebec (Grondin and Ouzilleau 1980). Here, the mineral-soil landscape consists of marine clays that slope gently towards the Bay. The clays are shallowly dissected by small, parallel streams, forming a base for the development of these striking feather fen wetlands.

Delta Marshes

Delta marshes may develop on inland deltas created by rivers discharging into large lakes. Some of these deltas are extensive (Figure 4–21), including: (1) the Slave River Delta in Great Slave Lake which covers 210 km^2 (English 1979); (2) the Peace–Athabasca Delta in Lake Athabasca which covers 3 775 km^2 (Bayrock and Root 1971); (3) the Saskatchewan River Delta in several infilled lake basins which covered approximately 9 300 km^2 before man-made flooding and drainage; (4) the Delta Marsh at the south end of Lake Manitoba which covers 1 500 km^2 (Walker 1965); and (5) the Netley Marsh on the Red River at Lake Winnipeg which covers approximately 200 km^2. In addition, there are numerous smaller deltas with marshes throughout the boreal wetland regions.

Delta environments are characterized by periodic inundations of variable severity and duration. These floods may occur annually in the active parts of the delta, but other portions may be flooded less frequently or rarely. Such floods and active river channels bring and distribute sediments, resulting in a maze of shallow lakes, oxbow lakes, cut-off channels, and levees. In the active parts of the delta, shallow open water and marsh wetlands can develop, while in the less frequently flooded, inactive parts, treed swamps may be found. In the inactive portions of the delta, shallow lakes may be filled in with peat, and fen and bog conditions may prevail (Dirschl 1972).

Vegetation occurrence on the Slave River Delta has been related to moisture conditions (English 1979). Under periodically flooded conditions, the prevalent vegetation is *Equisetum fluviatile*, with some *Carex rostrata*, *Carex aquatilis*, *Salix arbusculoides*, and *Salix glauca*. The underlying soil is fine-textured and alkaline (pH 8.2). In the less exposed wet areas, such as cut-off channels, small



Sources: Grondin and Ouzilleau (1980); Couillard and Grondin (1986).

Figure 4–20.
Diagrams of feather fens: (a) planar view; (b) cross section: ridges have shrubby bog vegetation, and drainage-ways have fen vegetation with tamarack, while stream swamps have black spruce vegetation.

Figure 4–21.
Aerial view of a delta marsh with willow swamps on abandoned levees near The Pas, Manitoba.

shoals, and protected littoral areas, sedges are dominant, with *Carex aquatilis* and *Carex rostrata* being the main species. Other vegetation includes *Equisetum fluviatile*, *Typha latifolia*, and *Salix interior*. In interlevee depressions where the depth to water table averages 5–10 cm, *Salix glauca*, *Salix arbusculoides*, and *Salix interior* may occur in delta marshes with *Equisetum fluviatile*, *Beckmannia syzigachne*, and *Calamagrostis canadensis*. The substrate is wet silt, with a pH value of 8.

In the Peace–Athabasca Delta, marshes, called "deep marshes" by Fuller and La Roi (1971), are characterized by *Scirpus validus*, *Eleocharis palustris*, *Glyceria grandis*, and *Typha latifolia*. In the marshes covered with shallow water, called "shallow marshes" by Fuller and La Roi (1971), the sedge *Carex atherodes* forms extensive stands, often intermixed with *Scolochloa festucacea*, *Beckmannia syzigachne*, *Glyceria grandis*, *Calamagrostis canadensis*, and *Carex aquatilis*. In areas where standing water does not persist, the vegetation is dominated by bluejoint (*Calamagrostis canadensis*), with minor amounts of *Polygonum amphibium* and *Mentha arvensis* (Raup 1935). In slightly drier areas, willow shrubs (*Salix planifolia*) invade these bluejoint grass meadows.

In southern deltas, the common reed grass, *Phragmites australis*, covers as much as one-third of the marsh area (Walker 1965), growing to a height of 4 m in water that may be up to 45 cm deep (Bird 1961). Shallow marshes are dominated by whitetop (*Scolochloa festucacea*), with lesser occurrence of *Carex atherodes*. Shallow water pools are dominated by *Potamogeton pectinatus*. *Typha latifolia* and its hybrid forms grow in damp ground and shallow water, aggressively colonizing drawdown sites (Shay and Shay 1986).

A fairly detailed investigation has been carried out for a delta marsh on the Saskatchewan River Delta near the Saskatchewan–Manitoba boundary (53°14′ N, 101°50′ W), on a part of the Delta that seldom receives floodwaters. The vegetation consists of *Carex* meadows with scattered willow (*Salix* spp.) shrubs. The tall shrubs are *Salix petiolaris* and the low shrubs are *Salix planifolia* and *Salix pedicellaris*. The herb layer is dominated by *Carex lacustris* and *Carex aquatilis*, with some *Equisetum fluviatile* and *Galium trifidum*. *Drepanocladus aduncus* forms a patchy moss layer.

The surface 32 cm of this delta marsh consists of a fibrous peat, composed mainly of *Carex* remains, underlain by a mesic peat containing thin alluvial soil layers. A clay-textured mineral soil is reached at 60 cm. Chemical analyses indicate that the peat material is moderately high in nutrients (Table 4–17).

Table 4–17. ***Total elemental analysis and other properties of peat and water from a delta marsh on the Saskatchewan River Delta***

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg)				
					Ca	Mg	Fe	S	P
Peat									
0–3	5.4	*Carex*	2	14.8	13 299	2 597	5 353	3 072	2 140
10–14	5.4	*Carex–Menyanthes*	4	14.3	13 824	2 151	4 420	3 554	1 488
32–36	5.4	*Carex–Menyanthes*	4	34.3	11 048	3 294	8 904	5 580	963
45–50	5.8	*Carex–Menyanthes*	4	22.6	17 682	2 792	14 594	5 452	1 109
60–65	5.8	Mineral	—	93.6	4 978	4 758	14 858	544	594
Water									
1	5.4	—	—	—	20.6	5.5	1.1	2.6	0.6

Shore Marshes

Shore marshes occur in basins on the margins of lakes or ponds. Boreal shore marshes can be classified on the basis of vegetation and environmental characteristics. In order to allow comparisons with other studies, four subform names for shore marshes are used in this chapter: deep shore marsh, shallow shore marsh, meadow marsh, and floating marsh–fen transition. The deep shore marsh is also discussed here in terms of deeper and shallower phases which vary seasonally.

Examination of shore marshes in northeastern Ontario has shown that all have a high concentration of available nutrients and mineral material relative to other wetlands. In some shore marshes, peat is mixed with mineral soil as a result of allochthonous input of mineral soil during high-water stages. The descriptions presented here are based on transects sampled at the south end of Nighthawk Lake near Timmins, Ontario (48°06′ N, 80°59′ W), and are generalized in Figure 4–22. Peat and water chemistry data from these various sites are presented in Table 4–18.

The deep shore marsh subform is characterized by patches of tall, widely spaced graminoids growing in standing water. *Scirpus lacustris* is the main emergent species in areas where summer water depths are usually in excess of 1 m. In shallower spots, the most common emergents tend to be *Typha latifolia, Eleocharis palustris, Zizania aquatica,* and *Phragmites australis.* A mixture of floating and submerged macrophytes may also occur, including *Myriophyllum spicatum* and several species of *Nuphar, Nymphaea, Polygonum,* and *Potamogeton.* Deep shore marshes represent a transition between open water and shallow shore marsh conditions.

A shallower phase of deep shore marshes is found in areas that can sometimes be flooded by water in excess of 1 m, but where by late summer the water level is near or within 20 cm of the soil surface. Vegetation here generally consists of dense stands of tall emergents. Deep shore marshes often contain open channels of water, sometimes caused by beaver or duck activities.

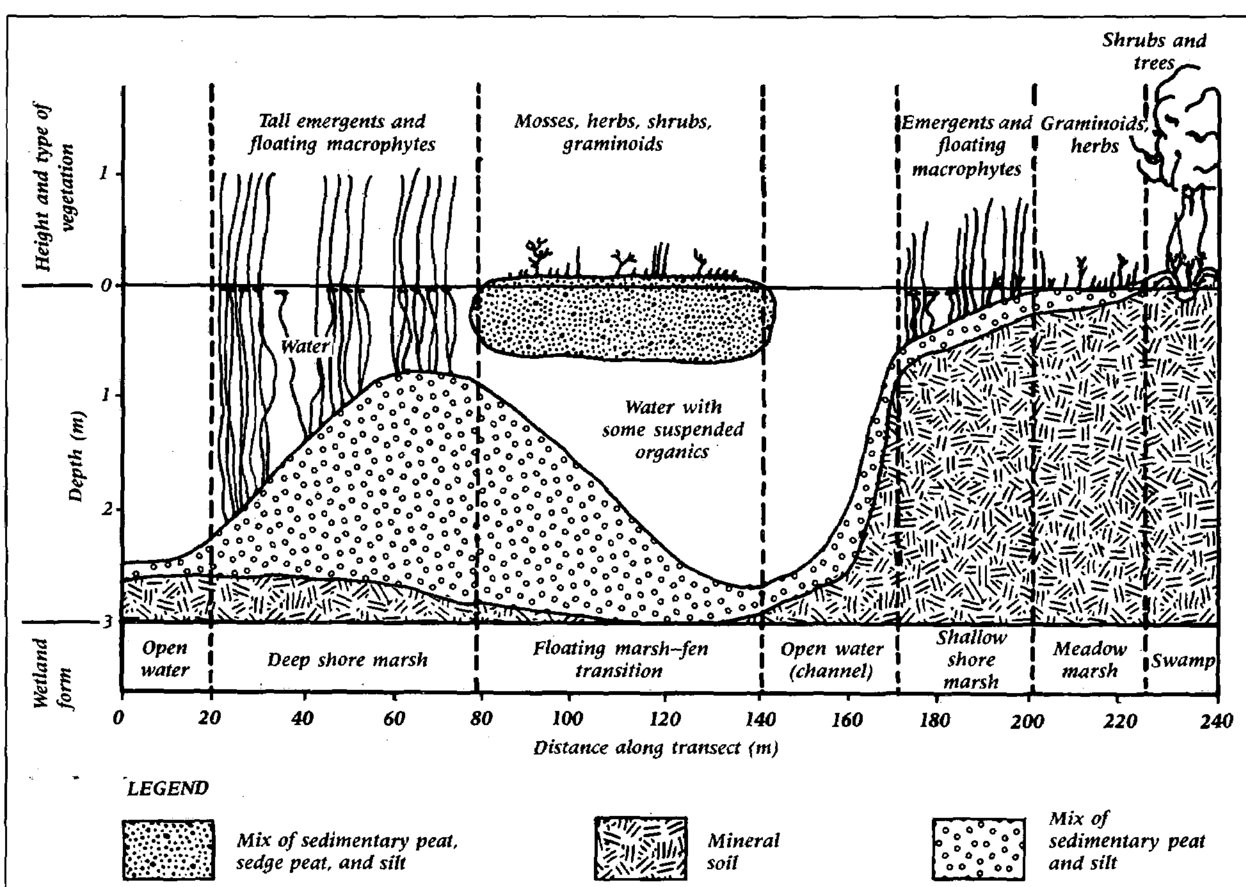


Figure 4–22.
A transect through a marsh complex showing different vegetation communities and peat stratigraphy.

The vegetation in shallow shore marshes is usually richer than that in deep shore marshes but generally contains the same species, except that *Scirpus lacustris* is absent. A number of other tall emergents also occur, including *Glyceria borealis, Equisetum fluviatile, Scirpus microcarpus, Dulichium arundinaceum,* and *Sparganium chlorocarpum.* In addition, the herb layer often includes *Pontederia cordata, Calla palustris, Caltha palustris,* and *Utricularia* spp.

Successionally, the shallow shore marsh is a transition from deep shore marsh to meadow marsh. It may develop on some shallow water sites without a previous deep shore marsh stage. *Typha latifolia, Phragmites australis,* and *Scirpus* spp. often dominate such areas.

As a shore marsh continues to be filled in, it eventually reaches the meadow marsh stage, where no standing water exists during the dry season. Meadow marshes are dominated by graminoid species, but many herbaceous species may be found as well. In addition, patches of shrubs (especially *Salix* spp.), some mosses that can tolerate some degree of seasonal flooding such as *Drepanocladus aduncus,* and other mosses typical of fens may occur. Occasionally, scattered *Larix laricina* trees may attempt to grow on such sites.

The most common graminoid species include *Calamagrostis canadensis, Scirpus cyperinus, Carex aquatilis, Carex lacustris, Carex pseudo-cyperus, Carex rostrata, Carex stricta, Carex vesicaria,* and *Iris versicolor.* Herbs often found in meadow marshes include *Cicuta bulbifera, Hypericum virginicum, Lycopus uniflorus, Lysimachia terrestris, Potentilla palustris, Potentilla norvegica,* and *Sium suave.* Also, *Myrica gale, Salix* spp., and *Spiraea alba* are shrubs often found in these wetlands. Mosses, which can sometimes be found among graminoids and dead material from the previous year, include *Drepanocladus aduncus.*

Mats of floating vegetation often develop in deep and shallow shore marshes. It appears that the degree of minerotrophy in these sites is determined, to some extent, by the thickness of the mat, by the amount of mineral material in the water, and, most importantly, by the degree to which the mat floats at high-water levels. If sediment-rich floodwater is able to wash over these sites at high water, then they will take on the characteristics of a minerotrophic marsh. *Typha latifolia, Sium suave,* and *Galium* spp. may form most of the vegetation. Conversely, the mat may rise during high-water stages. If the vegetation mat is thick, conditions will be less minerotrophic and the site will be best defined as the "floating fen" wetland form. Species indicative of this transition towards fen conditions include *Carex lasiocarpa, Carex chordorrhiza, Menyanthes trifoliata,* and *Sphagnum* spp.

Table 4–18 indicates some of the changes in peat chemistry that occur in the progression from a shallow shore marsh to a less minerotrophic meadow marsh, and then to a floating marsh–fen transition, as found at Nighthawk Lake near Timmins, Ontario. The ash content of the peat decreases from 45 to 24% across this sequence. Ash values from 25 to 75% represent carbon-rich mineral soils, rather than peat. In the marsh–fen transition, the substrate is peat, but in the shallow

***Table 4–18.* Total elemental analysis of peat and water from wetland subforms in a shore marsh on Nighthawk Lake near Timmins, Ontario**

Wetland subform	Sample depth (cm)	Ash (%)	pH	Total N (%)	Total exchangeable bases (me/100 g)	Total elements (mg/kg) Ca	Mg	Mn	Fe	P	K	Al	Conductivity (mS/cm)
Peat or soil													
Shallow shore marsh	10–20	45	6.3	1.51	31.8	6 780	3 530	180	12 300	870	8 630	—	—
Meadow marsh	10–20	39	6.1	1.66	22.1	5 900	3 090	90	9 330	950	6 910	—	—
Floating marsh–fen transition	10–20	24	6.1	2.10	29.8	6 080	1 200	30	4 510	920	3 870	—	—
Floating marsh–fen transition	250–350	23	6.3	2.27	63.7	15 020	2 260	120	9 080	880	4 740	—	—
Water													
Shallow shore marsh	—	—	7.0	—	—	16.4	—	—	0.25	—	—	0.04	0.095
Meadow marsh	—	—	6.8	—	—	15.1	—	—	0.24	—	—	0.03	0.097
Floating marsh–fen transition	—	—	5.6	—	—	9.0	—	—	0.46	—	—	0.02	0.083

shore marsh the 45% ash content is too high to qualify as peat. Total nitrogen also increases across the sequence, probably due to an increase in partially decomposed plant material. Although amounts of P and Ca are similar in all three wetland sites, quantities of K, Mn, Fe, and Mg are from two to several times higher in the shallow shore marsh than in the floating marsh–fen transition. In the meadow marsh, values are consistently intermediate between those for the other two. This possibly reflects a decrease in mineral enrichment of the soil. Calcium is an exception because it dissipates through aquatic systems more readily than the other elements because of its high exchangeability.

There is little difference between the three sites in the pH values of the peat. The acidity of the water, however, increases from the shallow shore marsh to the floating marsh–fen transition. Calcium levels in the water samples also decrease from the shallow shore marsh to the floating marsh–fen transition, whereas levels of Fe increase in the water of the floating marsh–fen transition. The conductivity values of the water drop slightly across the sequence. Generally, the chemical data support a trend towards less mineral input and more organic deposition in the sequence from a shallow shore marsh to a floating marsh–fen transition.

Floodplain Swamps

Floodplain swamps dominated by black ash (*Fraxinus nigra*) occur in the Low Boreal Wetland Region, but not in more northerly areas. They develop in areas that are subject to annual inundation by the slowly moving floodwaters of small streams. Both their internal and external drainage are slow on nearly level floodplains, creating wetland conditions. The small streams are a rich source of nutrients but they contribute only minimal amounts of sediment to these wetlands. As these sites are not subject to excessive mineral-soil deposition, their associated vegetation is not changed by the annual floods. Floodplain swamps can also be found in a narrow belt on the margins of larger wetlands, where minerotrophic waters reaching the wetlands create swamp conditions.

These swamps are characterized by luxuriant vegetation, with a great variety of tree, shrub, herb, and moss components. Peat deposition may occur, but it seldom exceeds 2 m. The peat consists of well-decomposed forest remains derived from treed swamps. The mineral-soil content of the peat is high, and, in some cases, distinct thin layers of mineral soil can be observed.

Floodplain swamps are characterized by profuse growth of a great variety of plant species. The upper story is dominated by *Fraxinus nigra* that can reach a height of 30 m and a diameter of 45 cm at breast height. Scattered *Betula papyrifera*, *Ulmus americana*, *Picea glauca*, and *Abies balsamifera* may be present. The shrub layer consists of tree regeneration and such species as *Sambucus racemosa*, *Prunus virginiana*, *Acer spicatum*, *Ribes americanum*, *Ribes glandulosum*, *Alnus rugosa*, and *Cornus stolonifera*. Ferns form a conspicuous part of the herb layer, with *Athyrium filix-femina*, *Onoclea sensibilis*, *Matteuccia struthiopteris*, and *Dryopteris cristata* (Figure 4–23). This herb layer is rich in species, with 20–30 different species commonly present. The main constituents are *Impatiens capensis*, *Galium triflorum*, *Rubus pubescens*, *Trillium cernuum*, *Caltha palustris*, and *Urtica gracilis*. Among the mosses, *Climacium dendroides*, *Plagiomnium cuspidatum*, and *Pylasiella polyantha* are the most numerous, the latter two species most often found around the base of trees and on rotting wood.

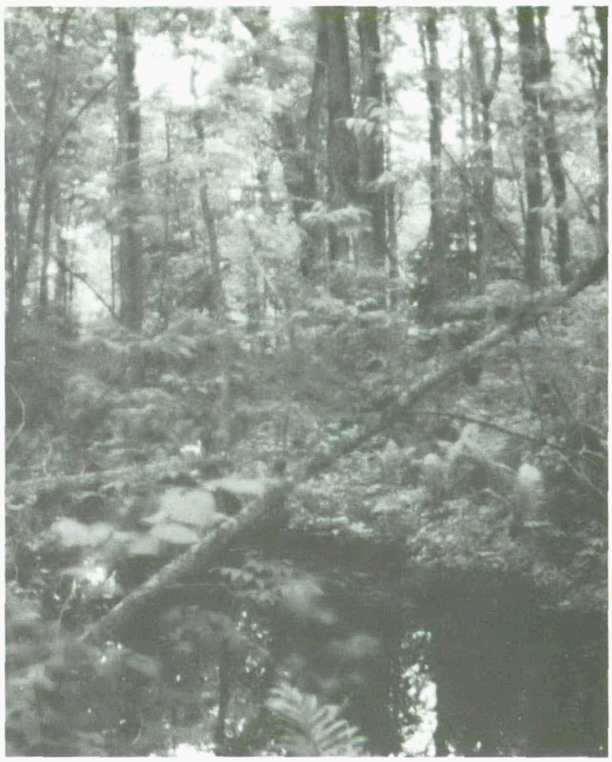


Figure 4–23.
Interior of a treed stream swamp with black ash and luxuriant ground vegetation.

A floodplain swamp near Manigotagan, Manitoba (51°04′ N, 96°17′ W), east of Lake Winnipeg, has been investigated in some detail. The tree cover consists of tall (23–30 m) *Fraxinus nigra*, with some *Picea glauca*. The shrub layer on this site is dominated by *Alnus rugosa*, *Cornus stolonifera*, and *Ribes glandulosum*. There are 31 species of vascular plants in the herb layer, dominated by *Impatiens capensis*, *Circaea alpina*, *Carex projecta*, *Schizachne purpurascens*, *Cinna latifolia*, *Bromus canadensis*, *Onoclea sensibilis*, and *Dryopteris cristata*. Mosses cover about 10% of the ground, the most common species being *Climacium dendroides*, *Plagiomnium ellipticum*, and *Plagiomnium cuspidatum*.

The peat at this site was cored for analysis. The depth of peat is 114 cm, with the water table observed at 4 cm. The top 7 cm consists of a fibrous root mat, underlain by well-decomposed forest peat containing wood fragments. Analyses of the peat (Table 4–19) show that the ash content is high, as would be expected in a well-decomposed, humic organic material. The levels of all nutrients are high, including S, P, and K. Such high levels of nutrients are reflected in the observed luxuriant plant growth.

Regional Wetland Development

Nutrient Status

The relationship between nutrient levels and the development of different kinds of wetlands has been well established in international literature (Sjörs 1950). Numerous studies of the chemical properties of water in the wetlands in relation to wetland development in the boreal wetland regions have confirmed the results obtained elsewhere. Analyses of groundwater (Table 4–20) show that the waters in fens are generally circumneutral to slightly alkaline, the specific conductivity is above 0.12 mS/cm, the Ca content is above 5 mg/kg, and the Mg content is above 2 mg/kg. In bogs of the boreal wetland regions, these values are much lower (Table 4–20). The very low nutrient levels found in poor fens, well below the levels in minerotrophic fens, are within the range found in bogs.

There is a comparable difference in the chemical properties of peat in various kinds of wetlands. Jeglum (1971) found that the pH values of moist peat reflect five fertility classes: very oligotrophic

Table 4–19. Total elemental analysis of peat and water from a stream swamp near Manigotagan, Manitoba

Depth of sample (cm)	pH	Material	Decomposition (von Post)	Ash (%)	Total elements (mg/kg) Ca	Mg	K	Fe	S	P	Conductivity (mS/cm)
Peat											
0–3	5.0	Roots–wood	2	13.1	15 532	4 429	353	5 267	4 965	1 093	—
15–18	5.0	Humus–wood	7	26.6	8 652	4 739	1 355	7 126	2 220	1 403	—
30–35	5.0	Humus–wood	7	17.7	12 704	4 273	685	5 203	5 296	957	—
45–50	5.2	Humus–wood	7	21.5	14 772	5 230	1 069	7 650	6 621	688	—
75–80	5.6	Humus–wood	7	27.8	13 914	5 211	1 439	7 922	6 683	928	—
98–103	6.4	Humus–wood	7	37.4	15 822	5 935	2 252	12 029	5 985	921	—
105–110	6.4	Humus–wood	7	54.7	13 565	6 558	2 958	14 603	4 810	989	—
123–137	6.5	Mineral	—	95.5	4 886	9 517	6 860	25 562	644	549	—
Water											
4	5.0	—	—	—	24.3	14.7	1.5	5.9	5.1	0.5	0.149

Table 4–20. Chemical properties of water from selected boreal wetlands

Chemical analysis	Rich fen (Slack et al. 1980)	Shrub fen (Dirschl 1972)	Fen (Mills et al. 1977)	Poor fen (Vitt et al. 1975)	Domed bog (Mills et al. 1977)	Ombrotrophic bog (Vitt and Bayley 1984)
pH	6.8–7.9	6.0	6.9–8.1	5.0	4.1–4.8	4.5
Conductivity (mS/cm)	0.140–0.456	0.183–0.455	0.2–0.6	—	0.0–0.1	0.025
Ca (mg/kg)	18–37	10–50	32–52	2.4	1.6–4.0	1.0
Mg (mg/kg)	4–18	2–19	4–16	0.4	0.6–1.1	0.4

Table 4–21. Chemistry of surface and middle tier peat materials in selected boreal wetlands

Wetland class and source of data	*No. of cases*	*Peat tier*	*pH*	*Ca* Total (mg/kg)	*Ca* Exchangeable (me/100 g)	*Mg* Total (mg/kg)	*Mg* Exchangeable (me/100 g)
Bog							
Zoltai and Johnson (in press)	320	Top 50 cm	4.3	2 664	—	998	—
Mills *et al.* (1977)	4	Surface	3.3	—	13.7	—	14.3
Zarnovican and Bélair (1979)	—	Middle	3.4	—	11.2	—	4.2
Gauthier (1980)	76	Surface	3.9	—	10.2	—	2.4
Nutrient-poor fen							
Zoltai and Johnson (in press)	58	Top 50 cm	4.6	3 465	—	908	—
Zoltai and Johnson (in press)	58	Top 50 cm	4.9	7 301	—	1 892	—
Zarnovican and Bélair (1979)	—	Middle	4.5	—	29.9	—	6.0
Gauthier (1980)	215	Surface	4.5	—	21.5	—	2.4
Nutrient-rich fen							
Zoltai and Johnson (in press)	539	Top 50 cm	5.7	19 779	—	3 599	—
Zoltai and Johnson (in press)	76	Top 50 cm	6.6	48 737	—	3 677	—
Zarnovican and Bélair (1979)	—	Middle	5.2	—	90.6	—	16.1
Mills *et al.* (1977)	6	Surface	6.6	—	96.2	—	28.4
Coniferous treed swamp							
Zoltai and Johnson (in press)	147	Top 50 cm	5.2	21 200	—	3 357	—
Smith *et al.* (1975)	5	Surface	6.4	—	112.4	—	28.6

(pH 3–3.9), oligotrophic (pH 4–4.9), mesotrophic (pH 5–5.9), eutrophic (pH 6–6.9), and very eutrophic (pH greater than 7).

Analyses of surface peat show that bogs have uniformly low amounts of Ca and Mg, but fens can have a wide range of these nutrients. Similarly, bogs have much lower levels of available Ca in the surface horizons than those in minerotrophic wetlands (Table 4–21).

In northern Ontario, bogs, whether treed, shrubby, or graminoid, are restricted to areas where the pH value of the groundwater is less than 4.4 and levels of Ca are below 2 mg/kg (Jeglum and Cowell 1982). The waters of fens, marshes, and swamps have a range of pH values from 5 to 6.5 and a Ca content of more than 4 mg/kg. The type of wetland is influenced both by the quality of the groundwater and by the depth of the water table.

In the James Bay region of Quebec, the pH value of peat from an intermediate depth served as the basis for a fertility classification (Zarnovican and Bélair 1979). Values of pH below 3.9 were associated with oligotrophic vegetation, pH values of 4–4.9 with mesotrophic vegetation, and pH values over 5 with eutrophic vegetation. The peat in oligotrophic vegetation contained the least amounts of available Ca (less than 17 me/100 g) and the eutrophic vegetation had the highest amounts (79 me/100 g), while the peat in mesotrophic vegetation units had levels of Ca between 18 and 25 me/100 g.

These studies suggest that, while a good relationship exists between vegetation and the nutrient levels (and pH) of peat and water, exact limits to trophic levels would be difficult to establish. It is possible that the development of vegetation indicative of various trophic levels is influenced by several other factors (such as water level, dissolved oxygen content, and degree of decomposition), compensating for the nutrient levels.

Regional Wetland Dynamics

Wetlands are dynamic ecosystems in which each component is subject to change, thereby inducing changes in the other components in order to adjust to the new conditions. The concept of wetland regions (National Wetlands Working Group 1986) allowed the establishment of the broad macroframework within which the local environmental wetland components exist. Water quality and quantity, soil (peat), surface form, flora, and fauna are the main constituents of the environment. Should any of these components change, a chain reaction (be it large or subtle) may occur throughout the wetland to accommodate the changed conditions. In wetlands, such changes may be generated by the wetland itself (such as peat accumulation) and are part of the "natural evolution" of the wetland, with changes occurring as the system becomes more mature. Changes may be induced by accidental occurrences, by changes in the landscape, or by anthropogenic means that affect the wetland. Repeated wildfires or catastrophic drainage events may be accidental occurrences, while landscape changes may entail coastal uplift, shifts in drainage channels, or the creation of natural barriers to drainage. Anthropogenic changes are numerous and are increasing in impact; competing land uses, drainage or damming projects, acid precipitation, and fertilizer use fall into this category. Wetlands react to these changes through a process of "induced" or "reactive evolution" in order to cope with or take advantage of the altered environment.

In the boreal wetland regions, the general tendency of wetland development (natural evolution) is towards the establishment of treed bogs. This can take several pathways, depending on the initial starting point. The following model is based on macrofossil analyses of many wetlands in the boreal wetland regions (Figure 4–24).

come established where the upland slopes reach the wetland. Small islands of treed fen may become established on the main fen (Figure 4–25d), particularly in the lee of obstructions where less of the minerotrophic water influence in the fen is received. Subsequently, ombrotrophic conditions may develop on part of the fen (Figure 4–25e), which may then spread to cover most of the wetland. Minerotrophic waters that enter the depression may continue to be drained by fen channels, but bog surfaces are raised above this level (Figure 4–25f). In areas of high rainfall, peat accumulation may proceed to such an extent that the bog surface is raised far above the original fen level.

The above scenario may take thousands of years to develop. In some areas environmental parameters may not permit it to proceed beyond an early marsh and open water stage. Other sequences

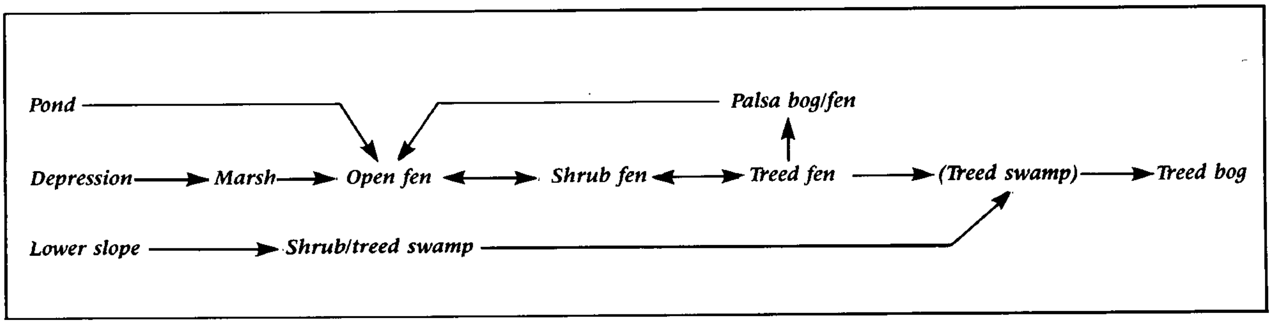


Figure 4–24.
Diagram of wetland developmental trends in boreal wetland regions.

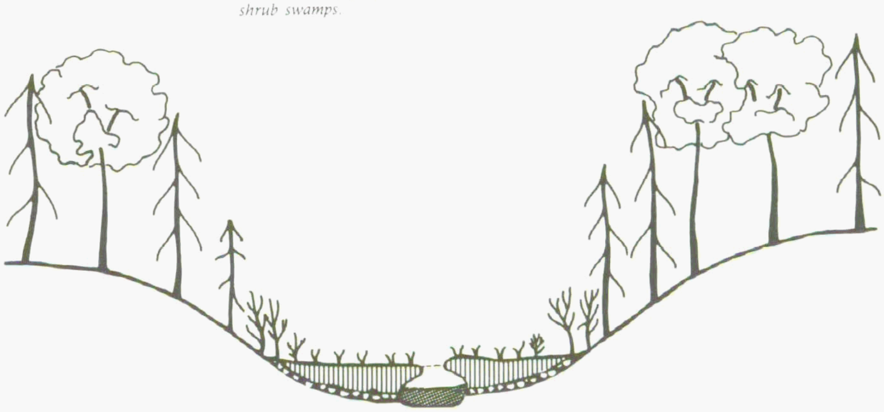
In the boreal areas of Canada, wetlands are initiated in depressional sites which receive water from external sources and which have poor internal and external drainage. Such depressions initially contain a wet meadow–marsh phase, ringed by a shrub–treed swamp (Figure 4–25a). As peat accumulates, open graminoid-dominated fen conditions prevail in the central part of the depressions. Peat accumulation is accompanied by a rise in the water table, and the fen extends into the former swamp fringe. Concurrently, the swamp extends farther up the slope as paludification proceeds (Figure 4–25b). This process continues, increasing the depth of peat. Small ponds gradually become covered by a fen mat (Figure 4–25c). Ultimately, the entire depression becomes covered by a fen, open at the centre and with shrubs near the margins. If the fen has a sufficient slope, patterns of ridges and flarks can develop on the surface. Shrub or coniferous treed swamps may be-

may be arrested at a more advanced stage by any one of several environmental conditions. Thus, a wetland may develop to a fen, but bogs often cannot develop on them because of environmental conditions such as the high nutrient content of groundwater, the abundance of groundwater, or low amounts of precipitation. In another example, the bog stage may be reached relatively quickly as a result of large amounts of precipitation or low mineral content in the groundwater and the bog may reach a domed convex form. The present conditions merely reflect a narrow slice of time in a long and natural evolutionary process. Some wetlands may take a very long time, if ever, to reach an "ultimate" developmental stage. Nevertheless, the developmental sequence shown in Figure 4–25 includes the extra dimension of time.

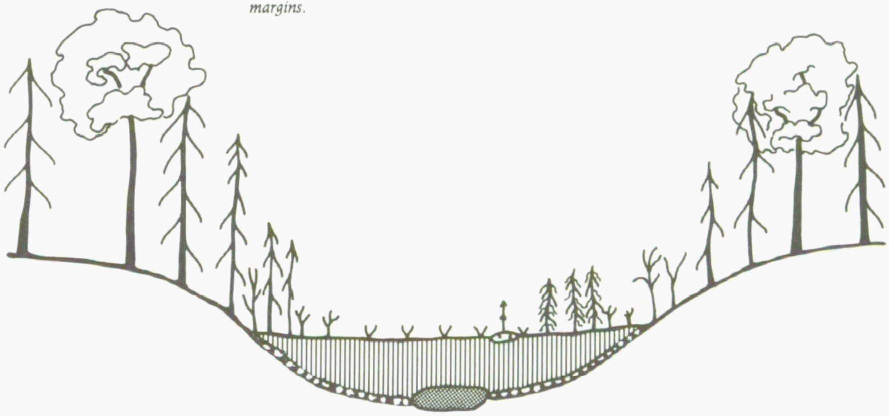
Because wetlands are dynamic in nature, it is to be expected that, at the present time, some wetlands are in a transitional stage from one class of wetland to another. There are wetlands that are neither "pure" fens nor bogs. Such transitions

A. *Initial stage: small pool, marsh, and marginal shrub swamps.*

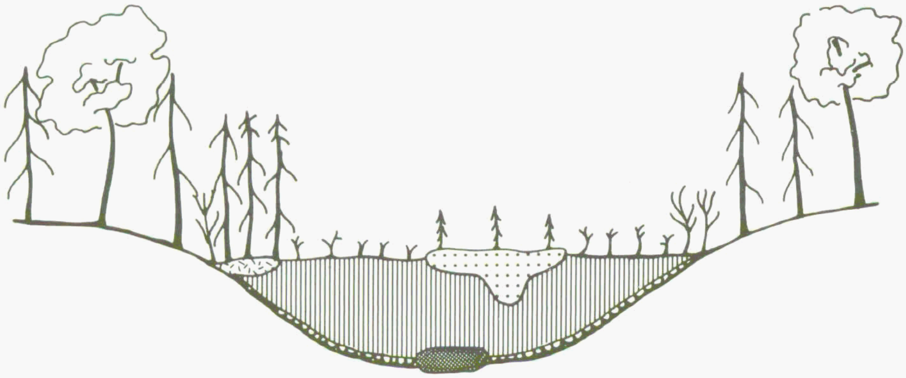
B. *Initiation of fen development around pool, with marginal shrub swamps.*



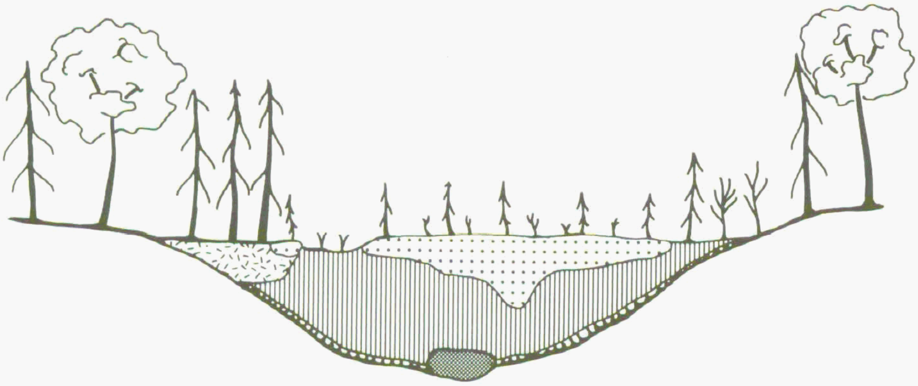
C. *Pool nearly overgrown by open fen, with tall shrub swamps on margins.*



D. *Fen occupies depression, differentiating into open shrub and treed fens. Small bog islands may be initiated. Marginal shrub or coniferous treed swamps are present.*



E. Bog develops on portion of diversified open shrub and treed fens. Marginal tall shrub and coniferous treed swamps are present.



F. Bog covers most of the wetland, but fens may be present as narrow strips draining surplus water. Coniferous treed and tall shrub swamps are present on margins.

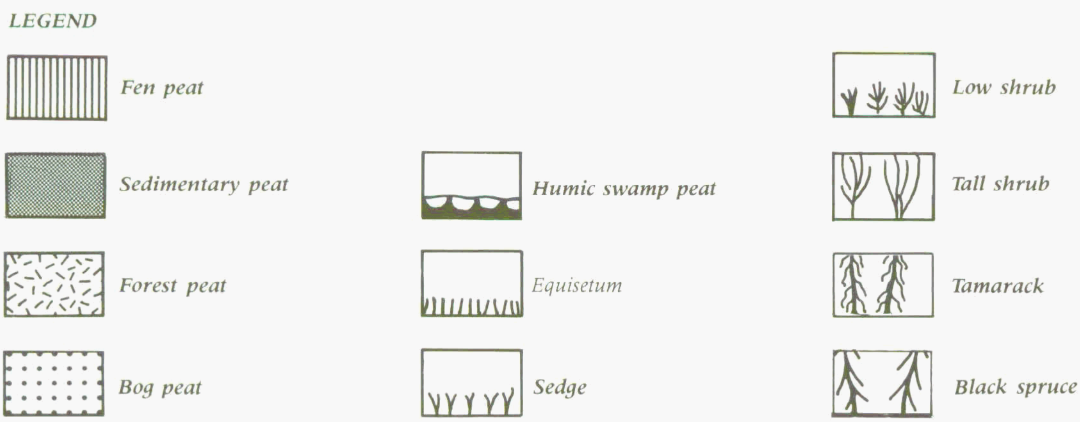


Figure 4–25.
Development of wetlands in boreal wetland regions.

may take different forms. There may be small cushions of mosses within a fen on which bog conditions exist. If conditions permit, such cushions may coalesce and form a bog mat over the fen. Conversely, small depressions containing fen vegetation (known as "fen windows") may persist on such bog mats and, in other areas, some deep-rooted fen species may tap into the fen groundwater, well below the bog surface. In the face of evidence of such transitional stages, classification becomes difficult as an attempt is being made to force a dynamic system into a static classification framework.

The development of permafrost in peatlands, resulting in the formation of peat plateau and palsa bogs, is discussed in detail in Chapter 3. Evidence suggests that the establishment of an insulating *Sphagnum* cap initiates the development of permafrost. This process raises the peatland surface above the water table, forming peat plateau or palsa bogs, depending on the amount of water available for ice formation. The frozen peatlands often proceed to an overmature stage (Zoltai 1972; Reid 1974), resulting in the thawing of permafrost and a collapse of the peat into the surrounding fen.

Stability of Wetlands

In general, wetlands are stable ecosystems where changes occur only infrequently. If these changes are part of the natural evolution of the wetland, the resulting changed wetland will also be stable. In a study of a treed bog "island" in a minerotrophic fen in Alberta, it was found that the treed bog had originated on a slight rise on the mineral terrain, but the bog has remained virtually unchanged for over 6 600 years to the present, although it has been surrounded by the fen (Zoltai and Johnson 1985). The surface of the bog has remained some 40–50 cm above the fen over the years, maintaining ombrotrophic conditions by keeping ahead of the peat accumulation in the fen. Far from being overwhelmed by the fen, the bog island is slowly expanding laterally over the fen.

Should a change in the wetland ecosystem be caused by interference (natural or artificial) in the natural evolution of the wetland, the change will be short-lived, unless the interference becomes constant or is repeated. A notable exception is provided by the thawing of permafrost-affected wetland forms, such as palsa and peat plateau bogs. In the boreal wetland regions, the frozen core of these forms is subject to thaw, causing the surface to subside into the surrounding fen. Such collapse can take place rapidly, within a few years (Thie 1974). The collapse can be initiated or accelerated by fires that kill the vegetation and consume the surface peat, or by a disturbance of the thermal regime caused by a rising water table. Some palsa and peat plateau bogs appear to be senescent, with large cracks in the dry surface peat that can initiate a collapse. The time of permafrost initiation in peat plateau bogs has been determined by radiocarbon dating of the base of the *Sphagnum* layer over peat of fen origin (Reid 1974). Dates of 1 580 and 1 700 years BP were obtained. Allowing time for *Sphagnum* growth before conditions were suitable for permafrost, the invasion of permafrost is estimated to have occurred some 600 years ago on these peat plateau bogs in northwestern Alberta.

Youthful stages of peat development (Zoltai 1972; Reid 1974) are often observed on the same peatlands that have collapsing forms, implying that permafrost aggradation and degradation can take place under present climatic conditions. This indicates that there is a delicate balance between the initiation and the degradation of permafrost in boreal wetland regions.

Peat Accumulation

Wetlands, especially peatlands, have a positive energy balance. The incoming energy is used to produce biomass, but only a portion of this biomass decomposes to provide nutrients for further growth. About 10% of the annual net primary production is stored as peat in bog ecosystems in southern Manitoba (Reader and Stewart 1972). Others estimate that up to 70% of the incoming energy is stored in peat accumulation (Terasmae 1972).

Peat is composed of the remains of plants that once grew on the surface. As peat accumulation proceeded, the surface became the growing medium (the soil) of subsequent peatland vegetation. Thus, the peat was subjected to some decomposition within the rooting zone, but it was also augmented by the remains of the roots of the plants that grew on it. As the peat build-up progressed, the active surface "soil" became permanently submerged within the water table and was no longer subject to significant decomposition. However, the weight of overlying deposits could compress the peat, decreasing the pore spaces occupied by water. It is evident that the rate of peat accumulation is only a crude measure of the biomass productivity of peatlands.

A long-term average rate of peat accumulation can be obtained from radiocarbon dates of basal peat. The rate of peat accumulation has been calculated in 19 peatlands in boreal wetland regions, where information on peat stratigraphy was available (Table 4–22), and in another 16 peatlands in the Glacial Lake Agassiz basin (Table 4–23). The long-term rate of peat accumulation varied from 2.8 cm/100 yr in northern Ontario to 10.6 cm/100 yr in southern Manitoba, with an average rate of 6.4 cm/100 yr. Additional data, from the Geological Survey of Canada (Table 4–24), do not provide details of peat stratigraphy and may include samples from dense, slowly accumulated layers. Only those data which clearly indicate that the basal material was peat and not more compact lacustrine peat ("gyttja") were selected. The average long-term accumulation rate in this set of data is 5 cm/100 yr, considerably lower than that in the peatlands with known peat stratigraphy. In southern Manitoba, peat accumulation rates of 2.5–4.2 cm/100 yr in four different bog ecosystems also have been recorded by Reader and Stewart (1972).

The rate of peat accumulation is not constant over time. A series of radiocarbon dates from a bog on the Porcupine Mountain, Manitoba (Nichols 1969), shows that, although the overall rate of peat accumulation was 3.3 cm/100 yr, the rate has varied periodically between 2.3 and 7.4 cm/100 yr (Table 4–25). This variation can be traced to the floristic composition, degree of decomposition, and compaction of the peat.

Another method of dating peat is through the identification of volcanic ash ("tephra") marker horizons. In parts of western Canada, three volcanic ash layers can be encountered in peat deposits: (1) the Mazama ash dated at about 6 600 years BP (Powers and Wilcox 1964); (2) the St. Helens "Y" tephra dated at about 3 500 years BP (Westgate *et al.* 1969); and (3) the Bridge River tephra dated at about 2 350 years BP (Mathewes and Westgate 1980). In southern Yukon and the adjacent Northwest Territories, the White River ash, dated at about 1 250 years BP (Lerbekmo *et al.* 1975), is also a useful marker horizon.

Using these three volcanic ash marker horizons in a fen–bog complex near Rocky Mountain House, Alberta, Zoltai and Johnson (1985) found that peat accumulated in the fen and bog at about the same rate (Table 4–26). The long-term mean rate of peat accumulation between 6 600 years BP and the present was 5 cm/100 yr at the fen location and 5.2 cm/100 yr at the treed bog site.

Zoltai and Johnson (1985) also calculated the rate of accumulation of organic matter in the same complex by deducting the weight of ash in the peat and taking the bulk density of the dry peat into account (Table 4–26). On this basis, the long-term mean rate of accumulation of organic matter in the fen was 39.1 g/m^2/yr and in the treed bog it was slightly higher at 44.8 g/m^2/yr. Accumulation rates of 27–52 g/m^2/yr in southern Manitoba have been reported by Reader and Stewart (1972).

The rate of production of organic matter can also be used to estimate the rate of carbon storage in boreal peatlands. As shown in Table 4–26, the rate of peat accumulation during the most recent period, 0–2 350 years, appears to represent an average rate for boreal peatlands. Hence, the rate of 33.7 g/m^2/yr for organic matter production can be regarded as an average figure. The organic carbon content of organic matter can also be obtained from analytic data for peat from southern Manitoba (Mills *et al.* 1977). The organic carbon content of 76 peat samples, with ash contents of less than 25%, was 56%, with a standard deviation of 4.7%. Thus, an annual organic carbon accumulation rate of 18.9 g/m^2 serves as an approximation. Crude estimates of the extent of peatlands, based on the boreal portion of various provinces (Tarnocai 1984), indicate that there are 52 million ha of peatlands within the boreal wetland regions of Canada. This would give an annual carbon storage capacity of approximately 9.8 million tonnes in these boreal peatlands.

Age of Organic Deposits

The final disappearance of glacial ice between 9 000 and 12 000 years ago marked the earliest possible initiation of wetlands. However, several thousand years usually elapsed before organic materials suitable for radiocarbon dating were deposited. The oldest dates for wetland deposits have been obtained from shallow ponds which were later overgrown with peat (Table 4–27). The basal dates range between 7 000 and 10 000 years BP,

Table 4–22. Radiocarbon ages of basal peat and long-term rates of peat accumulation in boreal wetland regions

Location	Depth of sample (cm)	Radiocarbon age (yr)	Radiocarbon lab. no.	Source	Rate of peat accumulation (cm/100 yr)
49°13′ N, 80°37′ W, Ont.	200	7 150±140	GSC–309	Terasmae (1970)	2.8
47°54′ N, 71°10′ W, Que.	413	8 510±140	GSC–1417	Richard (1973a)	4.8
48°22′ N, 71°32′ W, Que.	360	4 600±95	I–7289	Richard (1973a)	7.8
46°53′ N, 71°48′ W, Que.	550	7 970±140	GSC–1400	Richard (1973b)	6.9
52°22′ N, 102°37′ W, Sask.	190	3 415±165	S–2570	This paper	5.6
53°58′ N, 104°52′ W, Sask.	239	3 750±120	S–2573	This paper	6.4
55°11′ N, 105°20′ W, Sask.	360	8 010±170	S–2576	This paper	4.5
54°39′ N, 105°33′ W, Sask.	485	7 400±170	S–2579	This paper	6.6
55°54′ N, 108°35′ W, Sask.	420	6 855±160	S–2582	This paper	6.1
54°28′ N, 107°51′ W, Sask.	360	4 215±175	S–2584	This paper	8.5
52°51′ N, 116°28′ W, Alta.	202	4 460±170	BGS–771	This paper	4.5
54°45′ N, 115°52′ W, Alta.	548	8 940±240	BGS–778	This paper	6.1
54°58′ N, 112°00′ W, Alta.	288	6 900±240	BGS–780	This paper	4.2
54°37′ N, 112°09′ W, Alta.	236	2 900±160	BGS–784	This paper	8.1
55°51′ N, 115°09′ W, Alta.	296	4 400±150	BGS–790	This paper	6.7
50°18′ N, 77°24′ W, Que.	275	6 890±120	QU–499	Dionne (1979)	4.0
50°30′ N, 77°48′ W, Que.	200	5 840±100	QU–495	Dionne (1979)	3.4
51°22′ N, 77°45′ W, Que.	300	5 020±100	QU–493	Dionne (1979)	6.0
50°42′ N, 79°20′ W, Que.	275	3 830±120	QU–497	Dionne (1979)	7.2

Table 4–23. Radiocarbon dates of basal peat (P) and basal organic lacustrine deposit (L) with rates of peat accumulation in the Glacial Lake Agassiz basin, Ontario, Manitoba, and Saskatchewan

Location	Depth of sample (cm)	Stratigraphic position	Radiocarbon age (yr)	Radiocarbon lab. no.	Source	Rate of peat accumulation (cm/100 yr)
49°48′ N, 94°27′ W, Ont.	450	P over L	4 850±60	—	McAndrews (1982)	9.3
49°24′ N, 95°22′ W, Man.	350	P over mineral	3 685±240	S–2468	This paper	9.5
49°49′ N, 95°18′ W, Man.	205	P over L	3 240±235	S–2466	This paper	6.3
	470	L over mineral	4 980±270	S–2467	This paper	—
50°04′ N, 95°33′ W, Man.	172	P over L	3 210±130	S–2469	This paper	5.4
	230	L over mineral	5 400±170	S–2470	This paper	—
50°35′ N, 95°27′ W, Man.	390	P over L	4 275±255	S–2471	This paper	9.1
	590	L over mineral	6 120±310	S–2472	This paper	—
51°25′ N, 96°53′ W, Man.	459	P over mineral	4 340±155	S–2473	This paper	10.6
52°53′ N, 99°08′ W, Man.	75	P over mineral	940±60	WIS–173	Nichols (1969)	8.0
53°18′ N, 99°16′ W, Man.	282	P over mineral	4 180±120	BGS–854	This paper	6.7
53°28′ N, 101°29′ W, Man.	338	P over mineral	4 550±100	BGS–852	This paper	7.4
54°16′ N, 99°09′ W, Man.	240	P over mineral	4 900±100	BGS–868	This paper	4.9
54°18′ N, 101°16′ W, Man.	256	P over mineral	4 640±100	BGS–856	This paper	5.5
53°59′ N, 101°12′ W, Man.	153	P over mineral	4 670±130	GSC–410	Dyck *et al.* (1966)	3.3
54°36′ N, 98°34′ W, Man.	260	P over mineral	4 500±120	GSC–1958	Lowdon *et al.* (1977)	5.8
54°36′ N, 101°26′ W, Man.	225	P over mineral	2 970±100	BGS–864	This paper	7.6
54°53′ N, 102°05′ W, Sask.	308	P over L	5 975±210	S–2571	This paper	5.2
	400	L over mineral	7 255±250	S–2572	This paper	—
55°04′ N, 101°36′ W, Man.	330	P over mineral	4 550±100	BGS–859	This paper	7.2

indicating a lag of about 2 000 years after the disappearance of glacial ice.

The age of basal peat in boreal wetland regions shows a much greater range (Tables 4–22, 4–23, and 4–24), beginning about 9 000 years BP and continuing to about 3 000 years BP. This wide range can partly be explained by the glacial history of various parts of the boreal wetland regions. It is evident that most of the relatively recent basal peat dates are from the basin of Glacial Lake Agassiz (Table 4–24). Most of the other dates indicate that the rest of these boreal peatlands originated 6 500–9 000 years BP. Based on the assumption that the dated peat section was not necessarily always the oldest part of the peatland, it is probable that most peatlands originated 8 000–9 000 years ago, some 2 000 years after the disappearance of glacial ice.

In the James Bay Lowland, peat deposition occurred some 700–1 500 years after the land became exposed (Dionne 1979). The peat in this area is underlain by tree roots and stems that are up to 1 500 years older than the peat. This indicates that forests developed on the exposed lake or sea

Table 4–24. Radiocarbon ages of basal peat, and rate of peat accumulation, based on determinations by the Geological Survey of Canada Radiocarbon Laboratory

Location	Depth of sample (cm)	Radiocarbon age (yr)	Radiocarbon lab. no.	Source	Rate of peat accumulation (cm/100 yr)
47°58′ N, 69°26′ W, Que.	250	6 970±100	GSC–112	Dyck and Fyles (1963)	3.6
49°01′ N, 79°05′ W, Que.	300	6 460±140	GSC–788	Lowdon *et al.* (1971)	4.6
47°34′ N, 79°45′ W, Ont.	300	5 780±100	GSC–15	Dyck and Fyles (1963)	5.2
54°34′ N, 84°40′ W, Ont.	290	5 580±150	GSC–247	Dyck *et al.* (1965)	5.2
45°23′ N, 75°31′ W, Ont.	244	6 750±150	GSC–548	Lowdon *et al.* (1968)	3.6
46°13′ N, 82°56′ W, Ont.	390	8 760±250	GSC–514	Lowdon *et al.* (1968)	4.4
54°10′ N, 116°54′ W, Alta.	310	8 560±170	GSC–525	Lowdon *et al.* (1968)	3.6
54°34′ N, 116°48′ W, Alta.	320	4 150±140	GSC–674	Lowdon and Blake (1968)	7.7
54°42′ N, 116°00′ W, Alta.	410	8 320±260	GSC–500	Lowdon *et al.* (1968)	4.9
51°05′ N, 121°59′ W, BC	630	9 210±150	GSC–511	Lowdon and Blake (1968)	6.8

Table 4–25. Rate of peat accumulation from a bog on Porcupine Mountain, Manitoba

Location	Depth of sample (cm)	Radiocarbon age (yr)	Radiocarbon lab. no.	Length of section (cm)	Rate of accumulation (cm/100 yr)
52°31′ N, 101°15′ W	50	1 170±60	WIS–287	0–50	4.3
	80	2 000±55	WIS–289	50–80	3.6
	100	2 270±60	WIS–303	80–100	7.4
	145	4 180±75	WIS–286	100–145	2.3
	170	5 140±75	WIS–308	145–170	2.6
Average	—	—	—	0–170	3.3

Source: Nichols (1969).

bottom after a delay of 300–1 500 years, and the formation of bogs through paludification followed 400–900 years later. Paludification occurred at different times and it is believed to be related to geological rather than climatic events.

The Glacial Lake Agassiz basin, occupying most of the present area of Manitoba and large parts of Saskatchewan and Ontario, merits special consideration. In Canada, the Lake was established following the melting of glacial ice about 11 000 years BP (Fenton *et al.* 1983), its level dropping as new, lower outlets became available. Southern Manitoba became dry land about 9 200 years ago, but the Lake covered most of central Manitoba and large parts of Saskatchewan and Ontario until about 8 700 years BP (Klassen 1983). It finally disappeared from the central part of the basin about 7 500 years BP. Consequently, the basin became available for wetland formation much earlier in the south (9 200 years BP) than in the north (7 500–8 000 years BP).

The post-glacial climate, according to pollen analyses (Ritchie 1983), was initially cool; from 13 000 to 10 000 years BP, the mean summer temperature was 5–10°C, compared to the modern mean summer temperature of 13.5°C. Between 10 000 and 6 500 years BP, the climate became warm and dry, with summer temperatures of 15–17°C and with 10–20% less precipitation than at present. The period between 6 500 and 3 000 years BP was equally warm, but precipitation increased to levels near those of the present. About 2 500 years BP, the present climatic regime was established in the Glacial Lake Agassiz region. Last and Teller (1983) found that the sediments of Lake Manitoba, a large remnant of Glacial Lake

Table 4–26. Rate of peat and organic matter accumulation at two locations in a fen–bog complex, using volcanic ash marker horizons

Tephra layer and period	Rate of peat accumulation (cm/100 yr)		Rate of organic matter accumulation (g/m/yr)	
	Fen	Treed bog	Fen	Treed bog
Bridge River 0–2 350 yr	4.3	4.9	36.1	31.3
St. Helens "Y" 2 350–3 500 yr	5.2	4.3	38.0	37.3
Mazama ash 3 500–6 600 yr	5.4	5.8	41.7	57.8

Source: Zoltai and Johnson (1985).

Table 4–27. Radiocarbon dates of basal lacustrine peat ("gyttja") under peat in boreal wetland regions

Location	Depth of sample (cm)	Radiocarbon age (yr)	Radiocarbon lab. no.	Source
45°57′ N, 76°04′ W, Que.	895	9 910±200	GSC–680	Lowdon and Blake (1970)
45°32′ N, 75°30′ W, Ont.	515	7 650±210	GSC–681	Lowdon and Blake (1970)
45°08′ N, 74°56′ W, Ont.	475	9 430±140	GSC–8	Dyck and Fyles (1963)
46°03′ N, 77°22′ W, Ont.	760	9 540±250	GSC–177	Dyck *et al.* (1965)
46°13′ N, 82°56′ W, Ont.	390	8 760±250	GSC–514	Lowdon *et al.* (1968)
49°02′ N, 80°59′ W, Ont.	600	7 380±140	GSC–624	Lowdon *et al.* (1968)
51°23′ N, 84°31′ W, Ont.	412	7 140±170	GSC–831	Lowdon and Blake (1970)
51°26′ N, 93°43′ W, Ont.	427	8 860±250	GSC–9	Dyck and Fyles (1963)
52°43′ N, 105°13′ W, Sask.	280	7 100±150	GSC–539	Lowdon *et al.* (1968)

Agassiz, indicate an end of the dry period about 4 500 years BP.

Radiocarbon dates show that peat deposition was delayed after glaciation by up to 5 000 years. This appears to support the contention that the climate was not suitable for peat formation after the disappearance of Glacial Lake Agassiz, being warmer and drier than at present. Peat formation became possible between 4 300 and 4 800 years BP in the north, and between 3 200 and 3 700 years BP in the southern part of the basin. It appears that the delay in establishing peatlands, caused by the presence of Glacial Lake Agassiz, came at a critical time for peatland establishment. If already established, the peatlands flourished during the warmer and drier period, but new ones could not develop in the basin. Peatlands also formed in early times in other parts of the boreal wetland regions.

Boreal Wetland Values

Many wetlands of the boreal wetland regions lie near populated areas of Canada and are therefore relatively accessible. This results in increased use of the wetlands and consequent pressure on them, which will inevitably lead to changes in the natural ecosystem. Following is a brief overview of those boreal wetland values which are currently or potentially available.

Natural Environment Values

Boreal wetlands provide a domestic environment for various kinds of wildlife. The marsh and shallow water complexes are by far the most significant wetlands in this respect. The Peace–Athabasca Delta can serve as an example: it is a vital link in the annual migration of up to 1 million birds, including swans, 3 species of geese, and 14 species of ducks (Griffiths and Townsend 1985). Nineteen bird species reach their northern breeding limits here, including the rare Whooping Crane (*Grus americana*). The Delta supports 42 species of mammals from shrews and bats to lynx and wolves. The world's largest free-ranging herd of bison (*Bison bison*) depends on the *Carex atherodes* meadows in the Delta for forage.

Fens, and especially bogs, present much less varied habitats, which are reflected in their much simpler fauna. Few species of wildlife make the *Picea*-dominated peatlands their home, but many pass through them, obtaining food and shelter there (Muir 1977). Nevertheless, the wetland portion of the boreal landscape can be an important wildlife habitat. In montane areas, sedge and shrub wetlands are extremely important in winter for wapiti (*Cervus elaphus*), moose (*Alces alces*), wolf (*Canis lupus*), and coyote (*Canis latrans*) (Holroyd and Van Tighem 1983). These wetlands are also essential for small mammals, especially meadow voles (*Microtus pennsylvanicus*), western jumping mouse (*Zapus princeps*), northern bog lemming (*Synaptomys borealis*), and masked shrew (*Sorex cinereus*). There are 28 species of birds nesting in these habitats, including American Bittern (*Botaurus lentiginosus*), American Kestrel (*Falco sparverius*), Willow Flycatcher (*Empidonax traillii*), and Yellow Warbler (*Dendroica petechia*). Wood frog (*Rana sylvatica*), long-toed salamander (*Ambystoma macrodactylum*), and western toad (*Bufo boreas*) breed here.

Waterfowl utilization of peatlands is low when compared to that of marshes. In a study of boreal lakes and ponds (Table 4–28), it was found that those with shore marshes are used much more extensively by ducks than ponds with peaty shore

Table 4–28. Waterfowl use in hours, adjusted to comparable shoreline units, among lake shore and pond habitats during nesting period over an average of two years

Wetland type	Water pH	Conductivity (mS/cm)	Dabbling ducks: Hours of use	Dabbling ducks: Number of species	Diving ducks: Hours of use	Diving ducks: Number of species
Sedge-dominated marshy lake shore	8.7	0.396	137.5	5	1 104.6	8
Cattail shallow water pond	8.4	0.400	255.2	6	2 142.7	8
Fen pond	8.6	0.240	96.2	4	422.2	4

Source: Donaghey (1974).

fens (Donaghey 1974). In addition, ducks spent more time loafing and resting than feeding on ponds with fens than they did in other habitats. Fifteen duck species were found on lake-shore habitats, but six of these, including the dabbling, Northern Pintail (*Anas acuta*) and Gadwall (*Anas strepera*), and the diving, Redhead (*Aythya americana*), Canvasback (*Aythya valisineria*), White-winged Scoter (*Melanitta fusca*), and Ruddy Duck (*Oxyura jamaicensis*), were absent from the ponds with fens. Sandhill Cranes (*Grus canadensis*) are often encountered in fens but not in bogs, and the Lesser and Greater Yellowlegs (*Tringa flavipes* and *Tringa melanoleuca*) are common, noisy inhabitants of fens.

Among the fur-bearing animals, beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) are prime users of boreal wetlands. Both standing and running water environments suit beaver (Todd 1978), provided that there is a reliable source of water and sufficient acceptable food. Such habitats are found along channelized water courses, often associated with swamps. Muskrat, on the other hand, prefer standing water bodies with a marsh margin. Fens and bogs are not known to be utilized to any extent by beaver or muskrat, as such areas are essentially devoid of the aquatic habitats they need (Todd 1978).

Moose are frequently encountered in fens and swamps where the preferred *Salix* browse is abundant (Berg and Phillips 1974). Bogs are not used extensively by ungulates or fur-bearers, but bogs form an essential part of the habitat of woodland caribou (*Rangifer tarandus caribou*) (Fuller and Keith 1981). In northeastern Alberta, coniferous treed bogs constitute the forest type most often occupied by woodland caribou, although the caribou occur only in very low densities, with one animal per 32 km^2.

Wild rice (*Zizania palustris*), which commonly grows in the shallow (0.5–1.0 m) littoral zone of boreal lakes, is harvested for food. In 1983, 750 000 kg were produced in Canada, mainly in boreal wetland regions (Archibold *et al.* 1985).

Boreal wetlands often present a unique opportunity for the enjoyment and study of the natural environment. For example, the Wagner Bog, a protected natural area of spring fens and coniferous treed swamps a mere 13 km from the city of Edmonton, Alberta, has a remarkable variety of fauna and flora. Fifteen of Alberta's 25 orchid species can be found there (Thormin 1982a), as well as dozens of bird species, including five kinds of owls, and flycatchers, nuthatches, warblers, sparrows, and sandpipers (Thormin 1982c). The Wagner Bog is equally rich in butterfly species, some of which are specific to peatland areas, such as *Oeneis jutta*, *Erebia disa*, *Boloria eunomia*, *Boloria selene*, and *Boloria titania* (Thormin 1982b). This wetland complex provides ample opportunities for people to satisfy various interests, within a few minutes' drive from a large metropolitan area.

The role of wetlands as areas for water catchment and storage can be readily appreciated by the casual observer, but it is little studied. Wetlands act as water storage areas in depressional basins in the same way as lakes do. On some peatlands, much water can be stored above the gravitational water table, allowing the retention of more water than if the peatlands were not present. On the other hand, water losses occur in wetlands not only through evaporation, but also through transpiration of the wetland plants.

Wetland Utilization Values

Various uses, such as hunting or trapping, affect wetlands only through the harvesting of animals.

Some wetlands, especially marshes, annually yield enormous numbers of waterfowl (geese, ducks) to hunters, and thousands of muskrat pelts taken annually from marshes provide a livelihood for many trappers.

Other uses, however, are causing a significant alteration of some wetlands in the boreal wetland regions. Clearing and draining of wetlands for agricultural use are practised extensively at the local level, mainly for the production of hay and for grazing, since boreal climatic conditions are not favourable for more intensive agricultural uses. However, the potential for converting large tracts of wetlands into marginally productive agricultural land is present in the agricultural fringe areas of boreal wetland regions. Similarly, the practice of increasing tree productivity by lowering the water table on treed fens, swamps, and bogs is progressing beyond the experimental stage. Several thousand hectares of treed wetlands in Ontario and Alberta have been ditched in recent years to enhance tree growth.

Other uses of wetlands include the mining of peat for horticultural use or for fuel. Fibrous *Sphagnum* peat, found in bogs, is preferred for horticultural use. There are a number of peat processing plants in the boreal wetland regions. In Manitoba, three plants processed 41 000 tonnes of peat in 1978 (Bannatyne 1980), and many more suitable deposits have been identified. The use of peat for fuel is feasible, but, at present, economics do not favour its use in Canada. Technology is constantly developing new and less expensive methods of fuel peat production. In Europe, bricketting, wet carbonization, and peat gasification have progressed to the production stage. Moderately decomposed fen peat, abundant in many parts of the boreal wetland regions, is well suited for use as fuel.

Other land uses, although incidental to boreal wetlands, can also affect them. The creation of reservoirs for the production of hydroelectric power has resulted in the inundation of extensive areas of low-lying land, including wetlands. Fertilizers, herbicides and pesticides, and acid rain find their way into wetlands, changing the nutrient regime or biotic components. In addition, various wetland types have been suggested for use as sewage disposal sites, due to the high absorptive capacity of the peat (Hartland-Rowe and Wright 1974). Habitat modification in marshes is creating or enhancing suitable environments for waterfowl at the expense of the natural functions and values of these wetlands.

The large expanses of wetlands in the boreal wetland regions will continue to allow both nonconsumptive and consumptive uses. There is a danger, however, that critically important wetlands may be destroyed in local areas. Conservation programs for wetlands are being initiated in some provinces, based on the importance of particular wetlands in regional and local settings. However, there are still large wetland areas throughout the boreal wetland regions for which ecologically sound plans for their use and conservation do not yet exist. Trying to salvage highly modified wetlands in the future is a poor alternative to establishing rational wetland conservation policies and programs today.

Acknowledgements

Review comments by C. Tarnocai, G. Adams, H. Hirvonen, J. Pojar, H. Veldhuis, P. Grondin, and C. Rubec have assisted in the completion of this chapter. Material for the feather fen wetland form observed in Quebec has been contributed by P. Grondin. Data and draft text on boreal fens have also been contributed by R. Coulombe.

References

ÅHMAN, R. 1977. Palsar i Nordnorge. The Royal University of Lund, Sweden. Department of Geography Series. Avhandlingar No. 78. 165 p.

ANDERSSON, G., AND H. HESSELMAN. 1907. Vegetation och flora i Hamra kronopark (Vegetation and flora in the state forest of "Hamra Kronopark"). Medd. Statens Skogsförsöksanst. 4:35–102.

ARCHIBOLD, O.W., B.J. WEICHEL, AND J.E. FITZGIBBON. 1985. Factors in the ecology of wild rice in northern Saskatchewan. Canadian Geographic 29:100–112.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals 1951–1980. Volume 2: Temperature; Volume 3: Precipitation; Volume 4: Degree-days. Environment Canada. Downsview, Ontario.

AUER, V. 1920. Über die Entstehung der Stränge auf den Torfmooren. Acta Forestalia Fennica 12:23–125.

BANNATYNE, B.B. 1980. *Sphagnum* bogs in southern Manitoba and their identification by remote sensing. Mineral Resources Division, Manitoba Department of Energy and Mines. Economic Geology Report No. ER79-7. Winnipeg, Manitoba. 103 p.

BAYROCK, L.A., AND J.D. ROOT. 1971. Geology and geologic history of the Peace–Athabasca Delta area: a summary. *In* Proceedings, Peace–Athabasca Delta Symposium. University of Alberta, Edmonton, Alberta. pp. 28–31.

BERG, W.E., AND R.L. PHILLIPS. 1974. Habitat use by moose in northeastern Minnesota with reference to other heavily willowed areas. Naturaliste canadien 101:101–116.

BIRD, R.D. 1961. Ecology of the aspen parkland of western Canada in relation to land use. Canada Department of Agriculture. Publication No. 1066. Ottawa, Ontario. 155 p.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 9–30.

BROWN, G. 1980. Palsas and other permafrost features in the lower Rock Creek valley, west-central Alberta. Arctic and Alpine Research 12:31–40.

BROWN, R.J.E. 1970. Occurrence of permafrost in Canadian peatlands. *In* Proceedings, 3rd International Peat Congress. National Research Council of Canada. pp. 174–181.

BRYSON, R.A. 1966. Air masses, streamlines, and the boreal forest. Geographical Bulletin 8:228–269.

CAJANDER, A.K. 1913. Studien über die Moore Finlands. Acta Forestalia Fennica. Volume 2.

COUILLARD, L., AND P. GRONDIN. 1986. La végétation des milieux humides du Québec. Les publications du Québec. Quebec Ministry of Environment. Quebec, Quebec. 400 p.

DIONNE, J.C. 1979. Radiocarbon dates on peat and tree remains from James Bay area, subarctic Quebec. Canadian Journal of Forestry Research 9:125–129.

DIONNE, J.C. 1984. Palses et limite méridionale du pérgélisol dans l'Hémisphère Nord: le cas de Blanc-Sablon, Québec. Géographie physique et Quaternaire 38:165–184.

DIRSCHL, H.J. 1972. Geobotanical processes in the Saskatchewan River Delta. Canadian Journal of Earth Sciences 9:1529–1549.

DONAGHEY, R.H. 1974. Waterfowl use of boreal forest waterbodies near Utikuma Lake, northern Alberta. Ducks Unlimited (Canada) Ltd. Edmonton, Alberta. Unpublished. 97 p.

DYCK, W., AND J.G. FYLES. 1963. Geological Survey of Canada radiocarbon dates, I and II. Geological Survey of Canada. Paper 63-21. Ottawa, Ontario. 31 p.

DYCK, W., J.G. FYLES, AND W. BLAKE, JR. 1965. Geological Survey of Canada radiocarbon dates, IV. Geological Survey of Canada. Paper 65-4. Ottawa, Ontario. 23 p.

DYCK, W., J.A. LOWDON, J.G. FYLES, AND W. BLAKE, JR. 1966. Geological Survey of Canada radiocarbon dates, V. Geological Survey of Canada. Paper 66-48. Ottawa, Ontario. 32 p.

ENGLISH, M.C. 1979. Some aspects of the ecology and environment of the Slave River Delta, NWT, and some implications of upstream impoundment. M.Sc. thesis, University of Alberta, Edmonton, Alberta. 246 p.

FENTON, M.M., S.R. MORAN, J.T. TELLER, AND L. CLAYTON. 1983. Quaternary stratigraphy and history in the southern part of the Lake Agassiz basin. *In* Glacial Lake Agassiz. J.T. Teller and L. Clayton, editors. Geological Association of Canada. Special Paper No. 26. pp. 49–74.

FOSTER, D.R., G.A. KING, P.H. GLASER, AND H.E. WRIGHT, JR. 1983. Origin of string patterns in boreal peatlands. Nature 306:256–258.

FULLER, T.K., AND L.B. KEITH. 1981. Woodland caribou population dynamics in northeastern Alberta. Journal of Wildlife Management 45:197–213.

FULLER, W.A., AND G.H. LA ROI. 1971. Historical review of biological resources of the Peace– Athabasca Delta. *In* Proceedings, Peace–Athabasca Delta Symposium. University of Alberta, Edmonton, Alberta. pp. 153–173.

GAUTHIER, R. 1980. La végétation des tourbières et les sphaignes du parc des Laurentides, Québec. Forest Ecology Laboratory, Laval University. Études écologiques No. 3. Quebec, Quebec. 634 p.

GLASER, P.H., AND J.A. JANSSENS. 1986. Raised bogs in eastern North America: transitions in landforms and gross stratigraphy. Canadian Journal of Botany 64:395–415.

GLASER, P.H., G.A. WHEELER, E. GORHAM, AND H.E. WRIGHT, JR. 1981. The patterned mires of the Red Lake peatland, northern Minnesota: vegetation, water chemistry and landforms. Journal of Ecology 69:575–599.

GRIFFITHS, D.E., AND G.H. TOWNSEND. 1985. Northern deltas—oases for wildlife. Canadian Wildlife Service, Environment Canada. Ottawa, Ontario. 2 maps.

GRONDIN, P., AND J. OUZILLEAU. 1980. Les tourbières du sud de la Jamésie. Géographie physique et Quaternaire 34:267–299.

HARTLAND-ROWE, R.C.B., AND P.B. WRIGHT. 1974. Swamplands for sewage effluents. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 74-4. Ottawa, Ontario. 137 p.

HEINSELMAN, M.L. 1963. Forest sites, bog processes, and peatland types in the Glacial Lake Agassiz region, Minnesota. Ecological Monographs 33:327–372.

HOEKSTRA, P. 1966. Moisture movements in soils under temperature gradients with the cold-side temperature below freezing. Water Resources Research 2:241–250.

HOLROYD, G.L., AND K.J. VAN TIGHEM. 1983. Ecological (biophysical) land classification of Banff and Jasper national parks. Volume III. The wildlife inventory. Canadian Wildlife Service, Environment Canada. Edmonton, Alberta. pp. 445–691.

JEGLUM, J.K. 1971. Plant indicators of pH and water level in peatlands at Candle Lake, Saskatchewan. Canadian Journal of Botany 49:1661–1676.

JEGLUM, J.K., AND D.W. COWELL. 1982. Wetland ecosystems near Kinoje Lakes, southern interior Hudson Bay Lowland. Naturaliste canadien 109:621–635.

KJEARSGAARD, A.A. 1972. Soil survey of the Tawatinaw map sheet (83-I). Alberta Institute of Pedology. Report No. S-72-29. Edmonton, Alberta. 103 p.

KLASSEN, R.W. 1983. Lake Agassiz and the Late Glacial history of northern Manitoba. *In* Glacial Lake Agassiz. J.T. Teller and L. Clayton, editors. Geological Association of Canada. Special Paper No. 26. pp. 97–115.

LAST, W.M., AND J.T. TELLER. 1983. Holocene climate and hydrology of the Lake Manitoba basin. *In* Glacial Lake Agassiz. J.T. Teller and L. Clayton, editors. Geological Association of Canada. Special Paper No. 26. pp. 333–353.

LERBEKMO, J.F., J.A. WESTGATE, D.G.W. SMITH, AND G.H. DENTON. 1975. New data on the character and history of the White River volcanic eruption, Alaska. *In* Quaternary Studies. R.P. Suggate and M.M. Cresswell, editors. Royal Society of New Zealand. Wellington, New Zealand. pp. 203–209.

LOWDON, J.A., AND W. BLAKE, JR. 1968. Geological Survey of Canada radiocarbon dates, VII. Geological Survey of Canada. Paper 68-2, Part B. Ottawa, Ontario. pp. 207–245.

LOWDON, J.A., AND W. BLAKE, JR. 1970. Geological Survey of Canada radiocarbon dates, IX. Geological Survey of Canada. Paper 70-2. Ottawa, Ontario. pp. 46–86.

LOWDON, J.A., J.G. FYLES, AND W. BLAKE, JR. 1967. Geological Survey of Canada radiocarbon dates, VI. Geological Survey of Canada. Paper 67-2, Part B. Ottawa, Ontario. 42 p.

LOWDON, J.A., I.M. ROBERTSON, AND W. BLAKE, JR. 1971. Geological Survey of Canada radiocarbon dates, XI. Geological Survey of Canada. Paper 71-1. Ottawa, Ontario. pp. 255–324.

LOWDON, J.A., I.M. ROBERTSON, AND W. BLAKE, JR. 1977. Geological Survey of Canada radiocarbon dates, XVII. Geological Survey of Canada. Paper 77-7. Ottawa, Ontario. 25 p.

LUNDQVIST, J. 1962. Patterned ground and related frost phenomena in Sweden. Sveriges Geologiska Undersokning. Series C, No. 583. 101 p.

MATHEWES, R.W., AND J.A. WESTGATE. 1980. Bridge River tephra: revised distribution and significance of detecting old carbon errors in radiocarbon dates of limnic sediments in southern British Columbia. Canadian Journal of Earth Sciences 17:1454–1461.

MCANDREWS, J.H. 1982. Holocene environment of a fossil bison from Kenora, Ontario. Ontario Archeologist 37:41–51.

MILLS, G.F., L.A. HOPKINS, AND R.E. SMITH. 1977. Organic soils of the Roseau River watershed in Manitoba. Canada Department of Agriculture. Monograph No. 17. Winnipeg, Manitoba. 69 p.

MUIR, R.D. 1977. Wildlife, conservation, and recreation. *In* Muskeg and the northern environment in Canada. H.W. Radforth and C.O. Brawner, editors. University of Toronto Press. Toronto, Ontario. pp. 352–366.

NATIONAL WETLANDS WORKING GROUP. 1986. *Wetland regions of Canada and Wetland distribution in Canada. In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NICHOLS, H. 1969. The late quaternary history of vegetation and climate at Porcupine Mountain and Clearwater Bog, Manitoba. Arctic and Alpine Research 1:155–167.

PIERPOINT, G. 1962. The sites of the Kirkwood Management Unit. Ontario Department of Lands and Forests. Research Report No. 47. Toronto, Ontario. 91 p.

POWERS, H.A., AND R.E. WILCOX. 1964. Volcanic ash from St. Mazama (Crater Lake) and from Glacier Peak. Science 144:1334–1336.

RAILTON, J.B., AND J.H. SPARLING. 1973. Preliminary studies on the ecology of palsa mounds in northern Ontario. Canadian Journal of Botany 51:1037–1044.

RAUP, H.M. 1935. Botanical investigations in Wood Buffalo National Park. National Museums of Canada. Bulletin No. 74, Biological Series No. 20. Ottawa, Ontario. 174 p.

READER, R.J., AND J.M. STEWART. 1972. The relationship between net primary production and accumulation for a peatland in southeastern Manitoba. Ecology 53:1024–1037.

REID, D.E. 1974. Permafrost in peat landforms in northwestern Alberta. Canadian Arctic Gas Study Ltd. Biological Report Series, Volume 37, Chapter 2. Calgary, Alberta. 36 p.

REID, D.E., AND S. MORROW. 1974. Peat landforms in the Fort Simpson area. Canadian Arctic Gas Study Ltd. Biological Report Series, Volume 37, Chapter 3. Calgary, Alberta. 26 p.

RICHARD, P. 1973a. Histoire postglaciaire comparée de la végétation dans deux localités au nord du Parc des Laurentides, Québec. Naturaliste canadien 100:577–590.

RICHARD, P. 1973b. Histoire postglaciaire de la végétation dans la région de Saint-Raymond de Portneuf, telle que relevée par l'analyse pollinique d'une tourbière. Naturaliste canadien 100:561–575.

RITCHIE, J.C. 1983. The paleoecology of the central and northern parts of the Glacial Lake Agassiz basin. *In* Glacial Lake Agassiz. J.T. Teller and L. Clayton, editors. Geological Association of Canada. Special Paper No. 26. pp. 157–170.

ROSTAD, H.P.W., AND J.G. ELLIS. 1972. The soils of the provincial forest in the St. Walburg map area. Saskatchewan Institute of Pedology. Publication No. SF2. Saskatoon, Saskatchewan. 68 p.

ROWE, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Environment Canada. Publication No. 1300. Ottawa, Ontario. 172 p.

RUUHIJÄRVI, R. 1960. Über die regionale Einteilung der nordfinnischen Moore. Annals of the Botanical Society. "Vanamo" 31(1):360.

SAKAGUCHI, Y. 1980. On the genesis of banks and hollows in peat bogs. Department of Geography, University of Tokyo, Tokyo, Japan. Bulletin 12:35–58.

SANDERSON, M. 1948. The climates of Canada according to the new Thornthwaite classification. Scientific Agriculture 28:501–517.

SCHENK, E. 1963. Origin of string bogs. *In* Proceedings, 1st International Conference. National Academy of Science–National Research Council. Publication No. 1287. Washington, DC. pp. 155–159.

SEPPÄLÄ, M. 1980. Stratigraphy of a silt-cored palsa, Atlin region, British Columbia, Canada. Arctic 33:357–365.

SEPPÄLÄ, M., AND L. KOUTANIEMI. 1985. Formation of a string and pool topography as expressed by morphology, stratigraphy and current processes on a mire in Kuusamo, Finland. Boreas 14:287–309.

SHAY, J.M., AND C.T. SHAY. 1986. Prairie marshes in western Canada, with specific reference to the ecology of five emergent macrophytes. Canadian Journal of Botany 64:443–454.

SIMS, R.A., D.W. COWELL, AND G.M. WICKWARE. 1982. Classification of fens near southern James Bay, Ontario, using vegetational physiognomy. Canadian Journal of Botany 60:2608–2623.

SJÖRS, H. 1950. On the relation between vegetation and electrolytes in north Swedish mire waters. Oikos 2:241–258.

SJÖRS, H. 1961. Forest and peatland at Hawley Lake, northern Ontario. National Museums of Canada. Bulletin No. 171. Ottawa, Ontario. pp. 1–31.

SJÖRS, H. 1963. Bogs and fens on Attawapiskat River, northern Ontario. National Museums of Canada. Bulletin No. 186. Ottawa, Ontario. pp. 45–133.

SLACK, N.G., D.H. VITT, AND D.G. HORTON. 1980. Vegetation gradients of minerotrophically rich fens in western Alberta. Canadian Journal of Botany 58:330–350.

SMITH, R.E., C. TARNOCAI, AND G.F. MILLS. 1975. Soils of the Red Rose–Washow Bay area. Manitoba Soil Survey. Soils Report No. 19. Winnipeg, Manitoba. 156 p.

STANEK, W., J.K. JEGLUM, AND L. ORLOCI. 1977. Comparisons of peatland types using macro-nutrient contents of peat. Vegetatio 33:163–173.

SVENONIUS, F.V. 1904. Yttrande med anledning av R. Sernanders föredrag: Nagra bidrag till de centralskandinaviska fjälltrakernas postglaciala geologi. Geol. Foren. i. Stockholm Forhandle. Volume 26.

TARNOCAI, C. 1984. Peat resources of Canada. National Research Council of Canada. Publication No. 24140. Ottawa, Ontario. 17 p.

TERASMAE, J. 1970. Postglacial muskeg development in northern Ontario. Associate Committee on Geotechnical Research, National Research Council of Canada. Technical Memorandum No. 99. Ottawa, Ontario. pp. 73–90.

TERASMAE, J. 1972. Muskeg as a climate-controlled ecosystem. *In* Proceedings, 14th Muskeg Research Conference. 1971. Kingston, Ontario. National Research Council of Canada. Technical Memorandum No. 102. Ottawa, Ontario. pp. 147–158.

THIE, J. 1974. Distribution and thawing of permafrost in the southern part of the discontinuous permafrost zone in Manitoba. Arctic 27:189–200.

THOM, B.G. 1972. The role of spring thaw in string bog genesis. Arctic 25:236–239.

THORMIN, T. 1982a. Orchids in the Wagner Bog. The Edmonton Naturalist 10(2):23–32.

THORMIN, T. 1982b. Butterflies of the Wagner Bog. The Edmonton Naturalist 10(2):37–41.

THORMIN, T. 1982c. Birds of the Wagner Bog. The Edmonton Naturalist 10(2):42–45.

TODD, A.W. 1978. Methodology used for Alberta Land Inventory for furbearers. Alberta Department of Fish, Parks and Wildlife. Edmonton, Alberta. 68 p.

VITT, D.H., AND S. BAYLEY. 1984. The vegetation and water chemistry of four oligotrophic basin mires in northwestern Ontario. Canadian Journal of Botany 62:1485–1500.

VITT, D.H., P. ACHUFF, AND R.E. ANDRUS. 1975. The vegetation and chemical properties of patterned fens in the Swan Hills, north central Alberta. Canadian Journal of Botany 53:2776–2795.

WALKER, J.M. 1965. Vegetation studies on the Delta Marsh, Delta, Manitoba. Ph.D. thesis, University of Manitoba, Winnipeg, Manitoba.

WESTGATE, J.A., D.G.W. SMITH, AND H. NICHOLS. 1969. Late Quaternary pyroclastics in the Edmonton area, Alberta. *In* Pedology and Quaternary Research. S. Pawluk, editor. University of Alberta Printing Department, Edmonton, Alberta. pp. 179–186.

ZARNOVICAN, R., AND J.L. BÉLAIR. 1979. Les tourbières de la Baie James: la végétation et les sols. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 9. Ottawa, Ontario. 37 p.

ZOLTAI, S.C. 1965. Glacial features of the Quetico-Nipigon area, Ontario. Canadian Journal of Earth Sciences 2:247–269.

ZOLTAI, S.C. 1971. Southern limit of permafrost features in peat landforms, Manitoba and Saskatchewan. Geological Association of Canada. Special Paper No. 9. pp. 305–310.

ZOLTAI, S.C. 1972. Palsas and peat plateaus in central Manitoba and Saskatchewan. Canadian Journal of Forestry Research 2:291–302.

ZOLTAI, S.C., AND J.D. JOHNSON. 1985. Development of a treed bog island in a minerotrophic fen. Canadian Journal of Botany 63:1076–1085.

ZOLTAI, S.C., AND J.D. JOHNSON. (In press). Relationships between nutrients and vegetation in peatlands of the prairie provinces. *In* Proceedings, Canadian Wetlands Ecology and Conservation Symposium. August 1987. Edmonton, Alberta.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H.Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

ZOLTAI, S.C., AND C. TARNOCAI. 1971. Properties of a wooded palsa in northern Manitoba. Arctic and Alpine Research 3:115–129.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12:28–43.

5 Wetlands of the Prairies of Canada

G.D. Adams

Wetlands of the Prairies of Canada

The Prairies combine the forest–grassland transition (or parkland) zone as conceived by Rowe (1972) with open grasslands in semi-arid to subhumid climates such that trees when present are never the dominant vegetation. The Prairies, defined by the Soil Conservation Society of America (1982) as treeless tracts of level to hilly land with a predominance of grasses and forbs, are concentrated in the southern portions of three of Canada's provinces—Alberta, Saskatchewan, and Manitoba—as well as in intermountain portions of British Columbia. In this chapter, the wetlands of two disjunct wetland regions defined by the National Wetlands Working Group (1986) are presented—the Continental Prairie Wetland Region (PC) and the Intermountain Prairie Wetland Region (PI) (Figure 5–1). These are bordered to the north and east on the Prairies by boreal wetland regions and by mountain wetland regions in British Columbia, as discussed in other chapters.

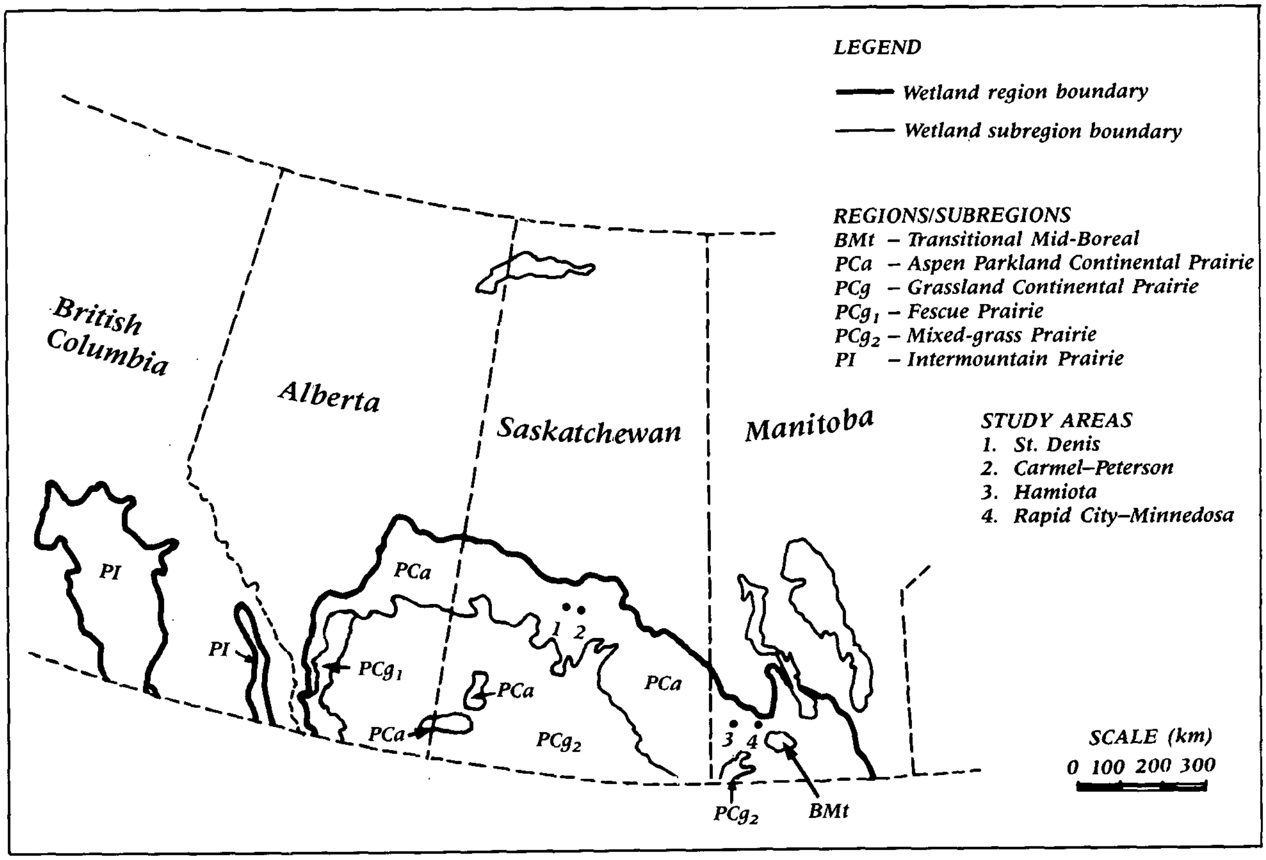


Figure 5–1.
Prairie wetland regions and subregions in western Canada and location of study areas noted in text.

Environmental Setting

Geography

The Continental Prairie Wetland Region occupies an area about 390 000 km² (Coupland 1961) extending in a northwest arc from latitude 49°N, longitude 96°30′ W, to latitude 54°N, longitude 113°W, and then southwards along the edge of the Alberta foothills to latitude 49°N, longitude 113°30′ W. Except for a northern outlier in the Peace River area, the northern boundary of the Continental Prairie Wetland Region meets the southern boundary of the mixed-wood or boreal forest (Strong and Leggat 1981).

The Continental Prairie Wetland Region comprises two subregions: the Aspen Parkland Continental Prairie Wetland Subregion (PCa) and the Grassland Continental Prairie Wetland Subregion (PCg). Although grasslands and parklands occur within the Intermountain Prairie Wetland Region, no subregions are recognized due to abrupt altitudinal gradients which affect climatic and vegetation changes within a localized area.

The Continental Prairie Wetland Region can be divided into three levels according to the elevation of underlying bedrock: (1) the Manitoba Lowland (elevation 220–335 m); (2) the Saskatchewan Plain (elevation 320–610 m); and (3) the Alberta High Plain (elevation 610–1 060 m) (Nicholson 1957; Richards and Fung 1969; Mitchell *et al.* 1944). The general terrain is level to undulating and rolling, broken by valleys, escarpments, and hills. The major drainages of the Continental Prairie Wetland Region are the South Saskatchewan, North Saskatchewan, Bow, Oldman, Red Deer, Qu'Appelle, Assiniboine, Souris, Swan, and Red rivers.

Located between the Rocky Mountains and the Coast Range, the Intermountain Prairie Wetland Region is situated on the Fraser and Kamloops plateaus (Nicholson 1957), encompassing an area described by latitudes 49 to 53°N and longitudes 115 to 123°W. Prairie grasslands occupy an area of more than 14 600 km² between elevations of 600 and 1 250 m, along the drainages of the Kettle, Chilcotin, Similkameen, Southern Fraser, Thompson, Nicola, Okanagan, Kootenay, and Columbia rivers (Tisdale 1947; Nicholson *et al.* 1982).

Geomorphology

The prairie landscape was largely shaped by the Pleistocene glaciers. Approximately 55% of the Continental Prairie Wetland Region consists of glacio-lacustrine and fluvial materials, whereas 40% consists of morainal materials (Coupland 1961). Deposits left during slow glacial retreats formed rolling ground moraines, temporary halts in glaciers formed steeply rolling end moraines and glacial meltwater channels, and the final stages of glacial disintegration formed hummocky moraines with knob and kettle topography (Kiel *et al.* 1972). Meltwaters scoured out valleys, deposited coarse-textured outwash, or accumulated in glacial lake basins to deposit silts and clays forming lacustrine plains. Several large sandy deltas deposited near the margins of glacial lakes were shaped by winds into sandhills when the waters receded. Bedrock uplands located in the southern Prairies are thinly glaciated, leaving numerous rock outcrops and dissected valleys.

The Manitoba Lowland portion of the Continental Prairie Wetland Region is underlain by flat-lying Mesozoic and Paleozoic bedrocks composed of sedimentary sandstone, limestone, shale, and dolomite (Nicholson 1957). Glacio-lacustrine clays and sandy deltaic deposits of varying thicknesses were left by the receding Glacial Lake Agassiz which at different stages covered most of the Manitoba Lowland. Areas of washed ground moraine, successive beach ridges, and alluvial sediments occupy the remainder of the Lowland. The predominant soils of the Lowland are Black and Dark Gray Chernozems and Gleysols (Weir 1960).

The Saskatchewan Plain is underlain by Cretaceous shale, except for Tertiary formations of sandstone, shale, and coal found in southeastern Saskatchewan (Nicholson 1957). The eastern boundary of the Plain is marked by cuestas, or remnant bedrock uplands, which are blanketed by morainal hills (Pembina, Riding, and Duck mountains). These formed topographic barriers to the expansion of Glacial Lake Agassiz, although rivers such as the Swan, Valley, and Assiniboine cut eroded reentrants to the glacial lake (Elson 1967). Local relief varying from 320 to 730 m influenced ice movements as glaciers sometimes overrode uplands and stagnated to form hummocky moraine (Edmunds 1962). Other prominent morainal uplands include Moose Mountain, Touchwood Hills, Allan Hills, and Minichinas Hills (Acton *et al.* 1960). Level to undulating plains occupying the former beds of glacial lakes Regina, Milden, Elstow, and Saskatoon are composed of lacustrine clays, silts, and fluvial sands (Edmunds 1962). Soils developed on these parent materials vary from Dark Brown, Black, and Dark Gray Chernozems to Solonetz.

Upper Cretaceous and Tertiary formations of sandstone, shale, and coal form the underlying bedrock throughout the Alberta High Plain (Wonders 1969). Outcrops of Cretaceous or Tertiary rocks are exposed on the tops of unglaciated plateaus or in eroded valleys and badlands. The eastern border of the High Plain is delineated by the escarpment of The Missouri Coteau. The uplands, which range from 730 to 1 370 m in elevation, include the Coteau, Eagle, Neutral, Rainy, and Cypress hills, and the Wood Mountain and Milk River Ridge (Acton *et al.* 1960; Wonders 1969). Glacial morainal deposits with minor areas of lacustrine silts and fluvial sands form the principal surface materials. Zonal soils develop, following a sequence from Brown in the semi-arid southeast to Black and Dark Gray Chernozems in the more humid northwestern edge of the High Plain.

The Intermountain Prairie Wetland Region occupies a series of eroded plateaus, hills, valleys, and terraces. A mantle of glacial drift overlies volcanic and sedimentary rocks of the Cenozoic, Mesozoic, and Paleozoic eras, with Tertiary deposits of major importance (Tisdale 1947). A variety of geomorphological processes has shaped and influenced the glacial drift and topography of the region (Ryder 1982). Fluvial down-cutting eroded the canyons and scarps; fluvial deposition resulted in floodplains, alluvial fans, and terraces; colluvial deposits formed talus and fans at the foot of slopes; and aeolian activity eroded dry valley landforms and deposited sand dunes and veneers on terraces and fans. Soils that developed on the glacial drift and alluvial terraces vary from Gray Luvisols to Dark Brown to Black Chernozems (Rowe 1972).

Climate

The Prairies are semi-arid, featuring cold winters, warm summers, and highly variable temperatures. In the Continental Prairie Wetland Region, midwinter isotherms run northwest to southeast, and temperature extremes vary from −40°C to 38°C (Hare and Thomas 1979). Summer temperatures usually decrease and rainfall increases with altitude and latitude. An east–west gradient from high to low summer humidity is due to the effects of the maritime tropical air masses usually affecting the eastern Prairies and the drier, modified maritime polar or maritime arctic air masses affecting the western Prairies. Lowest precipitation from May to September and highest soil moisture deficits are characteristic of the Intermountain Prairie Wetland Region, which is more arid than the Continental Prairie Wetland Region (Table 5–1).

The length of the growing season varies from 170 to 190 days (Hare and Thomas 1979), and the average length of the frost-free season ranges from 90 to 120 days in the Continental Prairie Wetland Region and from 100 to 140 days in the Intermountain Prairie Wetland Region (Chapman and Brown 1966). Approximately 50% of the precipitation received in the Continental Prairie Wetland Region falls from April through July, 25% from August 1 to October 31, and 25% in the winter (Coupland 1961). In the Intermountain Prairie Wetland Region, precipitation varies with altitude, but usually 25–40% of the annual precipitation falls from May to the end of September (Chapman and Brown 1966).

Winds and high temperatures contribute to high evaporation and surface water losses on the Prairies. Average wind speeds in the Grassland Continental Prairie Wetland Subregion range from 19 to 26 km/h, whereas wind speeds in the Aspen Parkland Continental Prairie Wetland Subregion average 14–19 km/h with maximums up to 50–60 km/h (Coupland 1961). Usually the winds with the highest velocity in summer are dry southwesterlies. They contribute to moisture losses and effectively limit shrub and tree growth on southern and western exposures.

Postglacial Ecology

Following the retreat of the Wisconsin Glacier from the southern Prairies (i.e. excluding areas in British Columbia) about 14 000 to 10 500 years before the present (BP), a boreal forest of spruce (*Picea* sp.) probably grew in proximity to the retreating ice, gradually moving northwards as the ice margin retreated (Ritchie 1976). South of latitude 52°N, an equally rapid replacement of the spruce forest by prairie vegetation occurred between 11 000 and 9 500 years BP. From 9 500 to 6 500 years BP, a deciduous forest comprising aspen (*Populus* sp.) and birch (*Betula* sp.) occupied a narrow belt west of the Glacial Lake Agassiz basin, separating the boreal forest from the grassland. This forest belt had shifted as far as latitude 55°N by 6 500 years BP. According to Love (1959), elements of the eastern deciduous forest invaded the rim of receding Glacial Lake Agassiz and then migrated westwards along river valleys, occupying uplands such as the Riding and Turtle mountains and the Tiger Hills. By 6 500 years BP most of the Lake Agassiz lowlands was occupied by prairie grassland. Oak (*Quercus* sp.) invaded the eastern uplands and the Assiniboine Delta between 4 000 and 3 000 years BP, eventually spreading

Table 5–1. Climatic variability in the prairie wetland regions and subregions

Wetland region or subregion	*Mean no. of growing degree-days*	*Mean Jan. temp. (°C)*	*Mean July temp. (°C)*	*Mean annual precip. (mm)*	*Mean May–Sept. precip. (mm)*	*Mean snow depth (cm)*	*Soil moisture deficit (cm)*
Aspen Parkland Continental Prairie (PCa)	850–1 400*	−12 to −18***	17–20***	300–450***	250–400*	15–30***	8–18****
Grassland Continental Prairie (PCg)	1 290–1 750*	−12 to −18***	18–21**	300–400***	170–290*	10–20***	18–30****
Intermountain Prairie (PI)	2 120**	−4 to −9***	18–20***	400–500***	100–200****	30***	30–40****

**Strong and Leggat (1981).*
***Hare and Thomas (1979).*
****Zoltai (1979).*
*****Chapman and Brown (1966).*

westwards along the Qu'Appelle River valley. Between 6 500 and 2 500 years BP, a climatic change to a cooler, moister period resulted in the southward migration of the boreal forest, replacing the grassland and occupying the approximate position of the modern boreal forest (Ritchie 1976). From 2 000 years BP to the present era, mixed forests have expanded, replacing deciduous forests and grassland on the Porcupine and Riding mountains. White spruce (*Picea glauca*) has invaded the parkland (Love 1959) and white spruce and white spruce–lodgepole pine (*Pinus contorta*) have been established as outliers in the Assiniboine Delta and Cypress Hills, respectively. In this century, the control of fires has contributed to the recent invasion of aspen into the prairie grassland (Bird 1961).

Hebda (1982) has outlined the postglacial history of the Intermountain Prairie Wetland Region as indicated by pollen records. A pioneering grassland occupied the deglaciated areas between 13 000 and 12 000 years BP. Between 12 000 and 11 000 years BP, forests of *Pinus* spp. and *Populus* spp. became established, but grasslands with sage (*Artemisia* spp.) persisted in the valley bottoms and at lower elevations. A peak period of grassland with a warm dry climate occurred between 10 000 and 8 000 years BP when sage grasslands occupied all lower elevations up to approximately 1 300 m. This was followed by a mesic period between 8 000 and 4 500 years BP, with continuous grass cover in lowlands and the occurrence of forest stands to about 1 100 m. From 4 500 years BP until recently, grasslands declined to occupy minimal areas on dry valley bottoms and south-facing slopes, and savannahs of *Pinus ponderosa* and *Pseudotsuga* spp. became widespread.

Prairie Wetland Regions and Subregions

The Prairies comprise two wetland regions: the Continental Prairie (PC) with its two subregions—Aspen Parkland (PCa) and Grassland (PCg)—and the Intermountain Prairie (PI).

Aspen Parkland Continental Prairie Wetland Subregion

The Aspen Parkland Continental Prairie Wetland Subregion (Bird 1961; Rowe 1972; Strong and Leggat 1981) comprises a belt of forest–grassland transition 50 to 160 km wide (Figure 5–1), occupying most of the Black and northern fringe of the Dark Brown Chernozem soil zones. Natural vegetation consists of large islands of aspen woodland (*Populus tremuloides*) in the north, and clumps and groves of aspen in the south, interspersed with rough fescue (*Festuca hallii*) (Pavlick and Looman 1984) or mixed-grass prairie (Coupland 1961). Under pristine conditions parkland is differentiated from grassland by the presence of more than 15% tree cover (Strong and Leggat 1981). Characteristic plant species include aspen and codominant balsam poplar (*Populus balsamifera*), willows (*Salix* spp.), Manitoba maple (*Acer negundo*), silverberry (*Elaeagnus commutata*), wolfberry (*Symphoricarpos occidentalis*), mossy cup oak (*Quercus macrocarpa*) on the eastern prairie, saskatoon-berry (*Amelanchier alnifolia*), wild sarsaparilla (*Aralia nudicaulis*), rose (*Rosa* spp.), bluegrass (*Poa* spp.), rough fescue, and northern wheatgrass (*Agropyron dasystachyum*). Prominent wetlands include fresh and variably saline marshes and semi-permanent shallow water ponds bordered by emergents, shrubs, and trees.

Grassland Continental Prairie Wetland Subregion

The Grassland Continental Prairie Wetland Subregion of the Continental Prairie Wetland Region consists of two dominant climax plant communities: fescue prairie (PCg1) and mixed-grass prairie (PCg2) (Strong and Leggat 1981) (Figure 5–1). Situated on Dark Brown and shallow Black Chernozem soils, the fescue prairie occupies the cordilleran foothills and benchlands of the Cypress Hills (Coupland 1961), where the climate is cooler and moister than that of typical mixed-grass prairie. Typical vegetation includes rough fescue (*Festuca campestris*) (Pavlick and Looman 1984), northern wheatgrass, slender wheatgrass (*Agropyron trachycaulum*), porcupine grass (*Stipa spartea*), hooker's oatgrass (*Helictotrichon hookeri*), sedges (*Carex* spp.), goldenrod (*Solidago missouriensis*), common yarrow (*Achillea millefolium*), and shrubby cinquefoil (*Potentilla fruticosa*) (Coupland 1961; Harris *et al.* 1983).

The mixed-grass prairie occupies semi-arid Brown and Dark Brown Chernozems, and Solonetzic soils. The vegetation consists of short and intermediate grasses such as porcupine grass, needle and thread (*Stipa comata*), blue grama (*Bou-*

teloua gracilis), northern wheatgrass, threadleaf sedge (*Carex filifolia*), and forbs such as prairie sagewort (*Artemisia frigida*) and moss pink (*Phlox hoodii*) (Coupland 1961). Shrubs such as silverberry, wolfberry, rose, and creeping savin (*Juniperus horizontalis*) are locally abundant. Scattered aspen and eastern cottonwood (*Populus deltoides*) may grow in river valleys. Prominent wetlands include rush-, sedge-, and grass-dominated marshes, and shallow water ponds lacking treed borders. Saline lakes are conspicuous features of the mixed-grass prairie.

Intermountain Prairie Wetland Region

The Intermountain Prairie Wetland Region is coincident with the montane forest region described by Rowe (1972) or the ponderosa pine (*Pinus ponderosa*)–bunch grass and interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) zones (Nicholson *et al.* 1982). Open grasslands merge with savannahs of ponderosa pine and occasional Douglas-fir in the southern part of the region. North of latitude 51°N, open grassland occupies lowlands and grades into aspen parkland and lodgepole pine–Douglas-fir forests.

Grasslands in the Intermountain Prairie Wetland Region consist of three dominant climax plant communities: the lower, middle, and upper grasslands as described by Tisdale (1947). The lower grasslands occupy valley bottoms below 600 m on fluvial and lacustrine terraces where the soils are chiefly Brown Chernozems and Regosols (Nicholson *et al.* 1982). The vegetation occupying mesic sites consists of bluebunch wheatgrass (*Agropyron spicatum*), sage brush (*Artemisia tridentata*), and Sandberg's bluegrass (*Poa sandbergii*). Dry sites may be dominated by needle grass and sand-drop-seed (*Sporobolus cryptandrus*). The middle grasslands occupy elevations of 600–900 m on Dark Brown Chernozems developed on gravelly, loamy moraines and silty aeolian deposits (Nicholson *et al.* 1982). Characteristic plant species include bluebunch wheatgrass, Sandberg's bluegrass, and rabbit-brush (*Chrysothamnus nauseosus*). The upper grasslands (800–1 250 m) occupy valley slopes and plateaus where Dark Gray, Black, and Dark Brown Chernozems have developed upon moraines with an aeolian mantle. According to Nicholson *et al.* (1982), three species associations occur: (1) bluebunch wheatgrass–rough fescue (*Festuca campestris*) and western fescue (*Festuca occidentalis* var. *ingrata*); (2) bluebunch wheatgrass–June grass (*Koeleria cristata*)–prairie sagewort; and (3) needle grass (*Stipa occidentalis* var. *minor*). Forbs such as common yarrow, lupine (*Lupinus sericeus*), and everlasting (*Antennaria rosea*) are common to the wheatgrass–fescue association.

Prominent wetland forms found in the Intermountain Prairie Wetland Region include floodplain, kettle, and shallow basin marshes dominated by grasses, rushes, and sedges, with occasional saline lakes in the valley bottoms.

Wetland Distribution and Abundance

Definition of Prairie Wetlands

Prairie wetlands and their associated vegetation impart scenic variety to the otherwise featureless landscapes of the Prairies. The less permanent wetlands undergo seasonal changes in aspect, changing from predominantly open water ponds in spring to drying basins covered by interspersed or closed stands of vegetation in summer. Vegetation changes from brown hues in spring to luxuriant greens in summer to varying shades of browns, yellows, and reds in the fall. Semi-permanent and permanent wetlands are characterized by a central open pond bordered by a fringe of persistent emergents such as cattail (*Typha latifolia*) or hardstem bulrush (*Scirpus lacustris* spp. *glaucus*). Drastic fluctuations in water levels causing drawdowns expose pond bottoms which are rapidly colonized by annual pioneering plants and some perennials. Reflooding usually kills all but the most persistent plants, resulting in expansion of germinating perennial emergents. Therefore, prairie wetlands are dynamic ecosystems, displaying seasonal and annual shifts in water regimes, vegetation zonation, and vegetation structure.

Dramatic cyclic changes in prairie wetlands may occur during a drought period. As a pond dries, plant succession in wetland communities usually proceeds from (1) a submergent stage, to (2) a marsh or emergent stage, to (3) a sedge meadow stage, to (4) a shrub stage, and to (5) a tree stage, in the parkland (Coupland 1961). A band of willows (*Salix petiolaris*) is usually located between high and low water levels around freshwater wetlands. At the high water level mark, *Salix discolor* and balsam poplar may form an outer band (Bird 1961). Persistent high water levels tend to reverse successional sequences, because the shrubs and trees are drowned. On slightly alkaline wetlands, sedges (*Carex* spp.) merge with prairie grasses (Coupland 1961).

Changes in vegetation zonation induced by the water regime create problems in delineating the boundaries of individual wetlands. Prairie wetlands usually fulfil the criteria for wetlands defined by Zoltai *et al.* (1975) and by Cowardin *et al.* (1979) as: (1) lands having water tables at or close to the surface; (2) areas with hydric soils and hydrophytic vegetation; or (3) areas covered by shallow waters usually less than 2 m deep. However, periodically during prairie droughts water tables may drop beneath the basins by more than 1 m; if this occurs, the prairie wetlands do not conform to the criteria for wetland classification because vegetation shifts to more xeric species. Millar (1976) defines wetlands by using the upper boundary set on the upland edge of the wet meadow. The wet meadow is a transitional wetland subform characterized by shifting boundaries, temporarily flooded or saturated conditions, and mesophytic species. With the exclusion of the wet meadow, the delineation of wetlands is improved by the utilization of the upper boundary of hydrophytic vegetation such as the shallow marsh (Millar 1976) or fen (Stewart and Kantrud 1971), which are more stable wetland conditions characterized by hydric or Gleysolic soils and subject to seasonal to permanently flooded water regimes.

Density of Prairie Wetlands

About 40% of the Continental Prairie Wetland Region, or 156 000 km², consists of ground or hummocky moraines (Coupland 1961), which produce landscapes pitted with numerous depressions of varying sizes. The remaining 60% of these landscapes consist of mostly lacustrine and fluvial materials which average less than five wetlands per square kilometre (Adams and Hutchison 1976). However, the density of wetlands varies regionally according to surface form patterns, relief, and the composition of glacial materials. On moraines, wetland densities as high as 60/km² (Harmon 1970) or even 90/km² (Munro 1963) have been observed. Normally, average wetland densities range from 9 to 13/km² in North Dakota (Cowardin *et al.* 1981), 20 to 28/km² in southwestern Manitoba, and 20/km² in central Saskatchewan (Table 5–2), with similar densities in central Alberta (Smith 1971). Based upon an assumed average wetland density of 18/km² for moraines and 5/km² for lacustrine–fluvial landscapes, the total estimated number of wetlands in the Continental Prairie Wetland Region is approximately 4 million. This estimate is lower than estimates of 6.6 million by Lynch *et al.* (1963) and 10 million estimated by Gollop (1963), although about 70% of the latter were considered temporary water areas.

Table 5–2. ***Regional differences in spring pond densities* on moraines in Saskatchewan and Manitoba (1976)***

Study area	Density (No. of ponds/km²)	No. of 65 ha plots sampled
Saskatchewan		
Carmel–Peterson	21.4±4.5**	14
St. Denis	20.0±4.0	15
Manitoba		
Hamiota	20.0±3.2	20
Rapid City	27.9±4.6	20

*Determined from ground surveys on random 65 ha plots.
**95% confidence limit.

Despite the relatively small size of prairie wetlands, their cumulative area covers a substantial portion of the land surface. On moraines in Saskatchewan, 36–63% of wetlands are less than 0.2 ha in size (Table 5–3), and few exceed 10 ha. Cowardin *et al.* (1981) recorded median sizes of 0.08 ha for temporary ponds and 0.8 ha for semipermanent ponds in North Dakota. In Alberta, 59% of ponds are 0.04–0.42 ha (Merriam 1978). Relative wetland coverage is 6.3–14.6% on the coteau and drift plains of North Dakota (Cowardin *et al.* 1981), 7.3–14.2% on hummocky moraines in central Saskatchewan, and 12.3–25.0% on ground and hummocky moraines in Manitoba (Table 5–4). In the Intermountain Prairie Wetland Region the cumulative area of wetlands, estimated at 23 954 ha, covers about 1.6% of the grassland area (British Columbia Ministry of Agriculture and Food 1981).

Table 5–3. Size class frequencies of wetlands in two Saskatchewan study areas (April 1976)

Size class of ponds (ha)	St. Denis		Carmel–Peterson	
	No. of ponds	%	No. of ponds	%
0–0.10	75	38.5	36	18.5
0.11–0.20	48	24.6	35	17.9
0.21–0.40	27	13.8	50	25.6
0.41–1.00	28	14.4	42	21.5
1.01–2.00	13	6.7	20	10.3
2.01–5.00	3	1.5	7	3.6
5.01–10.00	1	0.5	5	2.6
Total	195	100	195	100

Table 5–4. Yearly changes in proportional surface area occupied by wetlands in Saskatchewan and Manitoba (1974–1977)

Area	No. of plots	Amount of study area* occupied by wetlands (%)				Average
		1974	1975	1976	1977	
Saskatchewan						
St. Denis	14	7.7	8.1	7.3	—	7.7
Carmel–Peterson	15	13.3	14.8	14.4	—	14.2
Manitoba						
Hamiota	20	12.3	9.2	11.4	9.4	10.9
Rapid City	20	25.2	16.8	19.5	14.3	19.0

*Study areas are 13 km² in size in Manitoba and 9.1 km² at St. Denis and 9.8 km² at Carmel–Peterson in Saskatchewan.

Hydrology of Prairie Wetlands

Water Source and Runoff

Available water in prairie wetlands fluctuates widely both seasonally and annually, because it is dependent upon precipitation, water penetration, seepage inflow, runoff, and the surrounding topography. A hydrological regime consists of the following attributes: (1) source of water; (2) velocity of water movement; (3) renewal rate depending upon volume, frequency of precipitation, and flooding; and (4) seasonality (Gosselink and Turner 1978).

Snow is a major source of water, usually responsible for 25% of the precipitation but contributing 30–50% of the runoff to potholes (Shjeflo 1968). Snow accumulates in depressions or on the lee side of hills. The amount of runoff released from snowmelt is a function of melt rate, timing of melt, velocity of flow through the snow pack (Granger *et al.* 1978), and the saturated or frozen condition of the ground (Eisenlohr and Sloan 1968). Higher melt rates cause higher ratios of runoff to infiltration. Measurements of snowmelt rates (6.3–12.2 mm/day) have exceeded measurements of total discharge from snow packs (3.0–8.4 mm/day) (Granger *et al.* 1978). The amount of runoff water intercepted by a wetland depends more on the size of the contributing watershed than on the depth of the snow pack (Granger *et al.* 1978; Millar 1976).

Other sources of water are rainfall and seepage inflow. Direct precipitation on the pond surface can supply up to 50% of water received by a basin (Shjeflo 1968). Sudden increases in water levels may be caused by heavy infrequent rains and rapid runoff. Light rainfall occurring after dry periods contributes very little water as it infiltrates the soils rapidly. Wetlands which are in contact with the groundwater table may receive seasonal seepage inflows. In a permanent water body, basin inflow exceeds water loss due to evapotranspiration, overflow, or seepage outflow.

Wetland Catchment

Wetland formation and development depend upon periodic or seasonal catchment of surface water in depressions or discharge of groundwater at local sites. Novitzki (1978) identified four hydrological classes of standing water: (1) "surface water depression", where precipitation and overland flow collect in a depression elevated above the groundwater table; (2) "surface water slope", where wetlands occupy margins or littoral zones of lakes or streams receiving most water by overflow; (3) "groundwater depression", which intercepts flows from groundwater as well as overland and seepage inflow; and (4) "groundwater slope", where constant discharges of springs occur on or at the base of slopes, forming wetlands where drainage is impeded. Other classes of water catchment include overflow and channel wetlands as defined by watershed position (Millar 1976).

Water Tables and Groundwater Movement

The water table is the surface of a saturated zone in soils where vapour pressure is atmospheric; however, above the water table there is usually a continuous zone of capillary saturation where vapour pressure is less than atmospheric (Sloan 1970). In permeable materials, the water table is usually continuous with the water surface of ponds. According to Eisenlohr and Sloan (1968), groundwater movement is related to permeability and local topography; hence, the water table is usually a subdued image of the topography and the groundwater moves down a pressure gradient. In upland areas, water flow is generally downward, but upward and lateral flows can occur.

Normally there are three types of groundwater flow in ponds: (1) outflow; (2) throughflow; and (3) inflow (Sloan 1970). Outflow basins recharge through downward seepage to a water table which slopes away from the pond. Recharge wetlands, which usually occupy small basins on top of larger hummocks or in high-relief moraines, are often characterized by a ring of willow (*Salix* sp.) (Meyboom 1967a). Throughflow basins are characterized by a water table sloping down to the basin water surface on one side and sloping away from the opposite side of the basin (Sloan 1970). Inflow or discharge basins have water levels situated at elevations below surrounding water tables which slope to the basins.

On the Prairies, three groundwater flow systems are recognized: (1) regional; (2) intermediate; and (3) local (Meyboom 1967a). Regional systems involve large, deep flows or aquifers, which discharge only in regional lowlands or into deep lakes. The discharge areas of intermediate flow systems often contain permanent lakes more than 4 ha in size. Local systems involve groundwater flows between hummocks and depressions with discharges into semi-permanent ponds.

Seasonal and diurnal changes occur in groundwater flows in hummocky moraine, as the hydrology of a wetland may shift seasonally between discharge and recharge situations (Meyboom 1967a). In early May an initial rise in the water table above the pond water levels is probably due to thawing of ground frost (Shjeflo 1968). Elevated mounds of groundwater are produced under depressions in the spring, caused by infiltrating meltwaters (Meyboom 1966). By summer this condition changes to an inverted water table with a depression cone formed beneath the phreatophytic vegetation. These phreatophytes, such as willow, withdraw groundwater by evapotranspiration, eventually creating a reversal flow. Subsidence of the groundwater divide between adjacent ponds permits net shallow seepage flow between ponds in late summer or fall (Meyboom 1967a). By fall there is a normal downward flow from the depressions (Meyboom 1966) as the water table drops considerably below the pond surface.

Water Losses

Gradual decreases in water levels on prairie ponds are attributed to evapotranspiration and seepage outflow. According to Shjeflo (1968), variables influencing evapotranspiration rates are wind speed, barometric pressure, water body size and depth, roughness of the water surface, and air vapour pressure. Rates of evaporation increase with air temperature and vary inversely with water depth, as shallow waters tend to warm faster. Driver and Peden (1977) found that evaporation accounts for 5–25% of water volume lost seasonally from temporary ponds and 35–55% lost seasonally from semi-permanent and permanent ponds. Seasonal losses due to evaporation from vegetated ponds are reduced as a result of the interception of solar radiation and the sheltering effect of emergent vegetation (Shjeflo 1968; Eisenlohr 1972). The hydrophytes contribute to greater loss rates through transpiration, with these rates correlated with the heights of emergent plants (Eisenlohr 1972).

Seepage losses are usually greater and more than compensate for reduction of evapotranspiration in vegetated ponds (Shjeflo 1968). Seepage outflow has been measured at less than 3 mm/day over pond surfaces, although it is higher at the edges and may be extremely variable. Coarse materials at pond edges, and slow downward percolation through the vertical joints in impervious moraine, facilitate water outflow (Eisenlohr 1972). The relationship between seepage inflow and outflow often determines the freshness of water as salts concentrate in ponds with no outflow.

The rate of water loss in prairie wetlands is a function of pond size, pond depth, and shoreline–water area ratios (Millar 1976). Wetlands less than 0.4 ha usually lose all surface waters annually (Millar 1976) whereas wetlands larger than 2 ha are usually permanent (Dix and Smeins 1967). Small wetlands are prone to higher shoreline-related water losses due to proportionately more shoreline in relation to remaining water volume. According to Millar (1971), shoreline-related water loss accounts for 60% of the total loss from ponds less than 0.04 ha in size, up to 50% of the loss from ponds 0.05 to 0.3 ha, and 30–35% of the loss from ponds larger than 0.4 ha. Most of this loss occurs as evaporation and transpiration from the soil surface and marginal vegetation. Rates of loss fluctuate during May, stabilize in early June, increase to a peak in late July and August, and decline later in the fall.

Prairie Wetland Classification

Classification Hierarchy

According to the National Wetlands Working Group, wetlands in Canada are classified into a three-level hierarchical system proceeding in descending order of (1) class, (2) form, and (3) type (Tarnocai 1980). A classification key and definitions of wetlands in these three levels are presented in Appendix I. In the Prairies, three wetland classes are present: (1) marsh, (2) fen, and (3) shallow water. At least 20 wetland forms and a variety of wetland types occur as listed in Table 5–5. In addition, six subdivisions, called "subforms", of the marsh and shallow water forms are herein proposed to classify wetlands further according to water regime and salinity gradients. Classes, forms, subforms, and types are arranged hierarchically to show relationships. The subforms and types are described in more detail, followed by site descriptions of wetland examples found in the Prairies.

Wetland Forms

Prairie wetland forms are defined primarily by surface morphology such as the nature of the confining topography, by the surface mineral deposits, and by the origin of surface waters. Most prairie wetlands occupy glaciated terrain as illustrated by kettles and shallow basins, by water-eroded landforms such as valleys, streams, or channels, and by water-deposited landforms such as glacial lakebeds, floodplains, or deltas. Some wetlands exist because they occupy discharge sites of springs or groundwaters. Hydrotopographic features such as position in the watershed, physical features of the site (size, slope, depth, and material), and the gradient, linkage, and elevation of basins in relation to groundwater levels are all variables influencing the hydrology and development of wetland forms.

Table 5–5. ***Prairie wetland classification terminology***

Class	*Form*	*Subform*	*Type*
Marsh	Active delta Channel Floodplain Inactive delta Kettle Seepage track Shallow basin Shore Stream Terminal basin	Deep marsh Shallow marsh Wet meadow	Low rush Mixed forb Mixed grass Non-vegetated Sedge Sedge–grass Tall grass Tall rush Tall shrub
Shallow water	Channel water Delta water Kettle water Oxbow water Shallow basin water Shore water Stream water Terminal basin water	Intermittent open Intermittent saline lake Permanent open	Floating aquatic Non-vegetated Submerged aquatic
Fen	Basin Spring	—	Low shrub Sedge Sedge–grass Tall grass Tall rush Tall shrub

Prairie Wetland Subforms

The size of the water catchment or drainage area, the seasonal climate, the supply of groundwater, and the basin depth are characteristics that ultimately influence water permanency and, hence, the development of wetland vegetation. Factors that influence the development of vegetation in wetlands include periodicity, depth, duration, and extent of surface waters, as well as salinity and land use. Water regime exerts a controlling influence over the spatial and structural aspects of wetland development and wetland cover, and is the most important environmental gradient affecting wetlands (Walker and Coupland 1970). However, vegetation zonation rather than water regime is a better predictor of water permanency because water depths are seasonally and annually unstable. The presence or absence and the distributional pattern of vegetation are factors used in classifying prairie wetlands (Stewart and Kantrud 1971).

Although they are often transitory, wetland vegetation zones occupy predictable positions and sequences in prairie wetlands as determined by average environmental gradients. Kettle marshes with symmetrical profiles may show concentric bands of vegetation proceeding from an outer wet meadow to the open water, with the plant species present influenced by competition, adaptation, and germination conditions related to the duration of flooding (Weller 1978). Reversals of normal patterns may occur due to asymmetric basin profiles or to drawdown–flooding sequences whereby pioneering vegetation may become established in a former open water area (Millar 1976). These vegetation zones are differentiated by gradients in height, structure, and species composition and are further modified by different phases influenced by flooding, drawdown, and disturbance (Stewart and Kantrud 1971). The normal pattern, sequence, and position of the respective zones in relation to the basin centre or central pond are useful for classifying wetlands into permanency categories or subforms.

The following subforms are recognized as integral units of wetlands, and are named according to the wetland area dominating the central portion of the basin under normal water regimes (Stewart and Kantrud 1971; Millar 1976).

Wet Meadow

Although not considered true wetlands, wet meadows are transition areas occupying the central area of shallow depressions or peripheral bands of deeper ponds (Figure 5–2). Surface water persists temporarily for a few weeks in spring or after heavy rains, but is usually lost by rapid bottom seepage and evapotranspiration. Wet meadows are dominated by low to intermediate grasses, sedges, and herbs. Characteristic species include *Poa palustris*, *Calamagrostis inexpansa*, *Hordeum jubatum*, *Carex lanuginosa*, *Juncus balticus*, *Rumex maritimus*, *Mentha arvensis*, and *Salix petiolaris*.

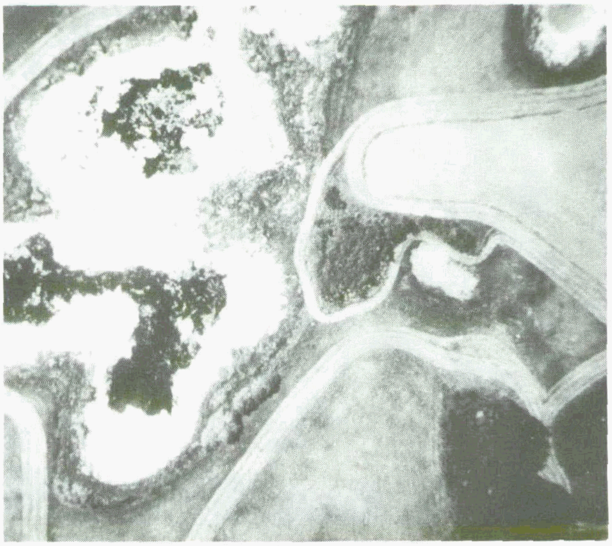


Figure 5–2.
Low oblique aerial view (1977) of shallow basin marsh showing zonation of open water, shallow marsh, and wet meadow, located near St. Denis, Saskatchewan (52°15′ N, 106°01′ W).

Shallow Marsh

The shallow marsh subform often forms an inner band to the wet meadow and may occupy central areas of seasonal ponds, or marginal bands of semi-permanent to permanent ponds or saline lakes. This area includes the "marsh–meadow" and shallow marsh areas which have 0–30 cm of water until midsummer (Walker and Coupland 1970) and it is classified as saturated to seasonally flooded (Cowardin *et al.* 1979). Having emergent, drawdown, open water, and disturbance phases, the shallow marsh is typically classified as an area with coarse grasses and sedges of intermediate height associated with water-tolerant herbs and some floating plants. By late summer this area is usually dry and exhibits a continuous cover of vegetation (Figures 5–3 and 5–4). Characteristic plant species include *Carex atherodes, Glyceria grandis, Scolochloa festucacea, Beckmannia syzigachne, Eleocharis palustris, Sparganium eurycarpum, Alisma plantago-aquatica, Polygonum coccineum, Sium suave,* and *Potamogeton gramineus.*

Deep Marsh

The deep marsh subform, also called "emergent deep marsh" by Millar (1976), is flooded until late summer or fall, and usually retains 1–30 cm of water (Walker and Coupland 1970). It occupies central areas of semi-permanent ponds or forms marginal bands bordering open water on permanent ponds. Depending upon water periodicity, deep marsh subforms may exhibit open water, emergent, or drawdown areas, usually with interspersed, patchy, or closed vegetation cover. Coarse or robust tall emergents such as reeds and rushes, tall grasses, and some floating leaf and submergent species are common. Species include *Scirpus lacustris* spp. *glaucus, Scirpus lacustris* ssp. *validus, Scirpus fluviatilis, Scirpus maritimus, Typha latifolia, Typha angustifolia, Phragmites australis, Potamogeton pusillus, Ceratophyllum demersum,* and *Drepanocladus* sp.

Intermittent Open Water

Intermittent open water is a periodically stable open water area which may persist for several years alternating as shallow marshes or drawdowns during dry periods (Figure 5–5). Also called "transitional open water" by Millar (1976), this prairie wetland subform usually develops by prolonged inundation of shallow marsh or deep marsh, causing die-offs of emergent plants. Typical submergent plant species characteristic of permanent open water are absent or slow to develop. Predominant floating and submergent plant species include *Potamogeton gramineus, Utricularia vulgaris, Potamogeton pusillus,* and *Ranunculus subrigidus* (Millar 1976).

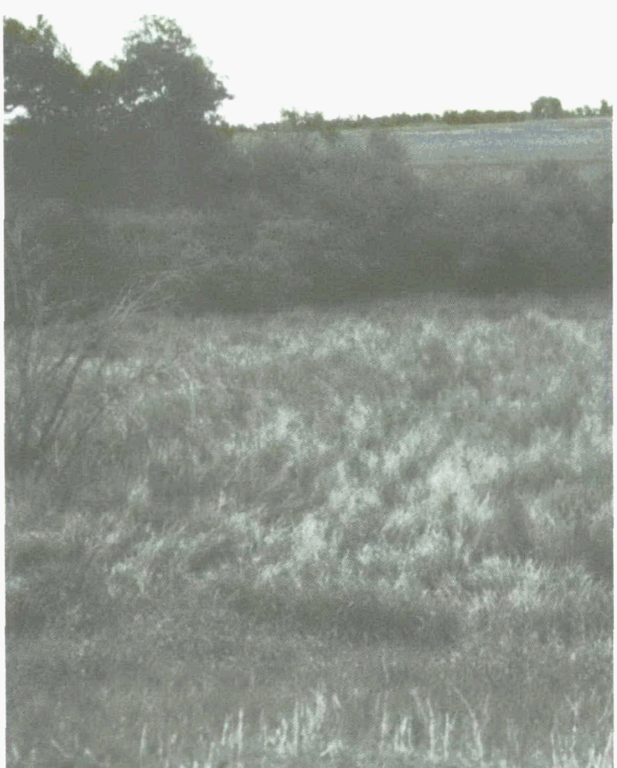


Figure 5–3.
Ground view (1972) of shallow marsh dominated by sedges with a bordering wet meadow and willow fringe, located near McConnell, Manitoba (50°19′ N, 100°36′ W).

Figure 5–4.
Ground view of drawdown basin which was formerly a shallow marsh, showing mats of pioneering vegetation such as Eleocharis acicularis *growing on mudflats, located near Carmel, Saskatchewan (52°15′ N, 105°21′ W).*

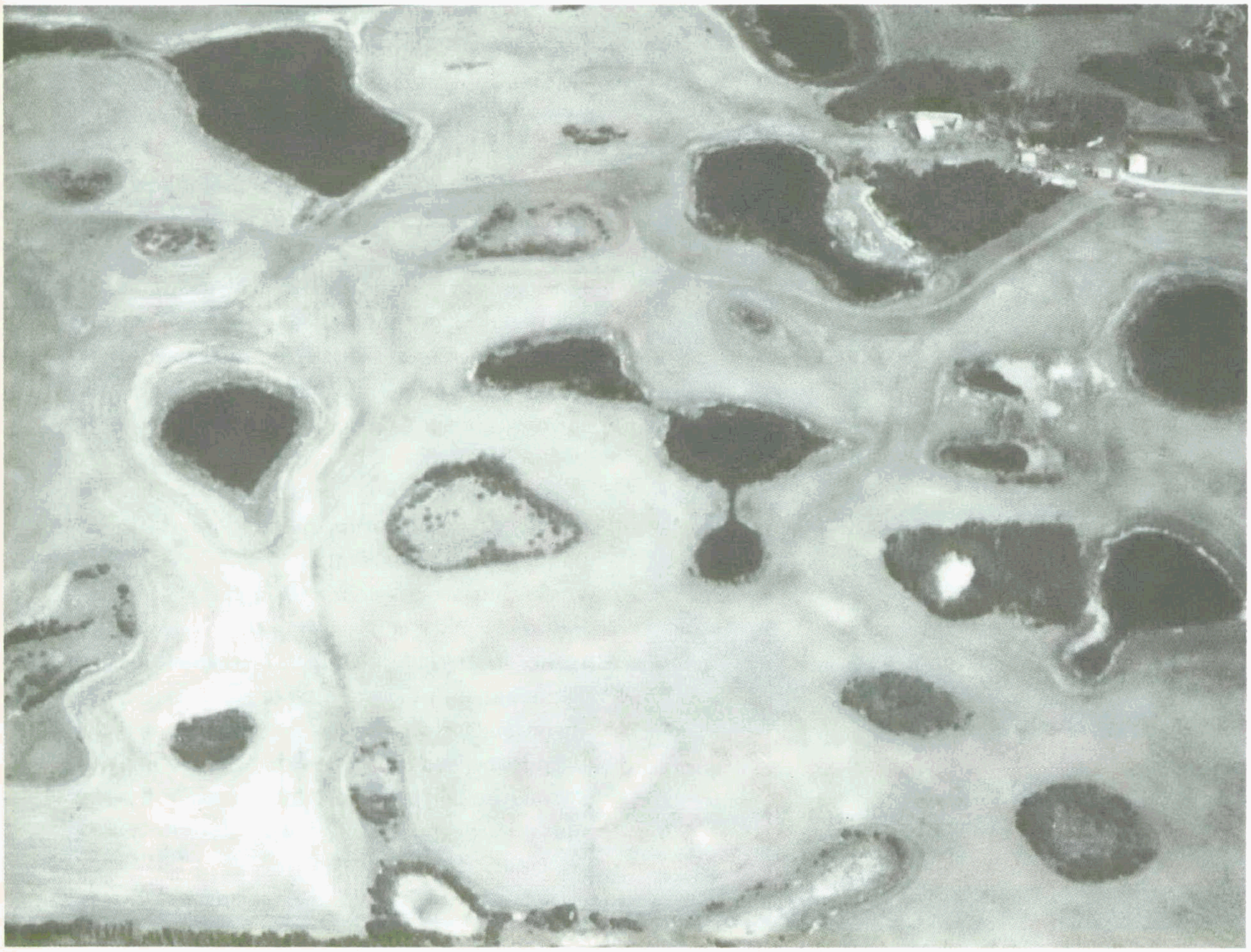


Figure 5–5.
Oblique aerial view of kettle basins holding semi-permanent and seasonal water on hummocky moraine near Rapid City, Manitoba (50°10′ N, 100°04′ W). Most of the upland is cultivated.

Permanent Open Water

Permanent open water, also called "shallow open water" by Millar (1976), is a stable shallow open water subform occupying the central or deepest portion of a basin, where water depths by September exceed 20 cm and may be 1 m or more (Walker and Coupland 1970). Submergent and floating aquatic plants characteristic of permanent open water are *Ruppia occidentalis*, *Potamogeton vaginatus*, *Potamogeton pectinatus*, *Potamogeton perfoliatus* ssp. *richardsonii*, *Myriophyllum spicatum* var. *exalbescens*, and *Ceratophyllum demersum*.

Intermittent Saline Lake

The intermittent saline lake is a shallow open water subform, also called "open alkali" by Millar (1976), which occupies periodically flooded flats or terminal basins where alkali salts (sodium [Na], calcium [Ca], and magnesium [Mg] sulphates and chlorides) are concentrated by evaporation (Figures 5–6 and 5–7). The only plant species that roots in such areas is *Ruppia maritima*, although an outer, less saline perimeter may be vegetated by *Scirpus maritimus*, *Scirpus americanus*, *Salicornia europaea* ssp. *rubra*, and *Suaeda maritima*. An expanded discussion of intermittent saline lakes can be found in the section on "Salinity and Wetland Development" in this chapter.

Wetland Types and Distribution

Wetland type constitutes the third level of the three-level hierarchical system used to classify wetlands, the first two levels being class and form. Wetland type refers to plant lifeform or general physiognomy of vegetation cover which is used in connection with wetland form (Tarnocai 1980). In the case of prairie marshes, the type description should refer to the vegetation which is usually

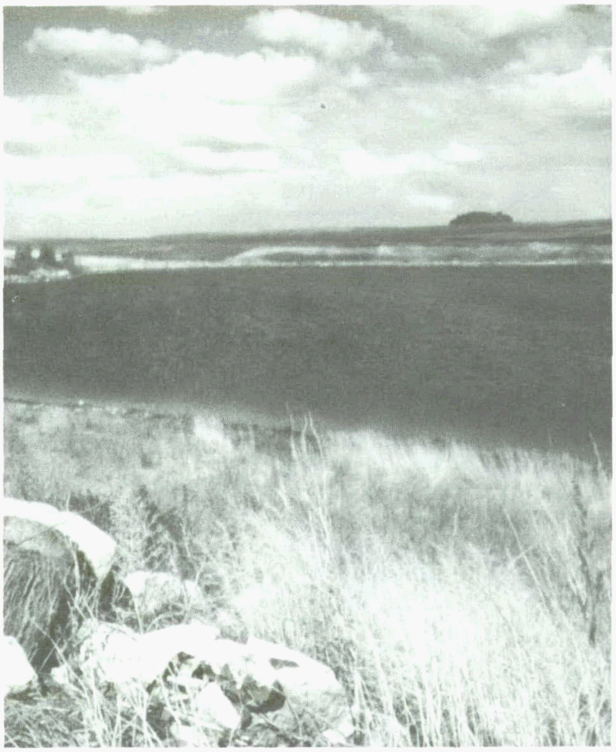


Figure 5–6.
Ground view of kettle shallow water wetland — a saline pond located near St. Denis, Saskatchewan (52°12′ N, 105°59′ W).

Figure 5–7.
Ground view of saline lake showing barren shore areas and halophytic vegetation such as Salicornia europaea *ssp.* rubra *bordering open water, located near Brumlie, Manitoba (50°17′ N, 100°22′ W).*

central or dominant in the basin. Emergents may be dominant despite the presence of central open water. Whenever dominance is difficult to determine in a large prairie marsh, the type should be described as a complex.

The wetland types common to prairie wetlands are listed together with prevailing plant associations in Table 5–6. Combinations of these types may occur in a zonal sequence on large wetlands, and mixed types such as sedge–grass are common. Tall shrubs are usually associated with wetland borders or wet meadows. Mixed forb types are most common in shallow marshes with saline, disturbed, or drawdown marsh conditions. Tall grass species such as *Scolochloa* and *Phragmites* are usually associated with the periphery of semipermanent to permanent marshes, whereas other grasses and sedges are usually dominant in shallow marsh and wet meadow subform areas. Short rushes are usually abundant in shallow marsh, wet meadow, or drawdown areas, whereas tall rushes such as *Scirpus* spp. are found in emergent deep marshes or in saline marshes. Floating and submerged aquatic plants are dominant in open pools in deep marshes or in shallow water wetlands.

The relative composition of marsh types such as sedge, rush, and tall grass varies regionally across the Continental Prairie Wetland Region (Table 5–7). In Manitoba, there are more rush marshes on hummocky moraine than on ground moraine, whereas sedge marshes are more common on the latter. Similarly, in central Saskatchewan, rush marshes and shallow open water have been observed to occur more frequently on moraines of high relief than on those of low relief (Table 5–7). Factors contributing to these differences are the larger, deeper, and more permanent kettles associated with hummocky, high-relief moraine.

Descriptions of Selected Prairie Wetland Forms

Site examples of a variety of prairie wetland forms and types are presented in this section. The following wetland forms with associated wetland types, all common in the Continental Prairie Wetland Region, are described and illustrated. Soil and water quality measurements are shown in Table 5–8. The descriptions relate to conditions as they were in 1972, when surface water levels were returning to normal, following high precipitation in 1970 and 1971. These wetlands had not yet been subjected to the severe modifications resulting from intensive agricultural development which has occurred since the mid-1970s (Rakowski and Chabot 1983).

Floodplain Marsh, Rush Type

This floodplain marsh, located on the Newdale Plain, Manitoba, occupies an abandoned channel of the Minnedosa River valley (50°30′ N, 100°22′ W). The wetland is 0.9 ha in size with a

Table 5–6. Wetland types and representative plant associations*

Wetland type	Association—dominant species
1. Tall shrub	*Salix petiolaris–Salix discolor*
2. Mixed forb	*Salicornia europaea* ssp. *rubra–Suaeda maritima* *Alisma plantago-aquatica–Sium suave* *Sagittaria cuneata–Hippuris vulgaris* *Rumex maritimus–Rorippa* sp.*–Polygonum amphibium*
3. Tall grass	*Scolochloa festucacea–Phragmites australis*
4. Mixed grass	*Distichlis stricta–Puccinellia nuttalliana* *Beckmannia syzigachne–Alopecurus aequalis* *Hordeum jubatum* *Calamagrostis neglecta*
5. Sedge or sedge–grass	*Carex aquatilis–Eleocharis palustris* *Carex atherodes–Scolochloa festucacea* *Carex rostrata–Glyceria grandis*
6. Tall rush	*Scirpus maritimus* *Scirpus lacustris* ssp. *validus* *Typha latifolia* *Scirpus lacustris* ssp. *glaucus–Typha latifolia*
7. Short rush	*Juncus balticus–Carex lanuginosa* *Triglochin maritima–Scirpus americanus* *Juncus bufonius–Isoëtes* sp.*–Alopecurus* sp. *Juncus balticus–Eleocharis palustris*
8. Floating aquatic	*Lemna trisulca–Lemna minor* *Potamogeton gramineus*
9. Submerged aquatic	*Myriophyllum spicatum–Ceratophyllum demersum* *Utricularia vulgaris* *Potamogeton pectinatus–Chara* sp. *Potamogeton pusillus–Ranunculus circinatus*

**Representative plant associations from Looman (1981, 1982) and Millar (1976).*

Table 5–7. Percent composition of emergent dominant wetland types in Saskatchewan and Manitoba (spring 1976)*

	St. Denis		Carmel–Peterson		Hamiota		Rapid City	
Wetland type**	No.	%	No.	%	No.	%	No.	%
Tall shrub	44	20.1	51	23.2	34	12.9	24	6.6
Sedge	86	39.3	65	29.5	69	26.1	32	8.9
Grass—mixed	16	7.3	16	7.3	10	3.8	13	3.6
—tall	55	25.1	33	15.0	98	37.1	139	38.5
Mixed forb***	3	1.4	2	0.9	1	0.4	1	0.3
Rush—cattail	9	4.1	44	20.0	35	13.3	89	24.7
—bulrush	4	1.8	1	0.5	0	0.0	19	5.3
—mixed	0	0.0	3	1.4	1	0.4	27	7.5
Aquatic****	2	0.9	5	2.3	16	6.1	17	4.7
Total wetlands	219	100	220	100	264	100	361	100

**Determined from wetlands with surface water in April to May.*
***Dominance determined by vegetation occupying basin centre or marginal band adjacent to open water and covering more than 30% of perimeter.*
****Mixed forb may be underestimated due to lack of seasonal persistence of plants.*
*****Central open water devoid of residual standing emergents and lacking shallow or deep marsh emergent bands.*

Table 5–8. Soil and water chemical analyses of selected prairie wetland forms/types

	Surface water				Submerged soil					
Wetland form (type)	pH	Specific conductivity (mS/cm)	Total alkalinity (mg/kg)	SO_4 (mg/kg)	Soil texture*	Specific conductivity (mS/cm)	Organic C (%)	NO_3-N (mg/kg)	PO_4 (mg/kg)	K (mg/kg)
1. Floodplain marsh (rush)	—	1.5	167	569	SiL	—	—	—	—	—
2. Stream marsh (sedge–grass)	8.0	1.1	—	—	C	0.8	6.1	1.0	12.0	585
3. Channel marsh (rush)	8.0	1.1	—	—	L	2.7	9.6	5.4	5.0	460
4. Terminal basin shallow water (submergents)	10.0	8.6	—	—	SCL	3.0	1.0	3.8	8.0	450
5. Shallow basin marsh (sedge)	8.2	0.4	187	3	C	0.5	7.4	2.4	9.0	700
6. Kettle marsh (rush)	—	2.1	120	507	C	1.3	3.2	2.4	3.0	445
7. Kettle shallow water (submergents–floating)	9.0	1.9	294	797	L	2.4	11.6	1.8	3.0	600

**Soil texture as: C—clay, L—loam, CL—clay loam, SiL—silt loam, SCL—sandy clay loam.*

perimeter length of 0.7 km, and 22% of the area is open water (Figures 5–8 and 5–9). Surface water originates by backflooding into the channel from a permanent stream, although some groundwater seepage may be involved. The marsh is a semi-permanent, freshwater wetland. On August 8, 1972, the water depth taken 10 m from the shoreline was 45 cm; the deep marsh area on this wetland was drawdown.

This marsh includes three subforms characterized by specific bands of vegetation: permanent open water–aquatic, drawdown deep marsh, and shallow marsh which includes a disturbed zone. The open water area, which is only 5 m in diameter, contains the following submerged aquatics: *Hippuris vulgaris, Sagittaria cuneata, Myriophyllum spicatum,* and *Potamogeton perfoliatus* ssp. *richardsonii*. Vegetation in the deep marsh, 3–6 m wide, is of patchy distribution and consists of *Sparganium eurycarpum, Scirpus lacustris* ssp. *validus, Typha latifolia,* and *Alisma plantago-aquatica*. The inner shallow marsh, which consists of *Carex* spp., *Beckmannia syzigachne,* and *Scirpus lacustris* ssp. *glaucus*, is 6–12 m in width. The outer disturbed shallow marsh (15–40 m) consists of *Carex* spp., *Beckmannia* sp., and *Scolochloa festucacea*. The surrounding valley bottom is used as a hay meadow.

Stream Marsh, Sedge–Grass Type

Located in a channel of the Oak River, Manitoba (50°19′ N, 100°36′ W), this freshwater wetland (Figures 5–10 and 5–11) is about 3.2 ha in size, with a perimeter length of 2.2 km bounded by the stream banks. Surface water furnished by runoff and intermittent stream flow is semi-permanent; on July 27, 1972, it exceeded a depth of 68 cm as measured 15 m from the shoreline. Open water pools occupy 26% of the wetland area and average 10–30 m in diameter.

Submergent and floating vegetation common to the open water areas are *Utricularia vulgaris, Lemna trisulca,* and *Lemna minor*. The bordering shallow marsh (10–50 m wide) consists of patchy stands of *Scolochloa festucacea, Carex* spp., *Eleocharis palustris, Typha latifolia,* and *Sium suave*. On July 27, 1972, about 14 m of this shallow marsh band was drawdown. The wet meadow, which occupies a 15–25 m band, consists of *Calamagrostis inexpansa, Poa palustris,* and *Salix* sp. The predominant land use on adjoining uplands is cropland, although the wet meadows are mowed for forage.

Channel Marsh, Rush Type

Located on the hummocky moraine of the Newdale Plain, Manitoba (50°30′ N, 100°31′ W), this

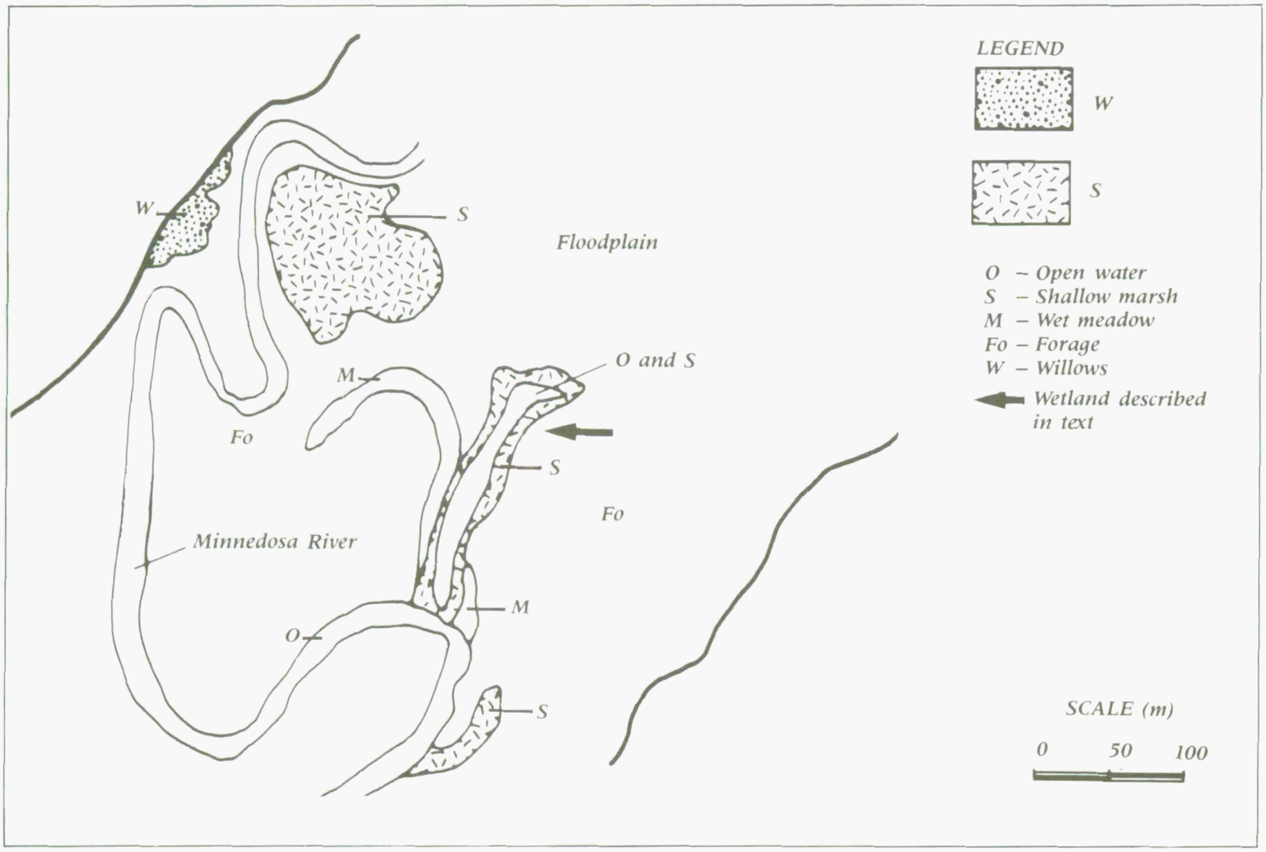


Figure 5–8.
Floodplain marsh (rush type) located in the Minnedosa River Valley near Elphinstone, Manitoba, at 50°30′ N, 100°22′ W (from 1972 aerial photograph).

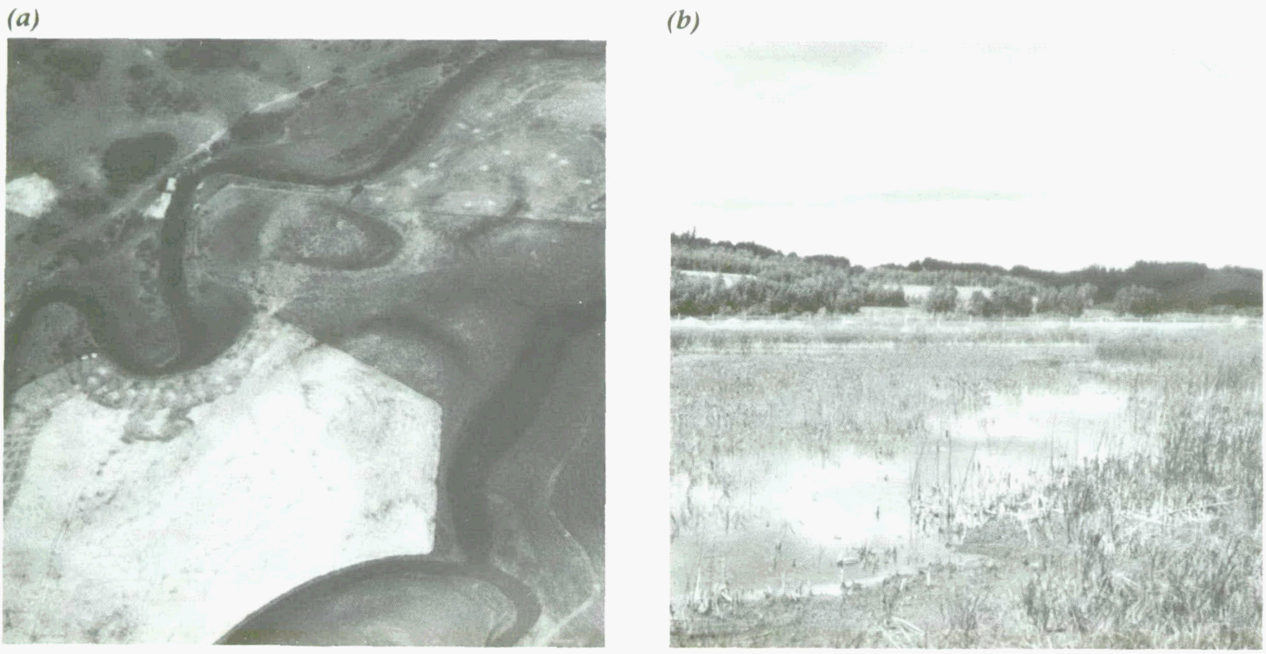


Figure 5–9.
Oblique aerial (a) and ground (b) view (1972) of a floodplain marsh located in the Minnedosa River near Elphinstone, Manitoba (50°30′ N, 100°22′ W); wetland has open water with interspersed deep marsh, drawdown deep marsh, and shallow marsh areas.

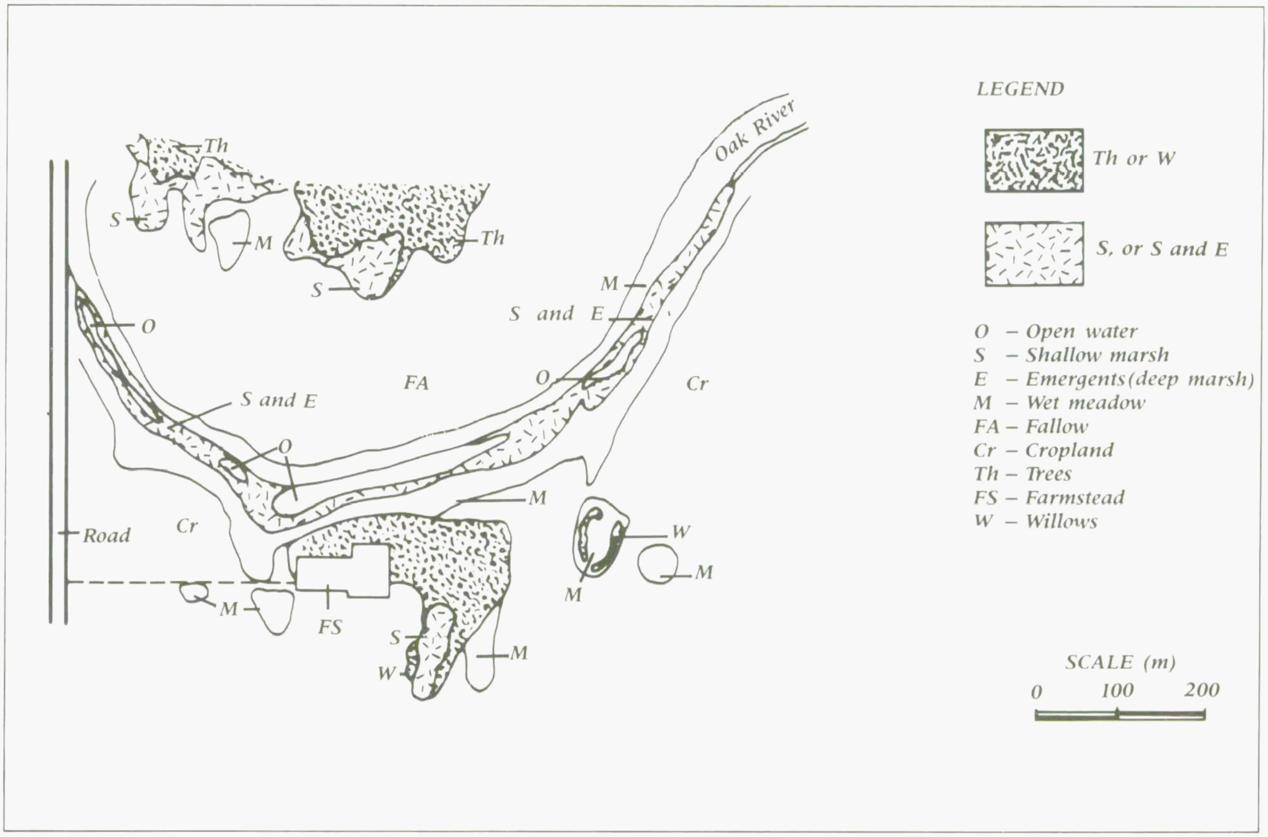


Figure 5–10.
Shallow basin marsh (sedge type) and associated wetlands located north of McConnell, Manitoba, at 50°20′ N, 100°30′ W (from 1972 aerial photograph).

Figure 5–11.
Ground view (1972) of a stream marsh located in the Oak River channel (50°19′ N, 100°36′ W) near McConnell, Manitoba. Open water, shallow marsh, and scattered stands of deep marsh emergents are prevalent.

freshwater wetland occupies 12.2 ha and has a perimeter of 2.3 km (Figures 5–12 and 5–13). The marsh receives runoff and intermittent inflows from other wetlands along natural drainage courses which have been ditched. In turn, the marsh drains south via a small stream which is a tributary of the Oak River. Surface water is semipermanent, with permanent open water 20–70 m wide, interspersed with patchy or closed stands of emergents in deep marsh. A random water depth of 60 cm was measured in a deep marsh area on August 9, 1972.

The marsh displays four stable wetland bands and an unstable drawdown area. Vegetation in the permanent open water and in patchy emergent areas includes the following submergents: *Potamogeton pectinatus*, *Utricularia vulgaris*, and floating *Lemna trisulca*. The deep marsh, which averages 20–40 m in width, is characterized by *Scirpus lacustris* ssp. *glaucus* and *Typha latifolia*. The shallow marsh, which is 15–25 m wide, consists of closed stands of *Scolochloa festucacea*, *Carex* spp., *Glyceria* spp., and *Eleocharis palustris*. The wet meadow (15–25 m) consists of *Hordeum jubatum* and *Juncus balticus*. A drawdown area, 8–15 m wide, is present in the shallow marsh. The bordering uplands

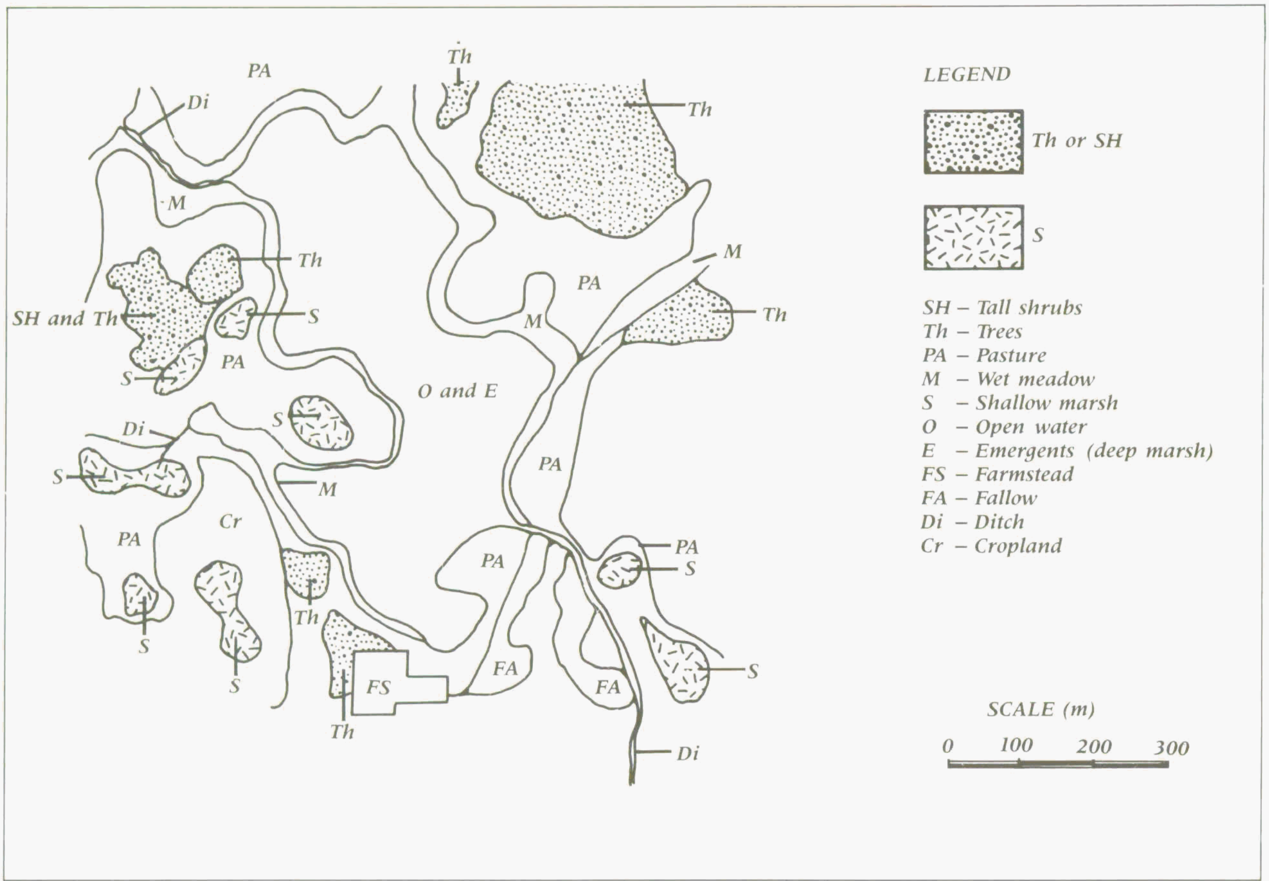


Figure 5–12.
Channel marsh (rush type) located near Menzie, Manitoba, at 50°30′ N, 100°31′ W (from 1972 aerial photograph).

Figure 5–13.
Oblique aerial view (1972) of channel marsh in flood stage, located near Menzie, Manitoba (50°30′ N, 100°31′ W). The marsh drains via a small stream in foreground.

have grazed pasture and associated stands of aspen woodland.

Kettle Marsh, Rush Type

This kettle marsh is also located on the hummocky moraine of the Newdale Plain in Manitoba (50°09′ N, 100°19′ W). The marsh occupies a bilobed basin which at low water levels may form two wetlands (Figures 5–14 and 5–15). The wetland occupies 5.3 ha, has a perimeter of 1.5 km, and has open water areas consisting of seven pools covering 30% of the surface area. Because the basin is isolated, it receives water only from precipitation and runoff from a local watershed. Water is slightly saline and assessed as nearly permanent as a result of a maximum water depth of 75 cm measured on June 23, 1972.

The marsh includes four subforms characterized by bands of vegetation: permanent open water–submerged aquatic, deep marsh, shallow marsh, and wet meadow. Vegetation in the open water area includes *Potamogeton pectinatus*, *Ceratophyllum demersum*, *Myriophyllum spicatum*, *Utricularia vulgaris*, and *Lemna trisulca*. The deep

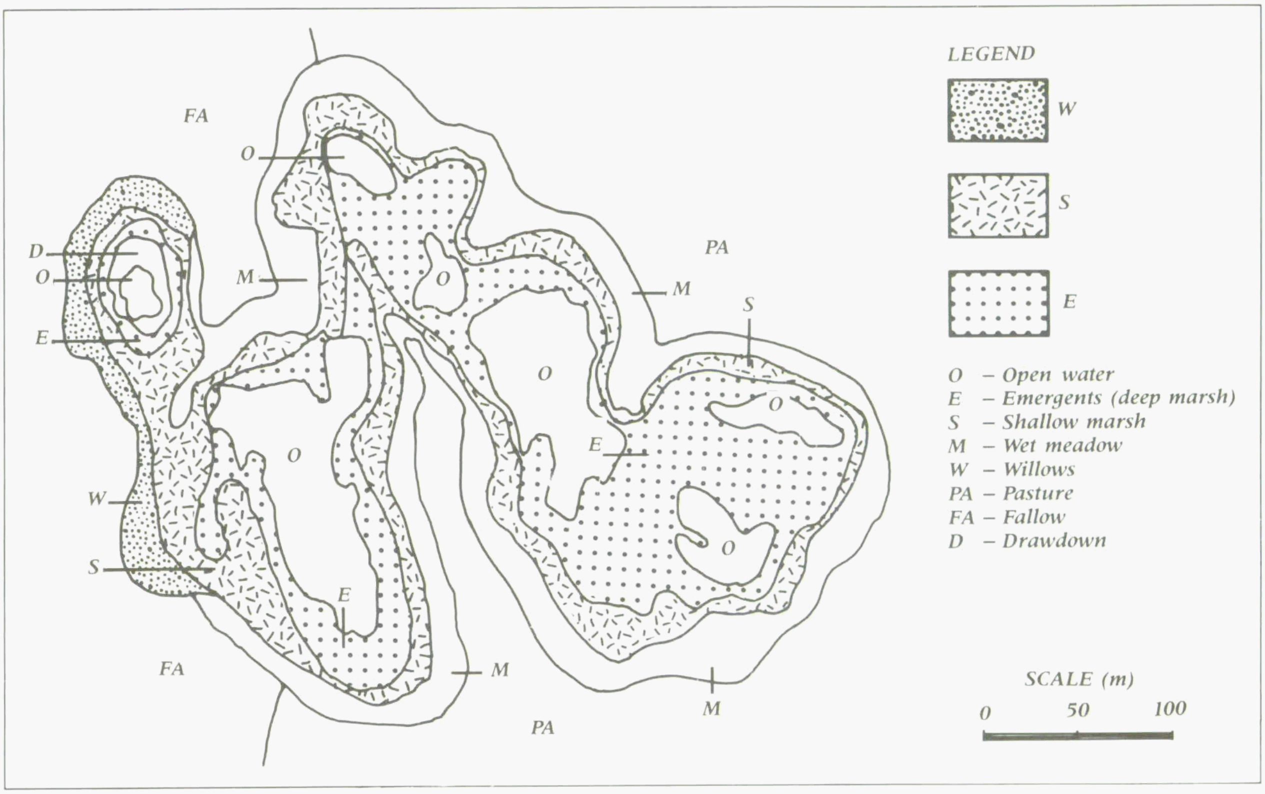


Figure 5–14.
Kettle marsh (rush type) located near Oak River, Manitoba, at 50°09′ N, 100°19′ W (from 1972 aerial photograph).

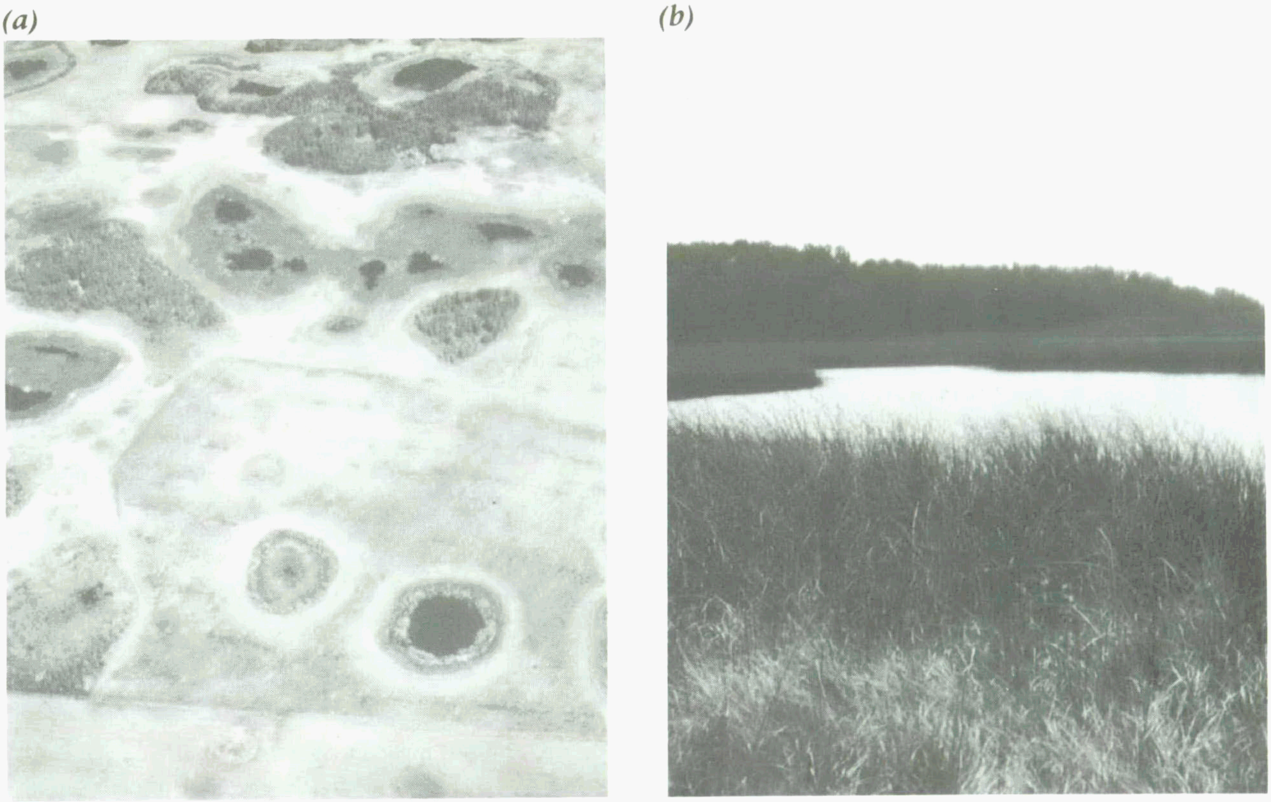


Figure 5–15.
*Oblique aerial (a) (1972) and ground (b) view (1973) of kettle marshes located near Oak River, Manitoba (50°09′ N, 100°19′ W). The marsh has open water pools bordered by deep marsh (*Scirpus lacustris *spp.* glaucus*) and shallow marsh areas (*Carex *spp.).*

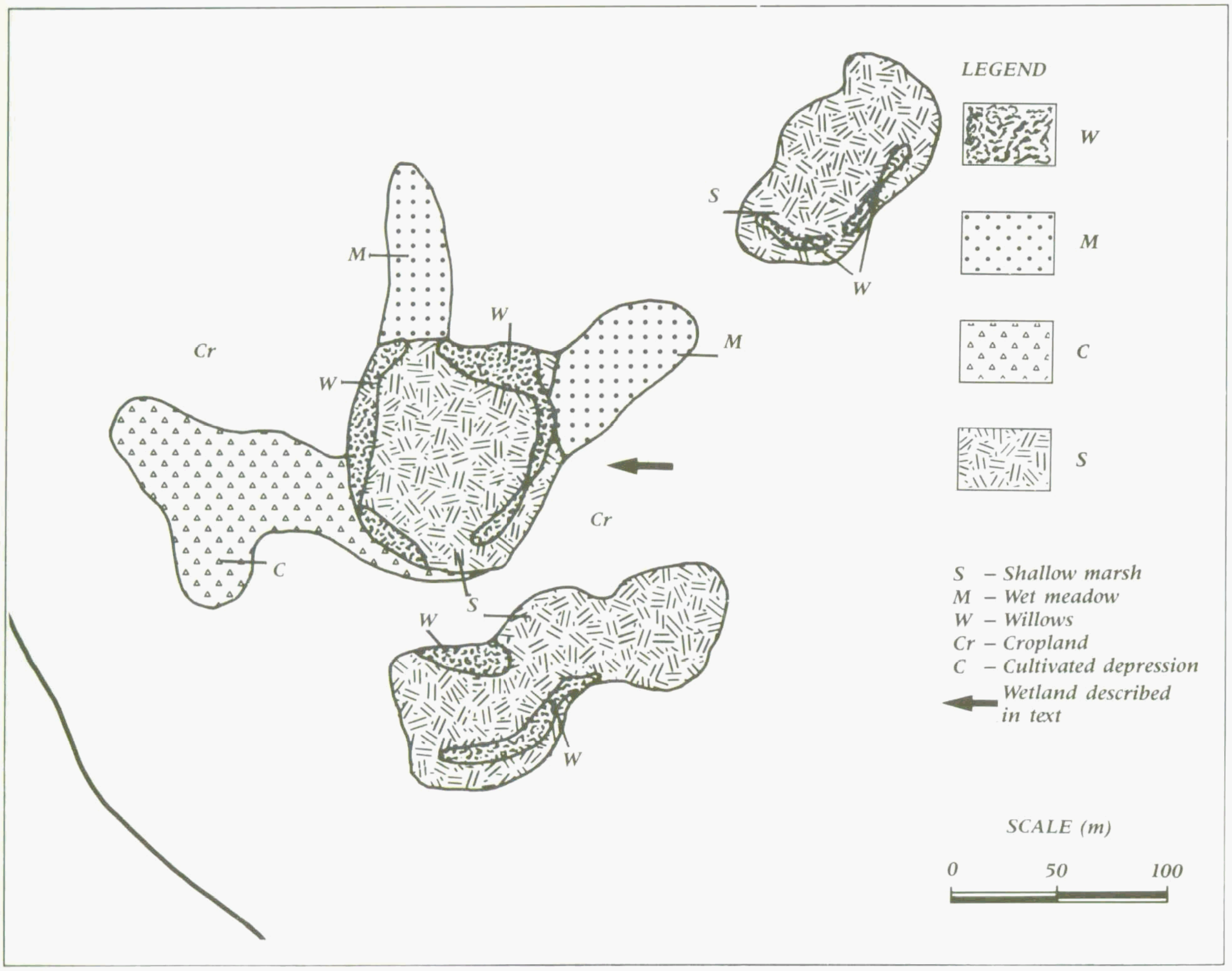


Figure 5–16,
Shallow basin marsh (sedge type) and associated wetlands located north of McConnell, Manitoba, at 50°20′ N, 100°30′ W (from 1972 aerial photograph).

marsh band, which averages 20 m in width, has a patchy distribution of *Scirpus lacustris* ssp. *glaucus* and *Typha latifolia*. The adjoining shallow marsh (5–10 m wide) consists of closed stands of *Carex* spp. and *Eleocharis palustris*. The wet meadow forms an outer fringe 25 m wide around the wetland. The characteristic species are *Hordeum jubatum*, *Distichlis stricta*, *Calamagrostis inexpansa*, *Juncus balticus*, *Triglochin maritima*, and *Salix* spp. On the surrounding upland, 25% of the perimeter is bordered by cropland and 75% by grazed grassland, low shrubs, and trees.

Shallow Basin Marsh, Sedge Type

This shallow basin marsh is located on ground moraine on the Newdale Plain in Manitoba (50°20′ N, 100°30′ W). The wetland (Figure 5–16) is an isolated basin with a relatively uniform depth; a maximum water depth of 60 cm was measured on July 26, 1972. On this date the wetland area and perimeter were 0.8 ha and 0.3 km, respectively. The wetland boundaries change under flooded conditions, as shown by adjoining wet meadows and cultivated depressions. Fresh surface water originates from runoff in a local watershed, resulting in a seasonal water regime.

The wetland has no permanent open water area, except for small pools which collectively occupy 5–10% of the surface. The dominant submergent plants are *Utricularia vulgaris* and *Potamogeton* sp. A shallow marsh which occupies most of the basin area consists of *Carex* spp., *Eleocharis palustris*, *Glyceria grandis*, and *Alisma plantago-aquatica*. The outer wet meadow band is dominated by *Beckmannia syzigachne* and a fringe of willows (*Salix* spp.). Some of these species are indicative of past disturbances in the basin. The wetland is surrounded by cultivated cropland.

Terminal Basin Shallow Water, Submerged Aquatic Type

This wetland (Figures 5–17 and 5–18) occupies moderately calcareous, clay loam Black Chernozem soils on the Newdale Plain, a hummocky moraine in southwestern Manitoba (50°31′ N, 100°36′ W). The wetland area, at its maximum, is about 43.6 ha, and the perimeter is 4.8 km. The basin is flooded semi-permanently by moderately saline waters derived from surface runoff and groundwater inflows. On the date of sampling, open water occupied approximately 59% of the wetland area; the remainder consists of a deep marsh with *Scirpus maritimus* and ranges in width from 10 to 100 m. A drawdown band, 10–20 m in width, is sparsely vegetated by *Scirpus maritimus* and *Salicornia europaea* ssp. *rubra*. A shore area (10–25 m) has a dense cover of shallow marsh and wet meadow species such as *Hordeum jubatum*, *Salicornia europaea* ssp. *rubra*, *Atriplex* sp., and *Distichlis stricta*. The open water area, the depth of which exceeded 60 cm on August 9, 1972, supports *Potamogeton pectinatus* and unidentified algae. The surrounding land is used as heavily grazed pasture with isolated cropland.

Kettle Shallow Water, Submerged/Floating Aquatic Type

This wetland (Figures 5–19 and 5–20) is also situated on the moderately rolling hummocky moraine of Manitoba's Newdale Plain (50°31′ N, 100°15′ W). It is located in a moderately deep kettle (a saucer-shaped basin) receiving surface inflow during flooding from two associated kettles and one shallow basin. In turn, the wetland may overflow into another kettle which has an artificial ditch draining into Wolf Lake. However, the slightly saline wetland has a permanent water regime and its depth exceeds 75 cm at low water levels. Having a surface area of 2.4 ha and a perimeter of 0.6 km, the wetland surface is predominantly open water (82%). The open water area is dominated by submerged and floating aquatic plants such as *Myriophyllum* spp., *Lemna trisulca*, and *Drepanocladus* sp. Narrow borders include a drawdown band, which was 3 m wide on July 28,

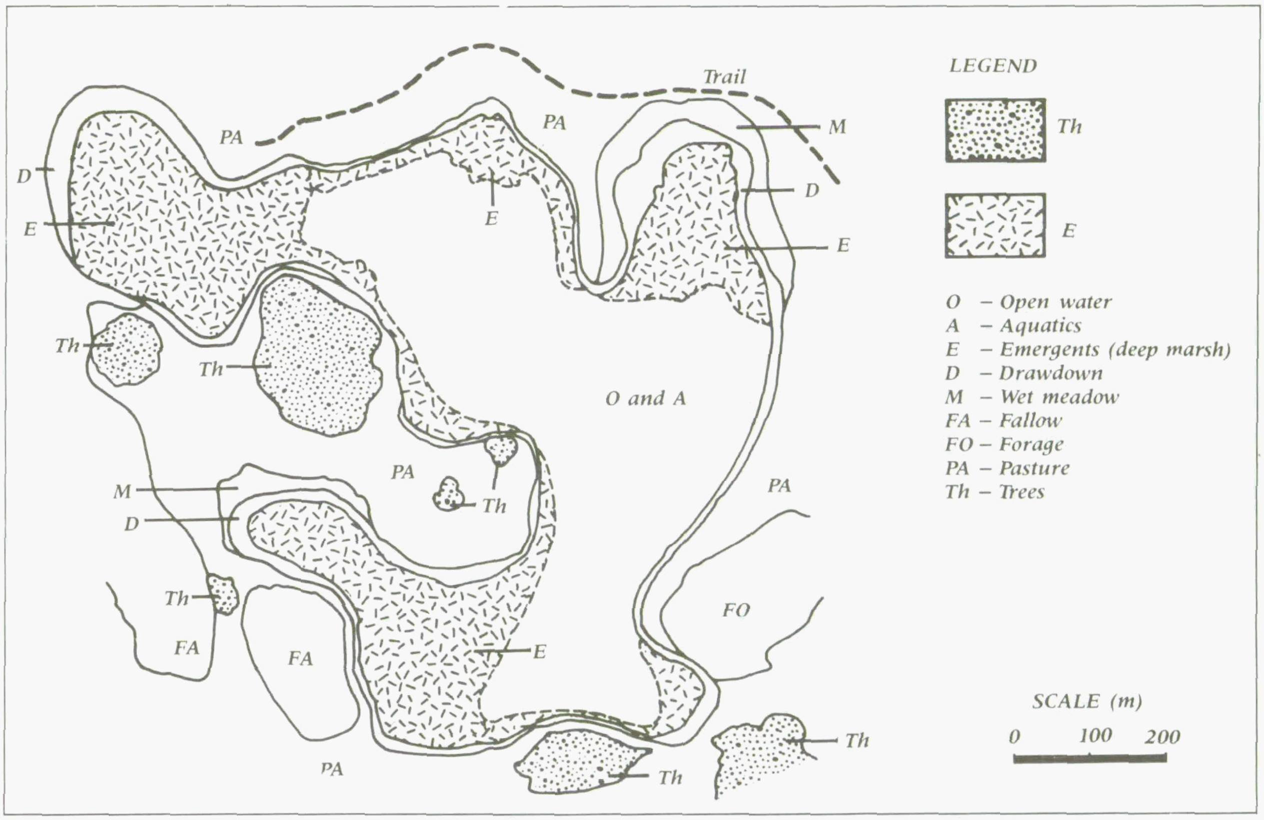


Figure 5–17.
Terminal basin shallow water wetland (submerged aquatic type) located north of Shoal Lake, Manitoba, at 50°31′ N, 100°36′ W (from 1972 aerial photograph).

Figure 5–18.
*Oblique aerial view (1972) of terminal basin shallow water, a saline wetland located near Shoal Lake, Manitoba (50°31′ N, 100°36′ W). Stands of deep marsh (*Scirpus maritimus*) occur in bays and the shorelines are sparsely vegetated.*

1972, adjoining a shallow marsh 3 m wide characterized by a closed stand of sedges (*Carex* spp.), *Scirpus lacustris* ssp. *glaucus*, and *Juncus balticus*. A shore area, which averages 3 m in width, includes closed stands of *Juncus balticus*, *Calamagrostis inexpansa*, *Cirsium arvense*, and *Hordeum jubatum*. On the surrounding uplands, a fringe of aspen and willow occupies about 60% of the perimeter; the surrounding land is used for cropland and pasture.

Basin Fen, Sedge–Grass Type

Basin fens occur as outliers within the northern and eastern edges of the Aspen Parkland Continental Prairie Wetland Subregion, especially on some elevated uplands and on highly calcareous soils such as in the Manitoba Interlake. Basin fens are flooded seasonally, but the water table may

(a)

(b)

Figure 5–19.
Oblique aerial (a) and ground (b) view (1972) of kettle shallow water wetlands located near Elphinstone, Manitoba (50°31′ N, 100°15′ W). Shallow marsh and wet meadow fringe the open water zone.

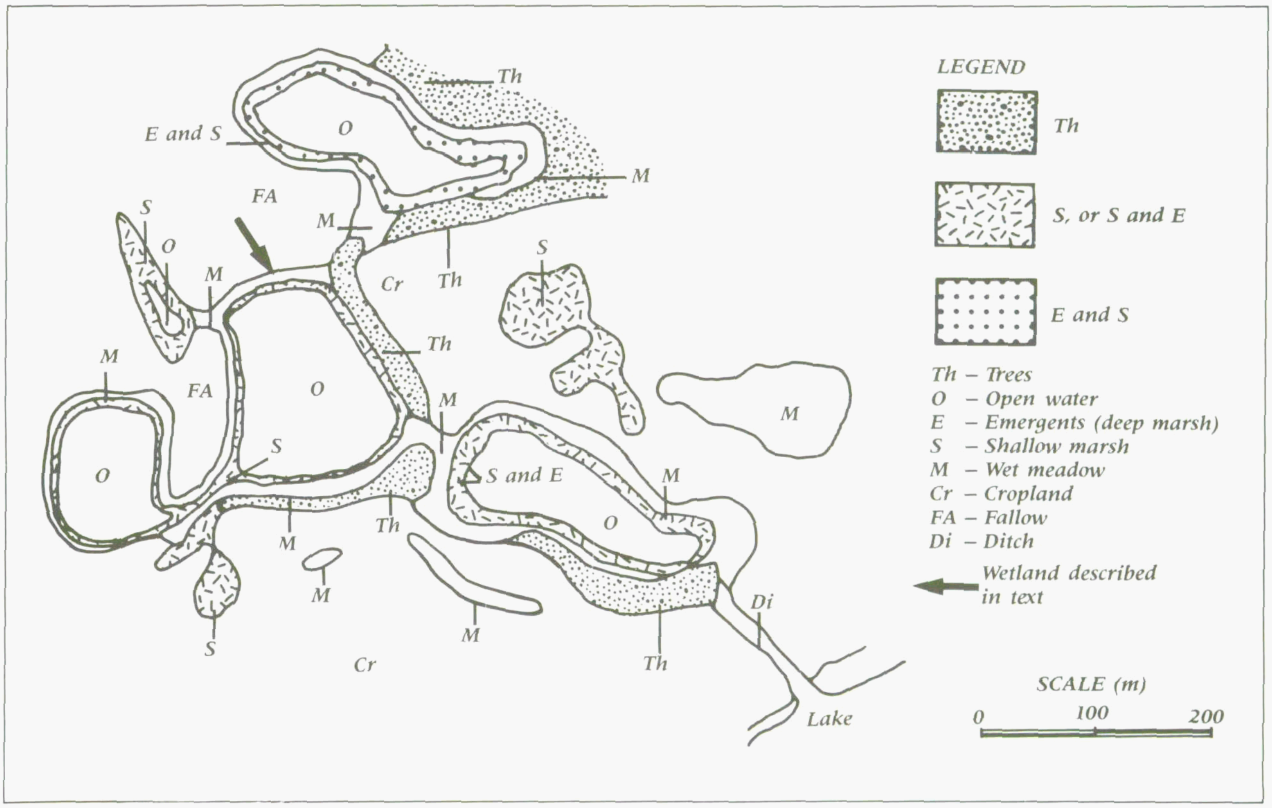


Figure 5–20.
Kettle shallow water wetland (submerged–floating aquatic type) and associated wetlands near Elphinstone, Manitoba, at 50°31′ N, 100°15′ W (from 1972 aerial photograph).

drop below the fen surface by midsummer. Surface water is usually alkaline, derived from seasonal runoff into isolated basins or from seasonal discharge of groundwater. Layers of humic or mesic peat from 40 to 100 cm in thickness may form a continuous mat, although central pools with exposed mineral soil may be present. The main peat-forming species are sedges and brown aquatic mosses (*Drepanocladus* spp.). Characteristic plant species also include *Carex aquatilis*, *Glyceria striata*, *Calamagrostis inexpansa*, *Typha latifolia*, *Phragmites australis*, *Salix interior*, and *Salix candida*. Aquatic plant species common in open pools include *Potamogeton gramineus*, *Utricularia vulgaris*, *Chara* sp., and *Nymphaea tetragona*.

Development, Formation, and Dynamics

Influence of Water Regime

According to Walker and Coupland (1968), water regime is of overriding importance in the ecology of wetlands. They determined that two environmental scales—initial water depth and rate of water loss—are important in influencing vegetation development in wetlands. Species inhabiting the wettest part of the gradient exhibit the lowest amplitude of variation, because rates of water loss have negligible effects upon species composition in deeper stands. At low initial water depths, small changes in rates of water loss produce greater changes in the numbers of species.

A typical prairie marsh is an example of an unstable ecosystem which undergoes short-term and reversible cycles from nearly terrestrial to nearly aquatic (Weller and Fredrickson 1973). The cycles include four main phases: (1) dry marsh—drawdown and germination of pioneer plants on exposed bottom; (2) regenerating marsh—reflooding after germination and replacement of annuals by perennial emergents; (3) degenerating marsh—after several years of continuous flooding, emergents die off leaving interspersed openings in emergent cover; and (4) lake marsh—elimination of central emergent cover by plant die-offs, leaving a transitory open water area (Van Der Valk and Davis 1980). This cycle lasts five years or longer (Weller and Fredrickson 1973), although a seven-year drought cycle in southwestern Manitoba has been postulated from precipitation and pond records collected from 1950 to 1963 (Shay and Shay 1983).

Weller and Fredrickson (1973) documented a decline in marsh productivity after seven years of inundation, followed by rejuvenation during drawdowns which resulted in nutrient recycling and the germination of new, diverse plant species. Thus, stability and species diversity were not equated with productivity. Van Der Valk and Davis (1980) state that water stability in a marsh leads to a reduction of diversity and to monodominant communities, as polydominant emergent communities are restricted to marshes where cycling occurs. Depending upon the availability of adequate seed banks, varying water levels favour changes in species dominance at different stages, eventually progressing to more simple communities unless drought intervenes.

Initially, drawdowns in wetlands result in a reduction of floating leaf plants and increases in sedges and other emergents on the margins (Kadlec 1962). The vegetation types pioneering on drawdown areas depend upon the timing of exposure and the duration of drying (Harris and Marshall 1963). Harris and Marshall studied drawdowns on a marsh in the Agassiz Refuge, Minnesota. Emergents such as *Typha latifolia* and *Scirpus lacustris* ssp. *validus* persisted on early June drawdowns that were slow in drying. Annual forbs, such as *Erigeron* sp., were usually established after midsummer exposure on flats which dried within three to five days. Areas exposed before August 1 of the first drawdown year lost emergent cover in the second drawdown year, although dense stands persisted on fine-grained soils. After three to five years of drawdown in the absence of reflooding, willow species invaded the area. Plant species that are characteristic invaders of drawdown areas in prairie wetlands include *Eleocharis acicularis, Senecio congestus, Rumex maritimus, Chenopodium rubrum, Polygonum coccineum, Beckmannia syzigachne, Alisma plantago-aquatica,* and *Sagittaria cuneata* (Dix and Smeins 1967; Stewart and Kantrud 1971). Drawdowns of one to two years' duration at intervals of five to ten years are usually required to maintain emergent marshes.

After a drawdown, reflooding of the marsh results in recovery of perennial aquatic plants and the spread of previously germinated emergents by vegetative means (Kadlec 1962). At the Agassiz Refuge, reflooding of a marsh eliminated mudflat and shoreline annuals, and stands of *Typha latifolia, Scirpus lacustris* ssp. *validus, Eleocharis* sp., *Carex* spp., *Salix* spp., and *Potamogeton pectinatus* developed in the first year (Harris and Marshall 1963). Weller and Fredrickson (1973) recorded the disappearance after flooding of *Scirpus lacustris* ssp. *validus*, the decline of *Typha glauca, Elodea* sp., *Chara* sp., and *Potamogeton foliosus*, and the increase of *Potamogeton pectinatus, Ceratophyllum* sp., and *Utricularia* sp. Under continuous flooding for two or more years, 27% of shallow marsh stands were converted to transitional open water, and at depths of 76–90 cm most shallow marsh emergents, such as *Scolochloa festucacea*, died after three years of flooding (Millar 1973). Flooding can temporarily reverse successional sequences by fragmenting emergent vegetation and reducing the accumulation of organic material.

Emergent plants show varying degrees of tolerance to depth and duration of surface water. At the Agassiz Refuge, *Typha latifolia* and *Carex* spp. were eliminated in four or five years of flooding at depths of 30–38 cm (Harris and Marshall 1963). Shay and Shay (1983) observed *Typha* spp. surviving in waterlogged soils at water depths up to 75 cm, but *Typha latifolia* was intolerant of inundation of up to 50 cm for more than two years. However, *Typha angustifolia* could tolerate water depths of 50–80 cm. *Scolochloa festucacea* flowers in optimum water depths of 21–40 cm, although the plants can survive temporarily in depths up to 70 cm (Smith 1973). *Phragmites australis* can tolerate variable water levels from 0 to 100 cm, but is usually eliminated by inundation at 100 cm (Shay and Shay 1983). Flooding at depths of more than 38 cm for three years has resulted in the elimination of stands of *Eleocharis palustris* and *Scirpus lacustris* ssp. *validus* (Harris and Marshall 1963).

According to Shay and Shay (1983), the bulrush species (*Scirpus* spp.) show varying degrees of tolerance to inundation. *Scirpus lacustris* ssp. *validus* is usually eliminated by flooding because optimum water depths are about 0–20 cm; *Scirpus lacustris* ssp. *glaucus* persists in depths from 0 to 80 cm and survives inundation to 2 m, but optimum depths are 15–45 cm; *Scirpus maritimus* tolerates fluctuating water levels from −40 to 65 cm, and tolerates wide yearly changes.

Nutrient Recycling

Plant growth and therefore the primary productivity of wetlands are dependent upon the availability of dissolved nutrients in water and soils. Nutrient availability is a function of source, concentration, and renewal rate due to flooding or flushing (Gosselink and Turner 1978). Depending upon the water regime, wetlands may export or accumulate nutrients (Kadlec and Kadlec 1979) and regular renewal of water prevents toxic salt concentrations (Gosselink and Turner 1978). The reason for the continuous productivity of freshwater marshes is the constant supply of water from external sources (Klopatek 1978), as nutrients such as nitrogen (N) increase in frequently flooded marshes. During flooding or at high water levels, colloidal sediments may adsorb ions, thereby removing them from the system until drawdowns cause release of the nutrients through leaching and rapid decomposition of organic matter (Kadlec 1962; Klopatek 1978). Oxygen (O) is depleted from marshes in saturated conditions where waters are not renewed. The resultant anaerobic conditions increase the availability of some nutrients such as phosphates, which become soluble (Gosselink and Turner 1978). Low water levels occurring during drawdowns result in increases of carbon dioxide (CO_2); this causes the solution of more carbonates in the form of bicarbonates (Kadlec 1962).

Nutrient uptake in plants is related to the concentration of nutrients and the quantity of plant material (Kadlec and Kadlec 1979). Primary producers absorb phosphorus (P) and N from water, but most P is organically bound in the sediment (Klopatek 1978). Emergents pump N and phosphates from sediments to water (Kadlec and Kadlec 1979). Emergent macrophytes obtain nearly all nutrients from the soil; there is a correlation between total soil N content, and N in the tissues of *Typha latifolia*, *Scirpus fluviatilis*, and *Carex lacustris* (Klopatek 1978). According to Klopatek (1978), the nutrient concentration in plants depends upon the phenotypic stage and is usually highest at the beginning of the growing season. However, the greatest accumulation of N and P in *Typha* spp. coincides with the peak above-ground biomass. In June and July, macrophyte uptake of exchangeable Ca and Mg causes decreases of these minerals in the soil.

Nutrients are released from plants by decomposition of plant tissues and by microbial conversions. Davis and Van Der Valk (1978) stated that the rate at which nutrients are converted from plant litter depends upon the timing of litter fall, site characteristics, duration of submersion, and range of initial concentration of nutrients. They found that decomposing litter of *Scirpus fluviatilis* contributed 39% of the available N, whereas litter of *Typha glauca* contributed 58% of the available N. Similarly, early leaching removed 37 and 65% of P respectively in *Scirpus* and *Typha* litter before November 15. Nutrients released through decomposition are returned to the sediments.

According to Klopatek (1978), submerged marsh soils are in an anaerobic state, except for a thin soil–water interface which is aerobic. Decomposition is retarded due to a low redox potential. The oxidized layer acts to trap P and to release N as ammonia which is available to plants. This process is called denitrification. Phosphates and N in soils occur in a dissolved state in interstitial waters, as adsorbed ions or precipitates, or are organically bound in sediment particles. In more stable marshes, the build-up of sediment and standing biomass may result in a closed nutrient cycle where there is less exchange of nutrients across soil–water boundaries (Gosselink and Turner 1978). Eventually, more nutrients are trapped in the sediment and are unavailable to plants unless a drawdown cycle intervenes. Under aerobic conditions, increases in available N in the soil are due to nitrification (Kadlec 1962).

In order to establish some baseline nutrient data in representative marsh soils, soil samples were taken from the surface horizons of submerged soils in semi-permanent shallow waters and marshes on the Manitoba Newdale Plain in 1972. Soil nutrients and textures were analyzed by the Manitoba Soil Survey Laboratory (Table 5–9). Although the soil textures varied from loam to clay, the parent materials were medium-textured with moderately calcareous moraine (Ehrlich *et al.* 1956). Only 8% of the sampled wetlands exceeded organic carbon (C) levels of 14%; one wetland exhibited a high accumulation of organic matter. Because saline wetlands were excluded, soil conductivities ranged below 3.5 mS/cm. Nitrate nitrogen levels ranged from 0 or trace amounts to 23.8 mg/kg, but 93% of the measurements were less than 10 mg/kg. Frequency data for both nitrate

Table 5–9. ***Soil chemistry analyses* of 41 samples from semi-permanent marshes, Newdale Plain, Manitoba (1972)*****

Analysis	*Mean*	*Range*
Soil conductivity (mS/cm)	1.18	0.3–3.4
Organic C (%)	7.75	0.6–42.8
NO_3-N (mg/kg)	3.86	0.0–23.8
Available P (mg/kg)	10.70	1.0–57.0

**Analyses conducted by Manitoba Soil Survey Laboratory, University of Manitoba.*

***Excludes samples from saline wetlands with water conductivity greater than 15.0 mS/cm.*

nitrogen and available P were skewed to the left. Phosphorus levels were generally low, as 85% were less than 20 mg/kg. Although most of these soil nutrient levels appear low, this may be due to infrequent drying of the substrate and seasonal uptake of nutrients by aquatic plants.

Salinity and Wetland Development

Salinity Classes

Salinity represents an estimate of the concentration of total dissolved inorganic solids or salts in water, as measured in milligrams per kilogram (mg/kg) or as specific conductivity in millisiemens per centimetre (mS/cm). Salinity levels in wetlands and surface waters may fluctuate widely within a season or yearly depending upon water levels and groundwater inflows. The composition of salts or ions varies considerably according to surface materials (Moyle 1945), groundwater (Last and Schweyen 1983), evaporation, soil permeability, and topography (Driver and Peden 1977).

Usually, inland surface water quality classifications are based upon total salinity, generally measured as specific conductivity. Depending upon the purpose, there are several salinity classifications in use. Limnologists usually define saline waters as waters with salt concentrations exceeding 3 000 mg/kg (Hammer 1978). Millar (1976) modified a salinity classification proposed by Stewart and Kantrud (1971) and suggested four groups: (1) fresh (0.04–2 mS/cm); (2) moderately saline (2–15 mS/cm); (3) saline (15–45 mS/cm); and (4) hypersaline (more than 45 mS/cm). The classification by Cowardin *et al.* (1979) proposes six classes, limiting fresh water to less than 0.8 mS/cm and hypersaline (or "hyperhaline") water to more than 60 mS/cm. As a result of large seasonal fluctuations in salinity in some wetlands, a single wetland could conceivably be placed in more than one class (Shay and Shay 1983).

More detailed classifications of salinity are based upon the ionic composition of surface water. Most prairie wetlands are classified as hard or alkali water types, in which total alkalinity exceeds 40 mg/kg and sulphate ions (SO_4) exceed 50 mg/kg (Moyle 1945). With the exception of the hypersaline class, most wetlands on hummocky moraine fit three water quality types as defined by Meyboom (1967a) and Rozkowska and Rozkowski (1969):

(1) Bicarbonate (HCO_3) with Ca and Mg. Total dissolved solids 100–700 mg/kg (less than 0.5 mS/cm). Typical of fresh, temporary, or recharge ponds.

(2) Bicarbonate–sulphate (HCO_3–SO_4) with Ca and Mg. Total dissolved solids 700–2 000 mg/kg (0.5–3 mS/cm). Typical of semi-permanent ponds or discharge ponds in local groundwater flow systems.

(3) Sulphate–magnesium (SO_4–Mg) or sulphate–bicarbonate–magnesium–calcium (SO_4–HCO_3–Mg–Ca). Total dissolved solids 2 000–12 900 mg/kg (15–25 mS/cm). Typical of semi-permanent to permanent discharge ponds in intermediate groundwater flow systems.

Driver and Peden (1977) found that the transition from HCO_3 ion to SO_4 ion dominance occurred at 0.6 mS/cm, whereas the shift from SO_4–HCO_3 to SO_4–Cl (sulphate–chloride) occurred above 12 mS/cm. In North Dakota, Adomaitis *et al.* (1983) found that specific conductivity values were lowest in temporary and seasonal ponds (0.15–2.8 mS/cm), intermediate in semi-permanent and permanent ponds (0.18–60 mS/cm), and highest in alkali (saline) ponds (4–67 mS/cm). Similar trends were recorded for the other ions.

Origins of Salinity

Differences in the chemical quality of surface waters often reflect the underlying surface materials and bedrock composition. Moyle (1945) related hard and alkali (saline) waters to calcareous glacial deposits overlying Cretaceous bedrock. Saline soils often develop on alluvium and lacustrine soils recently formed under impeded drainage, or on uplands subject to seepage from underlying preglacial shales (Coupland 1961; Meyboom 1967b). According to Last and Schweyen (1983), the dissolution of soluble Paleozoic evaporites such as carbonates and sulphates by groundwater has modified geological strata and has provided a source of ions for saline lakes; glacial meltwater channels and spillways, including some buried valleys, control the direction of flow and the quantity of groundwater discharged at these sites. Variations in salinity are dependent upon soluble salt concentrations in soils, glacial deposits, and groundwater flow conditions (Rozkowski 1969).

The chemistry of surface water as determined by groundwater and interflows is modified by surface evaporation which leads to concentration of soluble salts and precipitation of less soluble salts (Rozkowski 1969). Ions are also contributed by ion exchange processes and biological activity. Therefore, salinity usually increases in discharge ponds with no seepage outflow (Eisenlohr and Sloan 1968).

Variations in Salinity

Extreme yearly and seasonal fluctuations in water depth cause corresponding changes in salinity (Stewart and Kantrud 1972). Increases in water depth may flush out salt by overflows or reduce specific conductivities by dilution of surface water. Normally, increases in salinity are induced by evapotranspiration, but such increases in low saline ponds without corresponding declines in water depth are due to inflow of saline groundwaters. In perched basins, seepage outflow tends to reduce the concentration of salts. Despite water fluctuations, salinity in many saline marshes is gradually increasing because they receive a continuous supply of saline groundwaters (Looman 1981).

Driver and Peden (1977) related seasonal changes in salinity to water permanence. Over a four-year period (1968–1971), seasonal salinities in a temporary pond increased from 47 to 78% and dominant ions were Ca, K (potassium), Mg, and HCO_3. Salinity increased from 25 to 93% in semi-permanent ponds in which the dominant ions were Mg, Na, Ca, SO_4, and HCO_3. In a permanent pond, total seasonal increases in salinity ranged from 10 to 36%; dominant ions were Ca, Mg, K, HCO_3, SO_4, and Cl. Driver and Peden found that seasonal changes in salinity were least in permanent ponds in which general ionic patterns did not change appreciably.

Water quality parameters obtained from wetlands sampled in Manitoba and Saskatchewan show similarities and differences attributed to the composition of surface and geological materials. Values for specific conductivity and sulphate ions were higher at Rapid City, Manitoba, than at St. Denis, Saskatchewan, but total alkalinity and calcium ions were similar in both areas (Table 5–10). Surface materials in both areas consist of moderately calcareous glacial deposits overlying Cretaceous shales (Nicholson 1957; Ehrlich *et al.* 1956). However, differences in water quality parameters between wetlands located on the Saskatchewan Plain and wetlands located on the Manitoba Lowland indicate some geological or hydrological influence (Table 5–11). Specific conductivities were significantly higher and total alkalinities significantly lower in the Lowland. This may be related to dissimilar bedrock and surface materials and the probable presence of more discharge wetlands from regional flow systems in the Lowland.

Table 5–10. Water quality analyses in two hummocky moraine study areas in Saskatchewan and Manitoba (1973)*

Area	Parameter	Specific conductivity (mS/cm)	Total alkalinity (mg/kg)	Exchangeable cations: Ca (mg/L)	Exchangeable cations: SO_4 (mg/L)
St. Denis, Saskatchewan	Mean	1.73	300**	108**	870**
	Minimum	0.26	111	28	4
	Maximum	11.40	741	268	8 270
	Sample size	33	33	33	33
Rapid City, Manitoba	Mean	2.21	275	111	1 128
	Minimum	0.67	173	44	170
	Maximum	5.80	514	312	4 000
	Sample size	39	39	39	39

*Water analyses conducted by Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba.
**Decimals rounded to nearest integer.

Table 5–11. ***Regional comparison of water quality parameters* in Manitoba wetlands (1968)***

Parameter	Specific conductivity (mS/cm)		Total alkalinity (mg/kg)	
	Saskatchewan Plain	Lowland	Saskatchewan Plain	Lowland
Mean	0.95	3.14	694.18	369.96
Median	0.72	3.14	431.25	309.58
Minimum	0.17	0.28	170.00	40.00
Maximum	2.9	4.95	7 700.00	649.00
Sample size	40	110	79	181

**Water analyses conducted by Freshwater Institute, Fisheries and Oceans Canada, Winnipeg, Manitoba.*

Salinity and Plant Communities

Increasing salinity forces plants to regulate salt intake and to prevent dehydration through exertion of high internal osmotic pressure. Some species vary osmotic pressure seasonally to adjust to seasonal changes in salt concentration; other species have a narrow tolerance range due to dependence upon a consistent source of groundwater (Meyboom 1967b). Vegetation reflects average conditions of salinity; some species have wide tolerances to seasonal extremes, whereas halophytic species are often a good indicator of groundwater influence on salinity (Millar 1976). Species indicative of varying levels of salt tolerance are given in Table 5–12.

Plant species tolerant of moderate salinity (2–15 mS/cm) include *Scolochloa festucacea, Sium suave, Eleocharis palustris* (Walker and Coupland 1970), and *Scirpus lacustris* ssp. *glaucus* which can tolerate water conductivities up to 26 mS/cm (Shay and Shay 1983). *Phragmites* sp. survives in a range of conductivities from 0.03 to 22.4 mS/cm (Shay and Shay 1983) and *Scirpus maritimus* can survive at moderately saline to saline levels (Millar 1976). One species indicative of hypersaline con-

Table 5–12. ***Characteristic plant species* arranged according to wetland subform and declining salinity** levels***

Salinity class	Wetland subform			
	Wet meadow	Emergent marsh	Permanent open water	Exposed mudflat
Hypersaline	—	*Salicornia europaea* ssp. *rubra* *Suaeda maritima*	*Navicula* sp. *Dunaliella* sp. *Rhizoclonium* sp. *Nitschia* sp. *Ruppia maritima*	—
Saline	*Distichlis stricta* *Triglochin maritima* *Spartina gracilis*	*Scirpus maritimus* *Puccinellia nuttalliana* *Scirpus americanus*	*Stephanodiscus* sp. *Chaetoceros* sp. *Pediastrum* sp. *Cladophora* sp. *Ruppia maritima*	—
Moderately saline	*Spartina pectinata* *Glaux maritima* *Hordeum jubatum* *Juncus balticus* *Calamagrostis inexpansa*	*Eleocharis palustris* *Scolochloa festucacea* *Scirpus lacustris* ssp. *glaucus* *Phragmites australis*	*Fragilaria* sp. *Chaetoceros* sp. *Anabaena* sp. *Microcystis* sp. *Oscillatoria* sp. *Potamogeton pectinatus* *Zannichellia palustris* *Chara* sp. *Lemna trisulca*	*Chenopodium rubrum* *Chenopodium glaucum* var. *salinum* *Rumex maritimus* *Hordeum jubatum* *Spergularia marina*
Fresh	*Poa palustris* *Calamagrostis canadensis* *Carex praegracilis* *Boltonia asteroides* *Sonchus arvensis* *Mentha arvensis*	*Typha latifolia* *Scirpus lacustris* ssp. *validus* *Carex atherodes* *Carex aquatilis* *Alisma plantago-aquatica* *Sparganium eurycarpum* *Sium suave* *Polygonum coccineum*	*Ceratophyllum demersum* *Myriophyllum spicatum* *Potamogeton perfoliatus* ssp. *richardsonii* *Potamogeton gramineus* *Potamogeton pusillus* *Utricularia vulgaris* *Drepanocladus* sp.	*Senecio congestus* *Eleocharis acicularis*

**Species assembled from Looman (1981, 1982), Hammer* et al. *(1983), Millar (1976), and Stewart and Kantrud (1972). Species are community dominants.*

***Although listed in one salinity class, some species are tolerant of a wide range of salinities.*

ditions is *Ruppia maritima*, a submergent plant (Millar 1976; Stewart and Kantrud 1972).

Corresponding vegetation in saline marshes usually develops in water depths shallower than those in freshwater marshes. For example, saline shallow marshes seldom contain surface water by midsummer, leaving species such as *Salicornia europaea* ssp. *rubra* and *Distichlis stricta* growing on moist soil. When water tables drop below the soil surface in hypersaline areas, only *Salicornia* sp. and *Suaeda maritima* persist (Looman 1981). According to Stewart and Kantrud (1972), there is usually an inverse relationship between increasing salinity and average water depths. In saline marshes, plant species show a continuum of overlap according to gradients of salinity and moisture regime, often on the same wetland. Dodd and Coupland (1966) documented a succession of halophytic plant communities progressing from wet soil to dry upland. The dominant species range from *Salicornia europaea* ssp. *rubra* and *Triglochin maritima* on wet sites to *Hordeum jubatum* and *Agropyron repens* on dry sites.

Saline Lakes

As indicated earlier in this chapter, shallow, intermittently flooded saline lakes (with specific conductivity in excess of 15 mS/cm) are important wetland subforms which, in Canada, are restricted almost entirely to the Continental Prairie and Intermountain Prairie Wetland Regions. Located in terminal basins or in areas of regional groundwater discharge in hummocky moraine (Meyboom 1967b), saline lakes usually have a central intermittent alkali zone which alternates as open water or saline flats. These are evaporative basins in which salts are concentrated, as up to 45–100 cm of water may be lost annually (Meyboom 1967b). Therefore, saline lakes usually hold less than 1 m of standing water, often drying by midsummer.

Last and Schweyen (1983) discuss the sediments and hydrochemical processes in shallow saline lakes. The drying lake bottoms, called flats or salt pans, are composed of clay minerals intermixed with soluble efflorescent salts (Na, Ca, Mg, SO_4, CO_3), with layers of crystalline salts accumulating to depths of 12 cm. Solutions of supersaturated brine may form in as little as 10 cm of water, changing to dry crystalline salt under diurnal temperature variations. Salt springs may deposit tufas or beds of carbonate minerals. Processes such as wind drift, flooding, freezing–thawing, and desiccation affect the concentration and thickness of salt deposits. Dilution and dissolution may redissolve salt beds and create solution depressions in the lake bottom. The concentration of salts in solution acts to depress the freezing point and accelerate thawing (Hammer and Haynes 1978). Therefore, saline lakes tend to remain free of ice cover for a longer period than freshwater lakes in the same locality.

Saline lakes demonstrate large seasonal changes in water volume and salinity (Lieffers and Shay 1983). Long-term increases in rates of salinity tend to vary inversely with water depth; increases of 80% have been observed on Big Quill Lake, Saskatchewan (Hammer 1978). Lieffers and Shay (1983) documented seasonal increases in salinity from 3 to 22 mS/cm on Porter Lake, Saskatchewan, due to a 17% reduction in flooded area. They reported a gradient of sediment conductivities decreasing with depth and towards the lake margins. On hypersaline lakes, only the salinity levels at the outer margins are within the tolerance range of germinating *Scirpus maritimus* (Lieffers and Shay 1983). Maximum salinities as high as 370 000 mg/kg (total dissolved solids) have been reached on hypersaline lakes such as Muskiki Lake, Saskatchewan (Hammer 1978).

Disturbance and Wetland Plant Communities

Land use disturbances are important factors in the alteration of plant succession in prairie wetlands. Agricultural settlement of the Prairies with ensuing disturbances has led to fragmentation of wetland plant communities and may have caused genetic isolation of species populations by restricting transport of species or their genetic material (Dix and Smeins 1967). Isolation caused by elimination of numerous wetlands, as occurred in Minnesota and the Dakotas (Burwell and Sugden 1964), could limit wind-borne seed dispersal of deep marsh emergents such as *Phragmites australis* (Shay and Shay 1983), especially if no suitable germination sites are available.

There are two major types of disturbance which affect wetlands: (1) mechanical disturbance of the margin; and (2) cultivation or drainage of the entire wetland (Walker and Coupland 1968). Marginal disturbances involve grazing, clearing, burning, or cultivation, which result in replacement of natural woody or meadow vegetation by species such as *Hordeum jubatum*, *Rumex maritimus*, *Sonchus arvensis*, *Cirsium arvense*, and *Polygonum coccineum*. Cultivation of the entire wetland results in complete elimination of sedges (*Carex* spp.), which are replaced by colonizing species such as *Juncus bufonius*, *Eleocharis acicularis*, *Hordeum jubatum*, *Beckmannia syzigachne*, *Alisma plantago-aquatica*, and *Typha latifolia* (Walker and Coupland 1968). Species such as *Scolochloa festucacea*, *Alopecurus aequalis*, *Mentha arvensis*, *Poa palustris*, and *Polygonum coccineum* will often appear in the second year of succession following cultivation (Millar 1973; Walker and Coupland 1970).

On the Prairies, the elimination of seasonal shallow marshes and intermittent open waters by drainage and consolidation into larger permanent shallow water wetlands is altering the diversity of wetland ecosystems. This in turn reduces available shallow water feeding areas and reduces the available aquatic food base for waterfowl by causing shifts in species composition and abundance of aquatic invertebrates (Swanson and Meyer 1977). Factors influencing invertebrate abundance and biomass are related to nutrient recycling due to decomposition of litter and detritus (Kaminski and Prince 1981), the presence of algal food, and the structural microhabitat provided by submersed hydrophytic plants (Nelson and Kadlec 1984). In seasonal wetlands, water drawdowns followed by reflooding of drawdown vegetation result in rapid increases in invertebrates. According to Krull (1970) invertebrates are strongly associated with aquatic plants, being more abundant in vegetated than in unvegetated areas of ponds.

Land use practices that alter or destroy submerged or emergent plants can also influence invertebrate abundance. Kaminski and Prince (1981) observed that invertebrate populations were severely reduced on reflooded, tilled plots compared to invertebrate populations on reflooded, mowed areas. Contamination of wetlands by commonly applied agricultural herbicides and insecticides may have direct or indirect toxic effects on invertebrates and aquatic plants, thereby indirectly affecting survival of wetland wildlife (Grue *et al.* 1986).

Grazing and mowing disturbances alter the composition of plant species in wetlands. Under grazing, palatable species such as sedges (*Carex atherodes*) decline (Millar 1973), whereas tolerant plants such as *Eleocharis palustris* (Millar 1973), *Glyceria grandis*, *Hordeum jubatum*, *Beckmannia* sp., and *Poa palustris* (Walker and Coupland 1968; Dix and Smeins 1967), *Scirpus americanus*, and *Sparganium eurycarpum* (Stewart and Kantrud 1972) increase. Plant species that increase after mowing include *Scolochloa festucacea*, *Poa palustris*, and *Carex atherodes* (Walker and Coupland 1968, 1970; Stewart and Kantrud 1972). Those species that increase usually have protected perennating buds that remain viable under adverse conditions.

Marsh burns affect plant germination and growth by removing vegetation and litter, denuding soil surfaces, releasing nutrients, and raising soil temperatures. Fires create open water areas in dense emergent marshes through burning of organic soils (Ward 1968). Nutrients such as K, P, and Ca are released from burned vegetation and recirculated in the waters and soils (Sanderson and Bellrose 1969). Although fires may readily kill shrubs and sedges (Yancey 1964), only severe burns during dry conditions are effective in killing most emergent species. The denuded areas provide germination sites for pioneering species.

Prairie Wetland Values

Prairie wetlands in their intact state fulfil many uses and functions relating to hydrology, waste assimilation, ecosystem diversity and productivity, and wildlife. Society has usually viewed these values negatively, regarding wetlands as valuable only if eliminated or converted to some other function such as agricultural production. While the uses and values of wetlands are more thoroughly discussed in Chapter 10, their values in the Prairies are highlighted here.

Hydrological Values

Generally wetlands fulfil three hydrological functions: (1) flow stabilization; (2) groundwater recharge and discharge; and (3) erosion control (Sather and Smith 1984). According to Novitzki (1978), peak floods are reduced by water retention in wetland basins or by temporary storage in sloped wetlands. This is especially true of riverine or channel wetlands linked by overflow channels. The degree to which wetlands control flood waters is a function of the size of the wetlands, their location within the drainage basin, the texture of the substrate, and wetland vegetation lifeform (Sather and Smith 1984). The relative volume of flood flow is correlated with the percentage of basin area comprising wetlands and lakes; more runoff and less groundwater recharge occur in basins with a higher lake and wetland area (Novitzki 1978). Sather and Smith (1984) cite a study in Wisconsin which demonstrated that flood peaks were reduced by 60–80% in watersheds with a 30% wetland or lake area.

The role of wetlands in groundwater recharge has been questioned (Sather and Smith 1984); nevertheless, temporary prairie potholes do recharge regional groundwater flow systems in some situations (Meyboom 1966). The extent of the contribution is probably a function of the distribution, density, and size of recharge basins and the soil permeability. The relative rates of recharge increase as spring runoff decreases (Novitzki 1978). The wetland features usually related to groundwater recharge functions are water permanence, substrate, surface outlets, amount of edge, and vegetation type and cover (Sather and Smith 1984).

Sather and Smith (1984) also review processes whereby wetland vegetation may control erosion of shorelines by (1) stabilizing substrates; (2) dissipating wave and current energy; and (3) trapping sediments. Factors that affect erosion control depend upon the type of shoreline vegetation, its growth form and stand width, its resistance to undermining, and its tolerance of flooding. Erosion control is of greatest importance on riverine marshes, shore marshes, and large shallow water wetlands. The most suitable vegetation for erosion control includes tall robust perennials with extensive rhizome systems that anchor the shoreline materials.

Waste Assimilation

Wetlands improve water quality by acting as a filter to remove pollutants and sediments from moving water. Sather and Smith (1984) describe the processes involved: (1) reduction of water velocity; (2) decomposition of organic substances; (3) metabolism by plants and animals; (4) photosynthesis; and (5) sediment binding of particles. Wetlands are suitable for wastewater treatment because they have high rates of primary productivity and assimilative potential; the pollutants are adsorbed by mineral and organic sediments; anaerobic conditions within the substrate permit denitrification and conversion of soluble metals to insoluble forms; and populations of decomposers break down complex substances. Odum (1978) regards wetlands as solar-powered tertiary treatment systems that have the capacity to assimilate treated sewage and industrial wastes.

Heavy metals are removed by ion exchange and adsorption to sediment and organic compounds, by precipitation, and by plant uptake (Sather and Smith 1984). According to Kadlec and Kadlec (1979), heavy metals such as nickel and lead are absorbed by aquatic and semi-aquatic plants although sediments retain a portion. Nutrients and heavy metals may be transported by suspended solids.

Toxic chemicals such as hydrocarbons may be dissolved by microbial processes or may be absorbed by aquatic plants in shallow marshes (Kadlec and Kadlec 1979). Others are immobilized in sediments, changed to harmless forms, or incorporated into plant biomass in the food chain (Sather and Smith 1984). The ultimate fate or transport of these toxic chemicals is unknown.

According to Kadlec and Kadlec (1979), wetlands can improve added, secondarily treated wastewater. Initially, high levels of P are removed by direct adsorption in organic bottom sediments, and N is removed by bacterial metabolism through nitrification/denitrification processes (Sather and Smith 1984). The ability of wetlands to improve wastewater depends upon their capacity, the incoming load, hydrology and depth of wetlands, flushing rate, and the current level of contamination (Kadlec and Kadlec 1979). Prairie ponds have been studied by the Saskatchewan Research Council as nutrient traps to improve wastewater runoff from feed lots, farms, and small communities (Lakshman 1982).

Ecosystem Productivity

Wetlands play a significant role in supporting food chains by recycling nutrients and utilizing energy for photosynthesis to produce biomass for heterotrophic organisms (Sather and Smith 1984). The availability of nutrients is usually assumed to be associated with net primary productivity. Hence, estimates of primary production for dominant wetland plant species are used as indices for determining the productivity of wetland ecosystems. Sather and Smith (1984) cite factors which affect variability in estimates of net primary production. They include methodology, presence of critical nutrients, water quality, soil conditions, water regime, oxygen levels, and climate. Richardson (1978) claims that net primary production can be overestimated by failure to correct for biomass losses due to herbivory and leaf mortality, and the ash composition of plant tissues. Therefore, above-ground standing crop estimates of vegetation at stages of maximum growth are only approximations of wetland productivity within a specific time interval.

Table 5–13 compares standing crop estimates of emergent species and communities in west–central North America according to wetland forms. The stream marsh system may be the most productive because of more continuous exchange of nutrients. In the examples presented there is no clear-cut regional significance. Stands of *Typha latifolia* in Manitoba marshes seem to be more productive than or nearly as productive as *Typha* communities in Iowa and Wisconsin. Standing crops of *Scirpus* spp. vary, but they are usually more productive in the southern marshes. Low values for emergents in oxbow water probably reflect less frequent flushing and nutrient recharge. Yields of native species may be substantially increased by conversions of shallow wetlands, through water level manipulations and fertilizing, to produce forage yielding 4.5 tonnes/ha (British Columbia Ministry of Agriculture and Food 1981). There is a need for further quantification of standing crops of vegetation in different wetland forms under varying environmental conditions.

Wildlife Habitat

Prairie wetlands, ponds, and their associated vegetation furnish habitat and food for an array of wildlife species. Both terrestrial and aquatic species may utilize wetlands for different needs or seasonal life cycle requirements. Sather and Smith (1984) list several factors that determine the value of wetlands as habitat: vegetation structure and diversity, surrounding land use, spatial dispersion of wetlands, vertical and horizontal zonation, size, and water chemistry. According to Weller (1978), wildlife species adapt by niche specialization to the structural diversity of wetlands as reflected in variations in plant community lifeforms and heights. Species utilize specific feeding strategies and occupy specific spatial or ecological zones of wetlands to reduce interspecific competition. Various wetland features produce different environmental stimuli for species, thereby influencing habitat selection. Weller (1978) attributes increases in the abundance of bird species to increases in vegetation–water edges, openings in vegetation, increased vegetation layers, and complex zonation patterns. Although wetland vegeta-

Table 5–13. Estimated above-ground maximum standing crops of plant species or communities in prairie wetlands

Location	*Wetland form*	*Plant species*	*Net primary production ($g/m^2/yr$)*	*Source*
Eagle Lake, Iowa	Kettle marsh	*Typha glauca* *Scirpus fluviatilis* *Scirpus lacustris* ssp. *validus* *Scirpus lacustris* ssp. *glaucus* *Carex atherodes* *Sparganium eurycarpum*	1 156* 466 330 851 667 638	Van Der Valk and Davis (1978)
Theresa Marsh, Wisconsin	Stream marsh	Mudflat community *Typha* community *Scirpus fluviatilis* *Carex lacustris* *Salix interior*	924 1 852 984 940 664	Klopatek and Stearns (1978)
Alberta	Oxbow shallow water	Mature submergent Floating leaf Emergents Meadow	200 220 465 327	Van Der Valk and Bliss (1971)
Manitoba	Delta marsh Delta marsh Terminal basin Delta marsh	*Phragmites australis* *Typha latifolia* *Scirpus lacustris* ssp. *glaucus* *Scirpus lacustris* ssp. *validus*	1 812 1 754 365 570	Shay and Shay (1983)
Saskatchewan	Saline lake shallow water (subform)	*Scirpus maritimus*	625	Shay and Shay (1983)

**Average maximum standing crop.*

tion zones are put to different uses, the presence of a central pool promotes use of the entire marsh (Weller and Fredrickson 1973).

The values of prairie marshes as habitat for diverse wildlife species (Table 5–14) have been widely documented (Sanderson and Bellrose 1969; Harmon 1970; Smith *et al.* 1964; Munro 1963; Weller 1978). Marshes function as breeding, staging, and moulting habitats for numerous species of waterfowl, wading birds, colonial nesting birds, and shorebirds. Components of marshes show varied use by species ranging from truly aquatic-adapted birds such as ducks and grebes to terrestrial passerine birds which nest along the riparian edges. In turn, predatory birds such as hawks are attracted to the variety of prey species. Although marshes support complex food chains, birds ultimately depend upon the diversity and abundance of invertebrates and small vertebrates as sources of food.

Human exploitation of populations of gamebirds, fish, or fur-bearing mammals realizes real economic benefits from wetland wildlife. Waterfowl is an important resource, as shown by recent harvests of up to one million birds on the Prairies by over 70 000 active hunters (Metras 1985). Prairie ponds support few fish species of commercial value, although stream marshes provide spawning areas for pike (*Esox lucius*). Recent trends in fish farming demonstrate the value of prairie shallow waters for stocking rainbow trout (*Salmo gairdneri*) for commercial purposes (Swanson 1974). The most valuable fur-bearers frequenting prairie marshes include muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*), mink (*Mustela vison*), and raccoon (*Procyon lotor*).

Prairie wetlands also furnish essential habitat for rare, threatened, and endangered species. Migrating Whooping Cranes (*Grus americana*) traditionally use some saline lakes and marshes in central Saskatchewan. The sandy shorelines of large saline lakes are also preferred habitat for breeding and migrating Piping Plover (*Charadrius melodus*) (Renaud *et al.* 1979) and other shorebirds. Other rare and threatened species which may utilize prairie wetlands include the White Pelican (*Pelecanus erythrorhynchos*), the Caspian Tern (*Sterna caspia*), and the Trumpeter Swan (*Cygnus buccinator*).

Land Use

Agricultural land use has been increasing in intensity, resulting in severe changes to landscapes and wetlands in the Continental Prairie Wetland Region. In southern Saskatchewan, 52% of the land area is in cropland, 21% in forage lands, 23% in woodland, and 1% in permanent wetlands (Rump and Harper 1980). Total improved land now occupies 71.5% of the total area farmed. In high-capability agricultural areas, up to 83% of the uplands in central Saskatchewan (Sugden and Beyersbergen 1984) and 77–82% in southwestern Manitoba (Adams and Gentle 1978) are cultivated. Widespread clearing and cultivation remove natural vegetation which provides essential cover for wildlife.

Agriculture has had a considerable impact on wetlands. Approximately 1.2 million hectares of prairie wetlands have been converted to agricultural use (Whitesell 1970). Wetlands are eradicated through drainage, infilling, road building, and tillage. Some of these effects are summarized by Lynch-Stewart (1983).

Direct wetland losses attributed to drainage or tillage are difficult to quantify. In a study area in southwestern Manitoba, drainage affected 16% of wetlands during the period 1948–1964 (Kiel *et al.* 1972). Between 1964 and 1974, about 11% of the basins in the Minnedosa, Manitoba, region were partially drained (Adams and Gentle 1978). Rakowski and Chabot (1983) reported a 56% decline in wetland area in the same locality between 1970 and 1983. Cowardin *et al.* (1981) documented tillage affecting 40% of sampled wetlands in North Dakota.

Other practices, such as land clearing, burning, spraying, and grazing, usually have transitory impacts on wetlands, influencing plant succession and modifying water regimes. Clearing of the wetland margin decreases wetland size and depth by restricting snow accumulation, and promotes eventual basin filling by increased water erosion and siltation due to tillage of the margins (Kiel *et al.* 1972). In central Alberta, clearing of woody borders affected 32% of 398 wetlands (Merriam 1978), whereas in southwestern Manitoba clearing altered 37% of wetlands between 1948 and 1964 (Kiel *et al.* 1972). Near Rapid City, Manitoba, rates of burning increased from 6% of 363 wetlands in 1976 to 22% of 382 wetlands in 1977, a drought year (Table 5–15). In 1977, differences in the rates of impact of grazing and burning practices at Rapid City and Hamiota, Manitoba, on hummocky and ground moraine were also demonstrated (Table 5–15). Therefore, drought conditions and topography influence both the type of

Table 5–14. Characteristic invertebrate and vertebrate animals found in prairie wetlands

Wetland subform	Vegetation zone	Order	Species*
Shallow marsh	Open water	Crustaceans	*Chirocephalus bundyi* *Lepidurus* spp. *Branchipus* spp. *Limnetis* spp. *Estheria* sp. *Lynceus branchyurus*
		Insects	*Lestes dryasand* *Mochlonyx* sp.
		Molluscs	*Planorbis umbiliatellus* *Planorbis campestris*
		Amphibians	*Rana pipiens*
	Emergent	Birds	*Capella gallinago* *Anas* spp. *Cistothorus platensis*
Deep marsh/ Shallow water	Open water	Crustaceans	*Hyallela azteca* *Gammarus lacustris*
		Insects	*Glyptotendipes barbipes* *Phryganea cinerea* *Chironomus tentans* *Notonecta* sp. *Sympetrum corruptum* *Aeschna* spp. *Aedes vexans* *Culex tarsalis*
		Molluscs	*Lymnaea stagnalis* *Planorbis trivolis* *Physa gyrina*
		Fish	*Culaea inconstans*
		Amphibians	*Rana pipiens* *Ambystoma tigrinum* *Bufo hemiophrys*
		Mammals	*Ondatra zibethicus* *Mustela vison* *Castor canadensis*
	Emergent/ Open water	Birds	*Podiceps auritus* *Podilymbus podiceps* *Aythya* spp. *Fulica americana* *Chlidonias niger* *Anas* spp. *Xanthocephalus xanthocephalus* *Telmatodytes palustris*
Deep marsh/ Shallow marsh/ Wet meadow	Emergent/ Meadow	Mammals	*Procyon lotor* *Odocoileus virginianus* *Microtus pennsylvanicus*
		Birds	*Agelaius phoeniceus* *Botaurus lentiginosus* *Porzana carolina* *Circus cyaneus* *Asio flammeus*
	Tall shrub fringe	Birds	*Geothlypis trichas* *Melospiza melodia*
	Drawdown/ Water edge		*Actitis macularia* *Catoptrophorus semipalmatus*
	Saline shoreline		*Recurvirostra americana* *Charadrius melodus*

**Vertebrates assembled from Weller (1978). Invertebrates assembled from Driver and Peden (1977) and Bird (1961).*

Table 5–15. Frequency of wetland margins affected by land use practices in four Manitoba and Saskatchewan study areas (April–May 1976 or 1977)

Area	Year	Wetlands affected (%) by land uses								Total no. of wetlands studied
		Idle land	Grazing	Burn	Cultivated	Hay harvest	Drainage	Filling in	Clearing	
Manitoba										
Rapid City	1976	63.6	24.2	5.8	0.6	1.4	3.6	—	0.8	363
	1977	48.7	25.1	21.7	1.3	1.8	—	0.8	0.5	382
Hamiota	1976	74.7	7.5	8.3	1.5	—	0.4	1.1	3.4	265
	1977	52.3	15.1	28.3	3.6	0.7	—	—	—	279
Saskatchewan										
St. Denis	1976	50.7	44.7	0.9	0.5	3.2	—	—	—	217
Carmel–Peterson	1976	60.9	23.6	6.4	3.6	5.0	0.5	—	—	220

transitory land use practice utilized and its impact on wetlands.

Wetlands are altered or eradicated to create additional cultivated land, to improve farming efficiency, or to create additional forage or pasture. Use of wetland basins for forage production is a common practice because of favourable growth, good moisture regime, and tolerance of salinity by forage species (Lodge 1969). In the Intermountain Prairie Wetland Region, natural wetlands provide grazing and winter feed forage for the livestock industry (British Columbia Ministry of Agriculture and Food 1981). Wetlands in this region are also altered by water control practices, clearing, ploughing, seeding of introduced species, and fertilizing, to increase forage yields. Cultivation of a dry or drained basin may destroy the organic bottom seal, resulting in increased seepage loss when the wetland is reflooded (Millar 1969). Overgrazing, fires, and trampling lead to increased erosion and destruction of surface vegetation. The intensification of prairie agriculture is setting the stage for increased land degradation through wind and water erosion, depletion of organic matter, and greater soil salinity (Coote 1983).

Prairie Wetland Conservation

Ongoing losses and degradation of prairie wetlands demonstrate the need for a comprehensive inventory of wetlands to determine their distribution and the magnitude of these trends. Detection of such trends will direct wetland preservation and enhancement efforts and will help identify critical wetlands for waterfowl production. By 1990, Ducks Unlimited plans to complete a wetland inventory of the primary waterfowl production areas, in which the Continental Prairie Wetland Region is included (Koeln *et al.* 1986). Using LANDSAT satellite data from the thematic mapper system, Ducks Unlimited will map, classify, and generate statistics on wetlands throughout the region which are larger than 0.4 ha. This information, stored in computer files for rapid retrieval purposes, will constitute the most comprehensive inventory ever undertaken.

As a signatory of the RAMSAR Convention on Wetlands of International Importance, Canada has agreed to promote conservation of critically important wetlands. The goal of this Convention, sponsored by the International Union of Conservation of Nature, is to focus attention on the conservation of habitats and ecosystems of major biotic units, with particular attention to wetlands. RAMSAR-designated wetlands must be outstanding examples of a region, highly productive communities, valuable for educational or scientific purposes, or valuable as critical wildlife habitat. In the Continental Prairie Wetland Region, five RAMSAR sites were established in 1982 and 1987: Delta Marsh and Oak-Hammock Marsh, Manitoba; Last Mountain Lake and Quill Lakes, Saskatchewan; and Beaverhill Lake, Alberta.

The Intermountain Prairie Wetland Region is also recognized as an area of national and international importance to wildlife. In particular, the highest density of cavity nesting waterfowl in the world and the core of the world population of Barrow's Goldeneye (*Bucephala islandica*) are concentrated in this region (R. McKelvey, personal communication). The area is considered critical by the Canadian Wildlife Service.

In the Continental Prairie Wetland Region, millions of hectares of wetlands are protected in wildlife sanctuaries, in national wildlife areas, and in provincial and national parks. Through lease and agreements, Ducks Unlimited has also secured about 1.4 million ha of wetlands, mostly in western Canada, for waterfowl production purposes. Wetlands of high value to waterfowl and with ecological or societal significance are being designated and protected through Heritage Marsh agreements between Ducks Unlimited, provincial wildlife departments, and provincial wildlife federations. Designated wetlands include Range Slough, Foam Lake, Ponass Lake, and Chaplin Marsh in Saskatchewan, and Saskeram, Summerberry, Proven Lake, Grants Lake, and Oak-Hammock marshes in Manitoba.

Wildlife Habitat Canada, a conservation organization founded in 1984, is dedicated to the preservation and stewardship of Canadian wildlife habitat. The organization funds various habitat preservation and research projects from sales of Canada's first conservation stamp and prints. In cooperation with other government and nongovernment groups, Wildlife Habitat Canada is funding the acquisition of several critical prairie wetlands such as Horseshoe Lake, Saskatchewan. Also, pilot projects including the Redvers Prairie Pothole Project are being sponsored to develop landowner incentives to preserve wetlands and to modify land use practices harmful to waterfowl (Wildlife Habitat Canada 1986).

The North American Waterfowl Management Plan, signed in 1986 by the governments of Canada and the United States, outlines a rationale whereby management activities and jurisdictions can be coordinated to maintain and manage an appropriate distribution and diversity of high-quality waterfowl habitat to sustain an abundance of waterfowl (Environment Canada and the United States Department of the Interior 1986). The Plan hopes to generate one billion dollars over 15 years to protect and improve an additional 1.45 million ha of wetlands in Canada, with primary focus on the Continental Prairie Wetland Region. Goals for maintenance, restoration, and rehabilitation of duck habitat are based upon the extent of habitat during the period 1970–1979. Various methods to preserve wetland and upland habitat include acquisition of land, changing land use practices through financial incentives, promotion of soil and water conservation, and multiple use management of public lands.

Acknowledgements

Critical reviews of this manuscript were provided by S. Zoltai, C. Tarnocai, E. Oswald, H. Hirvonen, J. Pojar, R. Hebda, G. Trottier, and C. Rubec. Several photographs for illustrations were furnished by R. Zdan and G. Gentle. G. Gentle, W. Goerzen, and R. Zdan assisted in collecting and compiling wetland data on the study areas. L. Tomkewich provided word processing services and L. Jensen and G. Duff drafted maps.

References

ACTON, D.F., J.S. CLAYTON, J.G. ELLIS, E.A. CHRISTIANSEN, AND W.O. KUPSCH. 1960. Physiographic divisions of Saskatchewan. Map. Soil Survey and Geology Department, University of Saskatchewan, Saskatoon, Saskatchewan.

ADAMS, G.D., AND G.C. GENTLE. 1978. Spatial changes in waterfowl habitat, 1964–1974, on two land types in the Manitoba Newdale Plain. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 38. Saskatoon, Saskatchewan. 29 p.

ADAMS, G.D., AND R.C. HUTCHISON. 1976. Land capability for wildlife–waterfowl. Canada Land Inventory Map No. 62K. Riding Mountain. 1:250 000 map. Canada Department of Regional Economic Expansion. Ottawa, Ontario.

ADOMAITIS, V.A., G.A. SWANSON, AND J.A. SHOESMITH. 1983. Chemical characteristics of waters in northern prairie wetlands. North Dakota Academy of Science Proceedings 37:61.

BIRD, R.D. 1961. Ecology of the aspen parkland of western Canada in relation to land use. Canada Department of Agriculture. Publication No. 1066. Ottawa, Ontario. 155 p.

BRITISH COLUMBIA MINISTRY OF AGRICULTURE AND FOOD. 1981. Management and improvement of organic wetlands in the interior of British Columbia. Central Interior Forage Extension Committee. Victoria, British Columbia. 12 p.

BURWELL, R.W., AND L.G. SUGDEN. 1964. Potholes—going, going. *In* Waterfowl tomorrow. J.P. Linduska, editor. Bureau of Sport Fisheries and Wildlife, United States Department of the Interior. pp. 369–380.

CHAPMAN, L.J., AND D.M. BROWN. 1966. The climates of Canada for agriculture. Department of Forestry and Rural Development. Canada Land Inventory Report No. 3. Ottawa, Ontario. 24 p.

COOTE, D.R. 1983. Stress on land under intensive agricultural use. *In* Stress on land in Canada. W. Simpson-Lewis, R. McKechnie, and V. Neimanis, editors. Lands Directorate, Environment Canada. Ottawa, Ontario. pp. 228–257.

COUPLAND, R.T. 1961. A reconsideration of grassland classification in the northern great plains of North America. Journal of Ecology 49:135–167.

COWARDIN, L.M., D.S. GILMER, AND L.M. MECHLIN. 1981. Characteristics of central North Dakota wetlands determined from sample aerial photographs and ground study. Wildlife Society Bulletin 9(4):280–288.

COWARDIN, L.M., V. CARTER, F.C. GOLET, AND E.T. LAROE. 1979. Classification of wetlands and deepwater habitats of the United States. Fish and Wildlife Service, United States Department of the Interior. Report No. FWS/OBS-79/31. 103 p.

DAVIS, C.B., AND A.G. VAN DER VALK. 1978. Litter decomposition in prairie glacial marshes. *In* Freshwater wetlands—ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson, editors. Academic Press. New York, New York. pp. 99–113.

DIX, R.L., AND F.E. SMEINS. 1967. The prairie, meadow and marsh vegetation of Nelson County, North Dakota. Canadian Journal of Botany 45:21–58.

DODD, J.D., AND R.T. COUPLAND. 1966. Vegetation of saline areas in Saskatchewan. Ecology 47(6):958–968.

DRIVER, E.A., AND D.G. PEDEN. 1977. The chemistry of surface water in prairie ponds. Hydrobiologia 53(1):33–48.

EDMUNDS, F.H. 1962. Recession of the Wisconsinian glacier from central Saskatchewan. Petroleum and Natural Gas Branch, Geology Division, Department of Mineral Resources. Report No. 67. Regina, Saskatchewan. 23 p.

EHRLICH, W.A., L.E. PRATT, AND E.A. POYSER. 1956. Reconnaissance soil survey of Rossburn and Virden map sheet areas. Manitoba Soil Survey No. 6. Winnipeg, Manitoba. 121 p.

EISENLOHR, W.S. 1972. Hydrologic investigations of prairie potholes in North Dakota, 1959–1968. *In* Hydrology of prairie potholes in North Dakota. United States Geological Survey. Professional Paper 585-A. 102 p.

EISENLOHR, W.S., JR., AND C.E. SLOAN. 1968. Generalized hydrology of prairie potholes on the Coteau du Missouri, North Dakota. United States Geological Survey Circular. No. 558. 12 p.

ELSON, J.A. 1967. Geology of Glacial Lake Agassiz. *In* Life, land and water. Proceedings, 1966 Conference on Environmental Studies of the Glacial Lake Agassiz Region. W.J. Mayer-Oakes, editor. University of Manitoba Press. Winnipeg, Manitoba. pp. 37–95.

ENVIRONMENT CANADA AND THE UNITED STATES DEPARTMENT OF THE INTERIOR. 1986. North American Waterfowl Management Plan. A strategy for cooperation. Canadian Wildlife Service and United States Fish and Wildlife Service. Ottawa, Ontario, and Washington, DC. 19 p.

GOLLOP, J.B. 1963. Wetland inventories in western Canada. Transactions, 6th Congress, International Union of Game Biologists. Bournemouth, England. pp. 249–264.

GOSSELINK, J.B., AND R.E. TURNER. 1978. The role of hydrology in freshwater wetland ecosystems. *In* Freshwater wetlands—ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson, editors. Academic Press. New York, New York. pp. 63–78.

GRANGER, R.J., D.M. MALE, AND D.M. GRAY. 1978. Prairie snow melt. Proceedings, Saskatchewan Symposium on Hydrology. University of Saskatchewan, Saskatoon, Saskatchewan. 10 p.

GRUE, C.E., L.R. DE WEESE, P. MINEAU, G.A. SWANSON, J.R. FOSTER, P.M. ARNOLD, J.N. HUCKINS, P.J. SHEEHAN, W.K. MARSHALL, AND A.P. LUDDEN. 1986. Potential impacts of agricultural chemicals on waterfowl and other wildlife inhabiting prairie wetlands: an evaluation of research needs and approaches. *In* Transactions, 51st North American Wildlife and Natural Resources Conference. Reno, Nevada. pp. 357–383.

HAMMER, U.T. 1978. The saline lakes of Saskatchewan. III. Chemical characterization. International Revue Gestion. Hydrobiologia 63(3):311–335.

HAMMER, U.T., AND R.C. HAYNES. 1978. The saline lakes of Saskatchewan. II. Locale, hydrography and other physical aspects. International Revue Gestion. Hydrobiologia 63(2):179–203.

HAMMER, U.T., J. SHAMESS, AND R.C. HAYNES. 1983. The distribution and abundance of algae in saline lakes of Saskatchewan, Canada. Hydrobiologia 105(1):1–26.

HARE, F.K., AND H.K. THOMAS. 1979. The regional climates of Canada—prairie region. *In* Climate Canada. 2nd edition. John Wiley and Sons Limited. Toronto, Ontario. pp. 100–104.

HARMON, K.W. 1970. Prairie potholes. National Parks and Conservation Magazine 45(3):25–28.

HARRIS, S.W., AND W.H. MARSHALL. 1963. Ecology of water level manipulations on a northern marsh. Ecology 44(2):331–343.

HARRIS, W.C., A. KABZEMS, A. KOSOWAN, G.A. PADBURY, AND J.S. ROWE. 1983. Ecological regions of Saskatchewan. Forestry Division, Saskatchewan Department of Parks and Renewable Resources. Technical Bulletin No. 10. Regina, Saskatchewan. 57 p.

HEBDA, R.J. 1982. Postglacial history of grasslands of southern British Columbia and adjacent regions. *In* Proceedings, Symposium on Grassland Ecology and Classification. A.C. Nicholson, A. McLean, and T.E. Baker, editors. British Columbia Ministry of Forests. Victoria, British Columbia. pp. 157–191.

KADLEC, J.A. 1962. Effects of drawdown on a waterfowl impoundment. Ecology 43(2):267–281.

KADLEC, R.H., AND J.A. KADLEC. 1979. Wetlands and water quality. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. Lake Buena Vista, Florida. American Water Resources Association. Technical Publication Series S79-2. pp. 436–456.

KAMINSKI, R.M., AND H.H. PRINCE. 1981. Dabbling duck and aquatic macroinvertebrate responses to manipulated wetland habitat. Journal of Wildlife Management 45(1):1–15.

KIEL, W.M., JR., A.S. HAWKINS, AND N.G. PERRET. 1972. Waterfowl habitat trends in the aspen parkland of Manitoba. Canadian Wildlife Service, Environment Canada. Report Series No. 18. Ottawa, Ontario. 61 p.

KLOPATEK, J.M. 1978. Nutrient dynamics of freshwater riverine marshes and the role of emergent macrophytes. *In* Freshwater wetlands—ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson, editors. Academic Press. New York, New York. pp. 195–216.

KLOPATEK, J.M., AND F.W. STEARNS. 1978. Primary productivity of emergent macrophytes in a Wisconsin freshwater marsh ecosystem. American Midland Naturalist 100(2):320–332.

KOELN, G.T., P. CALDWELL, AND D.E. WESLEY. 1986. Inventory of wetlands with LANDSAT's thematic mapper. Proceedings, 10th Canadian Symposium on Remote Sensing. Edmonton, Alberta.

KRULL, J.N. 1970. Aquatic plant–macroinvertebrate associations and waterfowl. Journal of Wildlife Management 34(4):707–718.

LAKSHMAN, G. 1982. Natural and artificial ecosystems for the treatment of wastewaters. Saskatchewan Research Council. Publication No. E-820-7-E-82. Saskatoon, Saskatchewan.

LAST, W.M., AND T.M. SCHWEYEN. 1983. Sedimentology and geochemistry of saline lakes of the Great Plains. Hydrobiologia 105:245–263.

LIEFFERS, V.J., AND J.M. SHAY. 1983. Ephemeral saline lakes on the Canadian Prairies: their classification and management for emergent macrophyte growth. Hydrobiologia 105:85–94.

LODGE, R.W. 1969. Agricultural use of wetlands. *In* Saskatoon wetlands seminar. Canadian Wildlife Service, Environment Canada. Report Series No. 6. Ottawa, Ontario. pp. 11–15.

LOOMAN, J. 1981. The vegetation of the Canadian prairie provinces. III. Aquatic and semi-aquatic vegetation. Phytocoenologia 9(4):473–497.

LOOMAN, J. 1982. The vegetation of the Canadian prairie provinces. III. Aquatic and semi-aquatic vegetation. Part 2. Freshwater marshes and bogs. Phytocoenologia 10(4):401–423.

LOVE, D. 1959. The postglacial development of the flora of Manitoba. A discussion. Canadian Journal of Botany 37:547–585.

LYNCH, J.J., C.D. EVANS, AND V.C. CONOVER. 1963. Inventory of waterfowl environments of prairie Canada. *In* Transactions, 28th North American Wildlife and Natural Resources Conference. pp. 93–108.

LYNCH-STEWART, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. Ottawa, Ontario. 115 p.

MCKELVEY, R. (personal communication). December 1986. Canadian Wildlife Service, Environment Canada. Delta, British Columbia.

MERRIAM, G. 1978. Changes in aspen parkland habitats bordering Alberta sloughs. Canadian Field Naturalist 92(2):109–122.

METRAS, L. 1985. Migratory birds killed in Canada during the 1983 season. Canadian Wildlife Service, Environment Canada. Progress Notes No. 154. Ottawa, Ontario. 39 p.

MEYBOOM, P. 1966. Unsteady groundwater flow near a willow ring in hummocky moraine. Journal of Hydrology 4:38–62.

MEYBOOM, P. 1967a. Mass-transfer studies to determine the groundwater regime of permanent lakes in hummocky moraine of western Canada. Journal of Hydrology 5:117–142.

MEYBOOM, P. 1967b. Groundwater studies in the Assiniboine River drainage basin. Part 1. The evaluation of a flow system in south-central Saskatchewan. Geological Survey of Canada, Department of Mines and Technical Surveys. Bulletin No. 139. Ottawa, Ontario. 61 p.

MILLAR, J.B. 1969. Observations on the ecology of wetland vegetation. *In* Saskatoon wetlands seminar. Canadian Wildlife Service, Environment Canada. Report Series No. 6. Ottawa, Ontario. pp. 49–56.

MILLAR, J.B. 1971. Shoreline-area ratio as a factor in rate of water loss from small sloughs. Journal of Hydrology 14:259–284.

MILLAR, J.B. 1973. Vegetation changes in shallow marsh wetlands under improving moisture regime. Canadian Journal of Botany 51(8):1443–1457.

MILLAR, J.B. 1976. Wetland classification in western Canada: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Canadian Wildlife Service, Environment Canada. Report Series No. 37. Ottawa, Ontario. 38 p.

MITCHELL, J., H.C. MOSS, AND J.S. CLAYTON. 1944. Soil survey of southern Saskatchewan. College of Agriculture, University of Saskatchewan. Soil Survey Report No. 12. Saskatoon, Saskatchewan. 259 p.

MOYLE, J.B. 1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. American Midland Naturalist 34:402–420.

MUNRO, D.A. 1963. Ducks and the Great Plains wetlands. Canadian Audubon Magazine. September–October 1963. 8 p.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NELSON, J.W., AND J.A. KADLEC. 1984. A conceptual approach to relating habitat structure and macroinvertebrate production in freshwater wetlands. *In* Transactions, 49th North American Wildlife and Natural Resources Conference. Boston, Massachusetts. pp. 262–269.

NICHOLSON, A.C., J. POJAR, AND E.H. HAMILTON. 1982. Description of southern interior grasslands of British Columbia. Appendix 1. *In* Proceedings, Symposium on Grassland Ecology and Classification. A.C. Nicholson, A. McLean, and T.E. Baker, editors. British Columbia Ministry of Forests. Victoria, British Columbia. pp. 10–17.

NICHOLSON, N.L., DIRECTOR. 1957. Atlas of Canada: Geographical Branch, Department of Mines and Technical Surveys. Ottawa, Ontario.

NOVITZKI, R.P. 1978. Hydrological characteristics of Wisconsin's wetlands and their influence on floods, streamflow and sediment. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. Lake Buena Vista, Florida. American Water Resources Association. Technical Publication Series S79-2. pp. 377–388.

ODUM, E.P. 1978. The value of wetlands: a hierarchical approach. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. Lake Buena Vista, Florida. American Water Resources Association. Technical Publication Series S79-2. pp. 16–25.

PAVLICK, L.E., AND J. LOOMAN. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica*, *F. campestris* (*F. scabrella* var. *major*) and *F. hallii*, in Canada and the adjacent part of the United States. Canadian Journal of Botany 62:1739–1749.

RAKOWSKI, P.W., AND B.P. CHABOT. 1983. Changes in land use in the Minnedosa district of southwestern Manitoba: an update on the Kiel–Hawkins transect. Canadian Wildlife Service, Environment Canada. Winnipeg, Manitoba. Unpublished. 15 p.

RENAUD, E., G.J. WAPPLE, AND D.W. EDGETT. 1979. The piping plover in Saskatchewan: a status report. Blue Jay 37(2):90–103.

RICHARDS, J.H., AND K.I. FUNG. 1969. Atlas of Saskatchewan. University of Saskatchewan Modern Press. Saskatoon, Saskatchewan.

RICHARDSON, C.J. 1978. Primary productivity values in freshwater wetlands. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. Lake Buena Vista, Florida. American Water Resources Association. Technical Publication Series S79-2. pp. 131–145.

RITCHIE, J.C. 1976. The late-Quaternary vegetational history of the western interior of Canada. Canadian Journal of Botany 54:1793–1818.

ROWE, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Environment Canada. Publication No. 1300. Ottawa, Ontario. 172 p.

ROZKOWSKA, A.D., AND A. ROZKOWSKI. 1969. Seasonal changes of slough and lake water chemistry in southern Saskatchewan. Journal of Hydrology 7:1–13.

ROZKOWSKI, A. 1969. Chemistry of ground and surface waters in the Moose Mountain area, southern Saskatchewan. Geological Survey of Canada, Department of Mines and Resources. Paper 67-9. Ottawa, Ontario. 111 p.

RUMP, P.C., AND K. HARPER. 1980. Land use in Saskatchewan. 2nd edition. Policy, Planning and Research Branch, Saskatchewan Department of the Environment. Regina, Saskatchewan. pp. 58–71.

RYDER, J.M. 1982. Surficial geology of the grassland areas of British Columbia and adjacent regions. *In* Proceedings, Symposium on Grassland Ecology and Classification. A.C. Nicholson, A. McLean, and T.E. Baker, editors. British Columbia Ministry of Forests. Victoria, British Columbia. pp. 63–94.

SANDERSON, G.C., AND F.L. BELLROSE. 1969. Wildlife habitat management of wetlands. Annals Academy Brasil, Ciénc 41:153–204.

SATHER, J.H., AND R.D. SMITH. 1984. An overview of major wetland functions and values. Fish and Wildlife Service, United States Department of the Interior. Report No. FWS/OBS-84/18. 68 p.

SHAY, J.M., AND C.T. SHAY. 1983. Prairie marshes in western Canada. *In* Proceedings, Mire–Wetland Symposium. International Biological Sciences Association and Canadian Botanical Association.

SHJEFLO, J.B. 1968. Evapotranspiration and the water budget of prairie potholes in North Dakota. *In* Hydrology of prairie potholes in North Dakota. United States Geological Survey. Professional Paper 585-B. 49 p.

SLOAN, C.E. 1970. Prairie potholes and the water table. United States Geological Survey. Professional Paper 700-B. pp. B227–B231.

SMITH, A.E., J.H. STOUDT, AND J.B. GOLLOP. 1964. Prairie potholes and marshes. *In* Waterfowl tomorrow. J.P. Linduska, editor. Bureau of Sport Fisheries and Wildlife, United States Department of the Interior. pp. 39–50.

SMITH, A.G. 1971. Ecological factors affecting waterfowl production in the Alberta parklands. Fish and Wildlife Service, United States Department of the Interior. Research Publication No. 98. 49 p.

SMITH, A.L. 1973. Life cycle of the marsh grass, *Scolochloa festucacea*. Canadian Journal of Botany 51:1661–1668.

SOIL CONSERVATION SOCIETY OF AMERICA. 1982. Resource Conservation Glossary. 3rd edition. H.W. Pritchard, chairman. 126 p.

STEWART, R.E., AND H.A. KANTRUD. 1971. Classification of natural ponds and lakes in the glaciated prairie region. Bureau of Sport Fisheries and Wildlife, United States Department of the Interior. Research Publication No. 92. 57 p.

STEWART, R.E., AND H.A. KANTRUD. 1972. Vegetation of prairie potholes, North Dakota, in relation to quality of water and other environmental factors. *In* Hydrology of prairie potholes in North Dakota. United States Geological Survey. Professional Paper 585-D. 36 p.

STRONG, W.L., AND K.R. LEGGAT. 1981. Ecoregions of Alberta. Research Evaluation and Planning Division, Alberta Department of Energy and Natural Resources. Technical Report No. T/4. Edmonton, Alberta. 64 p.

SUGDEN, L.G., AND G.W. BEYERSBERGEN. 1984. Farming intensity on waterfowl breeding grounds in Saskatchewan parklands. Wildlife Society Bulletin 12(1):22–26.

SWANSON, M. 1974. Trout farming in Saskatchewan. Saskatchewan Department of Tourism and Renewable Resources. Regina, Saskatchewan. 18 p.

SWANSON, G.A., AND M.I. MEYER. 1977. Impact of fluctuating water levels on feeding ecology of breeding Blue-winged Teal. Journal of Wildlife Management 41(3):426–433.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–39.

TISDALE, E.W. 1947. The grasslands of the southern interior of British Columbia. Ecology 28:246–282.

VAN DER VALK, A.G., AND L.C. BLISS. 1971. Hydrarch succession and net primary production of oxbow lakes in central Alberta. Canadian Journal of Botany 49:1177–1199.

VAN DER VALK, A.G., AND C.B. DAVIS. 1978. Primary production of prairie glacial marshes. *In* Freshwater wetlands—ecological processes and management potential. R.E. Good, D.F. Whigham, and R.L. Simpson, editors. Academic Press. New York, New York. pp. 21–37.

VAN DER VALK, A.G., AND C.B. DAVIS. 1980. The impact of a natural drawdown on the growth of four emergent species in a prairie glacial marsh. Aquatic Botany 9:301–322.

WALKER, B.H., AND R.T. COUPLAND. 1968. An analysis of vegetation–environmental relationships in Saskatchewan sloughs. Canadian Journal of Botany 46:509–522.

WALKER, B.H., AND R.T. COUPLAND. 1970. Herbaceous wetland vegetation in the aspen grove and grassland regions of Saskatchewan. Canadian Journal of Botany 48:1861–1878.

WARD, P. 1968. Fire in relation to waterfowl habitat of the Delta marshes. *In* Proceedings, 8th Annual Tall Timber Fire Ecology Conference. pp. 255–267.

WEIR, T.R., EDITOR. 1960. Economic atlas of Manitoba. Manitoba Department of Industry and Commerce. Winnipeg, Manitoba.

WELLER, M.W. 1978. Wetland habitats. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. Lake Buena Vista, Florida. American Water Resources Association. Technical Publication Series S79-2. pp. 210–234.

WELLER, M.W., AND L.M. FREDRICKSON. 1973. Avian ecology of a managed glacial marsh. The Living Bird 12:269–291.

WHITESELL, D.E. 1970. Wetlands preservation–management in North America. Transactions, 35th North American Wildlife and Natural Resources Conference. pp. 327–335.

WILDLIFE HABITAT CANADA. 1986. Program highlights across Canada. Ottawa, Ontario. 12 p.

WONDERS, W.C., EXECUTIVE DIRECTOR. 1969. Atlas of Alberta. Technical Division, Alberta Lands and Forest Surveys Branch, Alberta Department of Highways. University of Alberta Press. Edmonton, Alberta.

YANCEY, R.K. 1964. Matches and marshes. *In* Waterfowl tomorrow. J.P. Linduska, editor. Bureau of Sport Fisheries and Wildlife, United States Department of the Interior. pp. 619–626.

ZOLTAI, S.C. 1979. An outline of the wetland regions of Canada. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 1–8.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

6 Wetlands of Eastern Temperate Canada

V. Glooschenko
P. Grondin

Wetlands of Eastern Temperate Canada

Wetlands in the Eastern Temperate Wetland Region (TE) are located in southern Ontario, the St. Lawrence Lowlands, the Appalachian Highlands in Quebec and New Brunswick, and along the St. Lawrence, Ottawa, and Richelieu river valleys in Quebec and the Saint John River Valley in southwestern New Brunswick. Temperate wetlands are also found in southwestern British Columbia in the Pacific Temperate Wetland Region (TP), but these are considered separately in Chapter 8.

*The Eastern Temperate Wetland Region is distinguished from other wetland regions by the occurrence of hardwood treed swamps dominated by maple (*Acer saccharinum* and *Acer rubrum*). It is specifically these maple species which characterize this region, since swamps dominated* by elm–ash (*Ulmus* spp.–*Fraxinus* spp.) occur in the Low Boreal Wetland Region (BL) and the Humid Mid-Boreal Wetland Subregion (BMh). The Eastern Temperate Wetland Region is also characterized by numerous and extensive marshes occupied by tall standing vegetation (such as *Typha* spp.), by shallow water wetlands with a wide variety of submerged and floating species, and by some of the most important coastal salt and brackish marshes in Canada. However, because the vegetation of this wetland region has been disturbed by man over a long period, the natural distribution pattern of wetland ecosystems is not clearly reflected in the present wetland occurrence.

The boundary between this region and the Low Boreal Wetland Region which adjoins it is difficult to define precisely. However, there is sufficient occurrence of soft maple swamps in the northwestern part of southern Ontario to justify the inclusion of this area in the Eastern Temperate Wetland Region. This revision, which is delineated in Figure 6–1, would amend the boundaries previously proposed by the National Wetlands Working Group (1986) (see Inside Back Cover).

The Eastern Temperate Wetland Region forms a linear band across Canada's most settled area, encompassing over 200 000 km^2. Agricultural use of this region is intensive, with the production of maple syrup from *Acer saccharum* trees a valued component in the economy. Wetlands in this area are under more severe pressure than anywhere else in the nation for conversion to urban and industrial uses, and to port, marina, highway, and agricultural development.

In this chapter the factors affecting the formation of eastern temperate wetlands, the common wetland forms observed, and the current status of

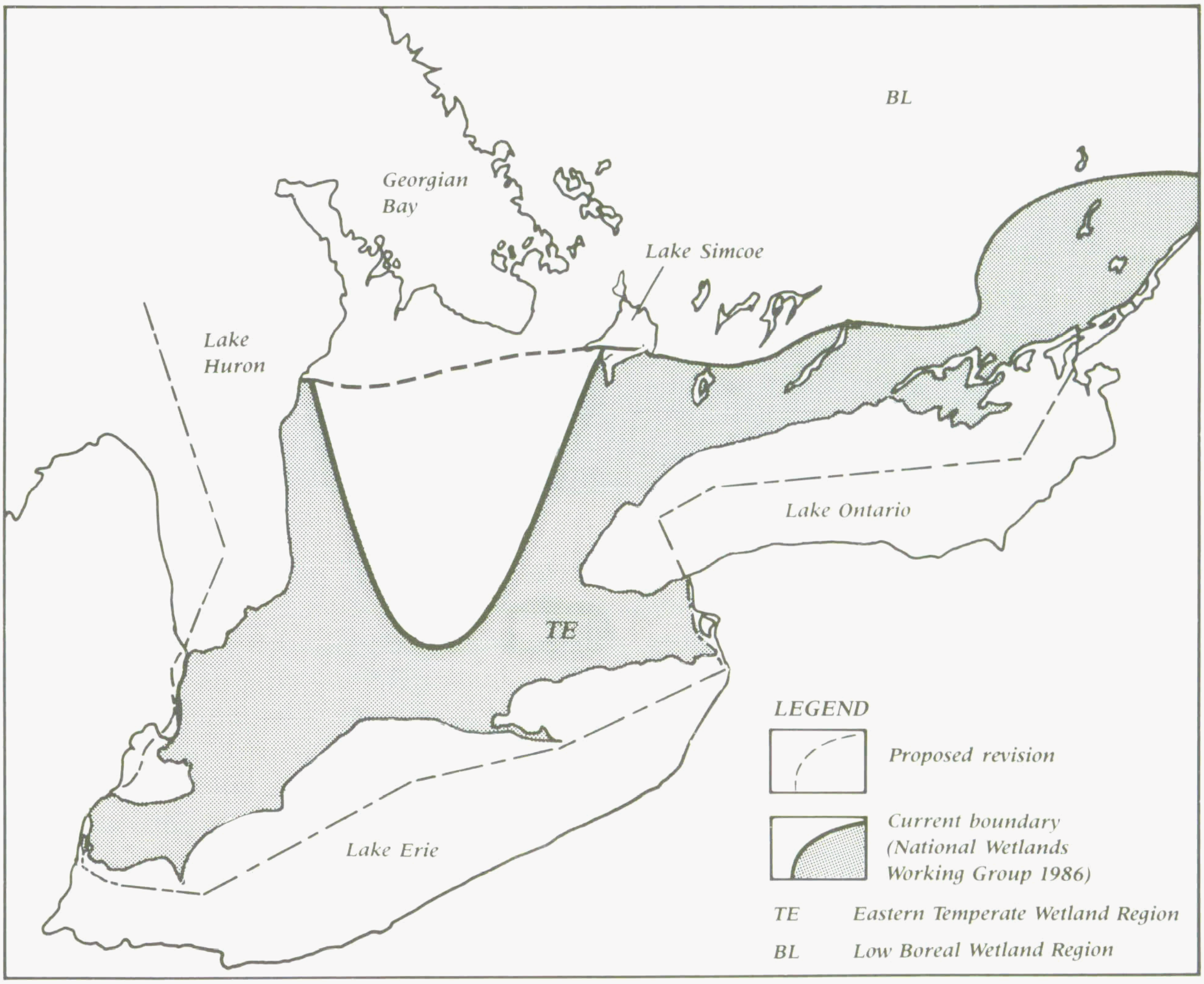
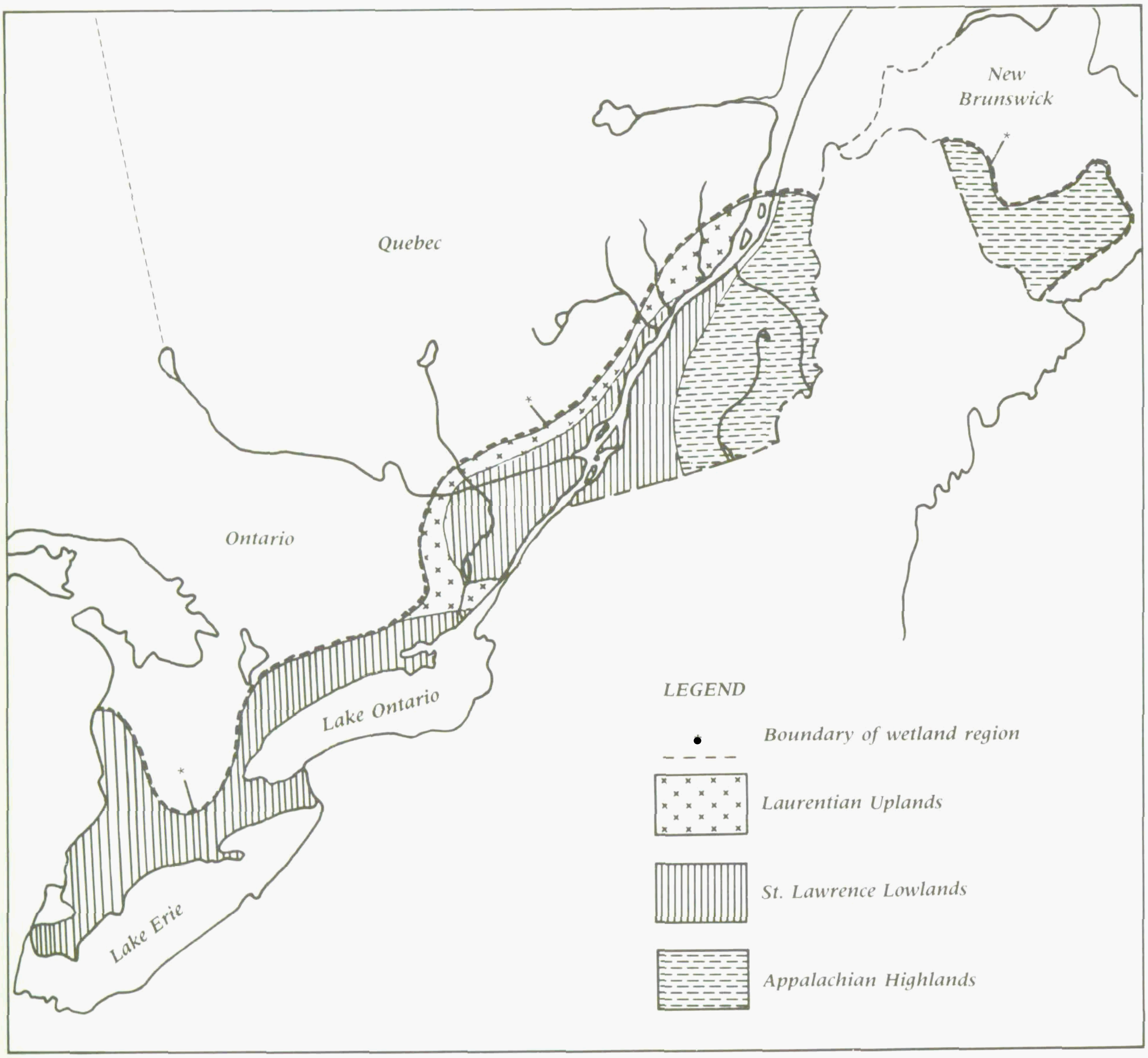


Figure 6–1.
Proposed revision to Eastern Temperate Wetland Region in southern Ontario.



Source: Bostock (1970).

Figure 6–2.
Physiographic subdivisions of the Eastern Temperate Wetland Region.

wetland evaluation and conservation programs in this wetland region are examined.

Environmental Setting

Physical Geography

The Eastern Temperate Wetland Region is essentially composed of two major physiographic subdivisions: (a) The St. Lawrence Lowlands extending from southwestern Ontario to the eastern townships in Quebec, and (b) the Appalachian Highlands in portions of the region in Quebec and New Brunswick. The northern fringe of this wetland region is bordered from the Frontenac Axis in eastern Ontario through to Quebec City by the Laurentian Uplands of the Canadian Shield (Bostock 1970) (Figure 6–2).

The St. Lawrence Lowlands are characterized by relatively flat relief reflecting the underlying sedimentary Ordovician bedrock. Glacio-lacustrine sediments mantle much of these Lowlands as a result of the Wisconsin glaciation 13 000–12 000 years before the present (BP) and the subsequent formation of the extensive Champlain Sea. This resulted in extensive areas of marine and lacustrine clay and fluvial sand deposits.

Water erosion and glaciation have formed numerous shallow basins within the limestone plains of the Eastern Temperate Wetland Region. Because of the level to very slightly sloping surface of these plains and the resistance to stream erosion of their bedrock surfaces, many of these basins remained undrained and provided wet sites in which wetlands have developed. The limestone plain which centres on Smiths Falls, Ontario, is a striking example. It has an area of some 3 600 km^2 with extensive wetlands.

On morainal plains, youthful stream courses developed after the Wisconsin glaciation. In shallower, flat portions of these plains, streams eroded to the underlying bedrock, at which time further down-cutting virtually ceased before the drainage system became extended throughout the entire plain. The Luther Bog, west of Orangeville, Ontario, is an example of this process. Limestone, exposed at Grand Valley about 5 km east of the Luther Bog, lies about 23 m below the surface of the adjacent plain. This bedrock has prevented further deepening of the Grand River, which in turn has prevented most of its tributaries from extending into the basin of the Luther Bog. On morainal plains with extensive, moderately deep deposits, adequate drainage systems have not yet developed. Wetlands have also developed in basins located in flat, poorly drained, water-laid clay plains, such as the Haldimand Plain near Niagara Falls, Ontario.

Natural drainage routes are considerably disrupted by drumlins in the extensive drumlin field centring on Peterborough, Ontario. Here, the inter-drumlin areas are poorly drained and sustain swamps dominated by cedar (*Thuja* spp.) or elm–ash (*Ulmus* spp.–*Fraxinus* spp.). Barrier beaches formed in glacial lakes have provided dams, which have impeded the drainage of the lagoons on their landward side, thus also providing sites in which wetlands have developed. Wetlands have also formed in the basins of former water bodies where there was no impediment to the establishment of drainage systems other than the lack of gradient of the surrounding areas. The Holland Marsh in Ontario is located in a flat, deeply drift-filled, preglacial valley in which the Schomberg River system has been shallowly incised. Consequently, this river frequently overflows its banks, preserving an open fen along its flanks, and has been ineffective throughout its history in draining the basin bogs inland of this fen.

The Mer Bleue Bog and Alfred Bog near Ottawa, Ontario, are examples of wetlands which have formed in postglacial drainage channels. Large sand deltas were built in the Champlain Sea, at two locations just east of Ottawa, by a precursor of the Ottawa River. When the glacial ice had receded completely from the Ottawa Valley and opened a lower outlet, several channels were eroded in these deltas. The Mer Bleue Bog and Alfred Bog developed in undrained portions of these channels.

Extensive marshes have developed in the Great Lakes Basin and along the shorelines of the St. Lawrence, Ottawa, and Richelieu rivers. Examples include the large marshes at Walpole Island on Lake St. Clair, and marshes at Point Pelee, Rondeau, and Long Point on Lake Erie, and along the reaches and bays near Prince Edward Point on Lake Ontario in Ontario, and Lac St-Pierre, Lake of Two Mountains, Kamouraska Bay, and Cap Tourmente in Quebec.

The Appalachian Highlands in the southeastern Quebec and southwestern New Brunswick portions of the Eastern Temperate Wetland Region provide a major change in the landscape affecting wetland formation. The general relief of the area is undulating and mountainous (Ducruc and Audet 1984; Dubois 1974). Devonian sedimentary bedrock underlies this area, covered by thin glacial moraine and reworked sedimentary deposits. Wetlands in these Highlands are relatively less common than in the St. Lawrence Lowlands and are distinctly different in form and character. This area is characterized by Podzolic soils which are acid, generally coarse-textured, and leached of most soil nutrients. Most of these soils are classified as either Humo-Ferric or Ferro-Humic Podzols. Hardpans, generally within 50 cm of the surface and developed from the cementation of leached organic carbon (C), iron (Fe), and aluminum (Al), are common. This condition, in time, has led to poor drainage conditions and swamp and bog development. Gleysols are characteristic of many of these sites with poorly drained mineral soils, while Organic soils are found in bogs and other wetlands (Hirvonen 1984).

Within southern New Brunswick, eastern white cedar (*Thuja occidentalis*) occurs extensively on calcareous soils. Because of the generally depressed nature of the terrain and the heavier texture of the soils, drainage plays a major role in the composition of vegetation. Large bogs are frequent; species such as black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), and red maple (*Acer rubrum*), which grow well on imperfectly drained soils, are common. The dominance of white pine (*Pinus strobus*) on valley outwash deposits is also characteristic of this area of New Brunswick. The Saint John River Valley is a sheltered enclave of temperate conditions. Sparse occurrence of white ash (*Fraxinus americana*), butternut (*Juglans cinerea*), ironwood (*Ostrya virginiana*), and basswood (*Tilia americana*) distinguishes this area. Black ash (*Fraxinus nigra*) is present on poorly drained sites.

The upland portions of Quebec remain characteristically vegetated by yellow birch–sugar maple (*Betula alleghaniensis–Acer saccharum*), beech–sugar maple, and yellow birch–balsam fir woodlots (Gilbert *et al.* 1985). Poorly drained sites are characterized by eastern white cedar and scattered balsam fir.

Climate

Table 6–1 provides an outline of climatic parameters in the Eastern Temperate Wetland Region. The region is characterized by relatively mild winter temperatures. Only the Pacific Temperate (TP) and Pacific Oceans (OP) Wetland Regions have milder winter conditions. The average daily July temperatures of 17–21°C at climate stations in the Eastern Temperate Wetland Region indicate that this area is generally warmer in the summer than any of the other wetland regions of Canada.

In Ontario, the number of frost-free days averages 167–172 in areas adjacent to Lake Erie and 150–155 near Toronto and London, with a low of about 142 in areas adjacent to Lake Huron in the western portion of the Eastern Temperate Wetland Region. In the St. Lawrence River Valley, the number of frost-free days ranges from approximately 100 near Sherbrooke, Quebec, to about 148 near Ottawa, Ontario. The number of frost-free days in the portion of the Eastern Temperate Wetland Region that lies in New Brunswick ranges from 115 to 120. This whole wetland region receives an average of 900–1 400 mm of precipitation annually, a moderately large amount of precipitation exceeded only by the Atlantic Oceanic and Pacific Oceanic Wetland Regions.

It is clear that, during the growing season, the soft maple–ash (*Acer* spp.–*Fraxinus* spp.) swamps which characterize the Eastern Temperate Wetland Region require a combination of reasonably warm temperatures, moderately high rainfall, and mild winters.

Wetland Forms of the Eastern Temperate Wetland Region

Wetlands characteristic of the Eastern Temperate Wetland Region are considered within the framework of the Canadian Wetland Classification System, presented in Appendix I (Tarnocai 1980). Five classes are used: bog, fen, swamp, marsh, and shallow water. The wetland forms which most commonly occur in the Eastern Temperate Wetland Region are listed below and examples of each are discussed in the subsequent sections.

Bogs: (i) flat, (ii) basin, (iii) domed, (iv) shore.
Fens: (i) shore, (ii) stream, (iii) channel.
Swamps: (i) peat margin, (ii) basin, (iii) stream, (iv) shore, (v) spring.
Marshes: (i) shore, (ii) tidal freshwater.
Shallow Waters: general description.

Eastern Temperate Bog Forms

Bogs of the Eastern Temperate Wetland Region occur in shallow depressions which receive negligible amounts of runoff from surrounding uplands, so that their source of water is the precipitation falling directly upon them. The water table is at or near the surface in the spring, and slightly below the surface during the remainder of the year. Mosses often form raised hummocks, sepa-

Table 6–1. Climatic data for representative meteorological stations in the Eastern Temperate Wetland Region

Station	*Mean daily January temp. (°C)*	*Mean daily July temp. (°C)*	*Growing degree-days above 5°C*	*Mean annual precipitation (mm)*	*Mean annual snowfall (cm)*
London, Ontario	−6.6	20.3	2 139.3	909.4	208.8
Barrie, Ontario	−8.9	19.1	*	949.5	280.3
Cornwall, Ontario	−9.3	20.9	2 171.2	927.9	215.9
Sherbrooke, Quebec	−11.7	17.8	1 602.3	1 075.1	322.6
Quebec, Quebec	−12.1	17.5	1 689.7	1 174.0	343.4
Saint John, New Brunswick	−7.8	16.9	1 499.4	1 444.4	292.7

Source: Atmospheric Environment Service (1982).
**No data.*

rated by low, wet interstices. The bog surface is often domed or, if flat or level with the surrounding wetlands, is virtually isolated from mineral-soil waters. Hence, surface bog waters and peat are strongly acid (pH values range from less than 4 to 4.5) and upper peat layers are extremely deficient in mineral nutrients. Peat is usually formed *in situ* under closed drainage and oxygen saturation is very low. Although bogs are usually covered with *Sphagnum* spp., sedges may grow on them. They may be treed or treeless, and they are frequently characterized by a layer of ericaceous shrubs. The peat depth in eastern temperate bogs averages about 4 m with a range from 40 cm to over 6 m (Pala and Boissonneau 1985).

Four forms of bog occur in the Eastern Temperate Wetland Region: flat, basin, domed, and shore. Bogs comprise about 10% of the land surface in the St. Lawrence Lowlands and 2–3% of the land surface in the Appalachian Highlands.

Flat and Basin Bogs

Flat bogs, mainly restricted to the southwestern Ontario portion of this wetland region, occur in shallow basins which are encircled by a very narrow watershed. Since a narrow to moderately broad zone at the edge of these bogs has a shallower peat depth than their centre (or a point near one side in asymmetrical basins), some of the bogs in the Eastern Temperate Wetland Region may be classified as basin bogs. The flat bog term used here is a tentative designation pending more accurate descriptions of their basin morphometry. Both the graminoid bog type and the tall shrub ("thicket") bog type discussed below have been included in the flat bog form first defined by Zoltai *et al.* (1975). "Graminoid" includes the sedge, rush, and grass wetlands types defined in Appendix I and "shrub" includes both the low and tall shrub types.

Graminoid flat bogs have a prairie-like appearance because of the dominance of a graminoid stratum in which *Carex oligosperma* or *Calamagrostis canadensis* is usually dominant. This is in contrast to the low shrub flat bog (Jeglum *et al.* 1974) in which the low shrub stratum is composed of *Chamaedaphne calyculata, Ledum groenlandicum,* and *Aronia melanocarpa.*

A graminoid flat bog with a dominant graminoid layer, principally of the sedge *Carex oligosperma*, has been observed to be a minor vegetation type of the Mer Bleue Bog located 20 km east of Ottawa; Joyal (1970) describes a floristic group called "sphagno-calamagrosetum" in the same bog.

A low shrub flat bog known as the Luther Bog is located at the south end of Luther Lake about 30 km west of Orangeville, Ontario. The tree story is composed of less than 1% cover of *Larix laricina* and *Picea mariana*. The dominant low shrub stratum has a cover of 30%, composed in descending order of dominance of *Chamaedaphne calyculata, Ledum groenlandicum, Andromeda glaucophylla,* and *Aronia melanocarpa*. The sedge *Eriophorum spissum* is present and there are lichens on the sides of infrequent depressions in the bog surface. The dominant ground cover is mound-forming *Sphagnum fuscum*.

The peat in this flat bog is, on average, 615 cm deep and composed of peat and inorganic horizons whose characteristics are summarized in Table 6–2. The pH value of the soil water is 4.5. The organic profile is composed of 290 cm of fibric (Of) peat soil horizons, 150 cm of mesic (Om) horizons, and 165 cm of humic (Oh) horizons; this profile is classified as a Typic Mesisol. The middle tier is about 70% mesic peat; fibric peat in the middle tier is only 25 cm thick and there are only 15 cm of humic peat in the bottom tier.

It is postulated that the silty textured parent material on this site was deposited in a postglacial lake, the water level of which eventually lowered to become shallow water with submergent, and possibly emergent, vegetation and silty sediments. These accumulated to form the mixed organic and inorganic soil horizon designated in Table 6–2 as "Ah", even though its origin is unlikely to be pedogenic. Organic horizons extending upwards to Of5 were accumulated in a fen which occupied a shallow water location at the lake shore. The mesic and fibric peat layers (horizons Of2 and Om1, Of3 and Om2, and Om3 to Om4) are *Sphagnum* materials accumulated, for the most part, after the lake had been drained and after the wetland had converted from a sedge fen to a *Sphagnum*-dominated bog. Horizons Oh1 and Oh2 are well-decomposed peat and ooze, respectively, which were probably deposited in small, short-lived pools which developed in local shallow depressions within the bog.

Table 6–2 also presents a summary of the chemical analyses of selected horizons of the Luther Bog, Ontario. The well-decomposed ooze of horizon Oh1 has a very high level of calcium (Ca) ions relative to the other horizons of this profile. This would imply the presence of blue-green algae in the bog pool and an inflowing stream which sup-

Table 6–2. ***Physical and chemical characteristics of a low shrub flat bog at Luther Lake, Ontario—the Luther Bog***

Soil horizon	Material	Depth (cm)	Mean sampling depth (cm)	pH (peat)	Decom-position (von Post)	Conduc-tivity (µS/cm)	Cation exchange capacity (me/100 g)	Total N (%)	Exchangeable cations (me/100 g)		
									Ca	Mg	K
Of1	Living moss	0–10	—	4.0	2	—	—	—	—	—	—
Of2	Fibric peat	10–65	25	4.5	3–4	65.5	85.55	0.82	4.99	0.62	0.71
Om1	Mesic peat	65–145	75	4.0	5	65.0	84.28	1.12	0.74	0.15	0.36
		—	125	4.5	6	50.0	83.19	1.12	0.94	0.15	0.28
Oh1	Ooze	145–190	175	4.5	8	58.5	59.81	0.96	16.84	1.23	0.24
Of3	Fibric peat	190–215	—	4.0	4	—	—	—	—	—	—
Om2	Mesic peat	215–235	225	4.0	6	41.3	82.10	0.80	0.94	0.15	0.24
Oh2	Humic peat	235–255	—	4.2	7	—	—	—	—	—	—
Om3	Mesic peat	255–285	275	4.5	5	36.5	76.12	1.32	2.81	0.85	0.06
Of4	Fibric peat	285–365	325	4.0–4.5	4	42.5	70.14	1.72	9.36	0.77	0.24
Om4	Mesic peat	365–385	—	4.5	6	—	—	—	—	—	—
Of5	Sedge peat	385–515	—	4.5–5.5	4	—	—	—	—	—	—
Oh3	Sedge peat	515–540	—	5.5	7	—	—	—	—	—	—
Oh4	Sedimentary peat	540–615	—	6.5	8	—	—	—	—	—	—
Ah	Mixed silt/humus	615–640	—	6.8	—	—	—	—	—	—	—
C	Silt, no stones	640+	—	—	—	—	—	—	—	—	—

plied the pool with cations. Chemical analyses of horizon Oh1 are not directly comparable with those of the overlying peat horizons.

Domed Bogs

Domed bogs are relatively common in the southern Quebec portions of the Eastern Temperate Wetland Region. They have formed in poorly drained depressions over several thousand years since the waning of the Glacial Champlain Sea. They are characterized by peat depths of 2–5 m over littoral sands (Figure 6–3), with pH values of about 4.5 at the water table and 4 in the surficial peat layers.

Most domed bogs of this wetland region generally have a uniform low shrub cover or, rarely, an herbaceous cover. Some have numerous round to slightly elongated small ponds on their central portion, each covering an area of 0.5–5 ha, with mean depths of 3 m (Couillard and Grondin 1986). They commonly have *Chamaedaphne calyculata* in wetter sites, while *Ledum groenlandicum* is common in slightly drier sites in these bogs. Fires have tended to result in the occurrence of *Rhododendron canadense* and *Betula populifolia* shrubs.

The major shrubs in these domed bogs include *Aronia melanocarpa, Vaccinium myrtilloides, Vac-*

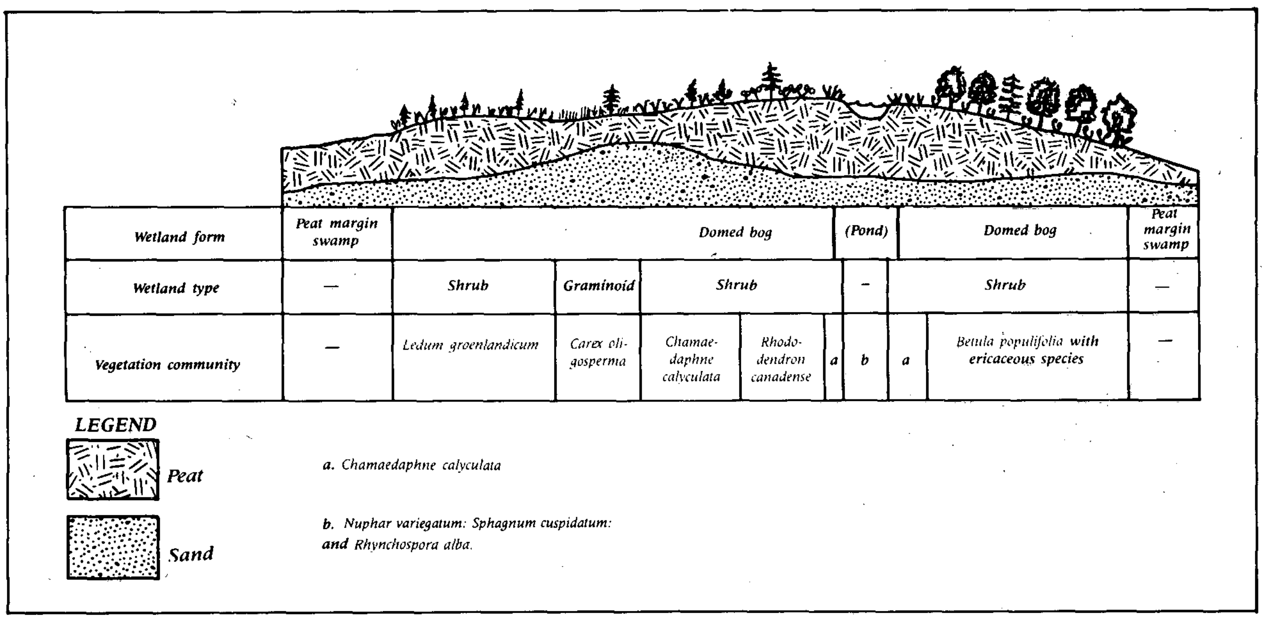


Figure 6–3.
Cross-section of an eastern temperate domed bog.

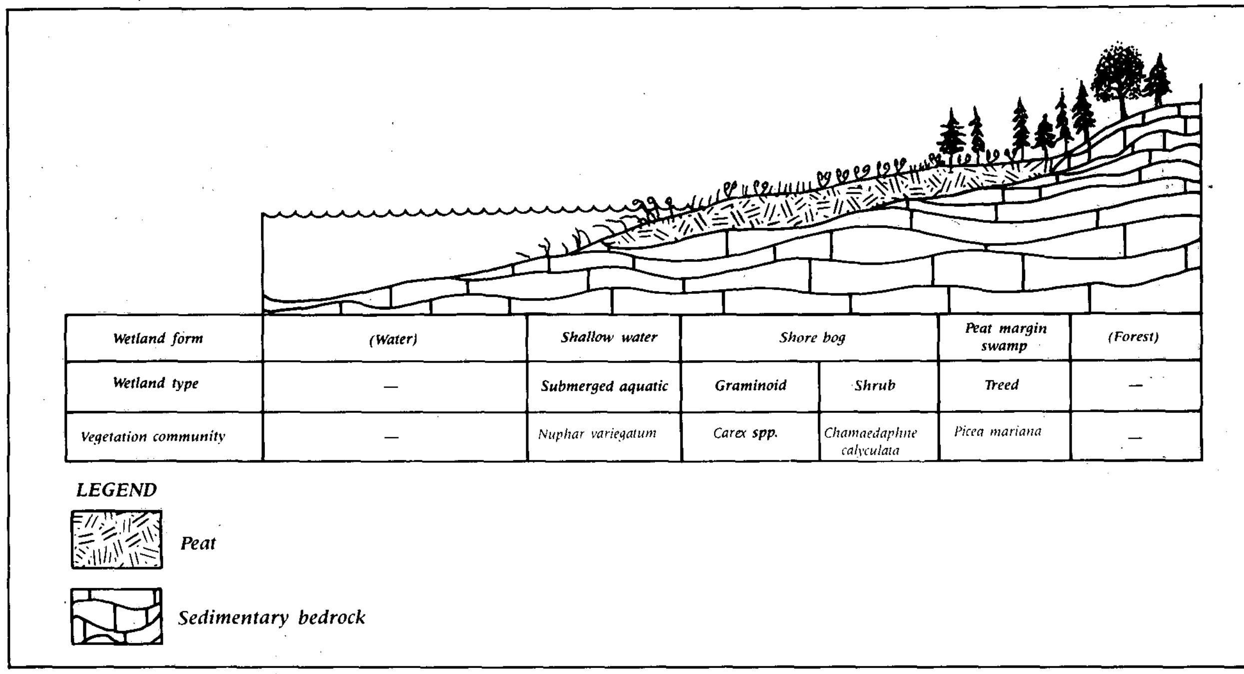


Figure 6–4.
Cross-section of an eastern temperate shore bog.

cinium oxycoccus, Kalmia angustifolia, Kalmia polifolia, and shrub-sized *Picea mariana* and *Larix laricina.* Herbs include *Eriophorum spissum, Eriophorum angustifolium, Sarracenia purpurea,* and *Drosera rotundifolia.* Three species of mosses—*Sphagnum fuscum, Sphagnum angustifolium,* and *Sphagnum nemoreum*—are common. Where herbaceous cover dominates, *Carex oligosperma, Carex stricta, Carex paupercula, Andromeda glaucophylla, Smilacina trifolia, Sphagnum fallax,* and *Epilobium palustre* are generally the most common species.

The central ponds in eastern temperate domed bogs feature aquatic species, *Nuphar variegatum* in particular. Along their edges, *Sphagnum cuspidatum* is common; along the boundary separating ponds and herbaceous or shrub bogs, *Rhynchospora alba* is characteristic.

Shore Bogs

This form of bog in the Eastern Temperate Wetland Region is generally found along the shores of small (less than 50 ha) lakes, particularly in the undulating terrain of the Appalachian Highlands in Quebec and New Brunswick. While the input of water to such wetlands is mainly from precipitation and small streams, their peat development and associated vegetation are characteristic of nutrient-poor (ombrotrophic) bog conditions. Shore bogs usually occur in association with shallow water areas (Figure 6–4).

Wetter sites feature herbaceous species, with shrubs in slightly better-drained sites. Relict tree trunks may often be found at the borders of shore bogs, suggesting that these sites were once treed bogs which have been transformed to their current form as a result of the rise of local water tables. Such a rise may be due to anthropogenic activities such as forestry or to activities of animals such as beaver (Desgranges and Houde 1987; Darveau *et al.* 1987).

The borders of shore bogs are characterized by black spruce with *Sphagnum* spp., ericaceous shrubs, *Nemopanthus mucronata,* and shrub-sized *Larix laricina.* Associated shallow waters have submerged aquatic and floating vegetation, including *Nuphar variegatum* and *Sparganium fluctuans.*

Eastern Temperate Fen Forms

Fens of the Eastern Temperate Wetland Region are usually restricted to three wetland forms: those in areas bordering stream courses (stream and channel fens), and those behind barrier beaches and along lake shores (shore fens). Horizontal fens may also occur but no such site has been described in detail in the literature. In stream fens, there are periodic enrichments of nutrients during periods of high-water streamflow; in shore fens there is some enrichment from streams flowing into the fen, but the wetland is only rarely enriched by nutrients from circumneutral lake waters. In eastern Ontario, moderately extensive fens without specific surface patterns have slow, lateral drainage during the growing season and mass surface flows during spring runoff as well as during periods of heavy rainfall. Overall, fens occupy less than 2% of the total area of wetlands in the Eastern Temperate Wetland Region.

In the eastern temperate fens studied to date, the water table is at the peat surface in stream fens, about 30 cm above the peat surface in shore fens, and 20 cm below the peat surface in the extensive unpatterned fens of eastern Ontario described above. The pH value of water in these fens averages 6.1 with a range of 5.8–6.8. Peat depth averages 2.3 m with a range of 1–3.5 m, which is shallower than that of most bogs.

Stream fens have a moderately tall stratum of graminoids dominated by *Cladium mariscoides*. Shore fens have a tall emergent layer of *Typha latifolia* and a moderately tall graminoid layer composed of *Calamagrostis canadensis* and *Cladium mariscoides*. The extensive unpatterned fens of eastern Ontario have a very diverse vegetation (at least 30 species), with a dominant graminoid layer of *Carex lasiocarpa* and local areas of *Phragmites communis* and tall graminoids.

Brown mosses often constitute the dominant ground cover in fens in the Eastern Temperate Wetland Region (Huikari 1952), and generally they all have herbaceous cover, commonly with *Carex pseudo-cyperus*, *Carex canescens*, and *Carex lupulina*, especially in the Montreal area (Champagne and Melançon 1985).

Shore and Stream Fens

Shore fens are distinguished from marshes by a peat accumulation which is greater than 2 m thick and by their location, often behind barrier beaches. Barrier beaches isolate shore fens from the nutrients contained in lake waters and also protect them from the destructive forces of these waters.

In general, the graminoid layer is dominant in these fens, with the most common graminoids being *Carex lasiocarpa* or *Cladium mariscoides*. Their shrub cover consists of scattered clumps of *Myrica gale* and *Salix pedicellaris*. The most conspicuous herbs and ferns are *Thelypteris palustris*, *Menyanthes trifoliata*, *Iris versicolor*, *Calopogon pulchellus*, and *Spiranthes romanzoffiana*.

Although fens of the Eastern Temperate Wetland Region are usually dominated by graminoid cover, treed shore and stream fens do occur. They have stunted tamarack (*Larix laricina*), which does not exceed a diameter of 10 cm at breast height, and a crown cover of the tree story which is greater than 10%. Treed shore and stream fens have a tree story composed of *Larix laricina* and *Thuja occidentalis*, with a shrub stratum composed of *Ilex verticillata*, *Cornus stolonifera*, and *Betula pumila*. The graminoid layer has sparse cover. The fern and herb stratum is dominated by *Thelypteris palustris*. Treed fens of *Larix laricina* occur rarely (particularly in locations enriched by runoff water from nearby eskers), and are easily distinguishable from treed bogs dominated by *Picea mariana*.

Stream Fen, Graminoid Type: An open graminoid stream fen on the east side of the Holland River, called the Holland River Fen, is at the south end of Lake Simcoe, Ontario, and is representative of stream fens in the Eastern Temperate Wetland Region (Figure 6–5, a and b).

The vegetation in this wetland consists of a graminoid layer, with about 75% cover composed almost exclusively of *Cladium mariscoides*. There are scattered clumps of the shrub *Myrica gale* and cattail (*Typha latifolia*), forming in total about 2% of the cover. There are a number of fen-indicator species present, such as *Spiranthes romanzoffiana*.

Layers of silt found within the sedge peat deposit of this fen indicate that the Holland River periodically overflowed its banks at this location, enriching the fen with mineral nutrients. This enrichment extends only to about 100 m from the river's edge; hence, bog conditions became established inshore of this point and *Sphagnum* peat has accumulated to a depth of 460 cm. The peat of this graminoid stream fen has a mean pH value of 6.4 and is 165 cm deep, which is about 35% of the comparable thickness of peat underlying a low shrub flat bog just to the east. As indicated in Table 6–3, the profile is predominantly fibric peat. Since there are only 30 cm of peat with a moderately decomposed rating (von Post 4–5), the Organic soil profile is classified as a Mesic Fibrisol. The water table at the time of sampling was at the peat surface. Table 6–3 also presents the chemical analyses of selected horizons of the Holland River Fen.

Comparison of Tables 6–2 and 6–3 indicates that, although the cation exchange capacity is somewhat lower for the fen peat on this site than for the *Sphagnum* peat of the Luther Bog, the exchangeable cations are considerably higher for the Holland River Fen.

Shore Fen, Graminoid Type: A graminoid shore fen is located about 4 km west of Port Royal, On-

(a)

(b)

Figure 6–5.
The wetlands of the Holland River near Simcoe, Ontario, cover 3 200 ha and include a large fen complex now being managed for wildlife: (a) examples of dredging and diking, (b) diked ponds.

tario, behind a barrier beach which isolates the fen from the nutrient-rich (minerotrophic) waters of Lake Erie except during stormy periods. A small creek empties into the fen, enriching it. The vegetation cover of this fen is 90% *Typha latifolia* with scattered clumps of the shrub *Cornus stolonifera* providing about 2% cover. Although the *Typha latifolia* on this fen might be considered more characteristic of the marshes of the Eastern Temperate Wetland Region, a peat depth of 313 cm in this fen is considerably deeper than the organic accumulation in marshes. The water table is about 60 cm above the level of the peat. Radiocarbon-dating for a sample near the base of the peat at 310 cm yielded a date of 3 250 ± 170 years BP. This indicates that, for over 3 000 years, the barrier beach has been effective in protecting this wetland from the destructive forces of storms.

Table 6–4 provides a description of the peat profile of this graminoid shore fen, which has a Fibric Mesisol soil with a middle tier of about 80 cm of mesic peat and an upper tier of 67 cm of fibric peat. The profile as a whole contains about 20% fibric peat, 25% mesic peat, and 55% humic peat. Mineral layers about 1 cm thick are found in three positions in the profile: between 55 and 58 cm in the fibric peat horizon, and between 153 and 160 cm and between 180 and 293 cm in the humic peat horizon. These inorganic deposits were probably introduced from the lake side of the fen during stormy periods.

Channel Fens

Two examples of channel fens in a graminoid and a shrub/treed condition are presented below.

Table 6–3. Physical and chemical characteristics of the Holland River Fen, Ontario

Soil horizon	Material	Depth (cm)	Sampling depth (cm)	Decomposition (von Post)	Conductivity (μS/cm)	Cation exchange capacity (me/100 g)	Total N (%)	Exchangeable cations (me/100 g)		
								Ca	Mg	K
Of1	Graminoids	0–10	—	2	—	—	—	—	—	—
Of2	Sedge peat	10–125	30	3	120.5	79.75	2.59	111.78	9.05	0.54
Of2	Sedge peat	10–125	85	3	112.2	77.57	2.57	91.07	8.63	0.13
Om	Sedge peat	135–165	138	4–5	109.5	58.72	1.66	76.91	6.78	0.13
Ah	Silt/humus	165–175	168	—	385.0	12.51	0.06	22.64	1.23	0.17
C	Silt	175+	—	—	—	—	—	—	—	—

Table 6–4. Peat profile of a shore fen at Port Royal, Ontario

Soil horizon	Material	Depth (cm)	Decomposition (von Post)	Field pH
Of	Fibric sedge peat	0–67	4	6.1
Om	Mesic sedge peat	67–147	6	5.6
Oh	Humic sedge peat	147–313	8	5.6
Cg	Gleyed sand	313+	—	6.8

Channel fens are most common in relict glacial channels, with flows of nutrient-enriched waters maintained from the glacial period to the present time in these ecosystems. Typical peat depths in these fens range from 1 to 2 m.

Graminoid Type: Mud Lake, located about 30 km northeast of Belleville, in eastern Ontario, is an example of a graminoid channel fen. The graminoid layer, the dominant stratum of this fen, has a 65% cover composed mainly of *Carex lasiocarpa* and minor occurrences of *Phragmites communis, Carex limosa,* and *Carex chordorrhiza.* Shrubs 1.5–5 m in height make up about 5% of the total cover, with *Thuja occidentalis* being the dominant species. This shrub also occurs at a height of 0.2–0.5 m with *Myrica gale* and *Betula pumila,* the three species providing a combined cover of 17% at this height. The herb stratum has a 30% cover composed chiefly of *Thelypteris palustris* and *Menyanthes trifoliata. Osmunda regalis, Iris versicolor, Habenaria lacera,* and *Calopogon pulchellus* are also present.

The peat depth of this fen is 330 cm, the pH value of the soil water is 5.8, and the water table has been observed at about 10 cm beneath the peat surface. Local microtopography consists of 80% low hummocks elevated about 10 cm above the depressions occupying the remaining 20% of the fen surface. Table 6–5 presents a summary of a Typic Fibrisol soil profile for this graminoid channel fen. In the profile as a whole, about 57% of the thickness of organic matter is fibric peat, about 43% is mesic peat, and about 20% of the profile includes woody peat. This is evidence of a low shrub channel fen having occupied this site during one of the earlier stages of its development.

Shrub/Treed Type: The peat depth of a shrub/treed channel fen, located about 150 m southwest of Mud Lake, Ontario, is 330 cm. The pH value of the peat water is 6, and the water table is, on average, 5 cm below the peat surface. Local microtopography consists of about equal areas of low hummocks and depressions in which the water table is generally at the peat surface. The hummocks are only 10 cm higher than the depressions. Table 6–6 provides a summary of a Typic Fibrisol soil profile for this channel fen, all three tiers of peat being composed of fibric peat. In the profile as a whole, 85% of the depth is composed of fibric peat and 15% is mesic peat.

This fen would appear to have formed in a lake basin, which became a marl lake in its last stage of development. After the lake was completely or partially drained, a fen occupied this site and sedge peat accumulated in horizon Of6. Horizons Of2, Of4, and Om are predominantly *Sphagnum* peat which probably accumulated during periods when water discharge from the fen was impeded. Since the two uppermost horizons of this fen are predominantly *Sphagnum* moss, it is possible that

Table 6–5. Peat profile of a graminoid channel fen at Mud Lake, Ontario

Soil horizon	Material	Depth (cm)	Decomposition (von Post)
Of1	Sedge peat with 40% *Sphagnum* peat	0–60	3
Of2	Sedge peat with 10–30% *Sphagnum* peat	60–120	3
Of3	Sedge peat with 10–30% *Sphagnum* peat	120–160	4
Of4	Woody peat with 30% sedge peat, 20% *Sphagnum* peat	160–190	4
Om1	Woody peat with 10% sedge peat, 10% *Sphagnum* peat	190–225	5
Om2	Sedge peat with 20% woody peat, 20% *Sphagnum* peat	225–330	5

Table 6–6. Peat profile of a shrub/treed channel fen at Mud Lake, Ontario

Soil horizon	Material	Depth (cm)	Decomposition (von Post)
Of1	Living and dead moss	0–20	2
Of2	*Sphagnum* peat with 30% sedge, 10% wood	20–60	3
Of3	Sedge peat with 10% *Sphagnum*, 10% wood	60–120	3
Of4	*Sphagnum* peat with 30% sedge, 20% wood	120–210	4
Of5	Sedge peat with 30% *Sphagnum*, 10% wood	210–250	4
Om	*Sphagnum* peat with 30% sedge peat	250–300	5
Of6	Sedge peat with 40% *Sphagnum* peat	300–330	4
Oh1	Marl and sedimentary peat	330–340	—
Oh2	Marl	340–350	—
C	Silt	350+	—

this wetland may eventually convert from a fen to a bog form.

The tree story of this shrub/treed channel fen, comprising 35% of the total cover, consists of *Larix laricina* and *Thuja occidentalis* with *Acer rubrum* and *Fraxinus pennsylvanica*. There is a 25% cover of shrubs composed of *Betula pumila* (in the 1.5–5 m height class), *Ilex verticillata*, and *Cornus stolonifera*. The graminoid layer has 9% cover composed of *Phragmites communis*, *Carex aquatilis*, and *Carex leptalea*. Herb cover is 28%, dominated by *Thelypteris palustris* and minor occurrences of *Solidago rugosa*, *Rubus pubescens*, and *Iris versicolor*, with *Galium labradoricum* also present. Ground cover is composed of about 50% *Sphagnum* spp. and 40% brown mosses.

Eastern Temperate Swamp Forms

Swamps are the most frequently encountered wetland class in those portions of the Eastern Temperate Wetland Region in southern Ontario (Glooschenko 1985; Glooschenko *et al.* 1987a). They are treed wetlands in which standing to gently flowing waters occur seasonally or persist for long periods on the surface. Frequently, there is an abundance of pools and channels indicating subsurface water flow. The substrate is usually continually wet. Waters are circumneutral to moderately acid in reaction, and show little deficiency in oxygen or in mineral nutrients. The vegetation cover of swamps generally consists of coniferous or hardwood trees, tall shrubs, herbs, and mosses. In many cases, however, current vegetation reflects disturbances due to the influence of forestry or agriculture. Many spring swamps are characteristically spring-flooded, with dry relict pools apparent later in the season. There is usually no deep accumulation of peat. Organic soil conditions are present in peat margin swamps and basin swamps, while mineral soils may be predominant in shore swamps.

Swamps include both the treed type, with either hardwood or coniferous trees of merchantable size, and the tall shrub ("thicket") type. Thickets are characterized by a dense growth of tall shrubs such as willow (*Salix* spp.), dogwood (*Cornus* spp.), *Spiraea* spp., and alder (*Alnus* spp.). Both treed and tall shrub swamps have similar characteristic water levels and chemistry. Soft maple, elm, and black ash are among the best indicators for hardwood treed swamps, and white cedar, tamarack, and black spruce for coniferous treed swamps. In analysis of LANDSAT multispectral data, treed swamps have been shown to be readily identifiable and separable from upland forests with no standing water (Pala and Boissonneau 1985; Guimond *et al.* 1985).

Hardwood treed swamps, such as the Beverly Swamp near Hamilton, Ontario (Figure 6–6), are dominated by maple and ash species (*Acer rubrum*, *Acer saccharinum*, *Fraxinus nigra*, and/or *Fraxinus pennsylvanica*) or elm and ash species (*Ulmus americana*, usually with *Fraxinus nigra*). Because of depredations by Dutch elm disease in elm–ash swamps, there are currently no undisturbed sites in Ontario which can be used to describe this swamp type. *Thuja occidentalis*, *Larix laricina*, and *Pinus strobus* are the common coniferous treed swamp species.

Because of the dense shade of the tree story in swamps, they have a scant cover of subordinate vegetation. In hardwood treed swamps, the subordinate vegetation commonly includes *Ilex verticillata* and *Alnus rugosa* shrubs, the ferns *Onoclea sensibilis* and *Osmunda regalis*, and the herbs *Bidens* spp., *Impatiens biflora*, *Eupatorium perfoliatum*, and *Lobelia cardinalis*. In coniferous treed swamps, the subordinate vegetation is commonly composed of *Sambucus racemosa*, the liana *Parthenocissus vitacea*,

Figure 6–6.
*The Beverly Swamp is one of Ontario's largest swamp forests and is characterized by both Carolinian and boreal biota. Silver maple (*Acer saccharinum*) and marsh marigold (*Caltha palustris*) are common.*

and the herbs *Solanum dulcamara* and *Maianthemum canadense.*

Although these swamps may not be flooded in summer, the presence of standing water in spring is often indicated in summer by pond weed (*Lemna minor*) covering much of the ground surface.

Pala and Boissonneau (1985) investigated the pH value and depth of organic material in hardwood and coniferous treed swamps. They reported an average pH value of 6.5 in peat water, with a range of 5.3–6.8 for 24 sites in hardwood treed swamps in Ontario. The depth of surface organic material averaged 1 m, with a range of 0.2–2.3 m. They also noted that the water table was at or near the ground surface for swamps dominated by soft maple species when sampled. However, in a subsequent dry year, the water table in these swamps was too deep to evaluate in the field. The same authors noted that the average pH value of coniferous treed swamps dominated by cedar was almost equivalent to that of hardwood swamps dominated by maple (6.4), while the mean peat depth was greater (1.7 m). They observed that the difference between the two swamp types was the high proportion of raw, woody material in the organic profile of coniferous treed swamps, which contrasted with the moderately well-decomposed organic matter in hardwood treed swamps with a lower proportion of wood.

Examples of the following swamp forms, which collectively represent the most common occurrences of swamps in the Eastern Temperate Wetland Region, are presented below: peat margin swamp; basin swamp; stream swamp; shore swamp; and spring swamp.

Peat Margin Swamps

This wetland form is common throughout much of the Eastern Temperate Wetland Region, particularly in southeastern Quebec. Peat margin swamps range in size from 20 to 500 m^2, generally with 1–3 m of peat (Figure 6–7). The depth and seasonal fluctuation of the water table and the density of tree cover on these wetlands determine the diversity of plants found.

The poorest sites with deep water tables and dense tree cover generally consist of *Pleurozium schreberi, Sphagnum girgensohnii, Dicranum* spp., and various acidophilic plants such as *Aralia nudicaulis, Coptis groenlandica,* and *Maianthemum canadense.* Richer sites with poor drainage may display species such as *Ilex verticillata, Nemopanthus mucronata, Alnus rugosa, Osmunda cin-*

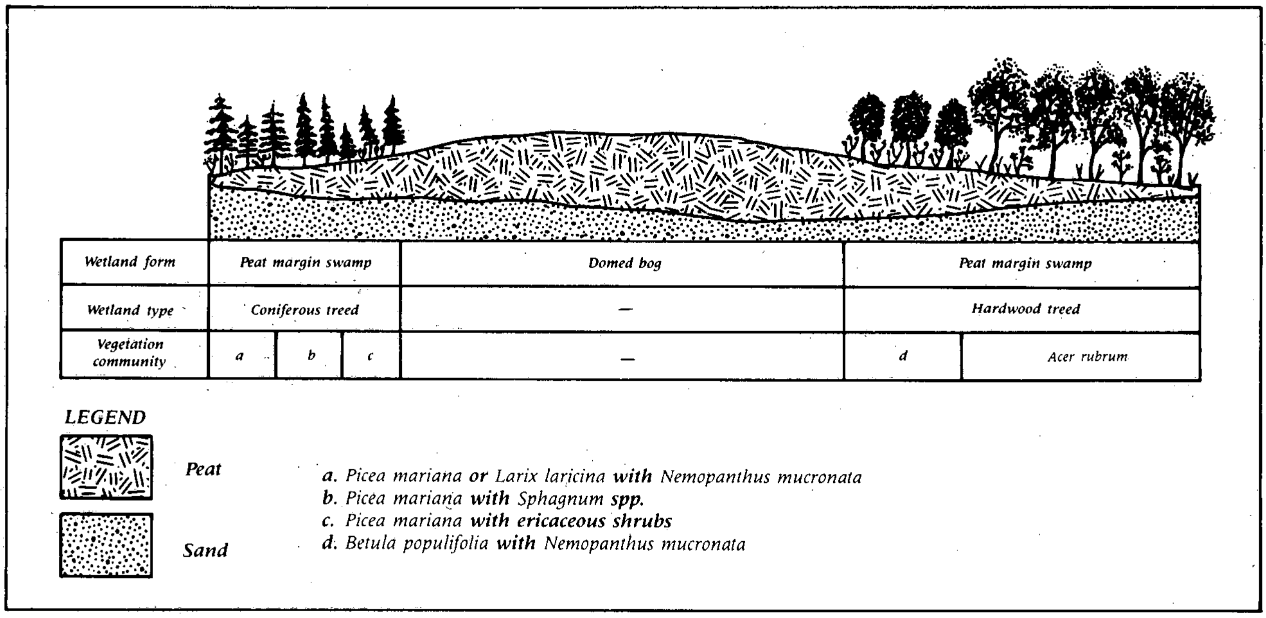


Figure 6–7.
Cross-section of an eastern temperate peat margin swamp.

namomea, Onoclea sensibilis, Rubus pubescens, Arisaema atrorubens, Carex brunnescens, Carex canescens, Carex crinita, Carex trisperma, Dryopteris cristata, Dryopteris thelypteris, Eupatorium maculatum, Eupatorium rugosum, Galium palustre, Impatiens capensis, Impatiens biflora, Iris versicolor, Lycopus uniflorus, Solanum dulcamara, Rumex verticillatus, Scutellaria lateriflora, and *Sium suave.*

Basin Swamps

Relatively little data are available for basin swamps, which have similar characteristics to the stream swamp form in terms of peat depth and peat decomposition as well as vegetation (Figure 6–8). The pH values for this wetland form rarely exceed 5, with exchangeable Ca values below 10 me/100g and with sphagnic and ericaceous peats. Detailed analyses for a typical basin swamp are given in Table 6–7.

In addition to black spruce trees, such sites include shrubs such as *Kalmia angustifolia, Ledum groenlandicum, Chamaedaphne calyculata, Vaccinium angustifolium,* and *Vaccinium oxycoccus.* The herb layer may consist of *Rubus chamaemorus, Smilacina trifolia, Eriophorum spissum, Drosera rotundifolia,* and various acidophilic species (such as *Maianthemum canadense*). Mosses include *Sphagnum nemoreum, Sphagnum angustifolium, Sphagnum robustum, Sphagnum fallax,* and *Sphagnum girgensohnii.*

Stream Swamps

This wetland form is common only in the Appalachian Highlands portion of this wetland region. Stream swamps occur in poorly drained depressions and along lake shores with traversing streams or minor seasonal water courses (Figure 6–8). They are characterized by shallow (1–4 m), mesic, and poorly drained peat. Water tables on these sites oscillate widely from 0 to 80 cm in depth. Stream swamps receive annual enrichment from high seasonal water flows in their associated stream or lake systems.

Chemical and physical data for a representative stream swamp are given in Table 6–8. Surface pH values generally exceeding 5.4, with high levels of calcium, have been observed for a site in Quebec (Blanchet 1982).

Stream swamps are generally characterized by cedar trees (*Thuja occidentalis*). Other predominant tree species include *Fraxinus nigra, Abies balsamea, Populus balsamifera,* and *Acer rubrum.* Shrubs can include *Rhamnus alnifolia, Alnus rugosa, Kalmia angustifolia, Ledum groenlandicum, Myrica gale, Acer spicatum,* and *Lonicera canadensis.* Numerous herbs, including *Smilacina trifolia, Mitella nuda,* and *Viola* spp., and mosses, such as *Rhytidiadelphus triquetrus, Sphagnum warnstorfii, Mnium punctatum,* and *Hylocomium splendens,* are present.

The cedar stands on stream swamps are often of commercial value to forestry. However, little is known about the regenerative capacity of these sites after logging. In general, the most rapid recolonizing species on these cedar-dominated

Table 6–7. ***Physical and chemical properties of peat in a*** *Picea mariana* ***treed basin swamp, southern Quebec***

Soil horizon	Depth (cm)	pH (water)	Organic matter (%)	Total N (%)	Total base saturation (%)	Cation exchange capacity (me/100 g)	Exchangeable cations (me/100 g)				P (ppm)
							Ca	Mg	K	Na	
L/F	0–5	3.7	83	0.79	7	150	5.8	3.5	0.9	0.22	32
H	5–6	3.6	97	1.32	9	158	10.5	3.1	0.4	0.16	11
Of	6–23	4.0	100	1.08	9	146	10.5	3.1	0.4	0.13	3
Om1	24–41	4.1	100	1.72	10	175	15.5	3.3	0.1	0.16	1
Om2	42–70	4.3	100	1.64	14	85	15.5	2.4	0.2	0.17	1

Source: Doyon (1975).

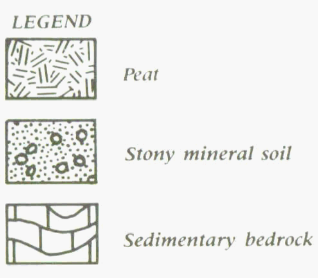
swamps are found where drier conditions predominate, and the wetter sites are invaded by species such as *Cornus stolonifera*.

Shore Swamps

The Eastern Temperate Wetland Region consists of numerous major waterways and lakes—including three of the Great Lakes (Huron, Erie, and Ontario), and several major rivers (the St. Lawrence, Ottawa, and Richelieu)—which frequently have shore swamps along their shorelines. The water regimes of these systems follow a seasonal cycle of levels characterized by spring flooding and summer drawdown. Along these shorelines, shore swamps dominated by silver maple (*Acer saccharinum*) are common. A common riverine sequence displays three vegetation zones in these swamps: (a) silver maple–*Matteuccia struthiopteris* on the higher dry sites; (b) silver maple–*Laportea canadensis* in mid-slope areas; and (c) silver maple–*Onoclea sensibilis* in the wettest conditions near the water level.

Annual flooding conditions on shore swamps can vary widely. Along the St. Lawrence River, flooding averaged 31 days per year on the silver maple–*Laportea canadensis* swamp zones in the 1972–1976 period, but only 12 days per year from 1980 to 1984. Similarly, silver maple–*Onoclea sen-*

Wetland form	(Forest)	Stream swamp			(Forest)	Basin swamp			(Forest)
Wetland type	—	Treed			—	Treed			—
Vegetation community	—	d	a	d	—	b	c	b	—



a. Open cedars with low shrubs (Thuja sp.)

b. Black spruce with Sphagnum spp.

c. Black spruce with ericaceous shrubs

d. Closed cedars (Thuja sp.)

Figure 6–8.
Cross-section of eastern temperate stream swamp and basin swamp.

Table 6–8. Physical and chemical properties of peat in a *Thuja occidentalis* **treed stream swamp, southern Quebec**

Soil horizon	Depth (cm)	pH (water)	Organic C (%)	Total N (%)	Total base saturation (%)	Cation exchange capacity (me/100 g)	Exchangeable cations (me/100 g)				P (ppm)
							Ca	Mg	K	Na	
Om1	5	5.4	47.9	1.52	72.0	123.7	76.5	9.7	1.6	1.3	100
Om2	12	5.9	44.0	1.79	70.6	176.9	113.0	10.0	0.6	1.3	70
Om3	22	5.9	47.1	1.80	68.9	170.2	105.7	10.1	0.2	1.3	40
Om4	45	6.0	46.2	1.62	71.5	175.0	113.0	10.9	0.2	1.1	40
Om5	60	5.4	45.0	1.20	54.6	130.5	65.0	4.9	0.2	1.2	10

Source: Blanchet (1982).

sibilis swamp zones were flooded 105 days per year on average from 1972 to 1976 and 31 days per year from 1980 to 1984, reflecting much wetter conditions. If these periods of flooding exceed critical thresholds, these swamps experience stress which may lead to their alteration or decline. For example, Couillard *et al.* (1985) have shown that flooding for more than 63 days after the beginning of the growing season in swamps (June 27 in the Montreal area) leads to deterioration or destruction of these swamp ecosystems. This has occurred in Lac Saint-Louis on the upper St. Lawrence River, with specific examples documented by Couillard *et al.* (1985) during years of abnormally high flood levels in the 1972–1976 period.

The flora of shore swamps on major waterways is highly diverse with over 100 species being recorded, including many shrubs (such as *Cornus alternifolia, Cornus rugosa, Rhamnus frangula, Rhus radicans, Vitis riparia,* and *Salix* spp.) and numerous herb species. However, the vegetation common to shore swamps along smaller rivers is quite different (Figure 6–9). With flooding levels generally much lower and less frequent, physical and chemical characteristics of soils on these sites and, hence, their associated flora are unlike those on the major water systems. Common tree species are elm and ash, and shrubs such as *Alnus rugosa, Prunus virginiana, Cornus alternifolia, Acer spicatum, Acer negundo, Corylus cornuta,* and *Matteuccia struthiopteris* are present. Associated herbs are very diverse, and mosses (*Climacium dendroides, Hypnum lindbergii,* and *Mnium punctatum*) are commonly present. Elm on these sites is apparently

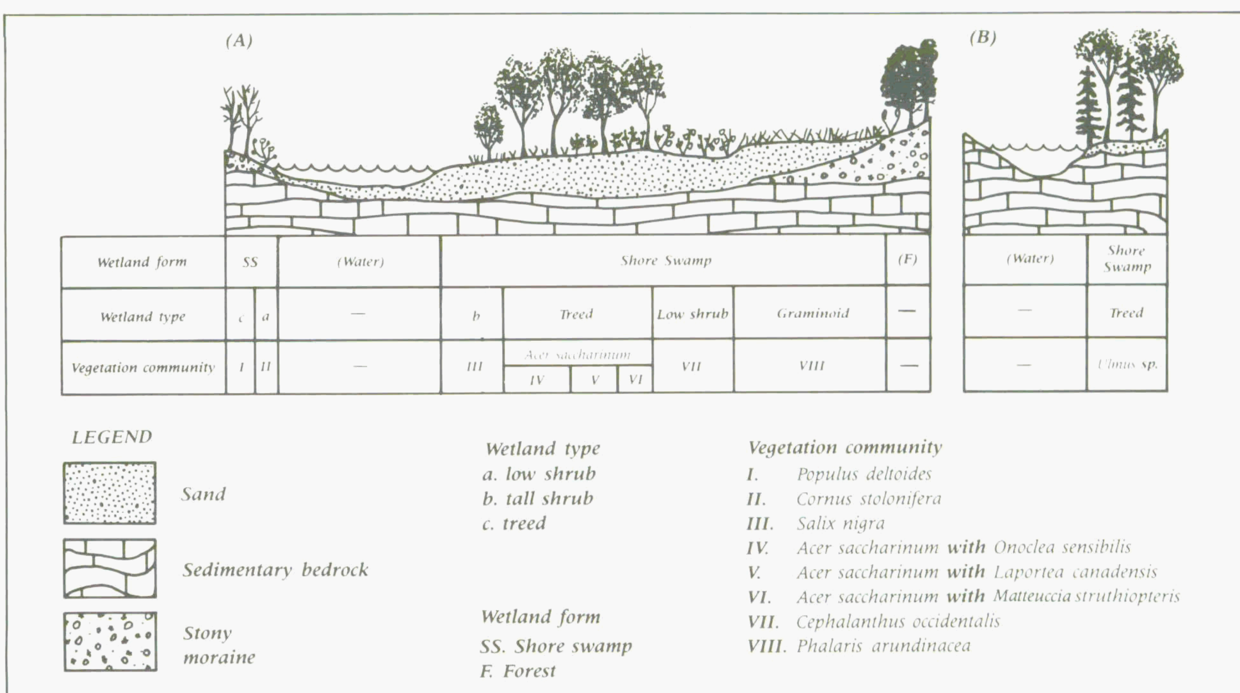


Figure 6–9.
Cross-section of eastern temperate shore swamp — (A) along major rivers such as the St. Lawrence and Ottawa, and (B) along minor rivers and streams.

gradually being replaced by balsam poplar and red maple due to devastation by Dutch elm disease.

Physical and chemical data for a shore swamp dominated by *Acer saccharinum* along a major waterway at the Îles de Berthier-Sorel in Lac St-Pierre, Quebec, and for a shore swamp dominated by *Fraxinus nigra* in a minor river in Lévis County, Quebec, are provided in Tables 6–9 and 6–10, respectively.

Spring Swamps

Although results of transects across spring swamps of the Eastern Temperate Wetland Region are fragmentary, it is probable that many of the spring swamps have basins and discharge areas which are poorly defined topographically and include numerous morainal islands supporting upland forests. Two examples of this wetland form are described below.

Table 6–9. Physical and chemical properties of peat in a shore swamp on the Îles de Berthier-Sorel, Lac Saint Pierre, Quebec

Vegetation zone	Wetness condition	Organic matter (%)	pH (soil)	Soil texture: Clay (%)	Silt (%)	Sand (%)	Exchangeable cations (me/100 g): Ca	Mg	K	P (ppm)
Acer saccharinum/Rorippa amphibia	Very wet	6.1	5.5	30.4	26.4	43.2	4.7	1.3	0.2	66.7
Acer saccharinum/Onoclea sensibilis	Wet	2.7	6.2	23.6	30.0	46.4	5.2	1.0	0.2	105.9
		4.8	6.4	23.6	30.0	46.4	7.8	1.6	0.2	63.3
		8.2	5.3	31.2	24.8	44.0	5.6	1.6	0.2	37.6
Acer saccharinum/Laportea canadensis	Moderate	5.6	6.5	20.0	28.4	49.6	7.8	1.6	0.2	56.8
		3.9	5.7	23.6	28.0	48.4	5.7	1.6	0.1	37.5
		3.6	6.0	31.2	24.4	44.4	5.7	1.4	0.1	77.9
		4.6	5.7	27.2	30.4	42.4	5.1	1.2	0.2	64.2
Acer saccharinum/Matteuccia struthiopteris	Dry	5.4	5.0	22.0	32.4	45.6	5.0	1.1	0.2	34.0
		3.5	6.2	26.8	26.8	46.4	6.2	1.3	0.2	101.3

Source: Adapted from Tessier *et al.* (1981).

Table 6–10. Physical and chemical properties of a Gleyed Regosolic soil in a *Fraxinus nigra* ***treed shore swamp bordering a minor river in Lévis County, Quebec***

Soil characteristic	Soil horizon: Ah	Cg1	Cg2
Soil texture			
Clay (%)	18.0	26.4	55.6
Silt (%)	12.0	20.4	67.6
Sand (%)	17.2	33.0	49.0
Total N (%)	0.25	0.09	0.06
pH (soil)	5.7	5.2	5.3
Organic matter (%)	5.8	0.9	1.0
Total base saturation (%)	56	32	25
Cation exchange capacity (me/100 g)	11	6	5
Exchangeable cations (me/100 g)			
Ca	5.50	1.50	1.00
Mg	0.80	0.30	0.30
K	0.17	0.02	0.02
Na	0.03	0.03	0.04
P (ppm)	22	12	15

Source: Doyon (1975).

Hardwood Type: Puslinch Swamp, a hardwood swamp dominated by soft maple–black ash (Figure 6–10) and located 15 km south of Guelph, Ontario, has been described by Dale and Hoffman (1969). The vegetation of the Puslinch Swamp has a tree story of *Acer rubrum, Fraxinus nigra, Betula papyrifera,* and *Thuja occidentalis* and a shrub stratum of *Cornus stolonifera* with *Parthenocissus vitacea* lianas. Herbs include *Cicuta maculata, Eupatorium perfoliatum, Aralia nudicaulis, Impatiens biflora, Iris versicolor,* and *Solanum dulcamara.*

The total peat depth is 170 cm, the pH value of the peat water is 6.5, and the soil on this site is a Mesic Fibrisol. In the soil profile as a whole, about 55% is fibric, 40% mesic, and 5% humic peat material. Table 6–11 presents data for a soil profile of the Puslinch Swamp. The surface Oml horizon is typical of eastern temperate spring swamps, being a rather well-decomposed organic material which has become aggregated into very cohesive particles. This aggregation may be a result of repeated alternations of wet and dry conditions in this surface horizon. Because of the cohesion of these organic particles, the von Post

Figure 6–10.
The wetlands of South Puslinch Lake, Ontario, are typical of treed spring swamp with species such as Fraxinus nigra *and* Acer saccharinum.

decomposition rating has not been applied to this horizon. The Of1, Om2, and Of2 horizons range from fibric to mesic woody peat (von Post decomposition ratings 3 to 5), while the Of3 and Om3 horizons are identified as sedge peat and their degree of decomposition increases with depth. The Om4 horizon is a shell-bearing, sedimentary, humic peat which is underlain by shell-bearing marl, marl, and silty sand. The suggested development sequence of this profile begins with a postglacial pond which, in its late stages, became a marl pond. Horizons Oh2, Oh1, and Om4 indicate a progressive shallowing of the pond resulting in the establishment of benthic fauna and submergent vegetation. The next phase was the establishment of a graminoid fen in which the organic material of horizons Om3 and Of3 accumulated. Subsequently, at some stage after the water table in the fen had receded to a depth below the peat surface, a treed spring swamp was established at this location and woody peat horizons were then accumulated.

Table 6–11 presents chemical data for selected soil horizons of the Puslinch Swamp. These data indicate that the upper three peat horizons of this site have been enriched by the nutrients of a relatively recent flow from the adjoining mineral-soil uplands. This is reflected in relatively high levels of cation exchange capacity and of exchangeable Ca, magnesium (Mg), and potassium (K). Although it might be expected that the underlying sedimentary peat would be nutrient-rich, nutrient stores were probably depleted during the early stages of vegetation succession at this location.

Coniferous Type: The peat horizons of various cedar-dominated treed swamps in Ontario have been sampled. Chemical analyses indicate a great range in the values of parameters in these swamps. A swamp located near Cavan, Ontario (the "Cavan Swamp"), is a typical spring swamp (Table 6–12). The vegetation consists of a tree story which is predominantly *Thuja occidentalis* with some *Picea mariana*. The presence of *Coptis trifolia*, *Linnaea borealis*, and *Clintonia borealis* indicates the boreal affinities of this spring swamp ecosystem.

The surficial organic horizon of the Cavan Swamp is similar to that found in the hardwood spring swamp discussed in the preceding section.

Table 6–11. Physical and chemical characteristics of a spring swamp in Puslinch Township, Ontario

Soil horizon	Material	Depth (cm)	Decom-position (von Post)	pH (peat)	Conduc-tivity (μS/cm)	Cation exchange capacity (me/100 g)	Total N (%)	Exchangeable cations (me/100 g)		
								Ca	Mg	K
Om1	Shot-structured organic material	0–15	—	6.4	218	62.85	1.61	100.90	19.74	0.77
Of1	Woody peat	15–27	3–4	6.4	281	66.99	1.99	93.80	21.96	0.12
Om2	Woody peat	27–65	5	6.4	—	—	—	—	—	—
Of2	Woody peat	65–120	4	6.4	212	58.94	2.50	100.00	25.66	0.11
Of3	Sedge peat	120–135	3	6.4	—	—	—	—	—	—
Om3	Sedge peat	135–165	5	—	—	—	—	—	—	—
Om4	Sedimentary peat, shell-bearing	165–170	6	—	515	39.09	1.47	63.62	14.06	0.20
Oh1	Marl, shell-bearing	170–190	—	6.8	—	—	—	—	—	—
Oh2	Marl	190–225	—	—	—	—	—	—	—	—
C	Silty sand	225+	—	—	580	17.40	0.93	38.17	6.41	0.20

The peat depth is 120 cm. The stratigraphy of this profile indicates the same progression in this site from marl pond to fen to swamp as that described for the Puslinch Swamp.

The average chemical values of various cedar-dominated treed swamps investigated in the Eastern Temperate Wetland Region are summarized in Table 6–13. It should be noted that the levels of cation exchange capacity and exchangeable Ca are somewhat higher than those for similar horizons in the Puslinch Swamp. It may be necessary to monitor nutrient inputs to hardwood and coniferous treed swamps over a considerable period in order to describe adequately the more frequent and persistent flows of runoff into swamps.

An example of a coniferous treed spring swamp dominated by *Larix laricina–Pinus strobus* (tamarack and white pine) in Puslinch Township, Ontario, has also been investigated. Its peat depth was found to be 740 cm. The surface peat is composed of *Sphagnum* spp. and the site is very hummocky. This swamp would appear to be nutrient-poor; if *Sphagnum* spp. continue to accumulate on this site it could develop into a treed or open bog ecosystem. Although the peat stratigraphy was found to be somewhat variable (Table 6–14), the profile summarized here is broadly representative of the sequence and thicknesses of deposition of organic matter in spring swamps. The low pH value of the upper peat horizon indicates the developmental trend towards a bog.

The soil of this profile is classified as a Mesic Fibrisol. In the profile as a whole, fibric peat constitutes about 70%, mesic peat 12%, and humic peat 18%. The profile indicates the common development sequence from sedimentary peat deposited on the bottom of a small depression, to peat deposited in a fen, to peat deposited in a treed swamp (Table 6–14). The levels of cation exchange capacity and exchangeable Ca and Mg are considerably lower at this site than those of comparable horizons in maple- and cedar-dominated spring swamps. This confirms the position of this swamp at the lower end of the productivity gradient of the swamp wetland forms.

The tree story of this swamp is dominated by *Larix laricina* with some *Pinus strobus*. The total cover of the tree story is about 40%. There is a dense shrub layer, which is predominantly 0.5–1.5 m high with a total cover of about 60%. It is mainly composed of *Chamaedaphne calyculata* with *Ledum groenlandicum*, *Kalmia polifolia*, *Vaccinium myrtilloides*, and *Vaccinium oxycoccus*.

Table 6–12. Characteristics of a peat profile in a coniferous treed swamp at Cavan, Ontario

Soil horizon	Material	Depth (cm)
Om1	Shot-structured organic material	0–25
Om2	Mesic peat	25–66
Of1	Fibric peat	66–111
Of2	Sedge peat	111–120
Oh	Marl with shells	120–200
C	Gritty silt	200+

Eastern Temperate Marsh and Shallow Water Forms

Marshes in the Eastern Temperate Wetland Region include periodically inundated wet areas with standing or slowly moving water and/or permanently inundated areas characterized by robust emergents and, to a lesser extent, anchored float-

Table 6–13. Chemical analyses of selected profiles of eastern temperate cedar-dominated coniferous treed swamps

Soil horizon	Material	Average depth (cm)	Total N (%)	Conductivity (μS/cm)	Cation exchange capacity (me/100 g)	Exchangeable cations (me/100 g)		
						Ca	Mg	K
Om	Shot-structured surface organics	15	1.51	120	86.27	127.24	13.98	0.26
Om	Mesic to fibric peat	39	1.52	73	74.67	66.93	5.06	0.13
Of	Fibric peat	82	2.28	92	73.02	102.79	14.80	0.12
Om	Mesic sedge peat	170	2.64	88	68.46	58.90	2.57	0.12
Oh	Marl with shells	250	0.23	33	65.65	23.80	0.23	0.06
C	Gritty silt	250+	0.10	31	13.79	13.90	1.76	0.13

Table 6–14. Physical and chemical characteristics of a coniferous treed spring swamp in Puslinch Township, Ontario

Soil horizon	Material	Depth (cm)	Sampling depth (cm)	Decom-position (von Post)	pH (peat)	Conduc-tivity (μS/cm)	Cation exchange capacity (me/100 g)	Total N (%)	Exchangeable cations (me/100 g)		
									Ca	Mg	K
Of1	*Sphagnum* moss	0–10	—	2	—	—	—	—	—	—	—
Of2	Fermeling moss	10–18	—	2	—	—	—	—	—	—	—
Of3	*Sphagnum* peat	18–24	—	3	4.0	—	—	—	—	—	—
Om1	*Sphagnum* peat	24–130	35	5	4.0	180.0	12.03	1.07	6.27	3.75	0.20
			85	5	4.2	58.0	29.85	1.14	7.67	2.47	0.21
Om2	*Sphagnum* peat	130–136	132	6	4.2	63.0	31.81	1.28	12.16	2.16	0.42
Of4	*Sphagnum* peat	136–360	190	3	4.8	51.8	34.07	0.75	24.44	4.16	0.22
Of5	Sedge peat	360–465	382	3–4	5.6	42.5	20.81	1.85	5.60	0.41	0.08
Om3	Sedge peat	465–485	—	5	5.0	—	—	—	—	—	—
Of6	Sedge peat	485–580	—	3–4	5.0–5.5	—	—	—	—	—	—
Oh	Sapropel	580–740	—	7–8	5.5–6.4	—	—	—	—	—	—
C	Gritty silt	740+	—	—	—	—	—	—	—	—	—

ing plants and submergents. Surface water levels may fluctuate seasonally, with spring flooding and declining summer water levels exposing draw-down zones of matted vegetation or mudflats. Water remains within the rooting zone of plants during at least a part of the growing season. The substrate usually consists of mineral or organic soils with a high mineral content, but in some marshes there may be as much as 2 m of peat accumulation. Waters are usually circumneutral to slightly alkaline, and there is a relatively high level of oxygen saturation.

Marshes characteristically display zones or mosaics of vegetation, frequently interspersed with channels or pools of deep or shallow open water. Marshes may be bordered by peripheral bands of trees and shrubs, but the predominant vegetation consists of a variety of emergent non-woody plants such as rushes, reeds, reedgrasses, and sedges. Where areas of open water occur, a variety of submerged and floating aquatic plants flourishes.

The marsh class of wetlands is associated with the shallow water class. The latter consists of areas of permanently open water, usually less than 2 m deep, with water chemistry closely related to the type of water body they border. Areas of shallow water wetlands are associated with flowing or standing lakes, rivers, or ponds, and usually have floating, submergent, or, to a lesser degree, partly emergent vegetation in shallower areas. Marshes and shallow water wetlands are the least stable of the wetland classes which occur in the Eastern Temperate Wetland Region. They are frequently subjected to drastic changes by wave action, ice, and lake currents during stormy periods (Barrett 1977).

Little research has been undertaken to investigate the peaty substrates of marshes in the Eastern Temperate Wetland Region. The water table is usually above the substrate surface of marshes but it may be at the surface or slightly below it during late summer and fall. In 1983, substrate examination of marshes was made at Long Point, Ontario (C. Tarnocai, personal communication). A modified Macaulay peat sampler (Zoltai 1978) was used to obtain samples of frozen marsh substrates in winter. The semicircular cores of the peat sampler were frozen after they had been described. The samples were then easily transferred to plastic tubes which were enclosed in plastic and kept frozen in transit and at the laboratory until they could be analyzed. This methodology could be further applied to studies of marsh ecosystems.

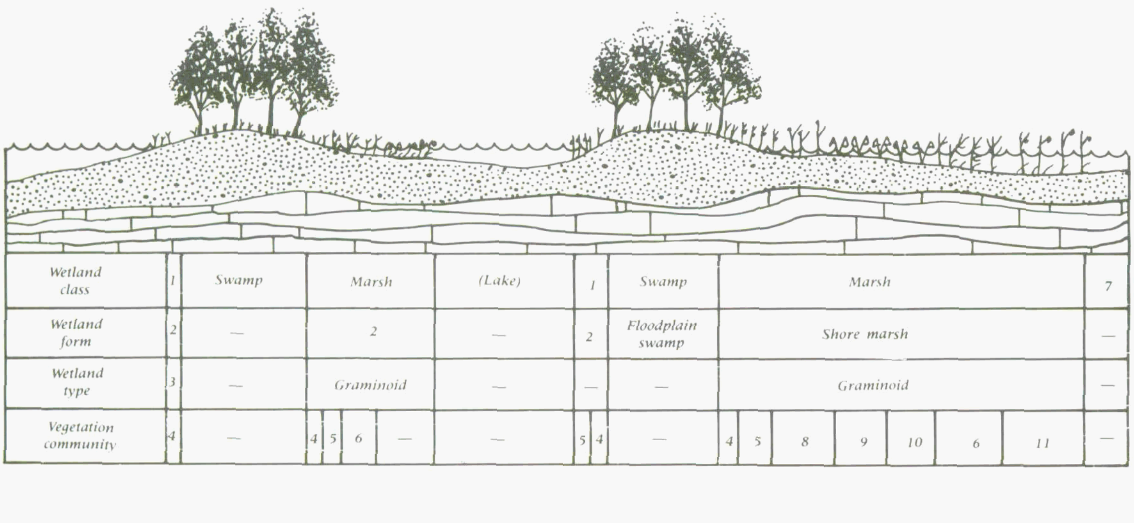
Tidal salt marshes are common along the shores of the lower St. Lawrence River. These are not examined in detail in this chapter but are discussed in Chapter 9 in the context of other salt marsh ecosystems across Canada. However, two significant freshwater marsh forms occur in the Eastern Temperate Wetland Region: shore marsh and tidal freshwater marsh.

Shore Marshes

Many of the water courses in this wetland region are fringed by shore marshes, particularly along the Ottawa, Richelieu, and St. Lawrence rivers. The soils of these shore marshes consist of fine-textured alluvial deposits, generally less than 1 m in depth, and rarely display significant accumulation of organic matter (Figure 6–11). Vegetation diversity on these marshes is generally low—usually less than 10 species. The most common emergent species are *Sparganium eurycarpum*, *Sagittaria latifolia*, *Sagittaria rigida*, *Typha* spp., *Scirpus lacustris* ssp. *glaucus*, *Butomus umbellatus*, *Eleocharis smallii*, *Eleocharis palustris*, *Acorus calamus*, and *Zizania aquatica*. Floating species include *Lemna minor*, *Lemna trisulca*, *Spirodela polyrhiza*, and *Hydrocharis morus-rani*. Several submergent plant species are also common in eastern temperate shore marshes; these include *Eleocharis acicularis*, *Elodea canadensis*, *Vallisneria americana*, *Heteranthera dubia*, *Myriophyllum spicatum*, *Ceratophyllum demersum*, and *Bidens beckii*.

Keddy and Reznicek (1985) recognized two broad vegetation types for marsh and shallow water conditions surrounding shore marsh openings in southern Ontario:

(i) Marsh—The dominant species are *Typha* spp., *Decodon verticillatus*, *Eleocharis smallii*, *Phragmites australis*, *Pontederia cordata*, *Sagittaria lati-*



Wetland class	1 Swamp	Marsh	(Lake)	1	Swamp	Marsh	7
Wetland form	2 —	2	—	2	Floodplain swamp	Shore marsh	—
Wetland type	3 —	Graminoid	—	—	—	Graminoid	—
Vegetation community	4 —	4 5 6 —	—	5 4	—	4 5 8 9 10 6 11	—

LEGEND

Soil

Sedimentary bedrock

1. Marsh
2. Marsh at edge of floodplain
3. Graminoid
4. *Phalaris arundinacea* or *Calamagrostis canadensis*
5. *Sparganium eurycarpum*
6. *Scirpus fluviatilis*
7. Shallow water
8. *Typha angustifolia* or *Typha latifolia*
9. *Sagittaria latifolia*
10. *Sagittaria rigida*
11. *Scirpus acutus*

Figure 6–11.
Cross-section of eastern temperate shore marsh.

Table 6–15. ***Physical and chemical characteristics of a shore marsh with a*** *Sparganium eurycarpum* ***vegetation community.***

Soil Sampling depth	pH (soil)	C (%)	N (%)	Exchangeable cations (me/100 g) Ca	Mg	K	Na	Mn	P (ppm)	Base saturation (%)	Cation exchange capacity (me/100 g)	Texture (%) Clay	Silt	Sand
Surface	5.4	10.8	0.58	16.1	4.3	0.37	0.47	3.1	122	64	33.2	19	28	53
Mid-profile	7.0	3.5	0.19	10.7	3.9	0.25	0.35	1.8	195	100	15.2	30	32	38
On bedrock	7.3	0.7	0.03	5.6	2.7	0.20	0.35	1.4	217	100	8.9	28	35	37

Source: Lamoureux (1969).

folia, Scirpus acutus, and *Scirpus fluviatilis. Sparganium eurycarpum* can also predominate in extensive areas.

(ii) Aquatic—These species occur in shallow water in marsh openings and in water deeper than the maximum tolerated by emergent species. The predominant species are *Ceratophyllum demersum, Elodea canadensis, Heteranthera dubia, Megalodonta beckii, Myriophyllum* spp., *Najas flexilis, Nymphaea odorata, Nuphar variegatum, Potamogeton* spp., *Ranunculus aquatilis, Utricularia vulgaris,* and *Vallisneria americana.*

Keddy and Reznicek (1985) also identified species in the wetlands of the Lake Erie area which are found only rarely or not at all in wetlands of the other Great Lakes. These include *Hibiscus palustris, Nelumbo lutea,* and *Nuphar advena.* Hayes (1964) discussed the rich flora which is especially prominent in the marshes of the St. Clair River Delta. Species found here are *Helianthus* spp., *Platanthera leucophaea, Pycnanthemum* spp., *Solidago iddelli, Vernonia* spp., and *Veronicastrum virginicum.*

Characteristics of soils within a shore marsh, adjacent to a riverine floodplain and with a *Sparganium eurycarpum* vegetation community, have been studied by Lamoureux (1969) and are summarized in Table 6–15.

Tidal Freshwater and Brackish Marshes

Tidal freshwater and brackish water marshes are characteristic of coastal environments at the interface of fresh and saline waters. In the Eastern Temperate Wetland Region such sites exist along the St. Lawrence River from Lac St-Pierre to Île d'Orléans. This form of marsh may also be found in other wetland regions, along the estuaries of the coasts of New Brunswick, and in subarctic or boreal locations on James Bay.

The St. Lawrence River upstream of Île d'Orléans, Quebec, has tidally influenced occurrences of freshwater (with salinity ranging from 0 to 3 ‰) and brackish water (salinity ranging from 4 to 17 ‰) (Gauthier 1982). Along these shores, where mean tidal amplitudes are about 1 m but which may be as high as 5 m at Île d'Orléans, tidal freshwater marshes dominated by *Scirpus americanus* are common.

Underlying sediments in these marshes are usually fine silts and clays, but occasionally, where reworked by currents, they have a gravelly sand texture. The chemical characteristics of these deposits are relatively uniform. A transect on the shore of Île d'Orléans, Quebec, has been described by Lacoursière (1969) and Lacoursière and Grandtner (1971, 1972), as outlined in Table 6–16 and Figure 6–12. Annual sedimentation rates in these marshes vary widely. Values of 4–26 cm/yr at Cap Tourmente, Quebec, have been reported (Brind'Amour and Lavoie 1983).

Vegetation in these marshes along the St. Lawrence River shorelines, while usually dominated by *Scirpus americanus,* displays distinct bands parallel to the shore, created by the interacting functions of duration of submersion in higher water levels and of levels of salinity as influenced by elevation relative to mean water levels. For example, the overall submersion period can range from 2 to 60% of the year depending on the site.

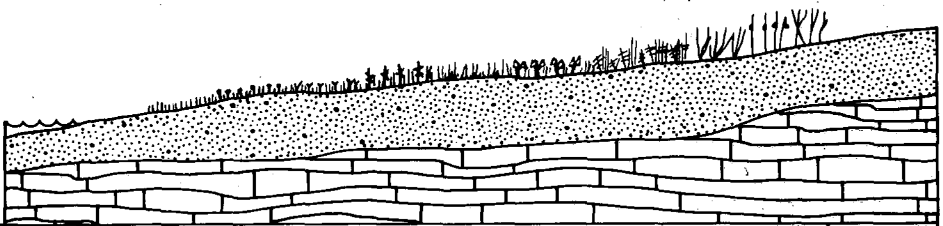
From Grondines to Île d'Orléans in Quebec, vegetation is typical of tidal freshwater marshes; however, from Trois-Saumons, 70 km east of Île d'Orléans, several halophytic species have been introduced where salinity ranges from 20 to 40 ‰. Salinity gradually increases downstream to the boundary of the Low Boreal Wetland Region, where halophytic species such as *Spartina alterniflora* are well represented at Saint-Roch-des-Aulnaies, 90 km east of Île d'Orléans.

In addition to *Scirpus americanus,* about a dozen plant species are endemic to these marshes. These include *Deschampsia caespitosa* var. *intercotidalis, Zizania aquatica* var. *brevis, Epilobium ciliatum* var.

Table 6–16. Physical and chemical characteristics of soils in a tidal freshwater marsh at Île-d'Orléans, Quebec

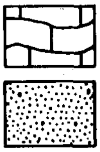
Soil depth (cm)	pH (soil)	C (%)	Total N (%)	P (ppm)	Exchangeable cations (ppm)					Base saturation (%)	Cation exchange capacity (me/100 g)	Texture (%)		
					Ca	Mg	K	Na	Mn			Clay	Silt	Sand
0–7	7.0	3.6	0.18	34	3 280	665	155	165	60	129	17.9	10	66	24
8–15	7.0	2.4	0.13	71	1 390	320	75	115	35	80	12.8	8	70	22
16–30	6.9	2.4	0.12	51	1 625	345	65	120	60	83	14.2	10	68	22
31–45	6.8	2.6	0.10	51	1 905	395	80	125	75	80	17.0	13	59	28
46–60	6.7	2.4	0.10	44	1 803	375	85	135	70	96	13.7	10	56	34

Source: Lacoursière (1969).



Wetland class	Shallow water	Marsh													Swamp
Wetland form	—	Tidal freshwater marsh													—
Wetland type	—	Non-vegetated	Graminoid/Forb												—
Vegetation community	—	—	Scirpus americanus and 1	2	3	4	5	Sagittaria latifolia	6	7	8	9	10		—

LEGEND



Sedimentary bedrock

Sand

1. *Scirpus americanus*
2. *Sagittaria rigida*
3. *Sagittaria cuneata*
4. *Zizania aquatica* var. *brevis*
5. *Eleocharis halophila*
6. *Sium suave*
7. *Eupatorium perfoliatum*
8. *Scirpus validus*
9. *Sparganium eurycarpum*
10. *Spartina pectinata*

Figure 6–12.
Cross-section of an eastern temperate tidal freshwater marsh.

ecomosum, Cicuta maculata var. *victorinii, Gentiana crinita* var. *victorinii, Lycopus americanus* var. *laurentianus, Gratiola neglecta* var. *glaberrima, Mimulus ringens* var. *colpophilus, Bidens tripartita* var. *orthodoxa,* and *Helenium autumnale* var. *fylesii* (Baillargeon 1981).

At least another 60 species may occur within these marshes as well. Tidal freshwater and brackish marshes are highly productive ecosystems. For instance, Brind'Amour and Lavoie (1983) have recorded an annual value for aerial biomass production at Cap Tourmente, Quebec, of 3 791 g/m^2/yr with production peaking in the first half of August 1983. Doran (1981) has evaluated total phytomass production at Cap Tourmente for *Scirpus americanus*. Aerial values of 0.16–0.30 tonnes/ha and subsurface values of 1.6–3.9 tonnes/ha were measured in advance of the annual arrival of Greater Snow Goose (*Anser caerulescens atlanticus*). Extrapolation of these values for all the marsh area of Cap Tourmente (172.8 ha) suggests an annual total *Scirpus americanus* production at this location exceeding 730 tonnes/yr, with about 35% of this consumed by migratory birds.

Shallow Water Forms

This wetland class forms the interface between other wetland classes and open water, and usually refers to sites which are permanently submerged in water. The water depth limit for these wetlands is defined as 2 m in the Canadian Wetland Classification System (Appendix I). The factors affecting the establishment of vegetation in these areas are: the texture of underlying sediments; water colour, turbidity, and depth; and the speed of currents. Depth, colour, and turbidity all affect light penetration. Examples of shallow water wetlands in brown and clear waters are shown in Figure 6–13. The relationship of water depth to vegetation occurrence is also examined in Figure 6–14, a and b.

The diversity of vegetation in shallow water wetlands is largely a function of the chemical properties of their waters. For example, in brown waters where pH values are neutral, such as those generally characteristic of the Ottawa River, the number of plant species is limited. Floating species include *Nymphaea tuberosa*, *Nuphar variegatum*, and *Sparganium fluctuans*. Submerged foliar species include *Vallisneria americana*, *Myriophyllum spicatum*, *Elodea nuttallii*, and *Potamogeton richardsonii*. Conversely, clear waters with pH values of about 8.1 and with elevated calcium levels have a more diverse flora (Pageau and Lévesque 1970; Pageau *et al.* 1971). The most representative floating species are *Nymphaea tuberosa*, *Nymphoides cordata*, and *Lemna trisulca*. Submerged foliar plant species in clear shallow water wetlands include *Vallisneria americana*, *Myriophyllum spicatum*, *Heteranthera dubia*, *Elodea canadensis*, *Alisma gramineum*, and *Ceratophyllum demersum*.

Some floating species (e.g. *Nymphaea tuberosa*) rely on a substrate of not more than 2 m in depth in order to root. Other floating species, such as *Lemna trisulca*, do not root and are subject to movement by wind and currents. Other species are variably affected by depth. *Vallisneria americana*, for example, grows well in 50 cm of brown water and in up to 3 m of clear water. Current is also a critical factor in the establishment of vegetation in shallow water wetlands, with rooting species faring poorly.

Dynamics of Eastern Temperate Wetlands

Marshes have formed in bays along lake shores, rivers, and other locations where there is protection from wave erosion. Marshes have also developed in estuaries and low-gradient sections of rivers and are the least stable of the wetland ecosystems of the Eastern Temperate Wetland Region. Investigations of the distribution and ecology of the region's wetlands should include a periodic resurvey of marshes. For example, there have been dramatic changes in recent years in Turkey Point Marsh on Lake Erie, Ontario, where wetlands currently range from a vast shallow water marsh with pools to virtually an open water area.

Shore fens, on the other hand, can be quite stable, as already illustrated by the shore fen at

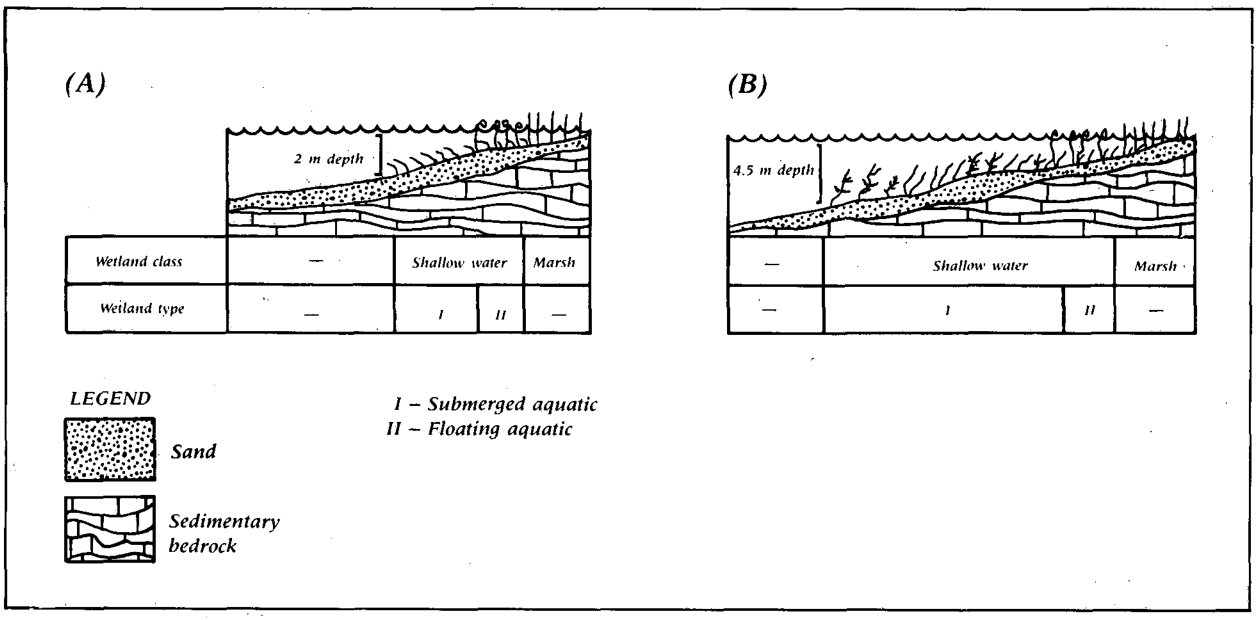


Figure 6–13.
Cross-sections of eastern temperate shallow wetlands along major waterways with (A) organic "brown" waters and (B) clear freshwaters.

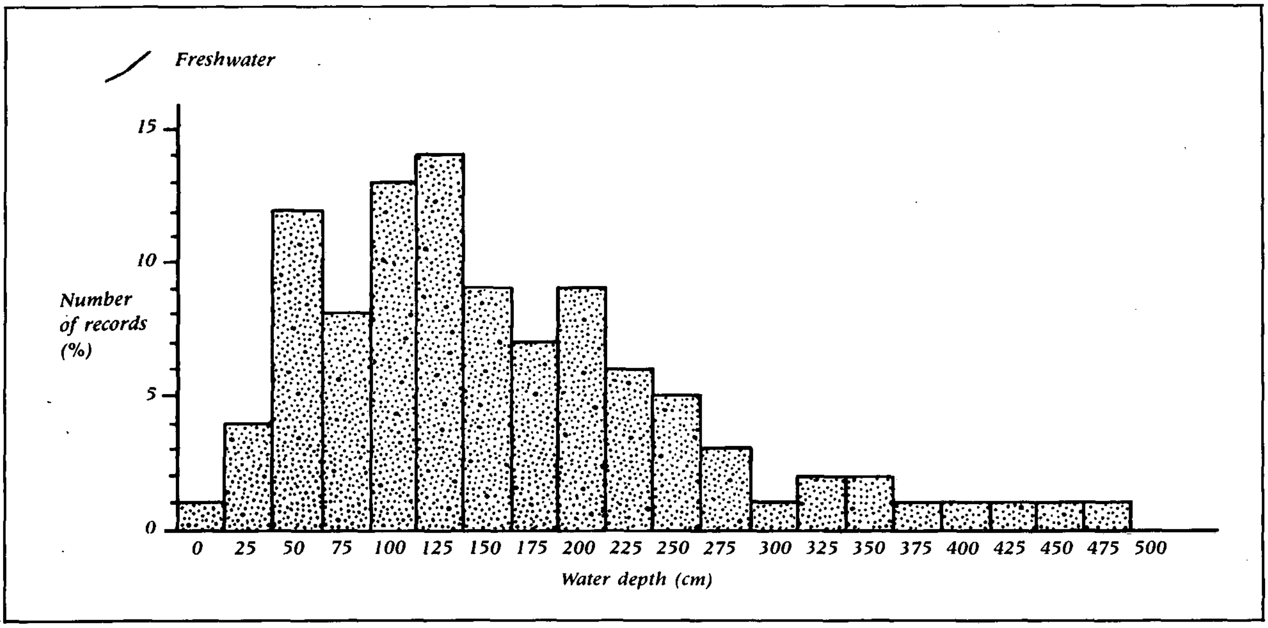


Figure 6–14a.
Distribution of aquatic vegetation with regard to water depth in a freshwater system in Quebec.

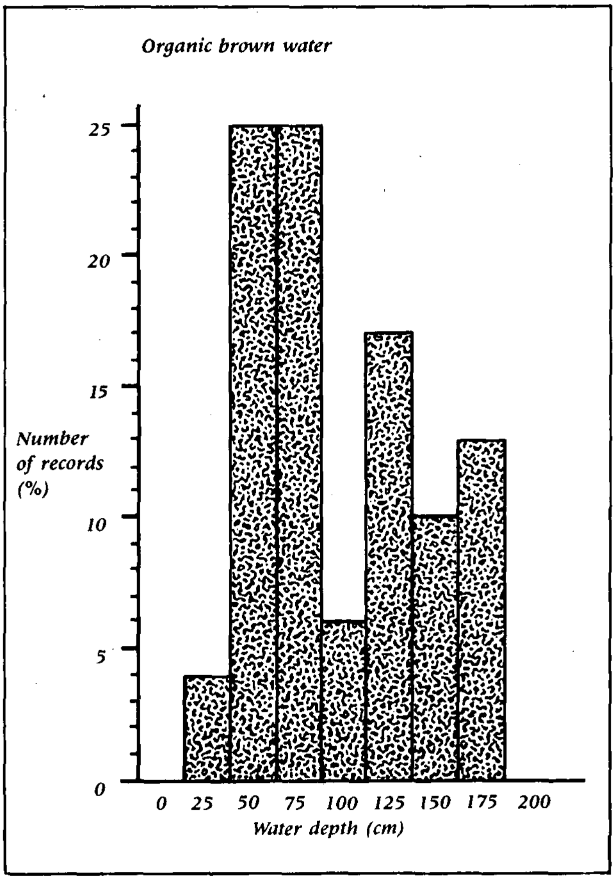


Figure 6–14b.
Distribution of aquatic vegetation with regard to water depth in brown waters in Lac Saint-Louis near Montreal.

Port Royal, Ontario, which has persisted behind a barrier beach for over 3 000 years. The persistence of stream fens is dependent upon the continuation of seasonal flooding of the stream into the fen. The Holland River Fen in Ontario, in which a low shrub bog has developed only 1 km inland from the fen, demonstrates that, in the absence of nutrient enrichment by flooding, an open bog can gradually succeed a fen.

The peat profiles of bogs indicate that, historically, fens associated with ponds which existed during the postglacial period were converted to bogs at a later stage when the ponds were drained. Data developed in Ontario by Vreeken (1981) indicate that in lowland areas these fens would have begun to form during a period 3 000–500 years BP. Once formed, open bogs are quite stable. Treed bogs are even more stable but can revert to open bogs if burned over during a very dry year.

Evaluations of numerous domed bogs in Quebec have been completed. Radiocarbon dating indicates that formation of basal peats in these bogs was initiated from 9 000 to 5 500 years BP (Richard 1977, 1978). The sites with higher elevation, and consequently the most rapidly drained after the decline of the Glacial Champlain Sea, contain accumulations dated to about 8 500 years BP, as compared with lower bog sites with initial basal peats dated to 5 500 years BP (Table 6–17).

In these bog-forming periods, significant amounts of organic materials were deposited. Peat depths in Quebec bogs range generally from 1 to 2 m but up to 5 m in some cases. Accumulation

Table 6–17. Basal peat ages in bogs in Quebec in the Eastern Temperate Wetland Region

Physiographic region	Elevation above sea level (m)	Depth (cm)	Age (before 1950)	Longitude	Latitude	Site	Source
1. Appalachians	282	565–575	11 400±340	72°35'05" W	45°21'33" N	Shefford	Richard (1977, 1978)
2. St. Lawrence Lowlands	160	550–560	7 970±140	71°48'30" W	46°53'30" N	St. Raymond	Richard (1973, 1977)
3. St. Lawrence Lowlands	140	580–590	8 835±145	71°30'00" W	46°27'00" N	Dosquet	Richard (1973, 1977)
4. St. Lawrence Lowlands	120	100+	8 220±150	71°10'00" W	46°39'15" N	Beauséjour	Chabot and Maynard (1978)
5. St. Lawrence Lowlands	75	295–300	8 760±180	73°53'40" W	45°05'40" N	Ormstown	Levesque *et al.* (1978) Mathur *et al.* (1982)
6. St. Lawrence Lowlands	68	320–335	6 100±160	70°56'00"W	46°56'00"N	Île-d'Orléans	Richard (1971, 1977)
7. St. Lawrence Lowlands	53	173–178	8 150±150	72°59'00" W	45°17'00" N	Farnham	Larouche (1980)
8. St. Lawrence Lowlands	51	261–270	8 600±110	74°13'40" W	45°07'05" N	Large tea field	Laframboise*
9. St. Lawrence Lowlands	50	374–384	10 570±210	74°17'30" W	45°08'00" N	Large tea field	Laframboise*
10. St. Lawrence Lowlands	50	429–444	9 140±180	74°17'30" W	45°08'00" N	Small tea field	Laframboise*
11. St. Lawrence Lowlands	20	275–285	4 730±95	73°13'00" W	46°00'00" N	Lanoraie (site St-Jean)	Richard*
12. St. Lawrence Lowlands	18	260–280	4 790±140	73°18'10" W	45°59'30" N	Lanoraie (site St-Joseph)	Comtois (1979, 1982)
13. St. Lawrence Lowlands	18	465–490	5 960±130	73°18'00" W	45°59'20" N	Lanoraie (site St-Henri)	Comtois (1979, 1982)
14. St. Lawrence Lowlands	18	280–300	6 490±110	73°20'30" W	45°57'40" N	Lanoraie (site Coteau-Jaune)	Comtois (1979, 1982)
15. St. Lawrence Lowlands	16	170–178	5 540±105	71°20'00" W	46°47'30" N	Sainte-Foy Plain (Nature Centre)	Larouche (1980)

**Unpublished data, Paleobiogeography and Palynology Laboratory, University of Montreal.*

rates of about 4 cm/100 yr during nutrient-rich (minerotrophic) periods and about 3 cm/100 yr in nutrient-poor (ombrotrophic) periods are documented in the literature.

The accumulated organic materials in bogs have strongly influenced the vegetation that dominates each site (Figure 6–15) (Comtois 1979, 1982). Three stages of succession have been proposed: (a) minerotrophic sites with herbaceous species dominated by Cyperaceae; (b) minerotrophic sites with trees dominated by *Larix laricina* and *Thuja occidentalis*; and (c) ombrotrophic sites with ericaceous shrubs. Comtois (1979, 1982) has proposed that the age at which herbaceous vegetation changes to treed conditions is about 4 500 years, while ombrotrophic conditions are introduced from 2 500 to 4 000 years after the initiation of wetland conditions. The main factors affecting these changes appear to be soil chemistry and the gradual accumulation of organic materials rather than any climatic influences. Studies by Comtois (1979, 1982) using $0^{18}/0^{16}$ isotope dating of peat cellulose fibres have verified that there is no relationship between climate variation and vegetation change.

Hardwood and coniferous treed swamps frequently develop on lower slope positions where frequent flows of groundwater occur, enriched by nutrient ions obtained from surrounding mineral uplands upslope from the swamps. These swamps are naturally quite stable, but because they produce large volumes of timber they are frequently clear-cut. In some cases marshes have been observed to become established on such severely disturbed swamps. These marshes are quickly succeeded by tall shrub swamps which are in turn succeeded by the re-establishment of hardwood or coniferous treed swamps. On some sites, however, such marsh vegetation may persist for many years.

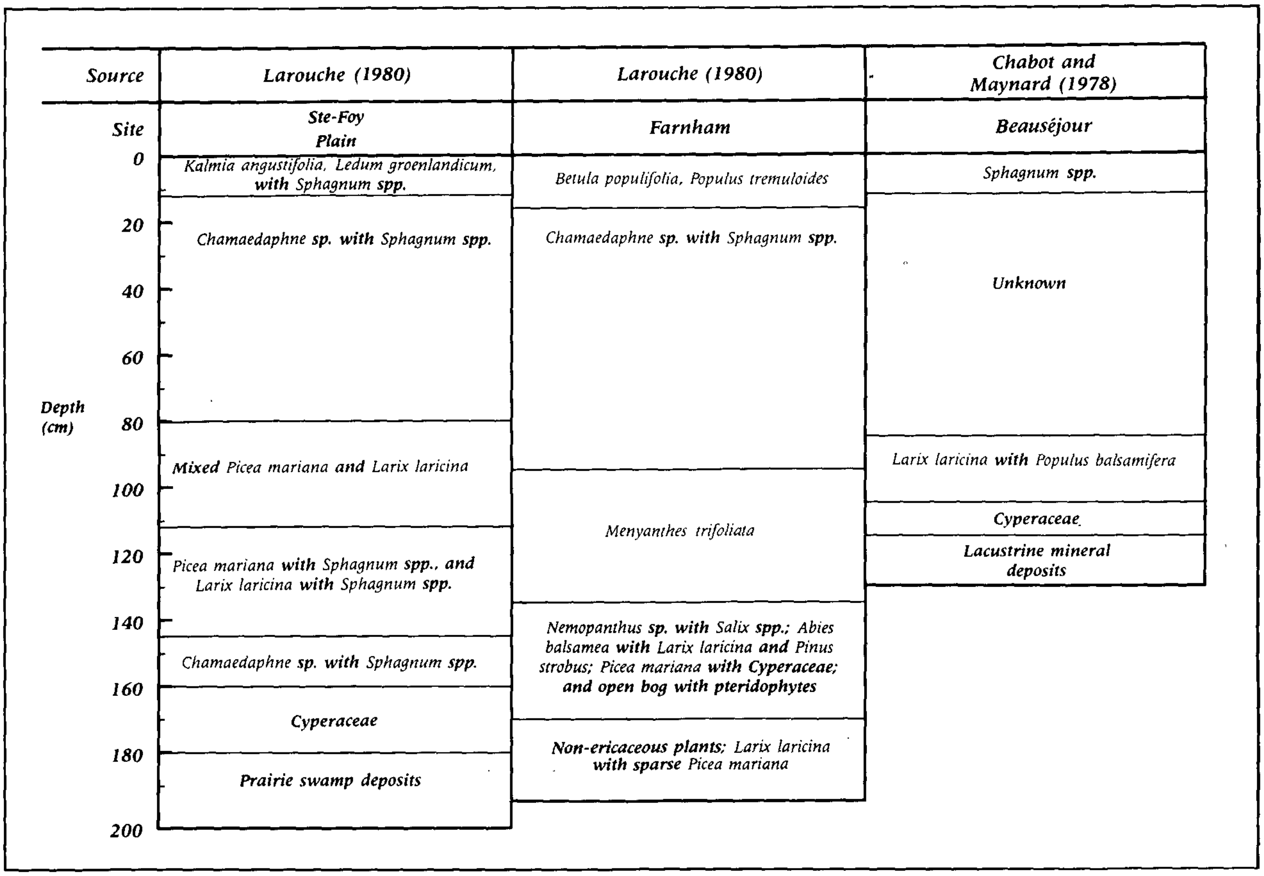


Figure 6–15.
Evolution of vegetation on several domed bogs in the eastern temperate areas of Quebec.

Values of Eastern Temperate Wetlands

Utilization of Eastern Temperate Wetlands by Birds

Use by waterfowl and other migratory birds is perhaps the most valued aspect of eastern temperate wetlands. Mallard (*Anas platyrhynchos*), Black Duck (*Anas rubripes*), Wood Duck (*Aix sponsa*), Blue- and Green-winged Teal (*Anas discors* and *Anas crecca*), and Canada Goose (*Branta canadensis*) appear to thrive, particularly in unaltered, natural environments along the Great Lakes in Ontario and in the St. Lawrence Lowlands in both Ontario and Quebec. However, these natural wetlands are being lost or degraded by agriculture, urbanization, industrial development and pollution, water control projects, and certain forestry projects. Wetlands in southwestern New Brunswick within the Eastern Temperate Wetland Region are not on a major flyway but do provide a dispersal route for waterfowl travelling up from the Bay of Fundy and staging areas for waterfowl south of Fredericton.

In 1986, southern Ontario provided habitat for over 79 000 Mallard and 12 330 Blue-winged Teal successful breeding pairs (D.G. Dennis, personal communication). This represents 29% of the Ontario total for these species. The most extensive and best quality habitat suitable for migratory waterfowl in southern Ontario is provided by the large shoreline marshes associated with Lake Erie and Lake St. Clair. The marshland along the east shore of Lake St. Clair currently serves as the most important staging area in southern Ontario for Mallard, Black Duck, Canada Goose, and Tundra Swan (*Cygnus columbianus*) (Dennis and North 1984a). Large numbers of these and other migratory birds use the St. Clair marshes. Estimated peak numbers are approximately 60 000 in the spring and nearly 150 000 in the fall. In addition to Lake St. Clair and associated Walpole Island, the Long Point marshes on Lake Erie provide excellent habitat for Canada Goose, Mallard, Black Duck, and other dabblers (Dennis *et al.* 1984a). Bird species identified as dependent on wetlands in southern Ontario are listed in Table 6–18.

Table 6–18. Bird species dependent on wetlands in southern Ontario

Red-necked Grebe	*Podiceps grisegena*
Pied-billed Grebe	*Podilymbus podiceps*
Great Blue Heron	*Ardea herodias*
Common Egret	*Casmerodius albus*
Cattle Egret	*Bubulcus ibis*
Black-crowned Night Heron	*Nycticorax nycticorax*
Least Bittern	*Ixobrychus exilis*
American Bittern	*Botaurus lentiginosus*
Mute Swan	*Cygnus olor*
Canada Goose	*Branta canadensis*
Mallard	*Anas platyrhynchos*
Black Duck	*Anas rubripes*
Gadwall	*Anas strepera*
Common Gallinule	*Gallinula chloropus*
American Coot	*Fulica americana*
Little Gull	*Larus minutus*
Forster's Tern	*Sterna forsteri*
Black Tern	*Chlidonias niger*
Acadian Flycatcher	*Empidonax virescens*
Long-billed Marsh Wren	*Cistothorus palustris*
Prothonotary Warbler	*Protonotaria citrea*
Northern Waterthrush	*Seiurus noveboracensis*
Common Yellowthroat	*Geothlypis trichas*
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
Lincoln's Sparrow	*Melospiza lincolnii*
Swamp Sparrow	*Melospiza georgiana*
Northern Pintail	*Anas acuta*
Green-winged Teal	*Anas crecca*
Blue-winged Teal	*Anas discors*
American Widgeon	*Anas americana*
Northern Shoveler	*Anas clypeata*
Wood Duck	*Aix sponsa*
Redhead	*Aythya americana*
Ring-necked Duck	*Aythya collaris*
Ruddy Duck	*Oxyura jamaicensis*
Hooded Merganser	*Lophodytes cucullatus*
King Rail	*Rallus elegans*
Virginia Rail	*Rallus limicola*
Sora	*Porzana carolina*
Yellow Rail	*Coturnicops noveboracensis*

Source: Hummel (1981).

In southwestern Ontario, certain locations such as areas of moraine feature large numbers of permanent and semi-permanent wetlands because drainage has thus far proven unfeasible or uneconomic (Dennis and North 1984b). Wetlands in moraine areas are now the most important natural areas for waterfowl production in southwestern Ontario because they are shallow, occur on fertile soils, and because periodic drought is accompanied by nutrient recycling. In eastern Ontario, the large number of waterfowl in the area centred on Wolfe Island near Kingston in both spring and fall makes this area as important to waterfowl as are Long Point and Lake St. Clair to the southwest. Important staging habitat for Canada Goose is found in four areas, including two along the Ottawa River (in the spring only), Morrisburg, and Wolfe Island.

In Quebec, wetland habitats within the Eastern Temperate Wetland Region are important for waterfowl population maintenance. The riverine wetlands of the St. Lawrence, Ottawa, and Richelieu rivers are all extensively utilized as habitat for many species of birds. During the spring and fall migration periods, over 750 000 birds inhabit the marshes and swamps of this region. This includes over 75% of the migratory populations of Greater Snow Goose (*Anser caerulescens atlanticus*), Canada Goose, diving ducks, and dabbling ducks.

Shore swamps, particularly those dominated by shrubs and trees, shore marshes, and shallow water wetlands are among the most favoured bird habitats in this wetland region. Habitats for wildlife in shore marshes and bogs are valued as well. Each is considered below in detail.

Shore Swamps

Many waterfowl throughout the Eastern Temperate Wetland Region use shore swamps during staging and migratory activity. These include sites inundated through the spring but dry through the summer. Some are characterized by herbs (e.g. *Phalaris arundinacea*) and agriculturally cultivated cover; others are shrub swamps with willows (*Salix* spp.) and *Cornus* spp., and hardwood swamps with maple (*Acer* spp.). Herb swamps are the most intensively used by migratory birds. Each year these areas generally receive only shallow flooding which serves to enhance site productivity. Native graminoid species such as *Polygonum* and *Equisetum*, as well as cultivated crops such as corn, may provide forage on such sites with productivity values of up to 5 kg/m^2/yr.

During the spring and fall migrations, up to 250 000 Snow Geese use wetland habitat along the St. Lawrence River. In addition, Canada Geese concentrate in several areas: 100 000 along Lac St-Pierre near Trois-Rivières, Quebec, 60 000 along the Ottawa River, and 15 000 on the Richelieu River. Approximately 15% of all Canada Geese that migrate through the Atlantic Flyway use the Lac St-Pierre area. Wetlands and cultivated lands here are believed to have been instrumental in an observed growth of the population of Canada Geese in this area from 20 000 birds in 1966 to 100 000 birds today (Lehoux *et al.* 1985). Canada Geese seek the St. Lawrence wetlands at night; during the day they take advantage of grassy cultivated fields. During early May, after a migratory resting period of up to 40 days, they leave the

Eastern Temperate Wetland Region for northern areas such as Foxe Basin and James Bay.

Dabbling ducks, such as Northern Pintail (*Anas acuta*) and Black Duck, occupy herb swamps in the St. Lawrence wetlands at about the same time as Canada Geese and are essentially there for the same reasons—resting and feeding. This population has grown to about 50 000 today. After the retreat of spring floodwaters, herb swamps serve as reproduction sites for a dozen species of dabbling ducks and other wetland-associated bird species, including Mallard and Northern Pintail.

It is noted that Redhead (*Aythya americana*) prefer breeding habitat in Lake St. Clair in Ontario, although they also breed in swamps along the western part of Lac St-François, the only reproduction site for this species in Quebec. Between Montreal and Sorel, as well as in the southwestern part of Lac St-François, occur the two most significant populations of Gadwall (*Anas strepera*) in Quebec. These populations have only appeared since the 1960s (Cantin *et al.* 1976). In eastern Ontario, marshes in which Gadwall are seen are located in the Cornwall, Morrisburg, Wolfe Island, Amherst, and Prince Edward Point areas. Gadwall known breeding sites are also located along Lac St-François in Quebec.

Other typical and common birds that occur in these shore swamps are American Bittern (*Botaurus lentiginosus*), Sedge Wren (*Cistothorus platensis*), Marsh Wren (*Cistothorus palustris*), Swamp Sparrow (*Melospiza georgiana*), Common Snipe (*Gallinago gallinago*), and Virginia Rail (*Rallus limicola*).

After the spring migration when water levels are high, shrub and treed shore swamps offer an attractive habitat for birds. Such species include Wood Duck, Mallard, and Black Duck. High water levels generally cause these birds to nest in elevated niches while feeding in the nearby marshes and shallow waters. Other species frequenting shrub and treed shore swamps include Common Yellowthroat (*Geothlypis trichas*), Swamp Sparrow, Northern Waterthrush (*Seiurus noveboracensis*), Willow Flycatcher (*Empidonax traillii*), Alder Flycatcher (*Empidonax alnorum*), and Red-winged Blackbird (*Agelaius phoeniceus*). Great Blue Heron (*Ardea herodias*) are found in scattered large colonies of 100 to 340 birds in a number of treed swamps in southwestern Ontario (Dunn *et al.* 1981) and also in a dozen major colonies along the St. Lawrence River in Quebec. Over 800 herons were observed in one such colony in 1986 on the Îles de Berthier-Sorel.

Freshwater Shore Marshes

These wetlands are mainly used by birds in midsummer when plant forage, invertebrates, crustaceans, and insect larvae are most abundant. The most common species using these sites are dabbling ducks and their broods, including Northern Pintail, Mallard, Black Duck, and Green-winged Teal.

Tidal Shore Marshes

From 300 000 to 400 000 waterfowl and other shore birds converge annually on coastal habitats on the St. Lawrence River, much of which lies in the Eastern Temperate Wetland Region. Black Duck, Snow Goose, and Semipalmated Sandpiper (*Calidris pusilla*) are particularly important. Over 250 000 Greater Snow Geese frequent marshes dominated by *Scirpus* spp. This species forms the largest concentration of birds in the St. Lawrence Lowlands.

Dabbling ducks make extensive use of intertidal marshes in this region—over 50 000 birds (70% of which are Black Duck) in the fall. They feed on *Scirpus americanus*, *Sparganium eurycarpum*, *Zizania aquatica*, and *Sagittaria latifolia*, as well as molluscs, crustaceans, and invertebrates in these wetlands. Semipalmated Sandpiper frequent shore marsh sites in the St. Lawrence Lowlands, including Beauport and Montmagny, Quebec, two of the most strategic areas for this species in eastern Canada.

Shallow Waters

Diving ducks are common users of shallow water areas for feeding, but they prefer other habitats for breeding. Major food sources for diving ducks in shallow water areas include molluscs, arthropods, mussels, and various plants. Surveys in these habitats have revealed that during migration periods almost 180 000 birds use the waters and lakes of the Montreal area. Lac Saint-Louis, Lac des Deux-Montagnes, Lac St-François, and Lac St-Pierre are the most important areas in Quebec, while the marshes and bays of the Long Point, Lake St. Clair, and Walpole Island areas (Figure 6–16), are the most important in Ontario.

Shore Bogs

Numerous shore bogs associated with small lakes in the Eastern Temperate Wetland Region are also valued sites for northern lacustrine birds. In particular, the central shallow ponds of these bogs serve as breeding areas for a multitude of aquatic

Figure 6–16.
The Walpole Island, Ontario, area on Lake St. Clair has numerous marshes well utilized by waterfowl for staging and migration activities; sedge community in marsh at south end of Bassett Island.

invertebrates favoured by birds. Wading birds are common in these habitats, including American Bittern, Black Duck, and Green-winged Teal. The Common Loon (*Gavia immer*) is common in small clear lakes (Desgranges and Darveau 1985). Passerine birds are also common in the central poorly drained part of shore bogs. Examples include various flycatchers, warblers, grackles, and sparrows (Desgranges and Houde 1987).

Utilization of Eastern Temperate Wetlands by Other Wildlife

Fish rely on temperate wetlands to a large extent. Marshes and swamps provide spawning grounds for many important freshwater species including northern pike (*Esox lucius*), muskellunge (*Esox masquinongy*), largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), brown bullhead (*Ictalurus nebulosus*), pumpkinseed (*Lepomis gibbosus*), and various minnows. Some of the fish species commonly found in the wetlands of southern Ontario are listed in Table 6–19.

After feeding for several weeks in flooded swamp areas, pike and pumpkinseed ("sunfish") tend to move into shore marshes for spawning in the May–July period. Here, female pike lay eggs which are semi-adhesive, adhering to such submergent plants as *Phalaris arundinacea* and *Calamagrostis canadensis*. Sunfish clean substrate gravel by mouth prior to laying eggs, while brown bullhead spawn in small tunnels in sediment or in vegetation.

Water levels are critical to pike and other fish, as the young are not able to swim into faster moving

Table 6–19. Fish species common in wetlands in southern Ontario

Northern pike	*Esox lucius*
Muskellunge	*Esox masquinongy*
Grass pickerel	*Esox americanus vermiculatus*
Carp	*Cyprinus carpio*
Golden shiner	*Notemigonus crysoleucas*
Blackchin shiner	*Notropis heterodon*
Blacknose shiner	*Notropis heterolepis*
Pearl dace	*Semotilus margarita*
Northern redbelly dace	*Chrosomus eos*
Finescale dace	*Chrosomus neogaeus*
Fathead minnow	*Pimephales promelas*
Brown bullhead	*Ictalurus nebulosus*
Rock bass	*Ambloplites rupestris*
Pumpkinseed	*Lepomis gibbosus*
Bluegill	*Lepomis macrochirus*
Largemouth bass	*Micropterus salmoides*
Yellow perch	*Perca flavescens*
Iowa darter	*Etheostoma exile*

Source: Hummel (1981).

waters until the major annual spring flood recedes. Studies conducted over a period of 50 years on the upper Richelieu River in Quebec have shown that water level and flooding period greatly influence pike up to two years of age. Depths below 20 cm in midsummer can result in reproductive failure and decline for many species. Insects, crustaceans, molluscs, frogs, and other amphibians are all dependent on minimum water levels in marshes and shallow water areas. Production of various fish in the wetlands of Lac St-Pierre in Quebec has been estimated: pike (750 fish/ha); perch (120 fish/ha); brown bullhead (75 fish/ha); sunfish (375 fish/ha); and minnows (3 000 fish/ha)—a total of 4 300 fish/ha.

The substrates in shrub and treed wetlands are covered by leaves, a situation unfavourable to fish reproduction; hence, fish are much less abundant in such sites. However, perch are known to deposit their eggs (attached to each other in long ribbons) on tree branches, while brown bullhead feed on worms in the mud of these wetlands. Treed swamps feature rapid growth of new vegetation attractive to other wildlife. These include snakes and frogs (e.g. leopard frog [*Rana pipiens*]), as well as various mammals (moles and voles).

Amphibians and reptiles are heavily dependent on wetlands. In Ontario, for example, eight species of turtle are wetland-dependent. These include Midland painted turtle (*Chrysemys picta marginata*), spotted turtle (*Clemmys guttata*), wood turtle (*Clemmys insculpta*), Blanding's turtle (*Emydoidea blandingi*), musk turtle (*Sternotherus odoratus*), and snapping turtle (*Chelydra serpentina*). Wetland-dwelling herptiles in Ontario include the eastern fox snake (*Elaphe vulpina gloydi*), eastern Massasauga rattlesnake (*Sistrurus catenatus catenatus*), cricket frog (*Acris gryllus crepitans*), and several Ambystomid salamanders.

Many mammals utilize wetlands for breeding and feeding habitat. White-tailed deer (*Odocoileus virginianus*) are a common wetland inhabitant, while moose (*Alces alces*) are seen in many eastern temperate wetlands such as the Alfred Bog near Ottawa. Wetlands also provide habitat for several commercially important fur-bearers such as mink (*Mustela vison*), beaver (*Castor canadensis*), river otter (*Lontra canadensis*), raccoon (*Procyon lotor*), and muskrat (*Ondatra zibethicus*). The muskrat is particularly prolific; over 492 000 were captured in 1985–1986 during the fur harvest in Ontario. Wetlands in southwestern Ontario (Chatham District) produced the greatest number of muskrat with over 97 000 captured, 19% of the total for all of Ontario.

Economic Values

In 1984–1986, wetland-dwelling fur-bearers yielded a harvest in Ontario worth almost $11 million, illustrating that wetlands are important not only for their ecological role but also from an economic and social standpoint. The muskrat harvest in Ontario in 1985–1986 was alone worth over $1.9 million. Other resources provided by wetlands include activities such as waterfowl hunting and fishing. In 1983, over 103 000 waterfowl hunters harvested almost 1 million ducks and geese in Ontario (Metras 1985). These figures translated into hunter expenditures of $16 million and a total economic value of almost $60 million. Waterfowl hunter expenditures are similar for Quebec.

Within the Eastern Temperate Wetland Region, data reported indicate that over 75 000 waterfowl hunters harvested a total of 680 000 waterfowl and 58 000 geese (Canadian Wildlife Service 1981). The percentage of hunters was fairly equally divided within the temperate wetlands of Ontario and Quebec, with 52% of hunters from Ontario and 45% from Quebec. A small percentage was also reported in the New Brunswick area of the Eastern Temperate Wetland Region.

The sport fishing industry is worth over $1 billion to the economy of Ontario alone. Although it is impossible to estimate what portion of this value is attributed only to wetlands, it is probably considerable as many sport fish use wetlands for feeding and reproduction. Wetlands are the scene of extensive non-consumptive uses of wildlife (e.g. bird-watching and wildlife photography). Based on 1979 figures (Kubursi 1981), it is estimated that all non-consumptive uses of wildlife in Ontario generated over $100 million in expenditures and had a total economic impact of over $300 million. Bird-watching as a pastime continues to increase in popularity, with a corresponding impact on the economies of local communities. Many of these non-consumptive uses take place in wetlands.

Fish and wildlife are not the only wetland resources which have significant economic value. Timber, wild rice, and peat are examples of other wetland-based natural resource products. The principal sources of eastern white cedar and soft maple are wetlands. In 1984, almost $1 million worth of wild rice was harvested in Ontario. Most of this harvest came from the northwestern portion of the province; however, the potential for extensive development of this resource exists throughout Ontario. The value of peat is also recognized, with extensive horticultural peat harvesting in the temperate portions of Quebec and New Brunswick. Peat may be used in the future to treat urban and industrial wastes, as an alternative energy source, and as a base for industrial materials such as synthetic waxes and metallurgical cokes for metal arc ovens.

In southeastern Quebec, numerous bogs have been developed for horticultural peat production since 1919, with some in Champlain County used for energy production. There are now over 40 peat-producing companies operating in Quebec. Over 10 000 ha of peatland in Quebec are also used to produce market garden crops such as carrots, lettuce, onions, apples, radish, celery, and corn—a provincial industry currently valued in excess of $50 million annually. Similar agricultural production is also occurring in southern Ontario on many managed peatland sites.

Hydrological Values

Most wetlands are hydrologically important within their catchment basins. The hydrological value of wetlands in southern Ontario has been recognized to be at a level equal to their biological and social values (Environment Canada and the Ontario Ministry of Natural Resources 1984). Although appreciation of the hydrological value of wetlands has increased in recent years, there still exists a great lack of knowledge about the specifics of wetland hydrology (Carter *et al.* 1978; Ingram 1983). Most existing hydrological studies of wetlands concentrate on various aspects of peat and the drainage or agricultural management of bogs. In the Eastern Temperate Wetland Region, some research has centred around water balance studies (Taylor 1982) and the water level–streamflow relationship (Woo and Valverde 1981).

Typically, the most notable hydrological values of wetlands are flow stabilization, improvement of water quality, and erosion control (Whitley 1975; Whitley and Irwin 1986). Of these, the most important is flow stabilization, particularly for swamps (Glooschenko *et al.* 1987a). Although variation from site to site is quite large, some wetlands have the ability to accumulate water during times of high water and hold back peak flow in rivers and streams. By doing so, they reduce flood crests and augment river flow at other times.

Several studies conducted in southern Ontario and other portions of the Eastern Temperate Wetland Region have examined the role of wetlands in flow stabilization. Bay (1969) concluded that wetlands are ineffective for water storage except in the short-term regulation of runoff. This study, however, was conducted in small wetlands under 10 ha in size. Woo and Valverde (1981) studied the hydrology of the Beverly Swamp near Hamilton, Ontario. They concluded that the regulatory role of this swamp was governed by groundwater storage capacity and that the main value of the wetland was its ability to absorb much of the rainfall deposited by summer storms. There was less flow regulation during spring and fall because the substrate was usually saturated.

Prassad (1961) and Rai (1962) studied a small coniferous treed spring swamp in the Speed River Watershed near Guelph, Ontario. They found that the wetland had little influence on streamflow rates as it merely covered an area of emerging groundwater which was dissipated primarily by evapotranspiration rather than by streamflow.

Taylor (1982) studied wetlands in the Telford Watershed near Peterborough, Ontario, and examined the seasonality of their contribution to local streams and aquifers. Taylor found that, in the summer months when water levels are low, these wetlands have a large unsatisfied storage capacity. This effectively holds back storm runoff which might otherwise cause flooding problems downstream. However, in wet months, especially during spring and fall, the regulatory role of the wetland is much less significant. After the storage capacity of the wetlands has been filled, they shed their runoff very rapidly. Taylor and Pierson (1985) concluded that the wetland area of the Telford Watershed substantially reduced quickflow.

The value of wetlands for flow augmentation is limited to either a short period after a storm (when augmented flow may be of dubious value) or subsequently to recharge of groundwater from the wetland. This is primarily a function of headwater wetlands. However, the evidence for linkage of headwater wetlands is confusing. Some wetlands discharge groundwater, others recharge aquifers (Carter *et al.* 1978), while others exist entirely independently of local groundwater systems (Verry and Boelter 1978). Isolated wetlands are generally sites of recharge for regional groundwater; how-

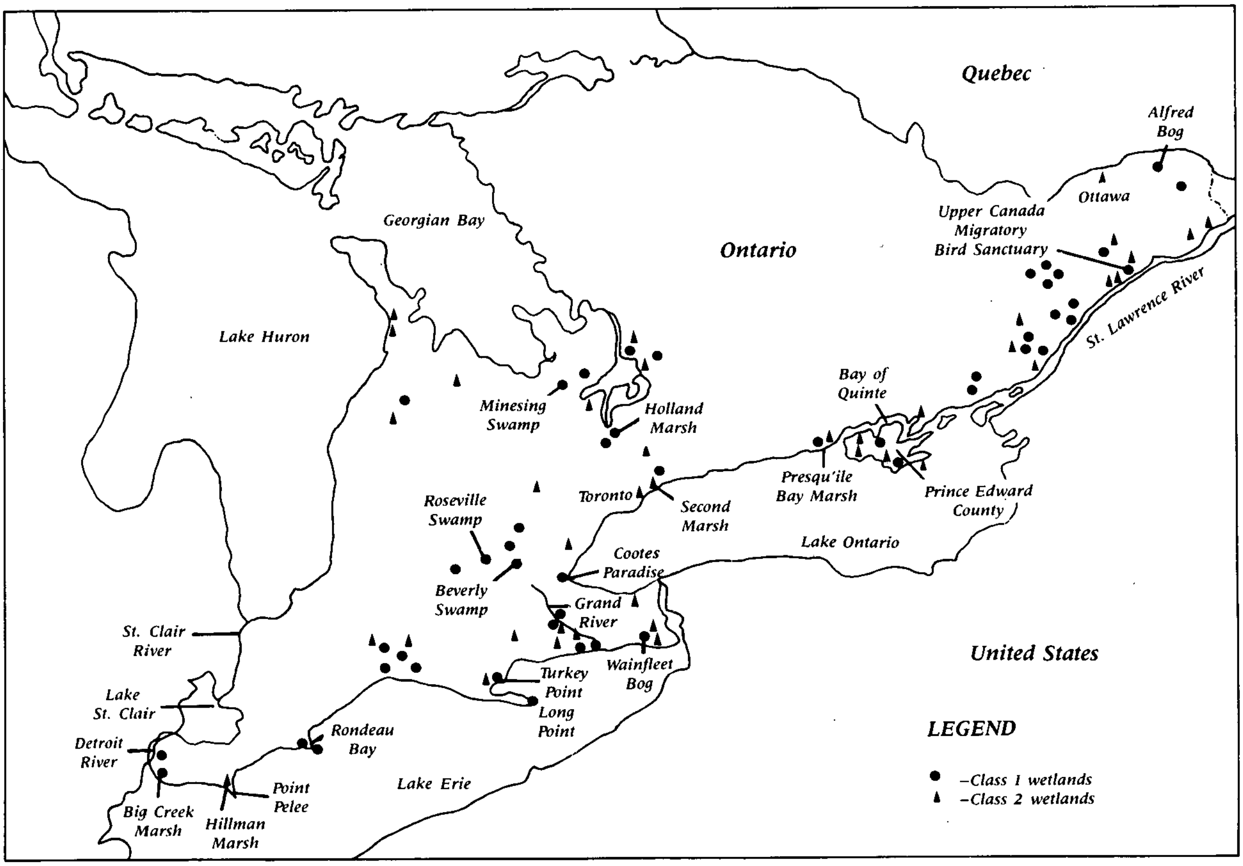


Figure 6–17.
Some significant wetlands of southern Ontario (wetlands evaluated to 1985).

ever, not all areas of recharge are wetlands (Roulet 1985).

Wetlands have the ability to improve water quality by removing nutrients from the water during the growing season and by permanently accumulating them in organic sediment. In Michigan and Minnesota, researchers have noted that incoming waters typically slow to a creeping flow, providing settling time for suspended material (Kadlec 1981; Oberts 1981), and that the retention of urban wetlands for sewage treatment appears to be beneficial. In the Eastern Temperate Wetland Region, Wile *et al.* (1981) found that suspended soil loadings and total phosphorus concentration were reduced by up to 95% by treatment of sewage in artificially created marshes near Listowel, Ontario.

Important Eastern Temperate Wetland Complexes

Numerous wetland sites and complexes are recognized by the Province of Ontario as being provincially or regionally significant (Figure 6–17). In addition, many other wetland areas in the Eastern Temperate Wetland Region are considered to be of international, national, and regional significance for waterfowl by federal and provincial agencies.

Southern Ontario

Seven key wetland sites for waterfowl in Ontario have been identified by Dennis *et al.* (1984), as listed below.

Long Point/Turkey Point: These areas are used by more migratory waterfowl than any other wetlands in southern Ontario (Dennis *et al.* 1984; McKeating 1983). They are vitally important to several rare or endangered species of birds and plants, such as the Bald Eagle (*Haliaeetus leucocephalus*) and the small white lady's slipper orchid (*Cypripedium candidum*) (Brownell 1981). Sixty plant and seventeen bird species in this area are rated provincially significant. Long Point has been designated as one of Canada's RAMSAR wetland sites of international significance and is mainly encompassed within the Long Point National Wildlife Area (Figure 6–18).

Lake St. Clair Marshes: A series of 17 separate marshes provides the most valued staging areas in

Figure 6–18.
The Long Point area on Lake Erie provides excellent marsh habitat for Canada Geese, Black Duck, and various dabbling ducks: cedar ridges at Long Pond.

southern Ontario for Mallard, Black Duck, Canada Goose, and Tundra Swan (Dennis *et al.* 1984). Almost all of this area is managed privately by hunting clubs, but 240 ha form the St. Clair National Wildlife Area. This area is also on Canada's list of RAMSAR wetland sites of international significance.

Prince Edward County: The marshes and bays of this area of Ontario collectively constitute a valued concentration of wetland resources. Big Island Marsh and Sawguin Creek Marsh together cover almost 2 700 ha. The waters of Lake Ontario in this area support a great number of migrating Greater and Lesser Scaup (*Aythya marila* and *Aythya affinis*) and large numbers of Canvasback (*Aythya valisineria*), Redhead, Common Goldeneye (*Bucephala clangula*), Merganser, and Canada Goose (Dennis *et al.* 1984). In addition to waterfowl, species found in these marshes which are rare in Ontario include Caspian Tern (*Sterna caspia*), Black Tern (*Chlidonias niger*), Marsh Wren, Sedge Wren, Black-crowned Night Heron (*Nycticorax nycticorax*), and Least Bittern (*Ixobrychus exilis*).

Lower Detroit River: The wetlands of the lower Detroit River, primarily Big Creek Marsh and River Canard Marsh, serve as very important staging areas for Canvasback and Redhead ducks. Dennis *et al.* (1984) considered this area the sixth most important waterfowl staging area in southern Ontario. The area is also an important stopover point for migratory raptors. In the fall of 1981, over 100 000 raptors of 16 different species were seen by observers at Big Creek Marsh (Patter and Hilts 1985). The area contains many species of flora rare in Ontario, including wild yam (*Dioscorea villosa*), American lotus (*Lotus americanus*), and prairie white-fringed orchid (*Habenaria leucophaea*). In addition, several uncommon halophytic plants are found in and around these marshes (Catling and McKay 1980).

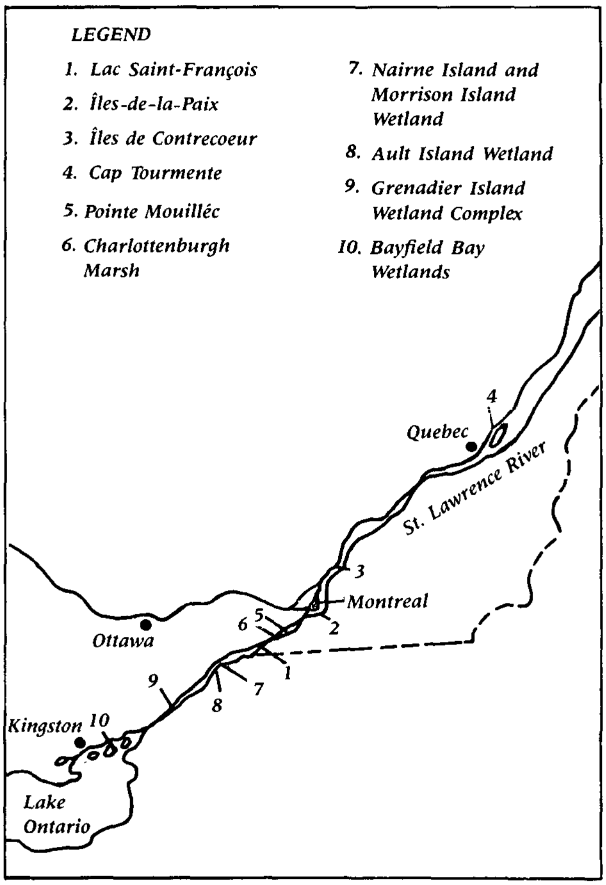
Grand River: The Grand River system is the main water supply for numerous large urban centres in Ontario. A section of this river contains 10 marsh areas, collectively totalling over 700 ha, which provide major waterfowl staging areas in the spring and fall periods.

Rondeau Bay: Located midway between Point Pelee and Long Point along Lake Erie, this area is encompassed by Rondeau Provincial Park and is the site of extensive wetlands annually providing internationally vital habitat for wildlife and waterfowl.

Point Pelee: One of North America's most critical waterfowl staging and migratory areas, this area comprises Point Pelee National Park. Its associated marshes annually host one of Canada's largest migrations of birds and waterfowl. In 1987 the area was added by Canada to the list of internationally significant wetlands for wildlife under the RAMSAR Convention.

Upper St. Lawrence River

The shoreline wetlands of the upper St. Lawrence River are of primary importance as migration–staging habitat for waterfowl, and as spawning and nursery areas for fish production in both eastern Ontario and southwestern Quebec. Some of the more important wetland areas have been discussed by Ringuet and De Repentigny (1985) and Bottomley (1986) (Figure 6–19). Surveys of migratory waterfowl carried out in eastern Ontario by the Canadian Wildlife Service (Ross 1984) showed that provincially significant waterfowl are centred on Wolfe Island, at the outlet of Lake Ontario. This island is strategically located on the northwest–southeast migration route, and is surrounded by abundant shallow waters with submerged vegetation beds. In this area the wetland complexes of Grenadier Island and Lac St-François (Ault, Nairne, and Morrison islands) are regionally and provincially significant, as are those of Charlottenburgh Marsh and Point Mouillée, also located in Lac St-François, Ontario.



Sources: Adapted from Ringuet and de Repentigny (1985); Bottomley (1986).

Figure 6–19.
Eastern temperate wetlands of importance to wildlife along the St. Lawrence River in Ontario and Quebec.

In the portion of the Eastern Temperate Wetland Region located in southern Quebec, a series of wetland complexes of national and international importance is also recognized. These wetland complexes include:

Lac St-Pierre: About 15% of all Canada Geese using the Atlantic Flyway use the marshes and swamps of this area during the spring. The Îles de Berthier-Sorel are particularly critical. Numerous aquatic birds and shorebirds also use Lac St-Pierre.

Cap Tourmente: The Cap Tourmente National Wildlife Area, studied by Ringuet and De Repentigny (1982) and Lemieux (1978), has long been recognized for its diverse flora and wildlife. The most spectacular elements are important colonies of Snow Geese and extensive *Scirpus americanus* marsh. The area is recognized as a wetland site of international importance for wildlife under the RAMSAR Convention (Figure 6–20, a and b).

Îles-de-la-Paix: These islands in Lac Saint-Louis are highly valued for waterfowl production (Laperle 1969a, 1969b; Ouellet 1974; Pageau *et al.* 1971). They contain maple-dominated treed swamps which from 1972 to 1976 were extensively disturbed by floodwaters, resulting in vegetation mortality and wetland stress. Current water levels are encouraging the re-establishment of numerous high-quality waterfowl sites.

Lac Saint-François: Bourget (1973), Ouellet (1974), and Chapdelaine and De Repentigny (1975) have all focused on the marshes and swamps of this area, such as those at Dundee, as critical, nationally significant staging and resting areas for waterfowl. The Îles de Valleyfield at the entrance of Lac St-François and Lac Saint-Louis are also critical areas and include Île Arthur, a Quebec Ecological Reserve. In 1987, the area was added to the RAMSAR list of internationally significant wetlands.

Îles de Contrecoeur: This area is composed of a series of small islands in the St. Lawrence River which are particularly productive for Northern Pintail, American Widgeon (*Anas americana*), and Blue-winged Teal (Environment Canada and the Province of Quebec 1985). Studies of this area have been carried out by Ouellet (1974), Cantin and Blais (1976), Cantin and Ringuet (1978), and De Repentigny (1982).

Lachine Rapids Islands: Located at the eastern end of Lac Saint-Louis, this area is noted for the

(a)

(b)

Figure 6–20.

Cap Tourmente east of Quebec City is one of Canada's most well known national wildlife areas featuring a broad coastal plain utilized by birds: (a) Pays-de-la-Falaise showing vegetation zonation, (b) Snow Geese.

rare occurrence of sugarberry (*Celtis occidentalis*). This species favours the rocky islands in the Lachine Rapids associated with a warmer winter microclimate created by the break-up of ice. Various duck species also favour these sites.

Huntingdon Marsh: This area on the St. Lawrence River has been extensively documented by Auclair *et al.* (1973) as a critical waterfowl habitat.

Southwestern New Brunswick

Wetlands in those southwestern New Brunswick areas within the Eastern Temperate Wetland Region are not on a major flyway but do provide a dispersal route for waterfowl travelling up from the Bay of Fundy and the Saint John River Valley. Staging areas for waterfowl are particularly popular in wetlands south of Fredericton, the most notable being the Portobello Creek National Wildlife Area, which receives backwater from Saint John River floodwaters (Whitman 1968; Hall 1971; Hounsell 1985). Osprey (*Pandion haliaetus*) can be seen here and the last breeding colony of Black Tern in New Brunswick is found here. Important wetlands also surround the Kennebecasis River and Belleisle Bay Creek where they enter the Saint John River, and are also found adjacent to Sunpolk Lake, the Oromocto River, and Grand Lake meadows. Studies on the wildlife resources of the Saint John River Valley include those of Wright (1967), Choate (1973), and Barkhouse (1979).

Wetland Losses

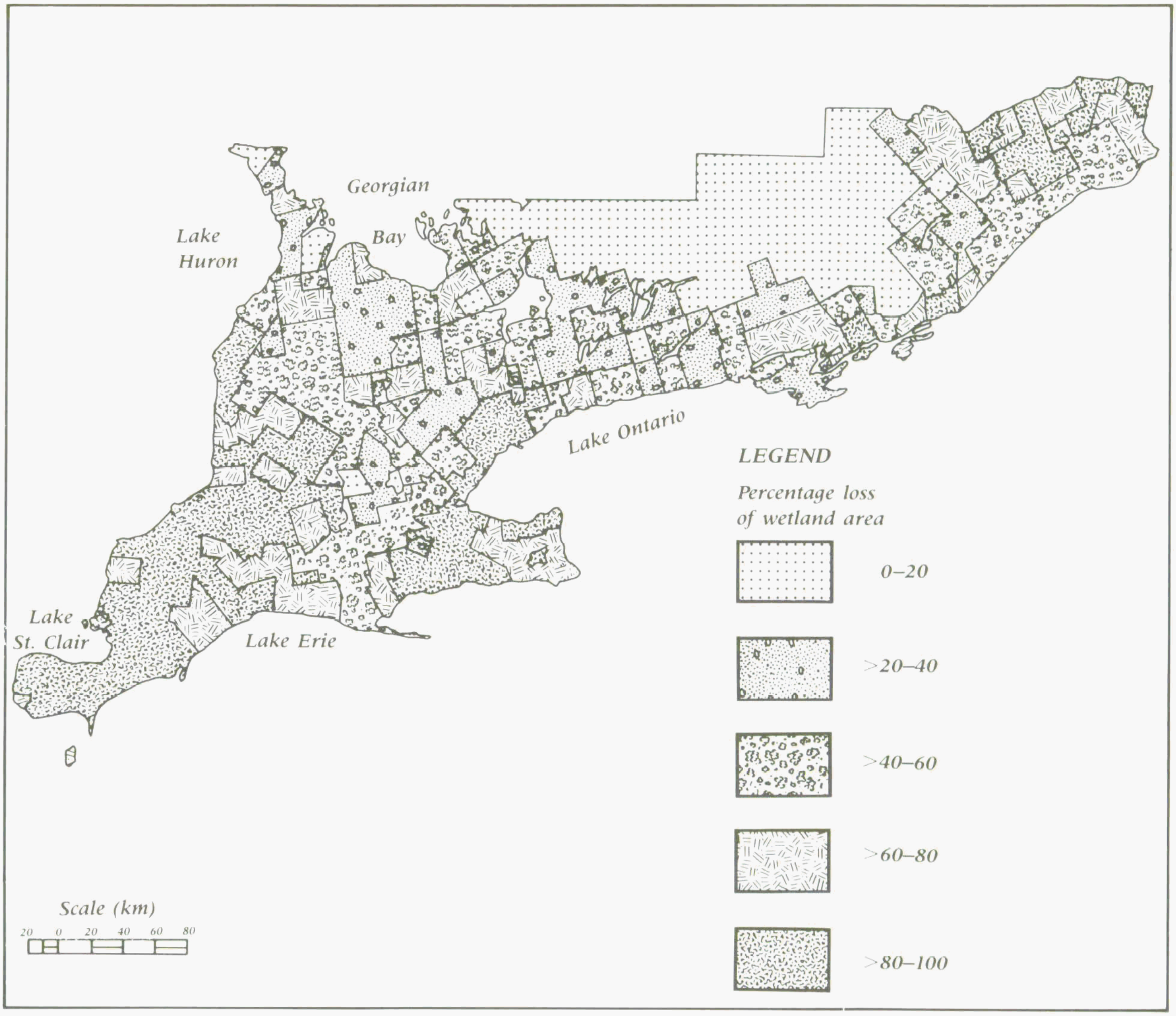
In recent years a number of studies have examined the impact of land use changes on wetlands in the eastern temperate area of Canada (Cox 1972; Rutherford 1979; Lemay 1980; McCullough 1981; Le Groupe Dryade 1980; Snell 1982, 1987). However, a dearth of knowledge and a lack of quantitative studies about patterns of land use changes still exist. In fact, as of 1983, less than 5% of all of southern Canada had been studied from this perspective (Lynch-Stewart 1983). In the Eastern Temperate Wetland Region, most of the studies to date have taken place in southern Ontario, along the shores of the St. Lawrence River, and in areas surrounding major urban centres.

Snell (1982, 1987) has estimated that over 1.4 million ha (61%) of southern Ontario's original wetlands have been lost since settlement times; agriculture is the main factor in this decline (Found *et al.* 1975; Laidlaw 1978; Reid and Keeping 1979; Bardecki 1981, 1982). In fact, agricultural reclamation continues to be the main reason for wetland loss in all of southern Canada. Bardecki (1981) concluded that 85% of wetlands altered in southern Ontario between 1966 and 1970 were converted to farmland. The most extreme loss in southern Ontario took place in the counties of Essex, Kent, and Lambton where 95, 93, and 81% respectively of the original wetland area were converted to other land uses. The percentage of original wetland loss in southern Ontario is shown in Figure 6–21.

There is considerably less information on wetland loss available for Quebec and the Maritimes than for southern Ontario. In Quebec, the greatest pressure from agriculture exists along the St. Lawrence River. In the St. Lawrence Estuary, 32% of the tidal marsh has been reclaimed for agriculture (Reed and Smith 1972). A report by Environment Canada (1986) includes data reporting an overall wetland loss of 7% along the St. Lawrence River shorelines from Cornwall to Quebec City from 1950 to 1978. The remaining wetlands are under considerable pressure for conversion to agricultural uses. In New Brunswick and the rest of Atlantic Canada, there is a long history of agricultural reclamation of tidal marshes (Lynch-Stewart 1983). Gartley (1982) calculated that there were over 11 000 ha of agricultural dikeland in New Brunswick at the time of settlement.

Originally, wetlands were converted to agricultural land because they were viewed as potentially prime farmland. Recently however, wetland drainage has often been the result of increased economic pressure to bring even marginal land under agricultural use. Federal and provincial governments have been criticized in recent years for accelerating the loss of wetlands by providing landowner incentives (e.g. subsidies, cost-sharing agreements, and tax incentives) to bring these marginal lands under agricultural production.

Urban and industrial development have also claimed a large amount of wetland area. Hence, wetlands near urban centres are often under greater pressure than wetlands in rural areas. Residential construction, harbour dredging, public utilities, and industrial expansion are the primary urban land uses encroaching on wetlands, as exemplified in a study of the Montreal area by Champagne and Melançon (1985). The wetlands of Lake Ontario have suffered rapid and severe



Source: Snell (1987).

Figure 6–21.
Loss of original wetland area, 1800–1982, southern Ontario.

losses due to industrial expansion (Lynch-Stewart 1983). McCullough (1981) estimated that most of the 42% loss of Lake Ontario's shoreline wetlands was attributable to urbanization.

The importance of wetlands in the St. Lawrence Lowlands for preservation of wildlife and concern for their loss have been acknowledged nationally (Lynch-Stewart 1983; Environment Canada 1986). The St. Lawrence riverine wetlands have been designated "prime wetlands" under the Canada Land Use Monitoring Program (Rump 1983). In Quebec, Le Groupe Dryade (1981) estimated that over 3 200 ha of wetlands had been lost because of urbanization along the St. Lawrence River between the Ontario border and Montreal. The extent of such wetland loss for the St. Lawrence River wetlands as a whole between 1950 and 1978 has been mapped (Le Groupe Dryade 1981) and evaluated in detail (Environment Canada 1986). The greatest losses in this area have been concentrated around Montreal.

In the Maritimes, coastal areas appear to be on the verge of undergoing greater pressure from industrial development projects. Expansion of port facilities and the development of large complexes of oil terminals and ancillary industries are examples of proposed developments which may impinge on existing wetlands.

Agricultural reclamation and industrial development continue to create significant loss of wetland area in the Eastern Temperate Wetland Region, but other human activities have also been responsible for wetland loss. These include energy-related developments (e.g. hydroelectric projects, peat extraction), recreational developments (e.g. lakefront cottages), and forestry.

Wetland Conservation Initiatives

Ontario

The Province of Ontario is in the process of developing a planning wetland policy. The initiative to undertake this process came from public and government concern about the future of wetlands in Ontario. In 1981 the Government of Ontario released a discussion paper entitled "Towards a Wetland Policy for Ontario" (Ontario Ministry of Natural Resources 1981) which was designed to solicit public input concerning wetland management. Of the many responses received, almost all recognized the need to protect at least some wetlands.

A further paper, "Guidelines for Wetlands Management in Ontario", was released in the spring of 1984 as a precursor to the planning policy statement (Ontario Ministry of Natural Resources 1984). These guidelines represent Ontario provincial concern for wetlands and wetland management. They also incorporate the public's concern for the wise management of wetlands with the recognition that other provincial and local interests—such as agriculture, housing, forestry, and recreation—must also receive consideration in land use planning.

To provide an objective base for many of the concerns which the guidelines address, the Ontario Wetland Evaluation System (discussed in a following section) was incorporated into the decision-making process advocated by the guidelines. This system, which is now being used by the Ontario Ministry of Natural Resources and other agencies, ranks wetlands on a point system according to their overall values and allows objective comparison of wetlands in different parts of southern Ontario. The evaluation system serves as a cornerstone for the guidelines by identifying valuable wetlands.

Although the evaluation system pertains only to the wetlands of southern Ontario, the guidelines encompass all of Ontario's wetlands, northern as well as southern. The guidelines are structured to take advantage of the decision-making process facilitated by the evaluation system for southern wetlands, but their principles also pertain to northern wetlands. The wetland guidelines were designed to be incorporated by municipalities into their municipal planning process. Ultimately, the guidelines will be revised according to input from Ontario's 843 municipalities and other government and public agencies and will be incorporated into the Ontario Planning Act as official government policy. The current estimate is that Ontario will have a wetland policy in 1988.

Federal interest in Ontario wetlands has been centred on the St. Lawrence River. The St. Lawrence Lowlands have been identified in the North American Waterfowl Management Plan as a high priority waterfowl staging and Black Duck area.

In 1985, the Canadian Wildlife Service of Environment Canada and the Ontario Ministry of Natural Resources initiated a cooperative study of St. Lawrence River wetlands. The objectives of this study were threefold: (1) to inventory and update site data for wetlands along the St. Lawrence River; (2) to document the status of these wetlands with respect to aquatic vegetation, waterfowl habitat, significant wildlife species, and waterfowl use; and (3) to identify issues affecting those wetlands that are of relevance to federal concerns. The Canadian Wildlife Service also conducted spring and fall surveys of migratory waterfowl use of the Ontario shorelines of the St. Lawrence River.

Southern Quebec

The Quebec Waterfowl Management Plan (Environment Canada and the Province of Quebec 1985) was formulated to provide for the management of migratory game-birds in Quebec and to identify possible approaches towards achieving this. This general plan provides a framework for the preparation of regional and provincial plans to conserve wetland habitat. The Quebec Wildlife Conservation and Development Act of 1986 has two elements with importance for wetland habitats: (1) the establishment of provincial wildlife reserves, and (2) the creation of a provincial wildlife habitat fund.

In 1986, the Government of Quebec announced that a new provincial lake and river shores policy would be implemented. This policy will have significant implications for wetland conservation along rivers and on the shores of lakes through land and shoreline management requirements. In particular, some of the vital areas along the St. Lawrence River will be afforded immediate protection. The Quebec Ministry of the Environment has developed this riverine habitats policy paper for public consultation. This proposed policy is directed to the protection and improvement of river and lake shores, in order to minimize shoreline degradation, reduce pollution, and reduce loss of wildlife habitat. Bands of varying width associated with each waterway and according to existing land uses are being defined through an interministerial cooperative program. In addition, many floodplain areas are already specially recognized through a federal–provincial mapping and protection agreement. The Quebec Ministry of the Environment as well as the Quebec Ministry of Recreation, Fish, and Game have pursued wetland studies for over 20 years in order to identify representative and critical sites. Thirteen provincial ecological reserves now exist. Most of these contain provincially representative wetland elements, while three (Point Heath, Île-aux-Sternes, and Micocoulier) are almost all wetlands.

Some degree of protection also results from the acquisition of land by government and private conservation groups. The Canadian Wildlife Service administers six National Wildlife Areas in Quebec (Figure 6–19), thus protecting 4 900 ha of habitat and many islands in the St. Lawrence Estuary. Four of these areas lie within the Eastern Temperate Wetland Region. The Quebec Ministry of Recreation, Fish, and Game also protects 9 700 ha of riparian land along the St. Lawrence and Ottawa rivers. Fourteen migratory bird sanctuaries have been established. In addition, wetlands in 16 provincial parks and in 31 wildlife reserves are directly protected within areas totalling over 77 000 km^2.

Southwestern New Brunswick

All wetlands over 0.25 ha in size in the maritime provinces have now been surveyed through the federal–provincial Wetland Protection Mapping and Designation Program led by the Canadian Wildlife Service of Environment Canada. This wetland inventory is assisting federal, provincial, and municipal planning agencies in making land use decisions regarding wetland areas and it is expected to lead towards a series of federal–provincial agreements for wetland conservation.

Wetland Evaluation Programs

The decline of wetland resources in Ontario prompted the Government of Ontario to initiate steps towards a wetland management policy in 1980. The first major components of this initiative centred on a cooperative federal–provincial inventory of the wetland resource and on development of an evaluation system. An inventory was completed by Environment Canada for all of southern Ontario (Snell 1982, 1987) and peat resources surveys in more northern portions of Ontario were completed (Riley 1983).

Development of a wetland evaluation system was initiated in 1980 by the Wildlife Branch of the Ontario Ministry of Natural Resources and the Canadian Wildlife Service of Environment Canada. From 1981 to 1983, preliminary versions of the Ontario Wetland Evaluation System were tested and modified. Glooschenko (1983) has discussed the evolution of this evaluation system. The current version (Environment Canada and the Ontario Ministry of Natural Resources 1984) has been in use for three complete field seasons.

The goal of the evaluation system is to rank wetlands so that the management strategies adopted for them are appropriate to their relative value. The evaluation intends neither to imply nor advocate the development or the protection of wetlands. Its role is purely objective and its main feature is that it quantifies wetland values in a manner which permits comparison of wetlands. In this way it can be used as a basis for making informed land use decisions. The primary use of the system, therefore, is as a planning tool which can be incorporated into government policy.

Ultimately, the evaluation system ranks wetlands into seven distinct classes, class 1 being the highest or most valuable and class 7 being the lowest or least valuable. The system classifies wetland values into four distinct components: biological, social, hydrological, and special features. Each component has a maximum of 250 points and each is weighted equally in the decision regarding the final ranking of a wetland. Ontario's provincial wetland guidelines give priority for protection to provincially significant wetlands (classes 1 and 2), and to those additional (class 3) wetlands identified by municipalities as significant and incorporated within their planning documents.

To the end of 1986, approximately 1 700 wetlands had been evaluated and identified on maps. Of a sample of 1 050 wetlands, 280 (26.7%) were classified as provincially significant (classes 1 and 2) and 218 (20.8%) as regionally significant (class 3). The locations of some of the significant wetlands across southern Ontario evaluated up to 1985 are shown in Figure 6–17.

Most of the wetlands in Ontario in classes 1 to 3 are dominated by marshes and swamps (Glooschenko *et al.* 1987b) (Table 6–20). Glooschenko (1985) investigated the evaluation scores of a selection of marshes and swamps and found that there were no significant differences between those for the biological, social, and special features components. However, a significant difference existed between marshes and swamps in their hydrological component scores. This was because most of the swamps evaluated are located inland and therefore scored higher by virtue of their location, not because they are swamps *per se*. Bog- and fen-dominated wetlands are rare, accounting for only 3% of the examined wetlands in classes 1 to 3. However, bogs were present as a subdominant type in 19 other welands and fens were present in 13 others. Nonetheless, they were markedly less common than swamps and marshes in southern Ontario.

Areas of southwestern New Brunswick are included in the coverage of the federal–provincial Wetland Protection Mapping and Designation Program implemented by Environment Canada. This program provides information on the classification, size, distribution, and value to wildlife and other resources of wetlands in all of New Brunswick, Nova Scotia, and Prince Edward Island. All areas in the maritime provinces have now been surveyed through this initiative which started in 1980 (Hudgins 1983). The inventory incorporates two earlier programs for evaluating marine and freshwater wetlands. The freshwater program was adapted from Golet (1972, 1973), while a marine classification and inventory was developed from regional pilot studies (Canadian Wildlife Service 1982). In addition, major peatland energy surveys in these provinces provide extensive data on inland bogs and fens.

The major features of the evaluation system covering the Maritimes include the identification of wetland classes and subclasses on the basis of dominant vegetation types, water depth and permanence, wetland size and hydrological location, types of surrounding habitat, and vegetation interspersion. The wetlands are evaluated by combining their classification with water chemistry and location relative to hydrology and surrounding habitat. Through the application of certain specifications and ranks, a numeric score is derived which reflects the value of the wetland to wildlife. The field data sheets used for the freshwater component of the inventory are coded for entry into a computerized data base (Canadian Wildlife Service 1982). This data base is now complete for Nova Scotia and Prince Edward Island.

The wetland evaluation system used in New Brunswick is based on a rating of the following 10 criteria: class richness, dominant class, size, subclass richness, site type, surrounding habitat, cover type, vegetation interspersion, hydrological juxtaposition, and water chemistry. Scores for all criteria are summed and a total wetland score is obtained; the final score represents the wetland's relative value to wildlife. The lowest possible score is 36 and the highest is 108.

Major differences between the Ontario and New Brunswick wetland evaluation systems lie in the criteria and the scoring systems used. The Ontario system evaluates four components (biological, social, hydrological, and special features) with equal weighting and does not aggregate scores. The New Brunswick system evaluates the physiographic location of wetlands taking into account hydrological considerations, while in Ontario there is much greater emphasis on such hydrological functions as flow stabilization and augmentation, as well as water quality improvement. There is also much more emphasis in Ontario on the presence of significant flora and fauna, and the resulting data base reflects this.

The end products of the inventory of wetlands in New Brunswick are a computer data base and a series of atlases. The wetland inventory of the maritime provinces is available to assist federal, provincial, municipal, and town planning agencies to develop wetland policies and will provide a data base for a wide variety of wetland research and management programs. Under federal–provincial agreements for wetland habitat protection, important wetlands could be designated for protection by both levels of government and neither level would finance activities which would alter the natural habitat. Thus, government as-

Table 6–20. Number of provincially and regionally significant wetlands in southern Ontario by class and location: 1983–1985 surveys

Location	*Number of wetlands*			
	Marsh	*Swamp*	*Bog*	*Fen*
Great Lakes shores	105	12	0	0
Inland areas	104	393	7	1

Source: Glooschenko *et al.* (1987b).

sistance for agricultural drainage, industrial installations, and sewage treatment plants would not be approved for designated wetlands. It is hoped that such federal–provincial agreements can be developed soon after completion of the whole inventory.

Extensive areas of Quebec have been inventoried through peat for energy programs, ecological land surveys, and wildlife habitat assessments, but no standardized provincial wetland survey has been developed. Several comprehensive classification systems have evolved, including Jaques and Hamel (1982). Additionally, a comprehensive provincial wetland evaluation system is not yet in use. However, a wide range of small sites have been evaluated with respect to protection for local, regional, and international interests. The majority of these evaluations have focused on vegetation, wildlife, and water quality.

Acknowledgements

The authors specially acknowledge A.N. Boissonneau for his contributions to preliminary drafts of this chapter. His significant contributions have led to better understanding of the ecology of wetlands in Ontario during his many years with the Ontario Ministry of Natural Resources (OMNR). The following individuals and agencies have contributed text, reviews, or suggestions which have assisted in the completion of this text: A. Smith, E. Hudgins, S. Wendt, E. Bottomley, D. Dennis, D. Lehoux, and J-L. Desgranges (Canadian Wildlife Service, Environment Canada), G. Massé, J-R. Mongeau, J. Dubé, S. Desjardins, and R. Sarrazin (Quebec Ministry of Recreation, Fish, and Game), P. Buteau (Quebec Ministry of Energy and Resources), A. Larouche (University of Montreal), C. Tessier (University of Quebec at Trois-Rivières), M. Brind'Amour and M. Doran (Laval University), D. Jaques (University of Quebec at Montreal), B. Gauthier (Quebec Ministry of the Environment), N. Roulet (York University), and C. Wedeles.

A contract with Le Groupe Dryade Limited by the Canada Committee on Ecological Land Classification (CCELC) Secretariat, Environment Canada, assisted in the acquisition of additional input to this chapter. This and review comments by C. Rubec, C. Tarnocai, H. Hirvonen, S. Zoltai, and E. Oswald were also compiled by the CCELC Secretariat. Chemical analyses used in various Ontario data sets in this chapter were conducted by the Ontario Tree Improvement and Forest Biomass Institute. D. Herman and E. Laan, OMNR, assisted in proofreading, and S. Taylor, OMNR, typed various drafts of this text. Several photographs in this chapter are courtesy of the Ontario Ministry of Natural Resources (Figure 6–5, A. Norman; Figures 6–6 and 6–10, D. Coulson; Figure 6–16, G. Allen; Figure 6–18, J. McCracken and D. Hussell). Figure 6–20 is courtesy of the Canadian Wildlife Service, Environment Canada, and Le Groupe Dryade Limited.

References

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals, 1951–1980. Volume 2: Temperature; Volume 3: Precipitation; Volume 4: Degree-days. Environment Canada. Downsview, Ontario.

AUCLAIR, A.N., A. BOUCHARD, AND J. PAJACZKOWSKI. 1973. Plant composition and species relations on the Huntingdon Marsh, Quebec. Canadian Journal of Botany 51:1231–1247.

BAILLARGEON, G. 1981. Zonation et modification de la composition de la flore vasculaire dans une région urbaine: la colline de Québec. Faculty of Agricultural and Nutritional Sciences, Laval University, Quebec, Quebec. 206 p.

BARDECKI, M.J. 1981. The role of agriculture in declining wetlands. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 64–73.

BARDECKI, M.J. 1982. The status of wetlands in southern Ontario. Wetlands 2:262–270.

BARKHOUSE, H.P. 1979. Breeding waterfowl in national wildlife areas—Atlantic region. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished.

BARRETT, H.B. 1977. Lore and legends of Long Point. Burns and MacEachern Limited. Don Mills, Ontario. pp. 229–234.

BAY, R.R. 1969. Runoff from small peatland watersheds. Journal of Hydrology 9:90–102.

BLANCHET, B. 1982. Les cédrières du Québec. Études écologiques No. 6. Forestry Ecology Laboratory, Laval University, Quebec, Quebec. 166 p.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 9–30.

BOTTOMLEY, E.J. 1986. Wetlands and waterfowl of the St. Lawrence River in Ontario: an initial baseline study. Draft report. Canadian Wildlife Service, Environment Canada, and Ontario Ministry of Natural Resources. Ottawa and Toronto, Ontario. 54 p.

BOURGET, A. 1973. Inventaire de la sauvagine le long du Saint-Laurent, Québec, printemps 1972. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec.

BRIND'AMOUR, M., AND V. LAVOIE. 1983. Évaluation de la dynamique et de la productivité nette de la végétation des marais intertidaux, région de Québec. Faculty of Agricultural and Nutritional Sciences, Laval University, Quebec, Quebec. 190 p.

BROWNELL, V.R. 1981. The small white lady's slipper (*Cypripedium candidum* Muhl. ex Wild.) in Canada: a status report. Wildlife Branch, Ontario Ministry of Natural Resources. Toronto, Ontario. Unpublished. 72 p.

CANADIAN WILDLIFE SERVICE. 1981. Harvest summary of ecological zones. Environment Canada. Ottawa, Ontario.

CANADIAN WILDLIFE SERVICE. 1982. Cooperative wetlands inventory in the Maritimes. *In* Proceedings, 46th Federal–Provincial Wildlife Conference. Ottawa, Ontario. pp. 13–16.

CANTIN, M.A., AND P. BLAIS. 1976. La végétation des Îles de Contrecöeur. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished.

CANTIN, M.A., A. BOURGET, G. CHAPDELAINE, AND W.G. ALLISTON. 1976. Distribution et écologie de la reproduction du Canard chipeau (*Anas strepera*) au Québec. Naturaliste canadien 103:469–481.

CANTIN, M.A., AND I. RINGUET. 1978. Les oiseaux des Îles de Contrecoeur. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished. 70 p.

CARTER, V., M.S. BEDINGER, R.P. NOVITZKI, AND W.O. WILSON. 1978. Water resources and wetlands. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. American Water Resöurces Association. Minneapolis, Minnesota. pp. 344–376.

CATLING, P.M., AND S.M. MCKAY. 1980. Halophytic plants in southern Ontario. Canadian Field Naturalist 94(3):248–258.

CHABOT, D., AND M. MAYNARD. 1978. Analyse pollinique d'une tourbière de la forêt de Beauséjour, comté de Lévis, Québec. Faculty of Forestry, Laval University, Quebec, Quebec. 57 p.

CHAMPAGNE, J., AND M. MELANÇON. 1985. Wetlands of the Montreal region. 1966–1981. Lands Directorate, Environment Canada. Working Paper No. 39. Ste-Foy, Quebec. 21 p. and map.

CHAPDELAINE, G., AND L.G. DE REPENTIGNY. 1975. Aménagement à Dundee: secteurs Therrien et Fraser. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished.

CHOATE, J.G. 1973. Wildlife resources of the Saint John River Basin, New Brunswick. Prepared by the New Brunswick Department of Natural Resources for the Saint John River Basin Board. Fredericton, New Brunswick.

COMTOIS, P. 1979. Histoire holocène du climat et de la végétation à Lanoraie, Québec. Faculty of Arts and Sciences, University of Montreal, Montreal, Quebec. 322 p.

COMTOIS, P. 1982. Histoire holocène du climat et de la végétation à Lanoraie, Québec. Canadian Journal of Earth Sciences 19:1938–1952.

COUILLARD, L., AND P. GRONDIN. 1986. La végétation des milieux humides du Québec. Les publications du Québec. Quebec Ministry of Environment. Quebec, Quebec. 376 p.

COUILLARD, L., P. GRONDIN, AND J. MILLET. 1985. Étude complémentaire de la végétation du lac Saint-Louis et du lac des Deux Montagnes, Archipel de Montréal: groupes écologiques de la plaine de débordement et de la zone aquatique, patrons d'inondations clés de végétation potentielle, et plans de gestion. Prepared by Le Groupe Dryade Limited for the Quebec Ministry of Recreation, Fish, and Game. Volumes 1–5.

COX, E.T. 1972. Estimates of cleared wetlands in southern Ontario. Wildlife Branch, Ontario Ministry of Natural Resources. Toronto, Ontario. Unpublished. 3 p.

DALE, H.J., AND D.W. HOFFMAN. 1969. Bogland ecosystem: some biogeographical units. Canadian Geographer 13:141–149.

DARVEAU, M., B. HOUDE, AND J-L. DESGRANGES. 1987. Étude des effets de l'acidification sur la faune aquatique du Canada. Volume 1: Phyto-écologie de l'habitat des oiseaux lacustres du Québec. Canadian Wildlife Service, Environment Canada. Report Series (at press). Ottawa, Ontario.

DENNIS, D.G. (personal communication). October 1986. Canadian Wildlife Service, Environment Canada. London, Ontario.

DENNIS, D.G., G.B. MCCULLOUGH, N.R. NORTH, AND R.K. ROSS. 1984. An updated assessment of migrant waterfowl use of the Ontario shorelines of the southern Great Lakes. *In* Waterfowl studies in Ontario, 1973–1981. S.G. Curtis, D.G. Dennis, and H. Boyd, editors. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 54. Ottawa, Ontario. pp. 37–42.

DENNIS, D.G., AND N.R. NORTH. 1984a. Waterfowl use of the Lake St. Clair marshes during migration in 1968–1969, 1976–1977, and 1982. *In* Waterfowl studies in Ontario, 1973–1981. S.G. Curtis, D.G. Dennis, and H. Boyd, editors. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 54. Ottawa, Ontario. pp. 43–52.

DENNIS, D.G., AND N.R. NORTH. 1984b. Waterfowl production of moraine areas in the vicinity of London, Ontario. *In* Waterfowl studies in Ontario, 1973–1981. S.G. Curtis, D.G. Dennis, and H. Boyd, editors. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 54. Ottawa, Ontario. pp. 14–20.

DE REPENTIGNY, L.G. 1982. Compilation des observations ornithologiques de la région de la réserve nationale de faune des Îles de Contrecoeur. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished.

DESGRANGES, J-L., AND M. DARVEAU. 1985. Effect of lake acidity and morphometry on the distribution of aquatic birds in southern Quebec. Holarctic Ecology 8:181–190.

DESGRANGES, J-L., AND B. HOUDE. 1987. Étude des effets de l'acidification sur la faune aquatique du Canada. Volume 2: Influence de l'acidité et d'autres paramètres environnementaux sur la distribution des oiseaux lacustres du Québec. Canadian Wildlife Service, Environment Canada. Report Series (at press). Ottawa, Ontario.

DORAN, M.A. 1981. Utilisation par la Grande Oie Blanche (*Anser caerulescens atlanticus*) de la végétation dans les marais intertidal de la réserve national de Cap Tourmente, Québec. M.Sc. thesis, Faculty of Forestry and Geodesy, Laval University, Quebec, Quebec. 142 p.

DOYON, D. 1975. Étude éco-dynamique de la végétation du comté de Lévis. Service de la défense des cultures. Quebec Ministry of Agriculture. Memoir No. 1. Quebec, Quebec. 428 p.

DUBOIS, J.M.M. 1974. Proposition des régions physiographiques pour les Cantons de l'Est: un apport à la classification de Bostock. University of Ottawa Geography Association. Géoscope 2:13–46.

DUCRUC, J.P., AND G. AUDET. 1984. Esquisse préliminaire des districts écologiques du Québec méridional (régions administratives 03 et 05). Quebec Ministry of the Environment. Contributions des services des inventaires ecologiques No. 7. Quebec, Quebec. 67 p.

DUNN, E.H., J. SIDERIUS, AND D.T. HUSSELL. 1981. Ontario heronry inventory—introduction. Long Point Bird Observatory, Long Point, Ontario.

ENVIRONMENT CANADA. 1986. Wetlands of the St. Lawrence River region. Lands Directorate, Environment Canada. Working Paper No. 45. Ottawa, Ontario. 29 p.

ENVIRONMENT CANADA AND THE ONTARIO MINISTRY OF NATURAL RESOURCES. 1984. An evaluation system for wetlands of Ontario south of the Precambrian Shield. Canada/Ontario Steering Committee on Wetland Evaluation, Environment Canada and Ontario Ministry of Natural Resources. Part I: Rationale and procedures, 72 p. Part II: Scoring, 21 p. Part III: Data record, 25 p. Part IV: Evaluation record, 6 p. 2nd edition. Toronto and Ottawa, Ontario.

ENVIRONMENT CANADA AND THE PROVINCE OF QUEBEC. 1985. Quebec Waterfowl Management Plan. Quebec Ministry of Recreation, Fish, and Game. Quebec, Quebec. 38 p.

FOUND, W.C., A.R. HILL, AND E.S. SPENCE. 1975. Economic and environmental impacts of land drainage in Ontario. Department of Geography, York University. Geographical Monograph No. 6. Downsview, Ontario. 175 p.

GARTLEY, C. 1982. Reclamation of dykeland for agricultural production in New Brunswick. Proceedings, 7th Annual Meeting, Canadian Land Reclamation Association. September 1982. Sydney, Nova Scotia. 13 p.

GAUTHIER, B. 1982. L'étagement des plantes vasculaires en milieu saumâtre, estuaire du Saint-Laurent. Naturaliste canadien 109:189–203.

GILBERT, G., R.G. HÉLIE, AND J.M. MONDOUX. 1985. Ecoregions and ecodistricts of Quebec. *In* Ecosystem sensitivity to acid precipitation for Quebec. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 20. Part A. Ottawa, Ontario. pp. 1–76.

GLOOSCHENKO, V. 1983. Development of an evaluation system for wetlands in southern Ontario. Wetlands 3:192–200.

GLOOSCHENKO, V. 1985. Characteristics of provincially significant wetlands as assessed by the Ontario evaluation system. *In* Coastal wetlands. H.H. Prince and F.M. D'Itri, editors. Lewis Publishers. Chelsea, Michigan. pp. 187–199.

GLOOSCHENKO, V., J.H. ARCHBOLD, AND J.M. WENINGER. 1987a. The importance of swamp wetland habitat in southern Ontario. *In* Proceedings, Wetlands/Peatlands '87 Symposium. August 23–27, 1987. Edmonton, Alberta. 8 p.

GLOOSCHENKO, V., J.H. ARCHBOLD, AND D. HERMAN. 1987b. The Ontario wetland evaluation system: replicability and bird habitat selection. *In* The ecology and management of wetlands. Proceedings, International Symposium on the Ecology and Management of Wetlands. D.D. Hook, editor. In press.

GOLET, F.C. 1972. Classification and evaluation of freshwater wetlands as wildlife habitats in the glaciated northeast. Ph.D. thesis, University of Massachusetts, Amherst, Massachusetts. 179 p.

GOLET, F.C. 1973. Classification and evaluation of freshwater wetlands as wildlife habitat in the glaciated northeast. *In* Proceedings, Northeast Fish and Wildlife Conference. Mount Snow, Vermont.

GUIMOND, A., P. GRONDIN, AND R. DUBUC. 1985. Développement d'une méthodologie de cartographie des tourbières par images satellite. Prepared by Le Groupe Dryade Limited for the Quebec Ministry of Energy and Resources. Quebec, Quebec. 58 p.

HALL, R.A. 1971. Land use and waterfowl habitat studies within the lower Saint John River Basin. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished.

HAYES, B.N. 1964. An ecological study of wet prairie on Harsen's Island, Michigan. Michigan Botanist 3:71–82.

HIRVONEN, H.E. 1984. The Atlantic region of Canada: an ecological perspective. Lands Directorate, Environment Canada. Dartmouth, Nova Scotia. 28 p.

HOUNSELL, R.G. 1985. Ecosystem classification mapping of the forested areas of Portobello Creek National Wildlife Area. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished. 10 p.

HUDGINS, E.J. 1983. Workbook for the initiation of the New Brunswick freshwater wetlands inventory. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished. 84 p.

HUIKARI, O. 1952. Suotyypion manaaritys maaja netsa talorurvua silmalla pitarm. Silvafan, F.E. VIV. Volume 75. pp. 1–22.

HUMMEL, M. 1981. Wetland wildlife values. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 27–32.

INGRAM, H.A.P. 1983. Hydrology. *In* Ecosystems of the world. Volume 4A. Mires: swamp, bog, fen, and moor. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 67–158.

JAQUES, D., AND C. HAMEL. 1982. Système de classification des terres humides du Québec. Laboratory for Aquatic Macrophyte Studies, Department of Biological Sciences, University of Quebec at Montreal, for the Wildlife Directorate, Quebec Ministry of Recreation, Fish, and Game. Quebec, Quebec. 131 p.

JEGLUM, J.K., A.N. BOISSONNEAU, AND V.F. HAAVISTO. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report 0-X-215. Sault Ste Marie, Ontario. 54 p.

JOYAL, R. 1970. Description de la tourbière à sphaignes, Mer Bleue près d'Ottawa. I: Végétation. Canadian Journal of Botany 48:1405–1418.

KADLEC, R.H. 1981. How natural wetlands treat wastewater. *In* Proceedings, Midwest Conference on Wetland Values and Management. R. Brandt, editor. St. Paul, Minnesota. pp. 241–254.

KEDDY, P.A., AND A.A. REZNICEK. 1985. Vegetation dynamics, buried seeds, and water level fluctuations on the shorelines of the Great Lakes. *In* Coastal wetlands. H.H. Prince and F.M. D'Itri, editors. Lewis Publishers. Chelsea, Michigan. pp. 33–58.

KUBURSI, A.A. 1981. The economic impact of wildlife-related expenditures in 1979. Econometrics Research Limited. Study commissioned by the Ontario Ministry of Natural Resources. Toronto, Ontario.

LACOURSIÈRE, E. 1969. Étude écologique de la végétation riparienne entre Sainte-Famille et la Pointe d'Argentenaye à l'Île d'Orléans. M.A. thesis, Faculty of Forestry and Geodesy, Laval University, Quebec, Quebec. 150 p.

LACOURSIÈRE, E., AND M.M. GRANDTNER. 1971. Contribution à l'étude écologique de la végétation riparienne de l'Île d'Orléans. Naturaliste canadien 98:443–459.

LACOURSIÈRE, E., AND M.M. GRANDTNER. 1972. Les groupements végétaux ripariens entre Sainte-Famille et la Pointe d'Argentenaye, Île d'Orléans, Québec. Naturaliste canadien 99:469–507.

LAIDLAW, S.A. 1978. A report concerned with the loss of wetlands in southern Ontario. Report prepared for Environmental Protection Service, Environment Canada. Toronto, Ontario. 118 p.

LAMOUREUX, J.P. 1969. Proposition: La baie Lavallière, une réserve nationale de la faune. Canadian Wildlife Service, Canada Department of Indian and Northern Affairs. Quebec, Quebec. 43 p.

LAPERLE, M. 1969a. A waterfowl ecological nesting study at Îles-de-la-Paix, Lake St. Louis, Quebec. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished.

LAPERLE, M. 1969b. Îles-de-la-Paix National Wildlife Area management plan. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished.

LAROUCHE, A. 1980. Histoire post-glaciaire comparée de la végétation à Sainte-Foy et au Mont des Éboulements, Québec par l'analyse macrofossile et l'analyse pollinique. Faculty of Forestry, Laval University, Quebec, Quebec. 117 p.

LE GROUPE DRYADE. 1980. Habitats propices aux oiseaux migrateurs le long des rives de la Rivière Outaouais, de la Rivière Richelieu, du Fleuve Saint-Laurent, de l'Estuaire du Saint-Laurent, de la Côte Nord du Golfe du Saint-Laurent, de la Péninsule gaspésienne, des Îles-de-la-Madeleine. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished. 65 p. and atlas of maps at 1:20 000.

LE GROUPE DRYADE. 1981. Habitats propices aux oiseaux migrateurs. Analyse des pertes de végétation riveraine de long du Saint-Laurent, entre Cornwall et Matane (1945–1960, 1960–1976). Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished. 65 p.

LEHOUX, D., A. BOURET, P. DUPUIS, AND J. ROSA. 1985. La sauvagine dans le système du Saint-Laurent. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. 76 p. and appendices.

LEMAY, M.H. 1980. Assessment of the effects of urbanization as a basis for the management of the waterfront marshes between Toronto and Oshawa, Ontario. M.A. thesis, University of Waterloo, Waterloo, Ontario. Unpublished. 280 p.

LEMIEUX, S. 1978. Les oiseaux de la Réserve nationale de faune du Cap Tourmente, Québec. Naturaliste canadien 105:177–193.

LÉVESQUE, M.P., P. RICHARD, AND H. DINEL. 1978. Pollen and micromorphological analysis of two peats in southwestern Quebec. Canadian Journal of Soil Science 58(4):525–528.

LYNCH-STEWART, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. Ottawa, Ontario. 115 p.

MATHUR, S.P., M.P. LÉVESQUE, AND P. RICHARD. 1982. The establishment of synchrony between subsurface layers and estimation of overall subsidence of cultivated organic soils by a palynological method. Canadian Journal of Soil Science 62:427–431.

MCCULLOUGH, G.B. 1981. Wetland losses in Lake St. Clair and Lake Ontario. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 81–89.

MCKEATING, G. 1983. Management plan—Long Point National Wildlife Area. Canadian Wildlife Service, Environment Canada. London, Ontario. 72 p.

METRAS, L. 1985. Migratory birds killed in Canada during the 1983 season. Canadian Wildlife Service, Environment Canada. Progress Notes No. 154. Ottawa, Ontario. 39 p.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

OBERTS, G.L. 1981. Impact of wetlands on watershed water quality. *In* Proceedings, Midwest Conference on Wetland Values and Management. R. Brandt, editor. St. Paul, Minnesota. pp. 213–227.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1981. Towards a wetland policy for Ontario—discussion paper. Queen's Park, Toronto, Ontario. 15 p.

ONTARIO MINISTRY OF NATURAL RESOURCES. 1984. Guidelines for wetlands management in Ontario. Queen's Park, Toronto, Ontario. 3 p.

OUELLET, H. 1974. Les oiseaux des collines monterégiennes et de la région de Montréal, Canada. Publications in Zoology No. 5. National Museums of Canada. Ottawa, Ontario.

PAGEAU, G., Y. GRAVEL, AND C. LÉVESQUE. 1971. The icthyofauna and flora of Lake St. Louis on the St. Lawrence River near Montreal, Quebec: general features and recent changes. *In* Proceedings, 14th Conference on Great Lakes Research. Toronto, Ontario. pp. 79–89.

PAGEAU, G., AND C. LÉVESQUE. 1970. Influence respective des eaux du Saint-Laurent et de l'Outaouais sur les poissons et les plantes du Lac Saint-Louis. *In* Travaux en cours en 1965. Wildlife Service, Quebec Ministry of Recreation, Fish, and Game. pp. 1–21.

PALA, S., AND A. BOISSONNEAU. 1985. Remote sensing inventory of peatlands, Kingston–Belleville. Centre for Remote Sensing, Ontario Ministry of Natural Resources. Toronto, Ontario.

PATTER, M.V., AND S. HILTS. 1985. Some important wetlands of Ontario south of the Precambrian Shield. Federation of Ontario Naturalists. Don Mills, Ontario. 103 p.

PRASSAD, R. 1961. The hydrology of a swamp near Guelph, Ontario. M.Sc. thesis, University of Toronto, Toronto, Ontario. 35 p.

RAI, R.K. 1962. Relationship of groundwater levels to streamflow from a swamp. M.Sc. thesis, University of Toronto, Toronto, Ontario.

REED, A., AND A.D. SMITH. 1972. Man and waterfowl in tidal shorelines of eastern Canada. *In* Proceedings, Coastal Zone Seminar. March 21–23, 1972. Bedford Institute. Dartmouth, Nova Scotia.

REID, R., AND D. KEEPING. 1979. Wetlands in southern Ontario: conservation authority actions and attitudes. Report prepared for the Federation of Ontario Naturalists. Don Mills, Ontario. 8 p.

RICHARD, P. 1971. Two pollen diagrams from the Quebec City area, Canada. Pollen et Spores 13(4):523–529.

RICHARD, P. 1973. Histoire postglaciaire de la végétation dans la région de Saint-Raymond de Portneuf, telle que révélée par l'analyse pollinique d'une tourbière. Naturaliste canadien 100:561–575.

RICHARD, P. 1977. Histoire post-wisconsinienne de la végétation du Québec méridional par l'analyse pollinique. Service de la recherche, Direction générale des forêts, Quebec Ministry of Lands and Forests. Quebec, Quebec. Volume 1, 312 p., Volume 2, 142 p.

RICHARD, P. 1978. Histoire tardiglaciaire et postglaciaire de la végétation au mont Shefford, Québec. Geographie physique et Quaternaire 32(1):81–93.

RILEY, J. 1983. Peatland inventory project. Geological Survey, Ontario Ministry of Natural Resources. Miscellaneous Paper No. 119. Toronto, Ontario.

RINGUET, I., AND L.J. DE REPENTIGNY. 1982. Les réserves nationales de faune au Québec. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec.

ROSS, R.K. 1984. Migrant waterfowl use of major shorelines of eastern Ontario. *In* Waterfowl studies in Ontario, 1973–1981. S.G. Curtis, D.G. Dennis, and H. Boyd, editors. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 54. Ottawa, Ontario. pp. 53–62.

ROULET, N. 1985. The hydrological response of wetlands in southern Ontario. University of Toronto, Toronto, Ontario. Unpublished.

RUMP, P.C. 1983. Land use monitoring in Canada. *In* Proceedings, International Conference on Renewable Resources Inventories for Monitoring Changes and Trends. Corvallis, Oregon. 4 p.

RUTHERFORD, L.A. 1979. The decline of wetlands in southern Ontario. B.E.S. thesis, University of Waterloo, Waterloo, Ontario. 68 p.

SNELL, E.A. 1982. An approach to mapping the wetlands of southern Ontario. *In* Proceedings, Preconference Session, Ontario Wetland Conference. M.J. Bardecki, editor. Department of Applied Geography, Ryerson Polytechnical Institute. Occasional Paper. Toronto, Ontario. pp. 1–26.

SNELL, E.A. 1987. Wetland distribution and conversion in southern Ontario. Inland Waters/ Lands Directorate, Environment Canada. Working Paper No. 48 (at press). Ottawa, Ontario.

TARNOCAI, C. (personal communication). February 1986. Land Resource Research Centre, Agriculture Canada. Ottawa, Ontario.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–38.

TAYLOR, C.H. 1982. The effect on storm runoff response of seasonal variations in contributing zones in small watersheds. Nordic Hydrology 13:165–182.

TAYLOR, C.H., AND D.C. PIERSON. 1985. The effect of a small wetland on runoff response during spring snowmelt. Atmospheric Oceanography 23:137–154.

TESSIER, C., A. MAIRE, AND A. AUBIN. 1981. Étude de la végétation des zones riveraines de l'archipel des Cent-Îles du fleuve Saint-Laurent (Québec). Canadian Journal of Botany 59(8):1526–1536.

VERRY, E.S., AND D.H. BOELTER. 1978. The influence of bogs on the distribution of streamflow by small bog–upland catchments. *In* Proceedings, Hydrology of Marsh-ridden Areas, UNESCO Symposium. UNESCO Publication No. 105. New York, New York. pp. 469–478.

VREEKEN, W.J. 1981. Distribution and chronology of freshwater marls between Kingston and Belleville, Ontario. Canadian Journal of Earth Sciences 18:1228–1239.

WHITLEY, H.R. 1975. The origins and chemical composition of streamflow in Blue Spring Creek, Ontario. Ph.D. thesis, University of Guelph, Guelph, Ontario.

WHITLEY, H.R., AND R. IRWIN. 1986. The hydrological response of wetlands in southern Ontario. Paper submitted to Canadian Water Resources Journal.

WHITMAN, W. 1968. Proposed Portobello Creek National Wildlife Area, Sunbury County, New Brunswick. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished.

WILE, J., G. PALMATEER, AND G. MILLER. 1981. Use of artificial wetlands for wastewater treatment. *In* Proceedings, Midwest Conference on Wetland Values and Management. R. Brandt, editor. St. Paul, Minnesota. pp. 255–272.

WOO, M-K., AND J. VALVERDE. 1981. Summer streamflow and water level in a mid-latitude forested swamp. Forest Science 27:177–189.

WRIGHT, B.S. 1967. Waterfowl breeding ground survey, Saint John River Estuary, New Brunswick. Northeastern Wildlife Station. Fredericton, New Brunswick. 6 p.

ZOLTAI, S.C. 1978. A portable sampler for perennially frozen stone-free soils. Canadian Journal of Soil Science 58:521–523.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

7 Wetlands of Atlantic Canada

E.D. Wells
H.E. Hirvonen

Contributors:

Salt Marshes in Atlantic Canada
D.B. Scott
K.D. MacKinnon
F.S. Medioli

Atlantic Freshwater Marshes
R.I. Goudie
E. Hudgins
A.D. Smith

Atlantic Wetland Values
D.G. Keys
A.R. Anderson

Wetlands of Atlantic Canada

The wetlands of Atlantic Canada occur throughout the nation's five most eastern provinces. These wetlands are predominantly peatland bogs and fens, and freshwater or coastal salt marshes. In this chapter, descriptions of the ecology and forms of wetlands in the five Atlantic wetland regions and their associated subregions are presented, with a discussion of their values and utilization.

Environmental Setting

Physiography

The majority of Atlantic Canada comprises a land mass of 563 500 km^2 divided among Labrador (53%), Newfoundland (22%), New Brunswick (14%), Nova Scotia (10%), and Prince Edward Island (1%). The Côte-Nord area of Quebec also encompasses several of the Atlantic wetland subregions considered in this chapter. The region extends from about latitude 43°20′ N in Nova Scotia to north of latitude 60°N at Cape Chidley in Labrador. It is characterized by coastal plains, rolling plateaus, and rugged mountains that rise in elevation to over 1 600 m above sea level (ASL), as well as 26 500 km of segmented and often rugged coastline.

The area is one of the most climatically, topographically, and ecologically diverse in all of Canada. The cultivated apple orchards of the Annapolis Valley in Nova Scotia contrast sharply with the exposed and treeless terrain of much of Labrador; similarly, the coastal cliffs and open windswept barrens of much of southern Newfoundland provide a sharp contrast to the beaches and sand dunes of Prince Edward Island (Hirvonen 1984).

Nova Scotia is an elevated and eroded plain that dips below the Atlantic Ocean in the south and rises to northern Cape Breton and southern New Brunswick. It is flat, rocky, and poorly drained along the coast, becoming increasingly irregular and hilly inland (Roland and Smith 1969). Locally, marine deposits and underlying limestone bedrock influence the richness of soils in northern Nova Scotia and some areas of Cape Breton Island. An extensive lowland connects Nova Scotia and New Brunswick, where thousands of hectares of peatlands, cattail marshes, and abandoned diked and ditched lands form the Tantramar Marshes.

Much of the terrain of New Brunswick is more rugged than that of Nova Scotia and therefore rapid drainage limits the potential for wetland development. The north–central part of the province is a large, rough, upland area with elevations up to 900 m. Other rugged areas occupy west–central New Brunswick along the upper Miramichi and Tobique rivers and the Southern Upland. In contrast, eastern New Brunswick is characterized by generally flat terrain, with large tracts of land being poorly drained. Bog development is extensive. These areas are dominated by glacial moraine and marine deposits that overlie flat-lying sedimentary bedrock.

Prince Edward Island has undulating topography with generally low relief. The bedrock of the Island is sandstone, and the glacial deposits and soils subsequently derived from this sandstone are of a loam to sandy loam texture. Due to iron compounds in the parent material, the derived soils are characteristically red in colour. The best-developed sand dune and beach systems in Atlantic Canada occur along the northern shores of the Island and extend along the Northumberland shore of New Brunswick.

Much of Newfoundland, as a result of long periods of glacial and climatic erosion, consists of peneplains characterized by relatively low relief. High points throughout the Island coincide with resistant granitic bedrock types, as other bedrock formations have been eroded through time. Major valleys and lakes occur along fault lines. Glacial erosion has created a rugged coastline of fiords and steep-sided hills. Drowned valleys such as Fortune, Conception, and Trinity bays attain depths greater than 300 m below sea level and are characterized by steep walls 300–600 m high. Along the Northern Peninsula, land-locked, freshwater fiords have been created by the uplifting of coastal marine sediments as glacial ice receded. Frost-shattered colluvial deposits cover much of the adjacent Long Range Mountains, whereas shallow morainal deposits characterize much of the remainder of the Island. In contrast, the valleys of western Newfoundland consist of deep, glacio-fluvial terraces flanked by deep moraines. Extensive lacustrine deposits are also present. As a result of the good soils which have developed on these deposits, the Humber Valley within this area contains some of the best farmland in the province (Hirvonen 1984).

The underlying geology of Labrador, and extending into eastern Quebec, is essentially a Precambrian plateau, part of the Canadian Shield modified by uplift, folding, glaciation, and erosion. Mountain uplift is prominent in the northeast where the Kaumajet, Kiglapait, and Torngat mountains rise from sea level to heights of 1 500 m. The Benedict and Mealy mountains form the other major concentrations of mountainous terrain. The coastline is heavily indented with many barren islands and fiords extending several kilometres inland. Hamilton Inlet, the longest such inlet, is 245 km long. Intrusive rocks, composed mainly of acidic granites and allied rocks, dominate the bedrock geology. The Labrador trough of western Labrador contains the largest concentration of sedimentary bedrock. This formation is characterized by iron-rich, red soils.

The soils of Atlantic Canada are characterized by Podzols. These soils are acid and generally coarse-textured, and leaching of soil nutrients is common. According to the Canadian system of soil classification (Canada Soil Survey Committee 1978), most of the Podzols are considered as either Humo-Ferric or Ferro-Humic Podzols. Hardpans (generally within 50 cm of the surface), developed from the cementation of leached organic carbon (C), iron (Fe), and aluminum (Al), are common. This condition leads in time to poor drainage conditions and swamp and bog development. Major associated soils include: Dystric Brunisols, which often develop on coarse-textured outwash deposits throughout the area; Gleysols, characteristic of poorly drained mineral soils; Organics, which develop as bogs and other organic wetlands; and Luvisols, developed on fine-textured marine and lacustrine deposits.

Palsa bogs and fens, which are peatlands with permafrost, are scattered throughout Labrador with large concentrations occurring within coastal areas. Podzolization is the main soil-forming process south of the continuous permafrost zone. Sometimes, a hardpan forms within a metre or so of the surface. This impervious layer impedes drainage and allows for the development of wetlands, even though the soil may be coarse-textured and permeable above and below this layer. In places, such as along the Churchill River and Cape Porcupine between Sandwich and Groswater bays, hardpans are over a metre thick—a fact that distinguishes the Labrador Podzols from normal hardpan development in Podzolic soils across the country (Hirvonen 1984).

The minimal soil development that does occur in northern Labrador forms under cryoturbation or frost churning. These Cryosols are soils that contain permafrost. They are predominant north of the tree line and extend into boreal forest conditions in some organic materials. Cryosols may be present in mineral soil as far south as the upper elevations of the Mealy Mountains in Labrador or the Long Range Mountains of the Northern Peninsula in Newfoundland.

Except for the soils derived from limestone and serpentine bedrock along the west coast, the soils of insular Newfoundland are acid. Podzolic and Organic soils are predominant. Because of the subdued topography, a large portion of the Podzols is imperfectly to poorly drained.

Climate

The Atlantic Ocean and associated waters have a profound influence on the climate and consequently the ecology of Atlantic Canada. Coastal areas are subject to strong modifications by ocean waters. Frost-free periods in these areas may approach 200 days, whereas in inland areas of New Brunswick and Labrador this period is approximately 40–50 days. Similarly, coastal areas may have annual precipitation of 2 000 mm. This total generally decreases inland and in the more northerly latitudes. The Cape Chidley area of Labrador, for example, averages 500 mm of precipitation annually.

Seasonal temperatures typically reflect the maritime influence on regional climate. Summers, with local exceptions, are warm but not hot, with mean daily temperatures of 18°C. In exposed locales and in Labrador, the average is somewhat lower. Mean daily winter temperatures are more variable. Coastal areas of the Maritimes and Newfoundland have mild temperatures, averaging from − 2° to − 5°C. Inland temperatures may vary from − 10°C in sheltered areas to − 24°C or lower in exposed plateau and mountain areas. Permafrost occurs sporadically throughout Labrador and is continuous in the northern plateau areas. The tree line extends to Okak Bay in northern Labrador, although coastal barrens are common along much of the coastline of Newfoundland and Labrador.

Atlantic Wetland Regions

Wetlands form a major component of the landscape of Atlantic Canada. Deep and sometimes extensive bogs occur throughout much of northeastern New Brunswick and parts of southwestern Nova Scotia. In Newfoundland and Labrador, both bogs and fens are abundant. Salt marshes occur, sometimes extensively, along the coast of the Bay of Fundy and Northumberland Strait, as well as along the Atlantic coast of Nova Scotia. Freshwater marshes have developed along rivers and lakes throughout the area, but are most abundant along the Saint John River and in the lowlands of the Sackville–Amherst area.

Five wetland regions, including 10 wetland subregions, have been identified for most of Atlantic Canada (Figure 7–1, Table 7–1) (National Wetlands Working Group 1986). The wetland regions covering the majority of Atlantic Canada are the Atlantic Boreal (BA), subdivided into the Acadian (BAa), Coastal (BAc), Eastern (BAe), Gulf (BAg), Interior (BAi), Maritime (BAm), Northern (BAn), and Oceanic (BAo) Wetland Subregions; the Atlantic Subarctic (SA), subdivided into the Coastal (SAc) and Oceanic (SAo) Wetland Subregions; and the Eastern Mountain (ME) and Atlantic Oceanic (OA) Wetland Regions. Portions of the Eastern Temperate Wetland Region (TE) cover western New Brunswick as discussed in Chapter 6. The northern tip of Labrador lies within the Low Arctic Wetland Region (AL) discussed in Chapter 2. Divisions of the subarctic, boreal, oceanic, and temperate wetland regions are based mainly on continental and/or global differences in climate; this has resulted in the recognition of distinct Atlantic wetland regions that may be attributable to these climatic features. The delineation of the Eastern Mountain Wetland Region is determined mainly from topographic features. Identification of the wetland subregions is based mainly on local variations of climate, topography, geology, elevation, and proximity to coastal areas.

The development of wetlands is controlled by a combination of biotic and abiotic factors. Freshwater wetlands are especially sensitive to hydrological conditions in the early stages of development, but in the later stages are controlled more by climatic factors. Thus, the boundaries of many of the wetland regions and subregions closely follow the abundance and distribution of peatlands. Salt marsh development, however, is controlled mainly by tidal fluctuations and the subsequent flushing of nutrients into and out of the system. In this chapter, the major wetland classes that occur in Atlantic Canada—bog, fen, and freshwater and salt marshes—and the processes and factors responsible for their development are described in detail. In addition, the economic and recreational values of these wetlands are discussed.

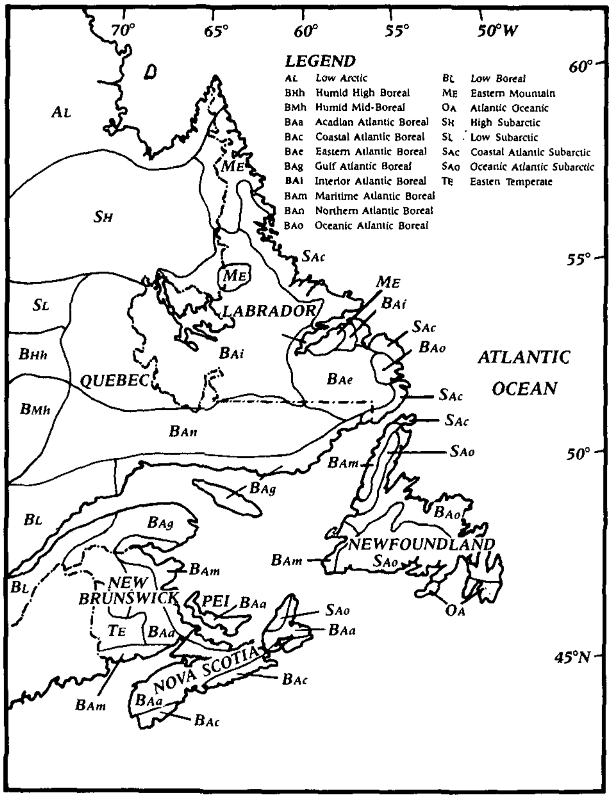


Figure 7–1.
The wetland regions and subregions of Atlantic Canada.

Atlantic Peatlands

Peatlands are common throughout most of Newfoundland and Labrador, eastern and southern New Brunswick, and southwestern Nova Scotia. Their extent and volume in Atlantic Canada have recently been estimated at 6 737 200 ha comprising about 264 billion cubic metres of peat (Table 7–2). The total area of peatlands in this region constitutes about 6% of the 111 328 000 ha of the peatlands that occur throughout the boreal and subarctic wetland regions of Canada (Tarnocai 1984).

During the past 10 years, there has been a renewed interest in the potential of peatlands as a result of rapidly increasing oil prices and the uncertainty of future sources of energy. Inventories of horticultural and fuel peats have been completed for the Island of Newfoundland (Northland Associates Ltd. 1978, 1979, 1980, 1981, 1982, 1984), for Nova Scotia (Anderson and Broughm, in preparation), for New Brunswick (Keys and Henderson, in preparation), and for Prince Edward Island (Graham and Associates Ltd. 1974). Incomplete inventories cover portions of the Côte-Nord area in Quebec (Simard 1976; Buteau 1984).

Phytosociological, morphological, and ecological classifications have also been completed for peatlands within Newfoundland and Labrador and Quebec (Pollett 1972a, 1972b; Wells 1981; Pollett and Wells 1980; Pollett and Bridgewater 1973; Wells and Pollett 1983; Gauthier 1981;

Table 7–1. Characteristic features of the wetland regions and subregions of Atlantic Canada

Wetland regions/ subregions	*Characteristic features*
BA	*ATLANTIC BOREAL*—Maritime climate with cold winters, cool summers, and frequent fog. Precipitation varies from 950–1 500 mm annually.
BAa	*ACADIAN ATLANTIC BOREAL*—Domed bogs (5–8 m deep) and black spruce-, tamarack-, and red maple-dominated basin swamps are common. Salt marshes occur in the Bay of Fundy. Fens are rare.
BAc	*COASTAL ATLANTIC BOREAL*—Characteristic wetlands are domed bogs, stream and slope fens, and salt marshes. Peat depths vary from 5 m in bogs to less than 2 m in fens.
BAe	*EASTERN ATLANTIC BOREAL*—Extensive areas of string bogs and Atlantic ribbed fens; average peat depth is 1.5 m.
BAg	*GULF ATLANTIC BOREAL*—Wetlands uncommon; locally, basin swamps (approximately 2 m deep) characterized by black spruce, cedar, or black ash.
BAi	*INTERIOR ATLANTIC BOREAL*—Atlantic ribbed fens and string bogs abundant; shallow (less than 1 m) basin bogs and slope fens occur in upland areas.
BAm	*MARITIME ATLANTIC BOREAL*—Domed and Atlantic plateau bogs, 7–10 m deep, occur in the Maritimes; Atlantic plateau bogs, 2–4 m deep, and slope fens occur in western Newfoundland.
BAn	*NORTHERN ATLANTIC BOREAL*—String bogs and Atlantic ribbed fens, 1–2 m deep, are most common; scattered occurrences of domed and basin bogs, and basin swamps.
BAo	*OCEANIC ATLANTIC BOREAL*—Domed bogs and string bogs abundant in Labrador; domed bogs, slope bogs, and slope fens common in Newfoundland.
ME	*EASTERN MOUNTAIN*—Upland areas (hills and mountains) with very cold winters and cool summers; dominated by shallow (0.2–1.5 m) slope and Atlantic ribbed fens.
OA	*ATLANTIC OCEANIC*—Cold winters and cool summers with annual precipitation of about 1 600 mm. Extensive areas of blanket bogs (1.5–2.5 m deep), slope bogs, and some slope fens.
SA	*ATLANTIC SUBARCTIC*—Cold winters, cool summers, and annual precipitation of about 1 200 mm.
SAc	*COASTAL ATLANTIC SUBARCTIC*—Atlantic plateau bogs dominant. Palsa fens and/or palsa bogs occur in Labrador. Peat mound bogs more common on Atlantic plateau bogs in northern Newfoundland. Extensive areas of exposed and treeless terrain.
SAo	*OCEANIC ATLANTIC SUBARCTIC*—Slope bogs and domed bogs very common; extensive complexes of slope bogs, slope fens, and Atlantic ribbed fens occur at higher elevations. Peat depths vary from 0.5–1.5 m in Atlantic ribbed fens to 1.0–2.0 m in slope and basin bogs.
TE	*EASTERN TEMPERATE*—Cold winters and warm summers. Hardwood (maple, black ash) basin and stream swamps and shore and stream marshes are common in southwestern New Brunswick. Bogs are small and scattered.

Dumont and Gauthier 1982; Guimond *et al.* 1983; Gerardin *et al.* 1984). Since these classifications, with few exceptions, can be applied to peatlands throughout Atlantic Canada, their features are briefly reviewed in this section. The various processes and factors responsible for the development of peatlands are also discussed.

Bog versus Fen in Atlantic Canada

Although the concepts of bog and fen are generally understood and accepted throughout the world, the definition and classification of both ecosystems are sometimes difficult. The distinctive features of each class, such as morphology, physiognomy, floristics, and nutrient status, are not always interpreted and applied uniformly. Classification systems based on any of these features may also have limited application outside the geographic region or country for which they were developed. Thus, this discussion of the differences between bog and fen ecosystems in Atlantic Canada will facilitate an understanding of the distribution, ecology, and floristics of these peatlands.

Bogs and fens may form in the same manner through the annual growth and accumulation of vegetation remains on poorly draining soils (Figure 7–2). However, bogs are nutrient-poor ("ombrotrophic"), receiving their nutrition solely from atmospheric sources (e.g. precipitation and atmospheric dust). Fens also receive nutrients from atmospheric sources but they are nutrient-rich or "minerotrophic": they receive additional nutrients via seepage waters from adjacent or surrounding upland soils. The dominant vegetation of bogs consists of *Sphagnum* mosses, dwarf shrubs, and lichens, whereas that of fens consists mainly of sedges and grasses with some *Sphagnum* mosses.

Table 7–2. Areas and volumes of peatlands in Atlantic Canada

Province	No. of deposits: Known	No. of deposits: Surveyed	Total area (ha)	Surveyed area (ha)	In situ volume ($m^3 \times 10^9$)	Peat type (% of volume): Horticultural	Peat type (% of volume): Fuel
New Brunswick[a]	1 050	817	140 000	133 000	2.4[g]	62[g]	38[g]
Nova Scotia[b]	n/a	267	162 000	33 000	4.4[h]	59[h]	41[h]
Prince Edward Island	25[d]	16[d]	6 337[c]	740[d]	0.01[d,g]	n/a	n/a
Newfoundland–Labrador[e]	n/a	n/a	6 429 000	n/a	257.2	—	—
Newfoundland (island only)[f]	6 771	n/a	1 115 000	n/a	15.3	45	55
Total			6 737 300		264.0		

n/a = not available.
[a]Keys and Henderson (in preparation).
[b]Anderson and Broughm (in preparation).
[c]MacDougall, Veer, and Wilson (in press).
[d]Graham and Associates (1974).
[e]Tarnocai (1984).
[f]Northland Associates Limited (1978, 1979, 1980, 1981, 1982, 1984).
[g]Volumes calculated for surveyed deposits.
[h]Volumes calculated for surveyed deposits and extrapolated for total area.

In most instances, bogs and fens can be easily distinguished from one another on the basis of nutrient parameters and vegetational features. An example of selected parameters used to distinguish a bog from a fen in Newfoundland is presented in Table 7–3. However, the nutritional and ecological amplitude of certain species may not remain constant throughout the range of forms of each peatland class. For example, the floristic composition and chemical characteristics of bogs in oceanic areas often vary from those in continental areas because of increased precipitation and added nutrient input from sea spray. Similarly, many shallow sloping bogs contain small areas of nutrient-enriched seepage water and, consequently, minerotrophic fen species. These peatlands are transitional and could be classified as either nutrient-poor fens or nutrient-rich bogs.

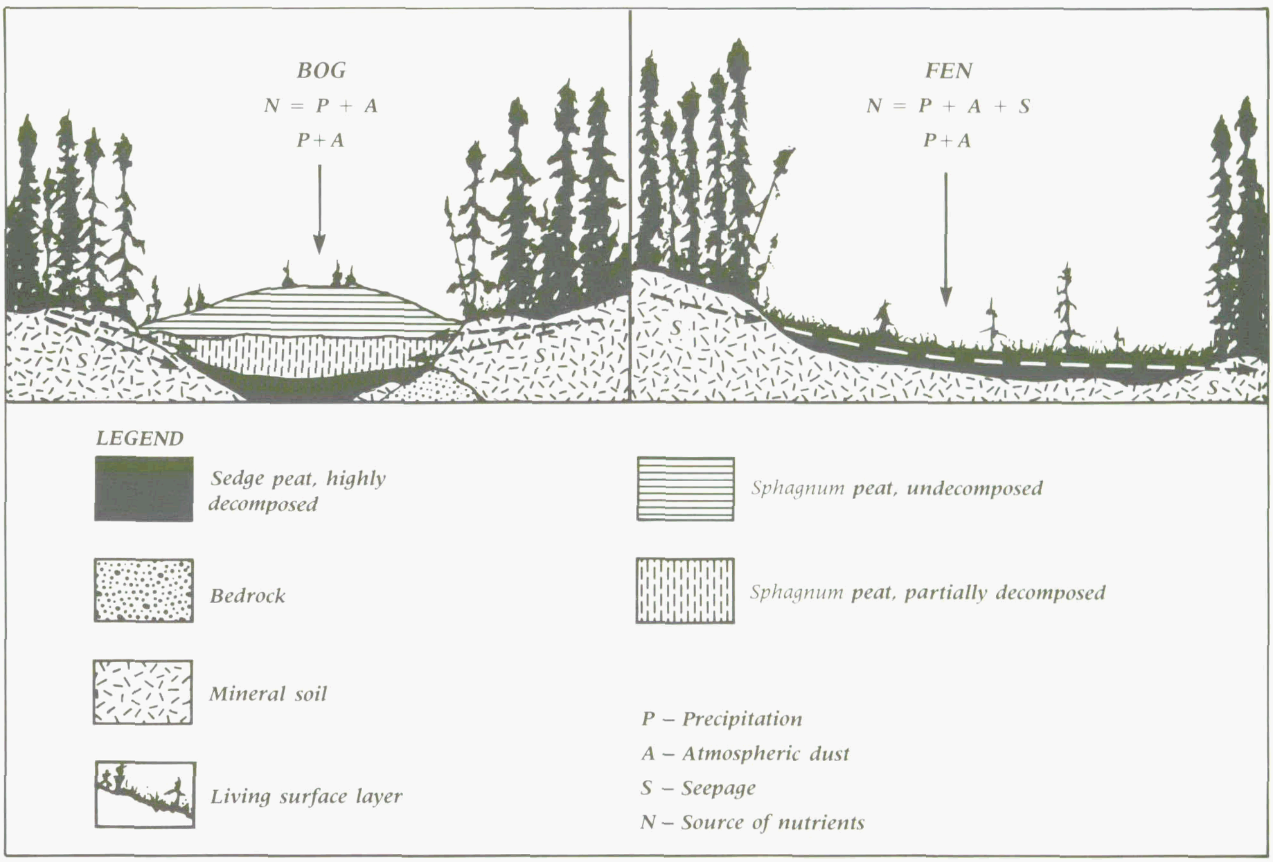


Figure 7–2.
Generalized illustrations of bog and fen showing differences in morphological development and sources of nutrient input.

Thus, it seems reasonable to assume that gradual variations rather than strict ecological boundaries should be used when describing the nutrient status of some peatlands in Atlantic Canada.

Peatland Development Processes

The formation and development of peatlands in Atlantic Canada are consequences of three major peat-forming processes: (1) infilling; (2) primary peat production; and (3) paludification. These three processes, which can occur together or separately depending on the influence of environmental factors, have also been described for peatlands in other regions of the world (Bellamy 1972; Moore and Bellamy 1974; Sjörs 1976; Tansley 1953). Since detailed descriptions of each process have been documented for peatlands in Newfoundland (Wells and Pollett 1983), only brief summaries of the processes are presented in this chapter.

Infilling

The infilling process of peat formation occurs when aquatic vegetation completely fills in a pond or water-filled basin. Oxygen concentrations and microbial activity are low in this cool, anaerobic environment, and rates of plant decomposition remain lower than those of plant production. Thus, the level of the surface vegetation in the basin eventually moves upwards in response to the increasing accumulation of undecomposed organic matter. The surface of the vegetation also progresses upwards to a level above the water table and the influence of any nutrient-enriched seepage water. Consequently, the vegetation changes from species characteristic of marshes and fens to those of bogs as the plants become increasingly dependent on nutrient-poor atmospheric inputs. One of the best examples of an infilled peatland is the domed bog form that occurs throughout much of Atlantic Canada.

Primary Peat Production

Primary peat production involves the formation of peat on wet, but not necessarily flooded, mineral soils (Sjörs 1976). A prerequisite for peat formation appears to be the development of a thick humus layer on the surface and/or an iron pan in the mineral soil. The humus layer, which forms primarily from an accumulation of ericaceous litter, will eventually become thick enough to retain sufficient moisture for peat-forming plants to become established. Likewise, an iron pan will impede drainage and consequently create wet conditions at the surface where peat-forming plants may become established (Taylor and Smith 1972; Ugolini and Mann 1979; Wells and Pollett 1983). Many of the Atlantic plateau bogs in western Newfoundland and eastern New Brunswick appear to have formed from primary peat production.

Paludification

Paludification occurs when primary peat deposits, which have formed in shallow depressions as a result of infilling and/or primary peat production, expand vertically and laterally to cover previously dry land. In many instances, the expanding peat deposits will further impede drainage and create conditions favourable for their own expansion. Blanket bogs in southeastern Newfoundland and, to a lesser extent, slope bogs throughout Newfoundland and eastern Nova Scotia typify peatland development by paludification.

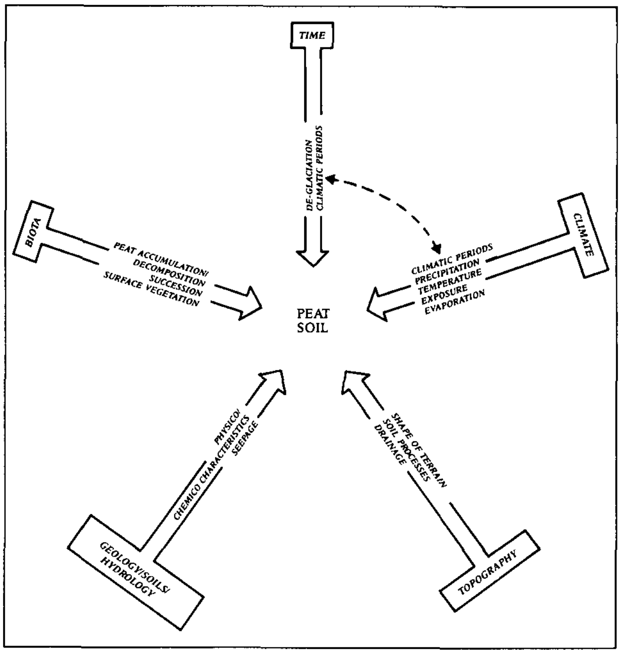
Developmental Factors

The occurrence of distinct wetland regions characterized by peatlands of different depths, floristic composition, and morphology is a reflection of the various biotic and abiotic factors that control peatland development in Atlantic Canada (Figure 7–3). With the exception of parts of northern Labrador, most of Atlantic Canada was ice-free about 10 000 years ago (MacPherson 1981, 1982) and

Table 7–3. Selected nutrient and physical parameters of organic soils used to separate bog from fen in Newfoundland

Wetland form (vegetation association)	*pH*	*Bulk density (g/L)*	*Total nutrients (mg/g)*							*No. of samples*
			N	*P*	*K*	*Ca*	*Mg*	*Mn*	*Fe*	
Ombrotrophic domed bog *(Kalmio–Sphagnetum fusci)*	3.54	30–80	6.7	0.34	0.58	1.24	1.17	0.06	0.74	375
Minerotrophic slope fen *(Potentillo–Campylietum stellati)*	5.47	90–250	20.9	0.92	0.41	16.13	1.31	0.30	10.07	68

Source: Modified from Pollett (1972b).



Source: Wells and Pollett (1983).

Figure 7–3.
Factors involved in peatland development.

therefore suitable for peatland development. However, the actual times of initial development vary considerably. Terasmae (1963) obtained dates of 7 400 years before the present (BP), 8 120 years BP, and 3 610 years BP for three peatland sites in eastern Newfoundland. Similarly, Davis (1984) recorded ages of 2 200–10 000 years BP for 14 peatland sites throughout the Island. Palynological studies (Davis 1984; Lamb 1980; MacPherson 1981) in southern Quebec, southern Labrador, and Newfoundland suggest that extensive peatland development did not commence until about 3 000–2 500 years BP, possibly in response to a change from a warm, dry climate to a cool, wet climate.

Floristic, morphological, and physical and chemical parameters for peatlands in most parts of Atlantic Canada have been described in detail (Anderson and Broughm, in preparation; Keys and Henderson, in preparation; Pollett 1972a, 1972b; Pollett and Wells 1980; Wells 1981; Wells and Pollett 1983). Thus, in this section, descriptions and discussions of each wetland form will be limited to graphical illustrations and brief outlines of characteristic features (Table 7–4, Figure 7–4) only as they relate to the biotic and abiotic factors that affect wetland development.

Biotic Factors

Peat formation occurs when rates of plant production exceed rates of plant decomposition. These processes, which involve both floristic and microbial populations, vary between different wetland forms, as well as within the same form. For example, in a domed bog (Table 7–4, Figure 7–4), rates of plant production, plant decomposition, and peat accumulation vary considerably from the centre of the bog to its edge (Damman 1979). Since the edge of the bog is influenced by nutrient-enriched seepage water from nearby upland mineral soils, the rate of vegetation production is usually quite high. However, total peat accumulation is very low because of high decomposition rates. In contrast, rates of plant production at the centre of the bog are usually quite low because of the acid soil conditions and the absence of any nutrient-enriched seepage water; however, these nutrient-poor soil conditions also inhibit microbial activity, thereby decreasing the rate of plant decomposition. Since rates of peat accumulation are much higher at the centre than along the edge, the centre becomes raised.

Rates of plant production are generally higher in fens than in bogs. However, since rates of plant decomposition are also high, peat accumulation is also less than that in bogs. In Atlantic Canada, fen depths vary from 0.5 to 2 m, whereas bog depths may be as great as 10 m.

The continuance of a fen ecosystem for long periods of time suggests a balance between plant production and plant decomposition. However, if rates of plant production continue to exceed rates of plant decomposition, the level of the surface vegetation increases in elevation to a height above the influence of the nutrient-enriched seepage water, and the fen eventually develops into a bog.

Determination of rates of peat accumulation is often difficult because of the variations in rates of plant production and plant decomposition, and the subsidence of the developing peat mass. Accumulation rates of 0.54, 0.92, and 1.75 mm/yr have been reported for peatland sites in New Brunswick (Keys and Henderson, in preparation). Similarly, Cameron (1970) suggests rates of 1–2 mm/yr for peat accumulation on peatlands in North America. Studies in Britain (Walker 1970) also indicate peat accumulation rates, or the actual upward growth of the peat deposit, of about 0.2–0.8 mm/yr.

Table 7–4. Characteristics of major peatland forms in Atlantic Canada

Wetland form	*Features*	*Wetland region or subregion*
Domed bog	Characteristic domed surface; often with concentric pool patterns; usually found in forested areas; 4–9 m deep.	BAo BAa
Atlantic plateau bog	Surface raised above surrounding terrain and plateau-like. Pools often large and scattered; common in western Newfoundland and southern coastal Labrador; 2–4 m deep.	BAm (northern Newfoundland)
Atlantic plateau bog	Morphologically similar to above except more extensive and surface of centre is often domed; common in eastern New Brunswick; 2–10 m deep.	BAm (eastern New Brunswick)
Slope bog	Generally small deposits topographically confined to poorly draining slopes; common throughout most of Newfoundland and eastern Nova Scotia; 1–2 m deep.	SAo
Basin bog	Small peat deposit often in areas of hummocky moraines; common in eastern and southern Newfoundland; 1–2 m deep.	SAo
Blanket bog	Extensive peat deposits that occur uniformly over hill and valley; common in south-east Newfoundland; 1–2 m deep.	OA
String bog	Characteristic orientation of pools perpendicular to direction of slope; very abundant in Labrador, especially the eastern portion; 1–2 m deep.	BAe BAi
Atlantic ribbed fen	Pool orientation similar to above; most common in alpine areas of Newfoundland and Labrador; shallow: 0.5–1.5 m deep.	SAo
Atlantic ribbed fen	Surface features similar to those of string bog; very abundant in western Labrador; 1–2 m deep.	SAo BAi
Slope fen	Ecologically similar to ribbed fen; however, surface features generally lack pools; occurs mainly in forested areas of central, western, and northern Newfoundland; 1–2 m deep.	BAo BAm
Ladder fen	Occurs mainly as narrow fen "strips" along edges of domed bogs; characteristic pool patterns as above.	BAo

Source: Wells (in preparation).

The development of any peat profile depends on the structure, composition, and dynamics of its surface vegetation. Unlike mineral soils, in which profiles develop from erosion and weathering of bedrock or parent materials as well as input of organic material from vegetative litter, peat soils are derived totally from plant remains. As the peatland ecosystem develops, annual vegetation production not only increases the peat mass but also may eventually modify its own hydrological and nutrient regimes, consequently changing the composition of the surface vegetation. The successional changes from marsh to fen to bog that occur during the development of many domed bogs, for instance, involve the accumulation of organic matter and a gradual change in condition from minerotrophic to ombrotrophic. Such a series of successional stages in the development of a peat deposit involves a number of different plant communities, ranging from aquatic to terrestrial and from nutrient-rich to nutrient-poor.

One of the best examples of successional changes in peatlands along nutrient and moisture gradients involves the genus *Sphagnum*. In fact, peat formation and *Sphagnum* mosses have become almost synonymous in descriptions of peatland development throughout the world. It is the growth and accumulation of these mosses that contribute most to the formation of peatlands, especially bogs, throughout Atlantic Canada. However, since most fen peats are composed of grasses and sedges, *Sphagnum* mosses usually play only a minor role in their formation.

A cross-sectional view of the leaves of a *Sphagnum* moss indicates two types of cells: (1) chlorophyllous and (2) hyaline. The first type of cell is responsible for the photosynthesis and respiration necessary for plant growth, whereas the second and larger type of cell absorbs water and maintains structure within the plant. The large size of the hyaline cell and its ability to absorb large amounts of water enable the *Sphagnum* plant to thrive in wet habitats.

The ecological amplitude and growth characteristics of many of these *Sphagnum* species vary considerably with changes in water level and nutrient status (Table 7–5). Vegetation communities of any ombrotrophic bog usually consist of about

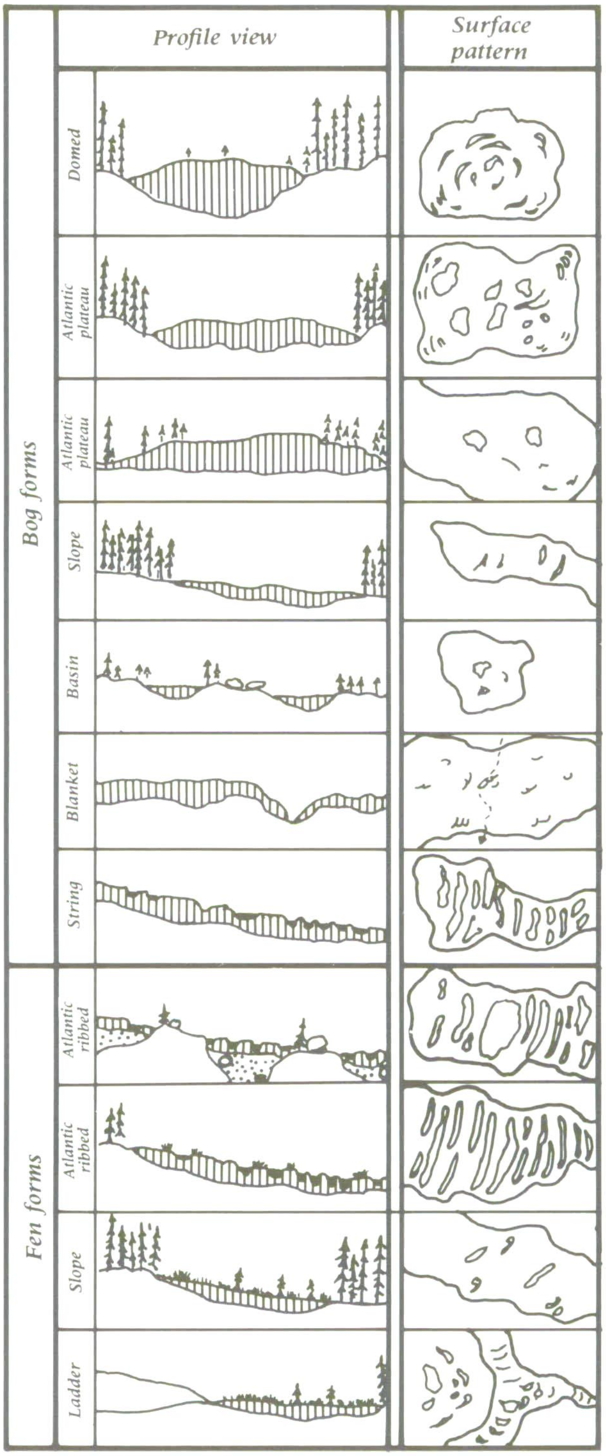


Figure 7–4.
Profile views and surface patterns of peatland forms in Atlantic Canada.

10–15 species of *Sphagnum* mosses occurring throughout a range of habitats. As the peatland deposit increases in thickness, the microtopography of the peat surface develops into hummocks, hollows, flats, and pools in response to changing hydrological and nutrient conditions produced by the differential rates of growth of the *Sphagnum* mosses.

The development and distribution of *Sphagnum* mosses also vary with altitude, exposure, and regional climatic variations. As a result, peatland plant communities, as well as the overall morphological structure of some of the peatland forms in Atlantic Canada, demonstrate developmental differences attributable mainly to these mosses.

Although *Sphagnum* mosses are usually the dominant form of vegetation in most peatlands, many other plant species are characteristic of both bogs and fens (Tables 7–6 and 7–7). These groups of species vary from the dry, ombrotrophic plant communities dominated by *Sphagnum* mosses, dwarf shrubs, and lichens to the eutrophic plant communities dominated by sedges, grasses, and brown mosses. Many "minerotrophic indicator species" occur only in fens, where most nutrients are more readily available. Other "ombrotrophic indicator species" grow only in bogs, either because of their inability to compete in the more nutrient-enriched environment of the fen or because of their competitive and adaptive ability to survive in the nutrient-poor soils of the bog.

Abiotic Factors

In the early stages of peatland development, the interactions between the biotic processes of plant production, plant decomposition, and the eventual formation of peat are influenced largely by such abiotic factors as geological substrates, pedogenic processes, and hydrological conditions. For example, peat forming in a basin influenced by nutrient-enriched seepage waters from limestone deposits will normally develop as a fen. This is especially true in western Newfoundland where eutrophic slope fens have developed on limestone bedrock and materials. Both plant production and plant decomposition are high in these eutrophic habitats and, consequently, peat accumulation is considerably slower than in nutrient-poor bogs.

Pedogenic processes in mineral soils do not appear to play a significant role in the development of peatlands, although the presence of iron pans may partly explain the process of primary peat production on thick humus layers and the formation of Atlantic plateau bogs on coarse-textured soils of river terraces and glacial outwash deposits in western Newfoundland. Although iron pans occur throughout the soils underlying these peat deposits, their role in the formation of peatlands

Table 7–5. ***Successional pattern of*** *Sphagnum* ***mosses in the development of bogs and fens in Atlantic Canada***

Ombrotrophic bog		*Minerotrophic fen*
Pools, pool edges, open water *Sphagnum pulchrum* *Sphagnum cuspidatum* *Sphagnum majus* *Sphagnum lindbergii* (n)		***Pools and wet flats*** *Sphagnum pylaesii* *Sphagnum subsecundum* (n, u) *Sphagnum tenellum* (r, s)
Wet flats (and hollows) *Sphagnum pulchrum* *Sphagnum rubellum* *Sphagnum magellanicum*		
Hollows *Sphagnum tenellum* (s) *Sphagnum rubellum* *Sphagnum cuspidatum* (r)	***Weakly minerotrophic flats and wet ombrotrophic flats*** *Sphagnum flavicomans* (o) *Sphagnum magellanicum* *Sphagnum papillosum* *Sphagnum rubellum*	***Strongly minerotrophic flats and low hummocks*** *Sphagnum subfulvum* *Sphagnum warnstorfii* *Sphagnum compactum* (u, n) *Sphagnum strictum* (u, s)
Bog hummocks *Sphagnum fuscum* *Sphagnum rubellum* *Sphagnum angustifolium* (n) *Sphagnum imbricatum* (c)	***Fen hummocks*** *Sphagnum fuscum* *Sphagnum rubellum* *Sphagnum angustifolium* (n)	

n = *northern (northern Newfoundland and Labrador).*
s = *southern (mainly Newfoundland, Nova Scotia, New Brunswick, and Prince Edward Island).*
o = *oceanic (eastern and western Newfoundland, Nova Scotia).*
u = *more common in upland sites.*
c = *coastal.*
r = *minor component of plant community.*

has not been ascertained; nor have the basal organic deposits of Atlantic plateau bogs been examined to determine if a thick ericaceous layer had developed initially.

Since the formation of peatlands is dependent on high levels of soil moisture, climate is perhaps the most important abiotic factor affecting peatland development. A positive correlation between climatic features and the development and distribution of peatlands is difficult to establish in such a heterogeneous terrain as that of Atlantic Canada. Delineation of strict climatic–peatland regional boundaries must take into account the continental, oceanic, altitudinal, and latitudinal gradients within the area, as well as the lack of adequate climatic data in the north. Some of these features are best illustrated along a south-to-north latitudinal gradient in Newfoundland and Labrador (Table 7–8, Figure 7–5).

The formation of true "climatic" peat is best exemplified by the development of blanket bogs in the oceanic climate of southeastern Newfoundland. In this area of high annual rainfall (1 246 mm), cool summers (mean daily June to September temperature of 12.2°C; 881 degree-days above 5°C), and frequent summer fogs (74 days annually), blanket bogs have developed extensively over both hills and valleys. These peatlands formed initially from infilling of small pools or from primary peat production on moist soils, and developed laterally and vertically in response to a wet climate.

However, high levels of precipitation do not always result in paludification of the landscape by peatlands. In southwestern Nova Scotia, where total precipitation and rainfall throughout the growing season are similar to those of southeastern Newfoundland, peatland deposits have developed primarily from infilling of topographic depressions. Peatland development in this area is probably limited by the high summer temperatures and the subsequent increase in evapotranspiration, which tend to shorten the effective growing season or the period of active growth of ombrotrophic *Sphagnum* hummocks (Damman 1979).

The developmental processes of slope bogs throughout Newfoundland and eastern Nova Scotia are similar to those of blanket bogs, but, because of slightly reduced annual rainfall (1 035 mm) and warmer summers (mean daily June to September temperature of 13.6°C; 1 052 degree-days above 5°C), these peatlands do not paludify the landscape but instead are confined to slopes.

In the more northern latitudes of Atlantic Canada, the climatic parameters that most strongly affect peatland development are low rainfall, high snowfall, a short growing season, and temperatures cooler than those in southeastern portions. Peatlands in this area are characterized by high water tables and, in spring, an abundance of surface water from snowmelt. Expanses of peatlands often occur on relatively flat and poorly

Table 7–6. Characteristic vegetation of bog communities in Atlantic Canada*

Dry bog communities
Rubus chamaemorus
Cladina mitis
Cladina alpestris
Cladina arbuscula
Cladina rangiferina
Empetrum nigrum
Kalmia angustifolia
Polytrichum strictum
Vaccinium angustifolium
Cetraria islandica

Bog hummocks
Sphagnum fuscum
Sphagnum rubellum
Microlepidozia setacea
Larix laricina
Mylia anomala

Peat mounds and palsas (northern Newfoundland and Labrador)
Cetraria nivalis
Vaccinium uliginosum
Ochrolechia frigida
Vaccinium vitis-idaea
Sphaerophorus globosus
Rhacomitrium lanuginosum
Cladonia uncialis
Alectoria nigricans
Cornicularia aculeata
Carex rariflora
Ptilidium ciliare
Cladonia boryi
Myrica gale
Eriophorum spissum

Wet bog communities
Sphagnum tenellum
Odontoschisma sphagni
Rhynchospora alba
Cladopodiella fluitans
Sphagnum pulchrum
Sphagnum rubellum
Mylia anomala
Cetraria islandica

Hollows
Sphagnum magellanicum
Carex oligosperma
Eriophorum spissum
Sphagnum cuspidatum
Utricularia cornuta
Cephalozia connivens

Hollows and wet flats (northern Newfoundland and Labrador)
Ochrolechia frigida
Carex rariflora
Vaccinium uliginosum
Ptilidium ciliare
Cornicularia aculeata
Eriophorum spissum
Sphagnum compactum
Rubus chamaemorus
Empetrum nigrum
Kalmia angustifolia

Large Sphagnum flats
Sphagnum magellanicum
Sphagnum flavicomans
Sphagnum papillosum
Microlepidozia setacea
Dicranum scoparium
Kalmia angustifolia
Carex oligosperma
Cladina arbuscula
Cladina rangiferina

Source: Modified from Wells (in preparation).
**Plant communities occur throughout Atlantic Canada unless otherwise indicated.*

*Table 7–7. Characteristic vegetation groups of fen communities in Atlantic Canada**

Fen hummock communities
Sphagnum rubellum
Mylia anomala
Cetraria islandica
Carex pauciflora
Picea mariana
Sphagnum magellanicum
Carex oligosperma
Larix laricina
Betula michauxii
Smilacina trifolia

- **Fen hummocks**
  Sphagnum fuscum
  Cladina rangiferina
  Cladina arbuscula
  Cladina mitis
  Polytrichum strictum
  Pleurozium schreberi
  Pohlia nutans
  Coptis groenlandica
  Carex exilis
  Myrica gale
  Sanguisorba canadensis
  Carex livida
- **String fen hummocks and/or ridges (Labrador)**
  Sphagnum angustifolium
  Vaccinium uliginosum
  Cladopodiella fluitans
  Carex limosa
  Ptilidium ciliare
  Sphagnum compactum

Fen lawn communities
Carex exilis
Sanguisorba canadensis
Myrica gale
Aster nemoralis
Aster novi-belgii
Lonicera villosa
Solidago uliginosa
Carex oligosperma
Larix laricina
Betula michauxii
Smilacina trifolia

- **Weakly minerotrophic fens (New Brunswick, Nova Scotia, Newfoundland)**
  Sphagnum papillosum
  Sphagnum magellanicum
  Sphagnum rubellum
  Sphagnum pulchrum
  Calamagrostis inexpansa
  Pyrus floribunda
  Rhynchospora alba
  Cladopodiella fluitans
  Juniperus communis
  Polytrichum strictum
- **String fens (Labrador)**
  Sphagnum compactum
  Vaccinium uliginosum
  Cladopodiella fluitans
  Carex limosa
  Coptis groenlandica
  Rubus acaulis
  Calliergon stramineum
  Sphagnum warnstorfii
  Sphagnum pulchrum
  Sphagnum magellanicum
  Sphagnum rubellum
  Betula glandulosa
- **Eutrophic fens (Newfoundland and Labrador)**
  Campylium stellatum
  Selaginella selaginoides
  Potentilla fruticosa
  Carex limosa
  Betula pumila
  Sphagnum warnstorfii
  Aulacomnium palustre
  Picea mariana

Source: Modified from Wells (in preparation).
**Plant communities occur throughout Atlantic Canada unless otherwise indicated.*

drained basins. Consequently, spring snowmelt, cool summer temperatures, and slow drainage all combine to produce wet soil conditions for long periods of time.

Perhaps the most obvious features of peatlands in the coastal areas of northern Newfoundland and eastern Labrador, as well as northwestern Labrador, are palsa bogs (Zoltai 1972; Zoltai and Tarnocai 1971, 1975), palsa fens, and/or frozen mounds on Atlantic plateau bogs. These features are large hummocks or mounds of peat that remain frozen throughout the growing season. In northern Newfoundland, the mounds are about 1 m in height and 2–3 m in length, but in the more northern parts of Labrador, palsa bogs may be as large as 2 m in height and 5–8 m in length.

Large areas of eastern and western Labrador are characterized by string bogs and Atlantic ribbed fens. In the upland areas of central and western Newfoundland, Atlantic ribbed fens also cover much of the landscape. Although the ecology, morphology, and surface features of these peatlands differ considerably from those of blanket bogs, the formation and development of both these peatland forms result primarily from excessive soil-moisture conditions. However, the devel-

Table 7–8. Variations in bog development along latitudinal and climatic gradients in Newfoundland and Labrador

Latitudinal range of bog forms*	Annual rainfall (mm)	Rainfall June–Sept. (mm)	Annual snowfall (cm)	Mean daily temp. (°C) Ann.	Mean daily temp. (°C) June–Sept.	Mean daily temp. (°C) Dec.–Mar.	Frost-free days (no.)	Degree-days above 5°C (no.)	Fog 1 km visibility June–Sept. (days)	Altitude (m)	Wetland subregion
58°											
57°											
56°											
	439	249	413	−1.5	9.1	−12.5	81	551	18	10	SAc (northern)
55°											
	479	378	475	−3.5	10.5	−18.1	81	710	6	495	BAi/BAe
54°											
53°											
52°	643	341	332	0.2	9.1	−8.2	105	529	59	65	SAc (southern)
51°											
50°	740	337	318	4.0	13.9	−5.7	100	1 088	19	87	BAo
49°											
	818	385	357	4.1	13.2	−4.6	126	986	21	18	BAm
48°											
	1 035	345	209	5.3	13.6	−2.6	126	1 052	32	31	SAo
47°											
	1 246	417	175	4.9	12.2	−1.9	127	881	74	42	OA
46°											

Sources: Atmospheric Environment Service (1982) and Wells (in preparation).

**Bog forms (see Figure 7–5):*
1. blanket bog;
2. slope bog, basin bog;
3. Atlantic plateau bog;
4. domed bog and slope bog;
5. Atlantic plateau bog with frozen peat mound bogs;
6. string bog;
7. Atlantic plateau bog with palsas.

opment of string bogs and Atlantic ribbed fens depends more on a combination of lower rainfall and cooler temperatures.

The effect of any particular climatic factor is less evident in the development of the deep ombrotrophic domed bogs and Atlantic plateau bogs that occur in Newfoundland, Labrador, Nova Scotia, and New Brunswick. Domed bogs, which are found mainly in the inland forested areas of Newfoundland and eastern Labrador, southern Nova Scotia, and central New Brunswick, have formed mainly in basins. They are convex when seen in profile, and are characterized by a concentric or eccentric arrangement of pools on the surface (Table 7–8, Figure 7–5). Peat plateau bogs, which occur throughout the coastal areas of western Newfoundland, Labrador, and southern and eastern New Brunswick, are characterized by steeply sloping margins and a flat to undulating surface. They have developed mostly on flat and sometimes extensive poorly drained basins.

The predominance of Atlantic plateau bogs in coastal areas and of domed bogs in mainly inland areas cannot be explained solely on the basis of precipitation or temperature. Both peatland forms have developed in response to a combination of topographic, climatic, hydrological, and microbial (biotic) conditions. However, in the absence of extremely cool temperatures and/or high precipitation, peat accumulation in these bogs appears to be affected more by the height of the water table or by periods of high summer temperatures and high evapotranspiration rates, when the bog surface dries out too much for active *Sphagnum* growth (Damman 1979).

In summary, the development and distribution of peatlands in Atlantic Canada are controlled by a variety of biotic and abiotic factors. Although climate appears to be the major factor controlling the development of most peatlands, the effect of such factors as hydrology, geology, and soils on nutrient status, microbial activity, and peat accumulation is most evident in the early stage of peat formation.

The rates of peat formation and the composition of the surface vegetation and the underlying peats are also controlled by the nutritional and hydrological gradients within the peat deposit as well as by the climatic variations within the area. Furthermore, peatlands are dynamic, unbalanced ecosystems which are not only affected and controlled by external factors but also gradually change and modify their own environment as they develop.

Salt Marshes in Atlantic Canada

The salt marsh is the most terrestrial extreme of the marine environment. Plants that live in this habitat are actually terrestrial species that cannot compete with other land plants (Hatcher *et al.* 1981) but that are able to tolerate saline conditions (Phleger 1971). For example, the salt marshes of Atlantic Canada are characterized by interstitial salinities of between 0 and 400 parts per thousand (‰) (Scott and Medioli 1980b). However, salinities demonstrate a characteristic pattern of low values in high marsh areas, generally increasing with decreasing elevation or increased tidal influence.

The salt marshes of Atlantic Canada are a northern extension of the vast salt marsh complex of the Gulf of Mexico and the east coast of the United States (Chapman 1974; Reimold 1977). These wetlands are dominated by *Spartina alterniflora* and *Spartina patens*, which occur only rarely in other Canadian salt marshes. *Spartina alterniflora* is found on the lower portion of a salt marsh where tidal inundations of the marsh and tidal creeks are common. On the higher parts of the marsh, *Spartina patens*, *Limonium carolinianum*, *Salicornia europaea*, *Suaeda linearis*, *Atriplex patula*, *Plantago maritima*, *Puccinellia maritima*, *Triglochin maritima*, *Glaux maritima*, and *Hordeum jubatum* are characteristic (Glooschenko 1979).

The salt marsh ecosystem comprises a relatively small part of the total wetland area of Atlantic Canada because of its narrowly defined physical limits (Table 7–9). Chapman (1960) suggested that marshes occupy a narrow zone between higher high water (HHW) and mean sea level (MSL) on a worldwide basis. Scott and Medioli (1980a) have found this to be true in Atlantic Canada, except in the extreme tidal ranges of the Bay of Fundy (Smith *et al.* 1984) where the absolute vertical range of the marsh appears to vary between 1 and 4 m. The horizontal extent of the marsh is highly variable, depending on the adjacent water body and on sediment supply, as well as on regional characteristics such as changes in relative sea level. The lower limits of the salt marsh do not include areas such as estuarine flats and eelgrass beds which are below MSL and are characterized

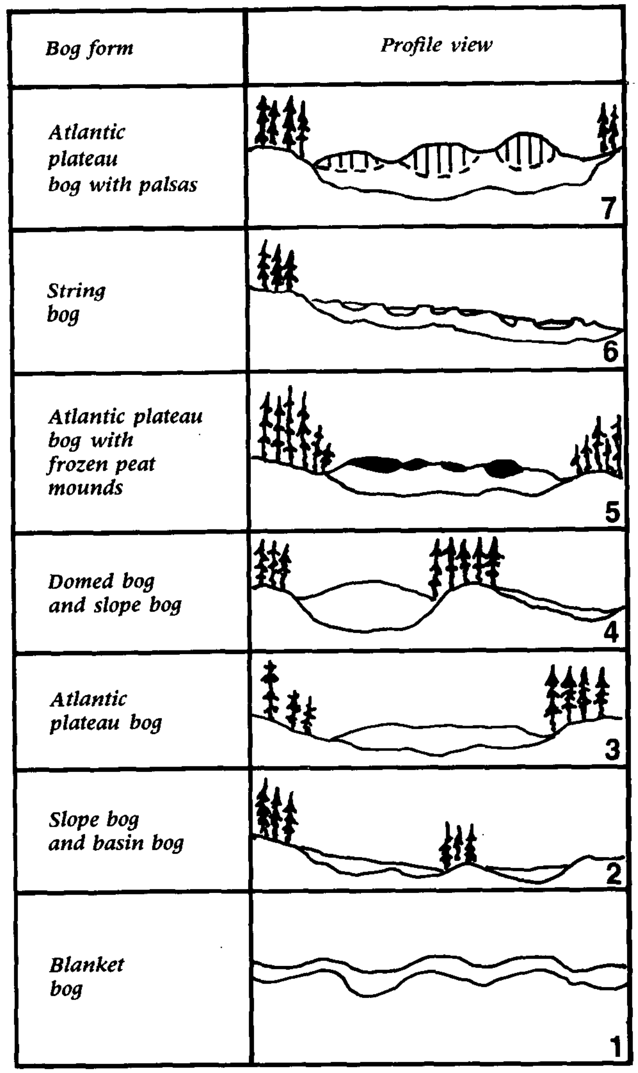


Figure 7–5.
Profiles of common bog forms in Newfoundland and Labrador. Numbers 1–7 refer to forms common to north–south gradient as outlined in Table 7–8.

by true aquatic grasses such as *Zostera* spp. and *Ruppia* spp. The latter areas, however, are shallow water wetlands and are considered separately.

One of the unique features of a salt marsh ecosystem is the dynamic tidal influence. Parameters such as temperature, salinity, pH, dissolved oxygen, and oxidation-reduction potential vary continuously with changing tides (Phleger and Bradshaw 1966). For example, in arid areas such as southern California, salinity increases at low tide as evaporation causes salts to concentrate. However, in Atlantic Canada where the freshwater table dominates the high marsh areas, salinity tends to decrease at low tide periods. In both areas, dissolved oxygen and pH are directly related and they vary together. Changes in pH affect the distribution of organisms such as clams and snails which have shells containing calcium carbonate. In most Atlantic marshes, pH is too low to allow mollusc colonization. Most animals that live in the marsh mud are marine protozoans such as foraminifera, worms, and molluscs which live at the upper limit of marine environments.

Early studies of Atlantic salt marshes include a floristic analysis of the Fundy marsh system (Ganong 1903) as well as more general reports on salt marshes in Nova Scotia (Chapman 1937, 1960). Thannheiser (1984) examined the vegetation characteristics of many marshes in New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland. The detailed data presented in this chapter are drawn largely from studies done in Atlantic Canada on both vegetation and foraminiferal associations (Scott and Medioli 1978, 1980a, 1980b; Scott *et al.* 1981; Scott and Greenberg 1983; Smith *et al.* 1984).

Classification of Salt Marshes in Atlantic Canada

The salt marshes of Atlantic Canada vary considerably in salinity, slope, and tidal range and influences. Since many of the marshes consist of both high and low extremes and remain ecologically and floristically similar in both estuarine and/or coastal situations, the proposed general terminology for subdivision of Canadian salt marshes into estuarine high and low marshes and coastal high and low marshes (as outlined in Appendix I and in Tarnocai 1980) is not sufficiently detailed for the classification of the range of salt marsh conditions in Atlantic Canada. Instead, the Atlantic salt marshes have been subdivided into four separate groups based on geographic location, tidal range (lower, middle, and upper marsh), and floristic composition.

The four groups of salt marshes are (1) the Atlantic coast, including the eastern shore of Nova Scotia; (2) the Bay of Fundy, including shores of both Nova Scotia and New Brunswick; (3) the Gulf of St. Lawrence, including shores of the Côte-Nord area in Quebec, the Magdalen Islands, Anticosti Island, Prince Edward Island, and the northern shores of New Brunswick and Nova Scotia; and (4) the northern group, including shores of northern Newfoundland and Labrador and extending to St-Augustin in Quebec. All the

*Table 7–9. Atlantic salt marsh areas**

Location	No. of marshes	Area of high coastal marsh (ha)	Area of low coastal marsh (ha)	Total salt marsh area (ha)	Portion of total salt marsh area (%)	
					High marsh	Low marsh
Prince Edward Island						
(a) Northumberland Strait shores	500	1 499.0	1 018.3	2 517.4	60	40
(b) Gulf of St. Lawrence shores	431	1 267.9	1 170.8	2 438.8	52	48
Total	931	2 766.9	2 189.1	4 956.2	—	—
Nova Scotia						
(a) Northumberland Strait to northeast Cape Breton Island	249	663.2	1 027.1	1 690.4	39	61
(b) Northeast Cape Breton Island to Shelburne	581	2 571.1	3 346.9	5 918.1	43	57
(c) Shelburne west to Bay of Fundy and east to Northumberland Strait	333	2 482.5	2 279.6	4 762.2	52	48
• Chignecto Bay only	(40)	—	—	—	—	—
• Cobequid Bay only	(520)	—	—	—	—	—
• Minas Basin only	(1 460)	—	—	—	—	—
• Bay of Fundy (proper) only	(680)	—	—	—	—	—
Total	1 163	5 716.8	6 653.6	12 370.7	—	—
New Brunswick						
(a) Passamaquoddy Bay	—	—	—	180	—	—
(b) Shepody Bay	—	—	—	900	—	—
(c) Cumberland Basin	—	—	—	1 260	—	—
Total	—	—	—	2 340	—	—

Sources: A. Smith (personal communication) and Pearce and Smith (1974).
**Complete data for Newfoundland and Labrador and the Côte-Nord area of Quebec are not available.*

marshes in these four groups differ in geographic setting and geology, yet they are almost all floristically similar in the upper, middle, and lower sections of the marsh (Table 7–10). The marshes of the northern group are an exception; they are characterized by the presence of *Salicornia europaea* in the lower marsh, whereas the most common plant in the low marsh of the other groups is *Spartina alterniflora*. *Spartina patens* is usually characteristic of the middle marsh but is more limited in some areas than in others. In high marsh areas, the vegetation is variable but is usually dominated by *Juncus* spp., *Scirpus* spp., *Carex* spp., or even *Spartina cynosuroides*.

Atlantic Coast Marshes

The Atlantic coast marshes are characterized by a wide range of differences in salinity, floristic diversity, channel morphology, marsh gradients, and the semi-diurnal influences of tides each day. Two transects (Figure 7–6, No. 1; Figure 7–7) from Chezzetcook Inlet, Nova Scotia, illustrate the variations observed within one estuarine system. Transect I is from the head of the Inlet where salinities are low and the marsh is mostly middle marsh with steep-sided channels; Transect II is from the open part of the Inlet where salinities are higher and there is a more gentle gradient into low marsh. Transect I represents a more mature marsh and is more diverse floristically than the marsh in Transect II. *Solidago sempervirens* is more abundant in Transect I, where it grows on the small levees that form along the steep channels at the head of this estuary. The HHW mark is approximately 100 cm above MSL at both sites and is marked by the occurrence of *Spartina cynosuroides* and terrestrial plants. The lower edge of the marsh also frequently extends slightly below MSL.

Bay of Fundy Marshes

The Bay of Fundy marshes are characterized by extreme tidal ranges. Salinities are generally higher than those in marshes from the other groups, because of the macrotidal influence. Marsh sediments also do not retain groundwater of low salinity because of a high clastic component (Smith *et al.* 1984). Transects of two marshes from this group are presented: Chebogue Harbour, Nova Scotia (Figure 7–6, No. 2; Figure 7–8), which has an expanded but not extreme tidal range (5 m), and Kingsport, Nova Scotia (Figure 7–6, No. 3; Figure 7–9).

The total vertical range of the marsh at Chebogue Harbour is larger (2.5 m) than that at Chezzetcook (1 m) but is still between HHW and MSL. The low marsh section actually accounts for almost four-fifths of the total vertical range, compared with one-half of the vertical range in marshes with a normal tidal range. Plant species are similar to those at Chezzetcook. The high marsh plants occur at the same absolute vertical range, while the low marsh plants (*Spartina alterniflora*) occupy the extra vertical distance imposed by the higher tidal range. Similar conditions characterize the foraminiferal zones. The greatest vertical extent occurs in the low marsh section dominated by *Spartina alterniflora*. The middle marsh, characterized by *Spartina patens*, is wide but restricted vertically, and the high marsh occurs in the upper 30 cm, again retaining its absolute vertical range.

The Kingsport transect is typical of an area with an extreme tidal range of 16 m (Smith *et al.* 1984). The total vertical range of the marsh is about 4 m but the lower edge of the marsh does not extend to MSL. Salinity is highest in the lower marsh area which is dominated by *Spartina alterniflora*. In the

Table 7–10. Vegetation common to maritime salt marshes

Geographic group	Low marsh	Middle marsh	High marsh	Tidal range (m)
Atlantic	*Spartina alterniflora*	*Spartina patens*	*Juncus* sp., Cyperaceae	2
Gulf	*Spartina alterniflora*	*Spartina patens*	*Spartina cynosuroides*	2–4
Fundy	*Spartina alterniflora*	*Spartina patens*, *Distichlis* sp.	*Spartina patens*, *Juncus gerardii*	5–16
Northern	*Salicornia europaea*	*Puccinellietum pauperculae*	*Juncus* sp., Cyperaceae	2

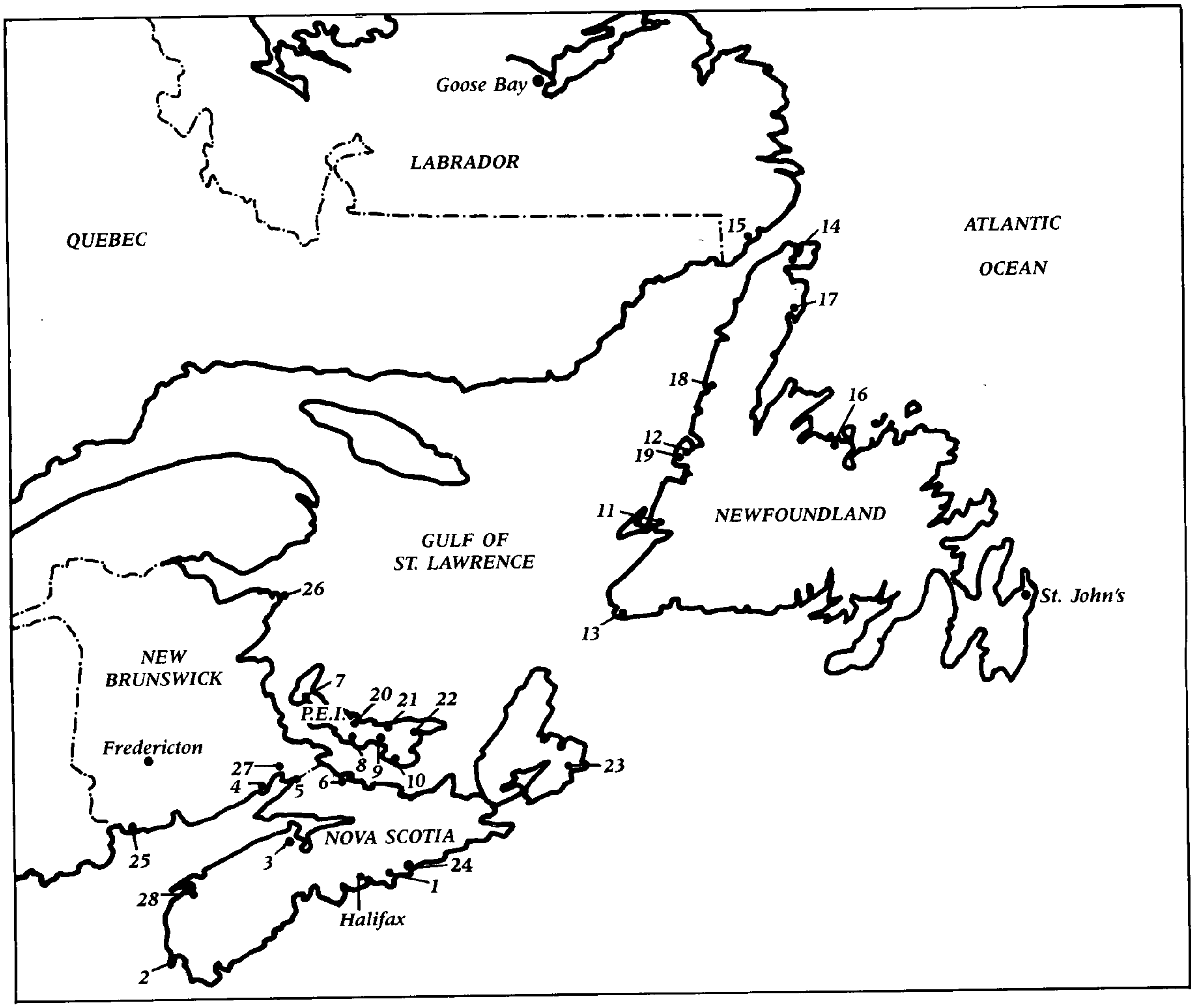


Figure 7–6.
Locations of salt marshes in Atlantic Canada that have been investigated by Thannheiser (1984) and/or Scott and Medioli (1980a, 1980b). Stratigraphies and vegetation transects discussed in this chapter are numbers 1 – 3, 6 – 9, 11 and 12.

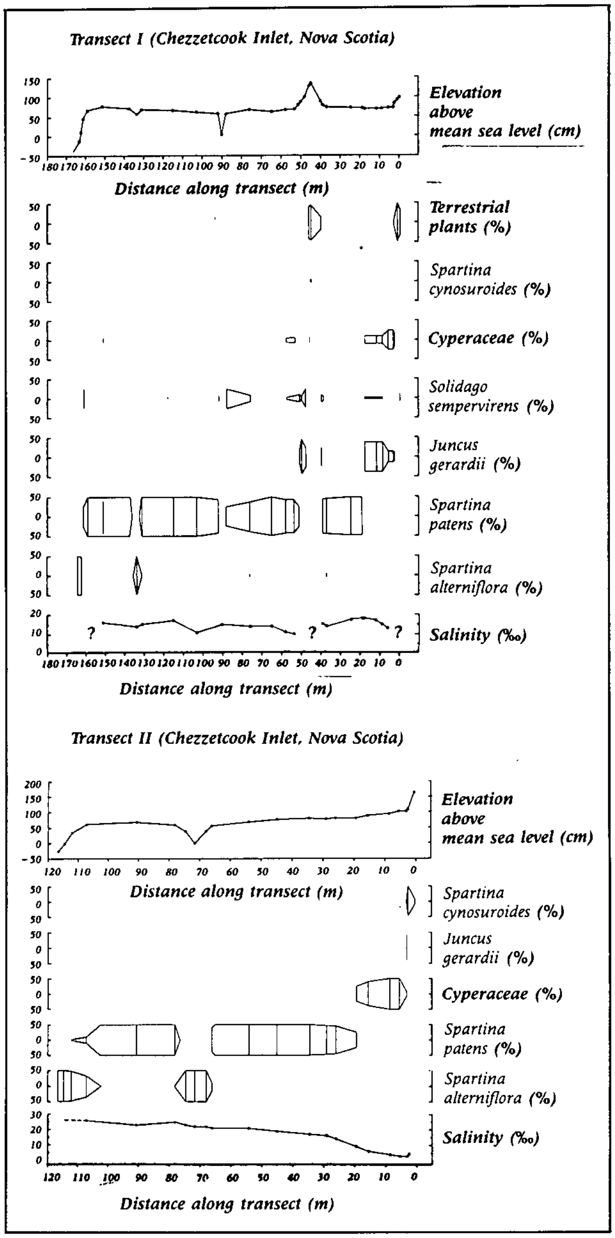
middle to upper marsh, *Spartina patens* is more abundant.

Gulf of St. Lawrence Marshes

Tidal ranges in the Gulf of St. Lawrence marshes are relatively normal (2–4 m). However, the tidal regime is a mixed tidal system which is unique to the Gulf. There are equal components of semi-diurnal and diurnal influences which appear to affect plant zonation. A transect from Wallace Basin, Nova Scotia (Figure 7–6, No. 6; Figure 7–10), shows high marsh (*Juncus gerardii*) in the upper 50 cm, middle marsh (*Spartina patens*) occupying a narrow (5 cm) section, and *Spartina alterniflora* growing in the lower 70 cm. Foraminiferal species follow the same pattern.

Three transects from Prince Edward Island—Mount Stewart, Tryon, and Wolfe Inlet—all display wide variations in plant zonation. At Mount Stewart (Figure 7–6, No. 9; Figure 7–11), where the tidal range is 3 m, plant zonation is very uncharacteristic and complicated, with *Spartina patens* occurring both above and below the tidal limit. Only *Spartina alterniflora* is similar to other areas in its distribution. At Tryon (Figure 7–6, No. 8; Figure 7–12), the pattern is more stable but *Spartina patens* still spreads into the high marsh. *Spartina alterniflora* occupies a steep-sided channel, up to 1 m below MSL. At Wolfe Inlet (Figure 7–6, No. 7; Figure 7–13), where the tidal range is less than 2 m, plant distribution is more similar to that of the Atlantic coast marshes, except that here also *Spartina patens* extends well into the high marsh.

All these marshes within the Gulf of St. Lawrence demonstrate profoundly different plant zonations. The situation at Mount Stewart may have been affected by a nearby causeway; how-



Source: Scott and Medioli (1980a).

Figure 7–7.

Transects of vegetation occurrences from the head (No. I) and from the mouth (No. II) of Chezzetcook Inlet, Nova Scotia. Notice the more gentle slope of the marsh and the higher salinities characteristic of the open part of the estuary. Salinity is indicated at bottom (taken at low tide). Vertical bars are percentages and horizontal connecting lines are subjective.

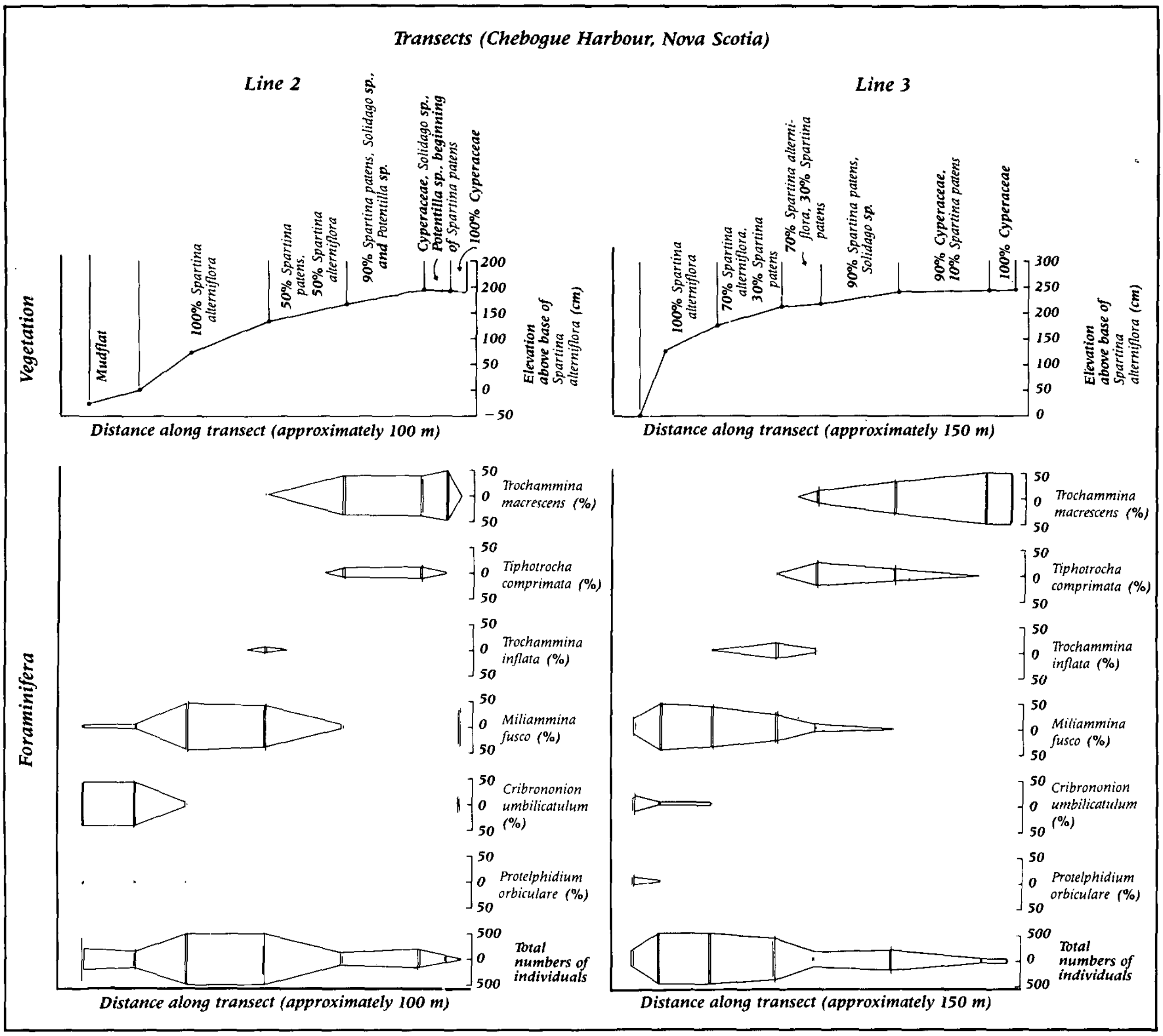
ever, plant ranges, especially that of *Spartina patens*, vary considerably within all the sites. Foraminiferal distribution from the same transects is much less variable and is comparable to that of other Atlantic coast sites (Scott and Medioli 1980a; Scott *et al.* 1981).

Inventories of salt marshes in the Quebec portion of the Gulf of St. Lawrence by Groupe Dryade Ltd. (Environment Canada 1986) report the occurrence of 8 595 ha of various kinds of salt marshes along the shores of this area as of 1978 (Table 7–11). This inventory covered the north shores of the Gulf from Pointe-des-Monts to Blanc-Sablon, the Gaspé Peninsula, and Magdalen Islands. Anticosti Island was not included. The inventory by Groupe Dryade Ltd. indicates that salt marshes in the Gulf of St. Lawrence are confined to sites favouring sedimentation of fine deposits, especially at river mouths and in deep bays. Salt marshes of the Mingan Islands are described in Grondin and Melançon (1980a, 1980b), Marcotte (1982), and Grondin *et al.* (1980, 1983, 1986). The salt marshes of Anticosti Island, as described in Grondin (1982), and the Mingan Islands are dominated by *Glaux maritima*, *Carex paleacea*, and *Spartina alterniflora*, particularly on sheltered sites. On exposed sites, *Salicornia europaea* and *Glaux maritima* are more common. In the Côte-Nord area of Quebec, common Atlantic salt marsh species such as *Juncus gerardii* and *Spartina patens* are present.

Salt marshes are common along about 35% of the shores of the Magdalen Islands, especially the protected lagoon shorelines of Île du Havre-aux-Maisons, Île du Havre-Aubert, and Île de l'Est. Selected studies which permit description of the floristic composition of this area include Beaumont and Chamberland (1976) and Grandtner (1966a, 1966b). Little data are available for the rare occurrences of salt marshes along the Côte-Nord areas of the northern Gulf of St. Lawrence in Quebec.

Northern Marshes

The main distinguishing feature of the northern group of marshes is that the low marsh sections are characterized by *Salicornia europaea*, a species that is rare in other marshes in Atlantic Canada. *Puccinellia paupercula* is also uncommon in areas farther south and may suggest a link between temperate and subarctic areas. The Saint Paul's transect (Figure 7–6, No. 12; Figure 7–14), is typical of salt marshes on the Island of Newfoundland. Although elevation is not indicated, the different plant zones are shown. In southwestern Newfoundland (Figure 7–6, No. 11; Figure 7–15), *Spartina alterniflora* is again present, suggesting a closer relationship with marsh groups in the Atlantic coast and Gulf of St. Lawrence.



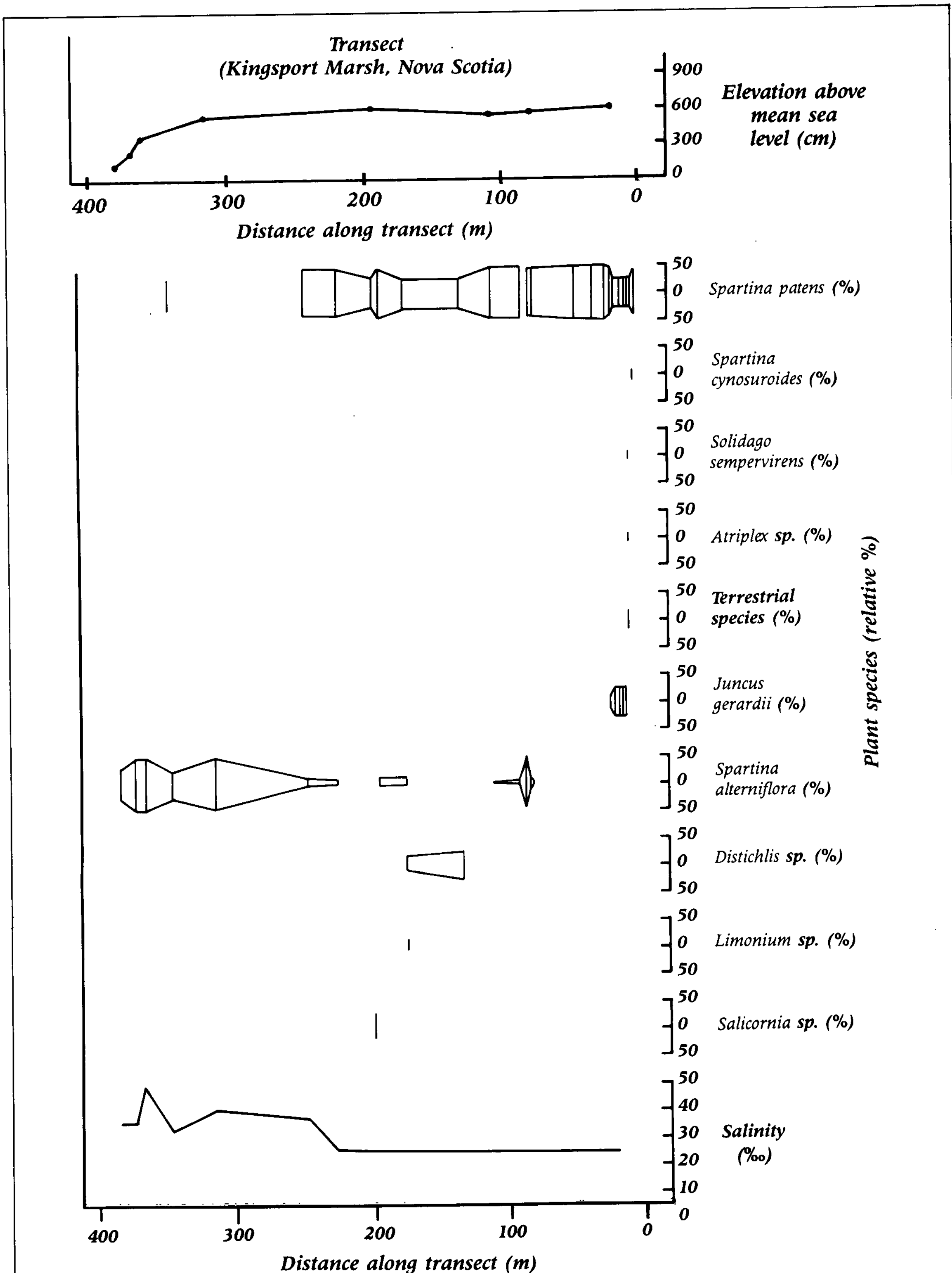
Source: Scott and Medioli (1980a).

Figure 7–8.
Two transects from Chebogue Harbour, Nova Scotia, showing both foraminifera (quantitative) and vegetation (qualitative). Format same as that in Figure 7–7; Line 2 at left, Line 3 at right.

Very little work has been done on the salt marshes of Labrador. Roberts and Robertson (1986), in their review of the ecology and distribution of the salt marshes of Atlantic Canada, indicated that the larger intertidal marshes of southeastern Labrador are typical delta complexes, i.e. with sediments supplied mainly by rivers. Numerous shallow ponds with boulders are generally present. Figure 7–16 provides a vegetation profile of a salt marsh at Groswater Bay in southeastern Labrador. Both *Salicornia europaea* and *Spartina alterniflora* are common constituents of this marsh, thus indicating an extension into Labrador of the characteristics of the salt marshes of insular Newfoundland.

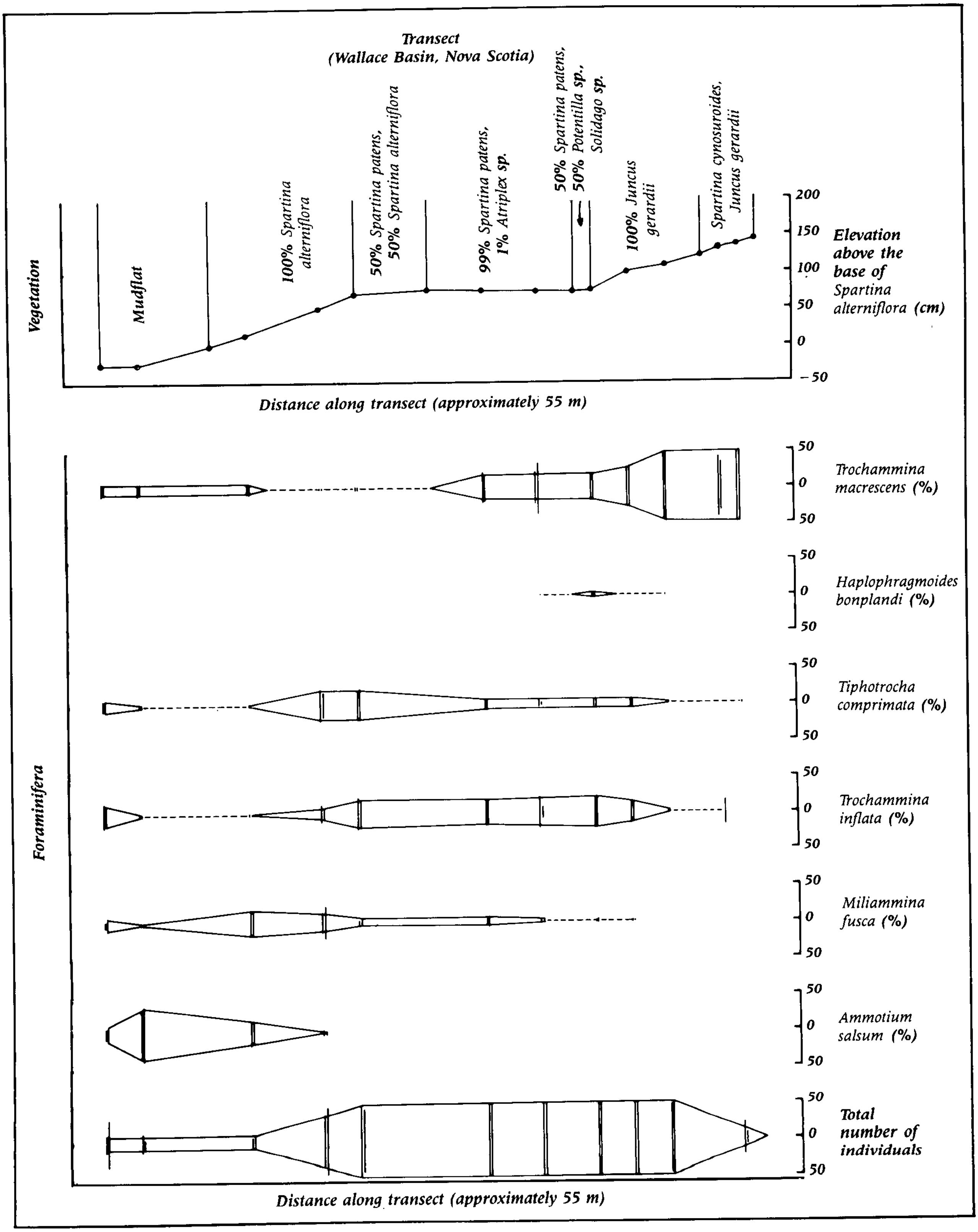
Nutrient Production

Salt marshes play a very important role in the food chains and primary productivity of estuaries throughout the world. The continuous cycling of nutrients between the marsh and the estuary replenishes the marsh with nutrients, promotes productive mollusc and crustacean growth in the estuary (Figure 7–17), and enhances offshore fisheries (Teal and Teal 1969). Rates of decomposition are high and essential compounds such as nitrates, phosphates, and various carbon-based units are quickly released into the ecosystem. The algae replace themselves in a matter of days, while bacteria may replace themselves within hours. The longest-living plants, the *Spartina* grasses, are annuals; hence, nutrients are not tied up for more than half a year as opposed, for example, to tens of years in a hardwood forest. Since the nutrients are



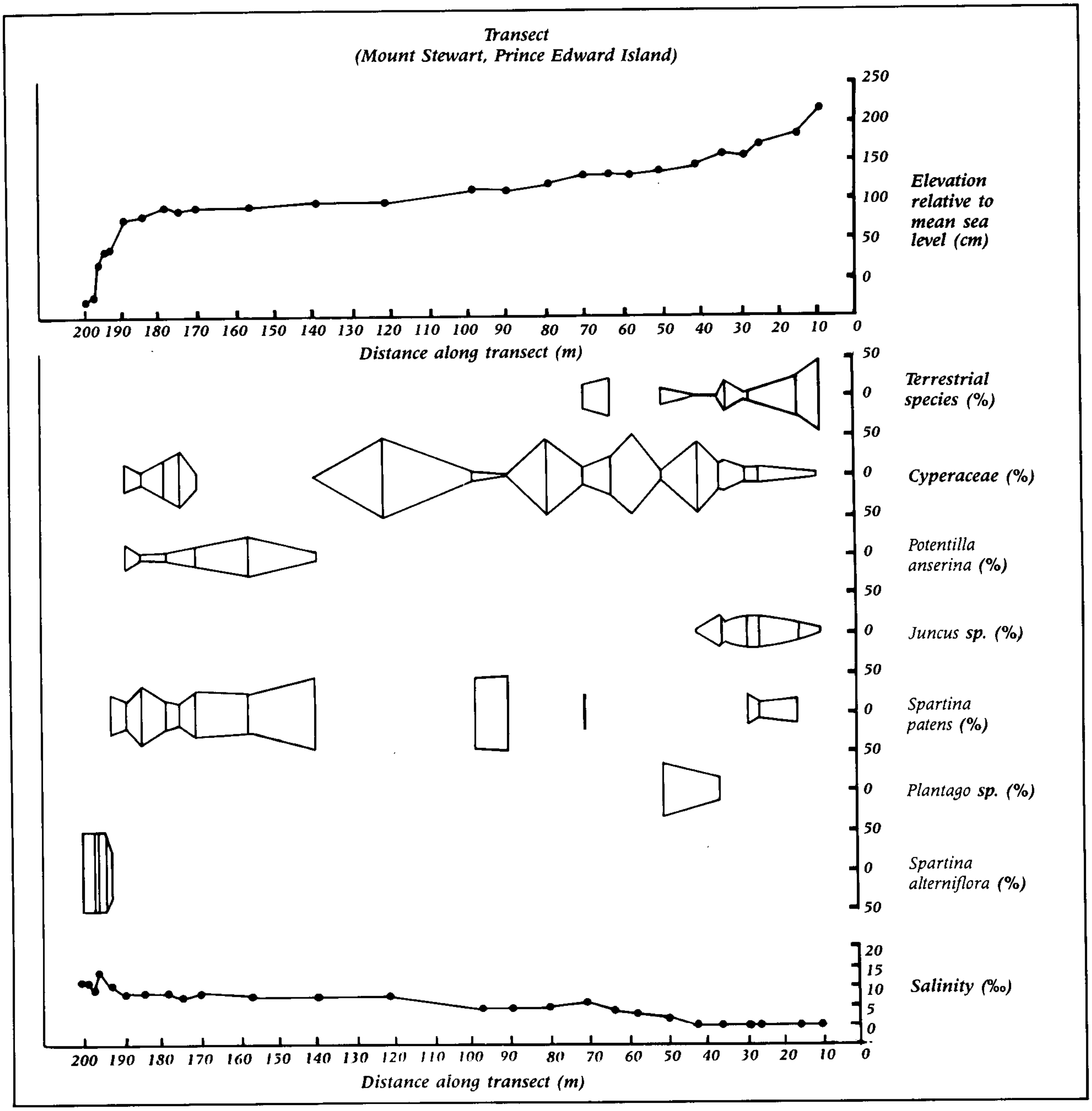
Source: Smith *et al.* (1984).

Figure 7–9.
Vegetation transect from Kingsport Marsh, Nova Scotia. Format same as that in Figure 7–7.



Source: Scott and Medioli (1980a).

Figure 7–10.
Vegetation–foraminiferal transect from Wallace Basin, Nova Scotia. Format same as that in Figure 7–7.



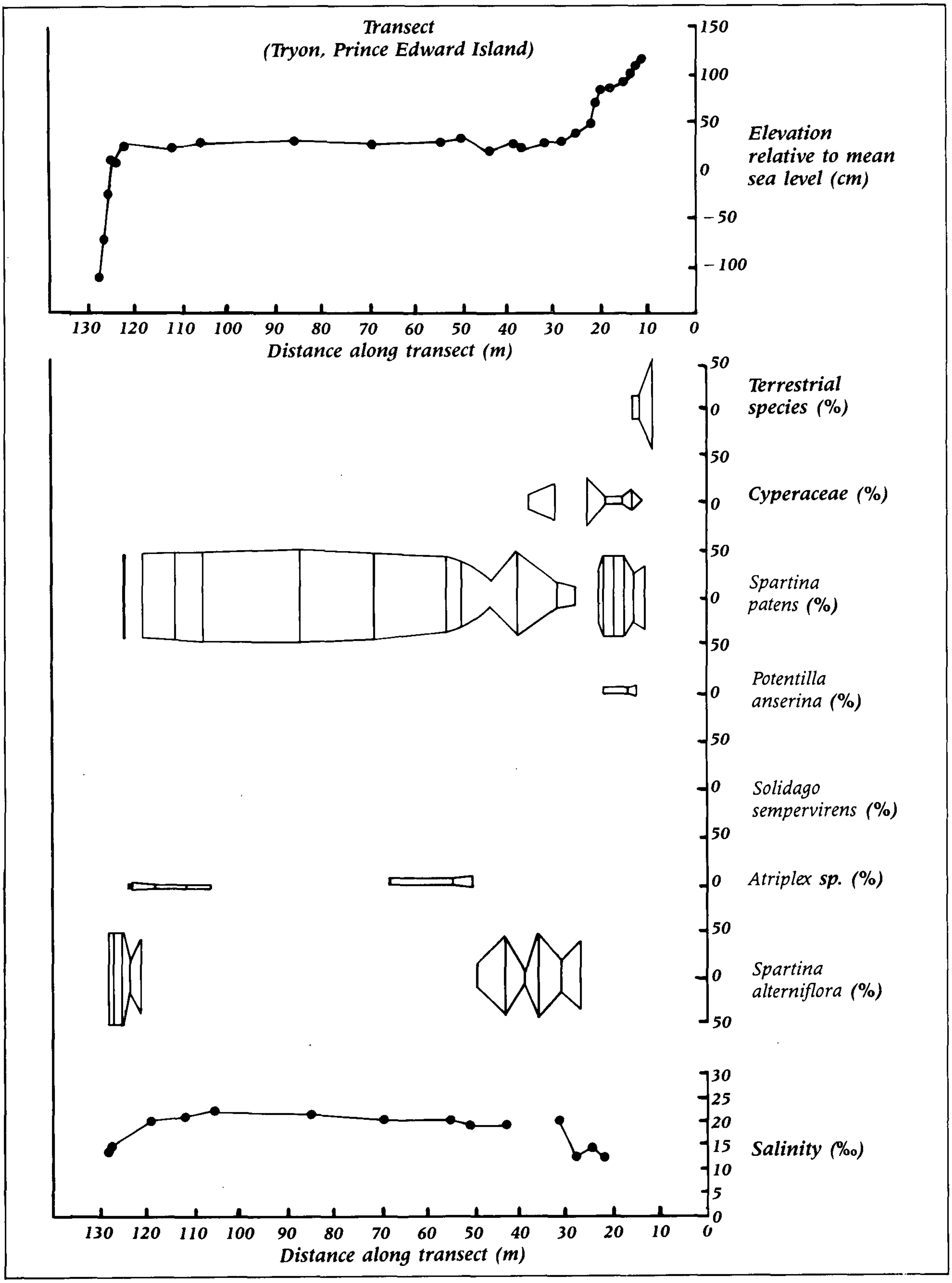
Source: Scott and Medioli (1978).

Figure 7–11.
Vegetation transect from Mount Stewart, Prince Edward Island. Note the confused pattern in the high marsh in this case. Format same as that in Figure 7–7.

rapidly released, there is little limitation of growth because of nutrient deficiency (Teal and Teal 1969).

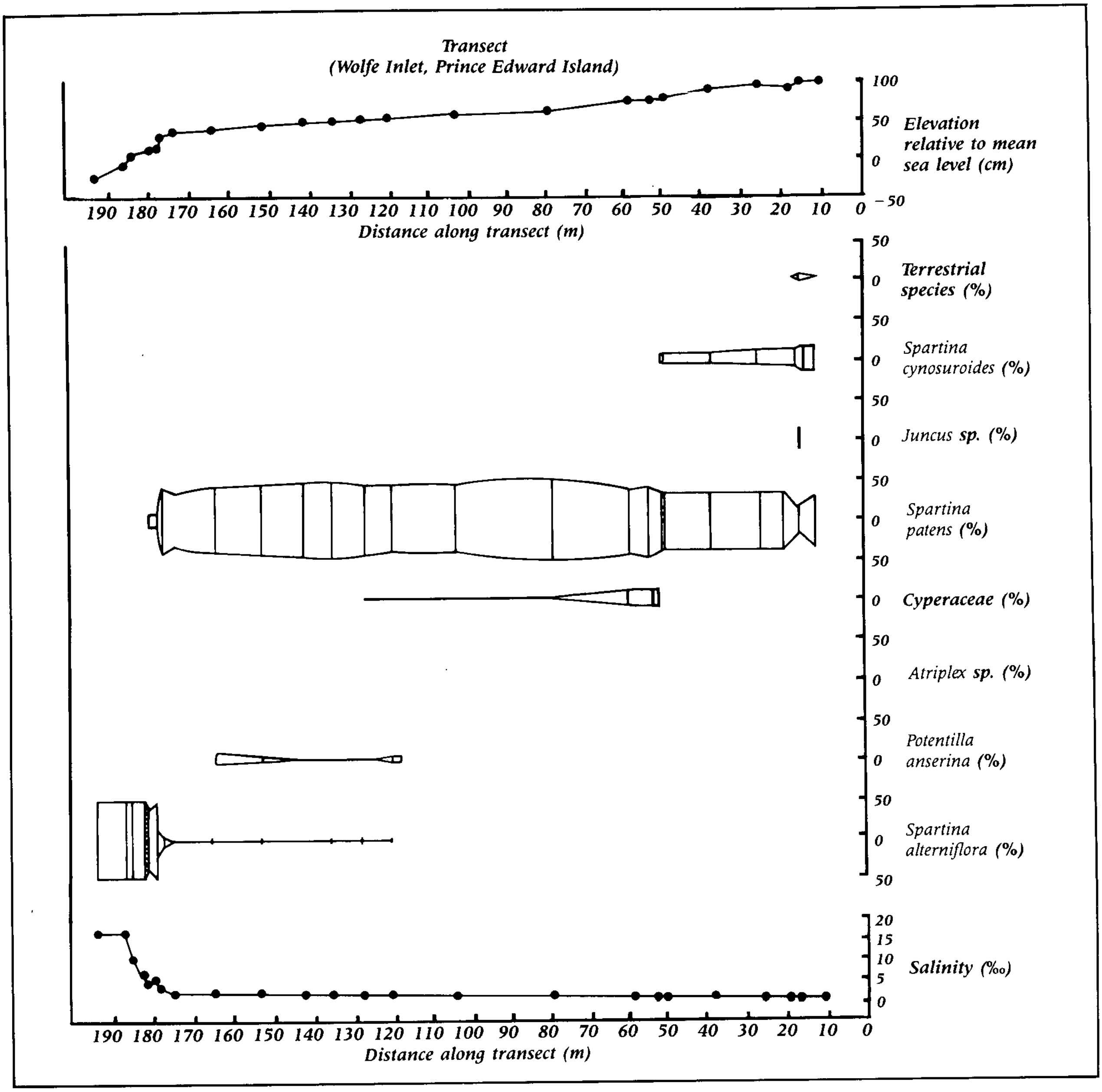
The marshes of Atlantic Canada are productive year-round, even though some plants (*Spartina* spp., for example) cease growing in the winter. Some algae continue to grow throughout the year, with a midwinter bloom. This year-round photosynthetic activity in the marshes keeps their productivity ahead of that of adjacent land areas (Teal and Teal 1969). The main colonizing grass of these marshes, *Spartina alterniflora*, has a highly efficient photosynthetic pathway which results in exceptionally high productivities in this area, compared with less efficient plants like *Carex paleacea* and *Spartina patens*. None of the nutrients are limited in a marsh and *Spartina alterniflora* may act as a "phosphorus pump", taking up phosphorus (P) from the sediments and releasing it into tidal waters (Hatcher *et al.* 1981).

No agricultural crop, except possibly rice or sugar cane, approaches the food production levels of a salt marsh, where approximately 22 000 kg of food per hectare of marsh can be produced an-



Source: Scott and Medioli (1978).

Figure 7–12.
Vegetation transect from Tryon, Prince Edward Island. Format same as that in Figure 7–7.



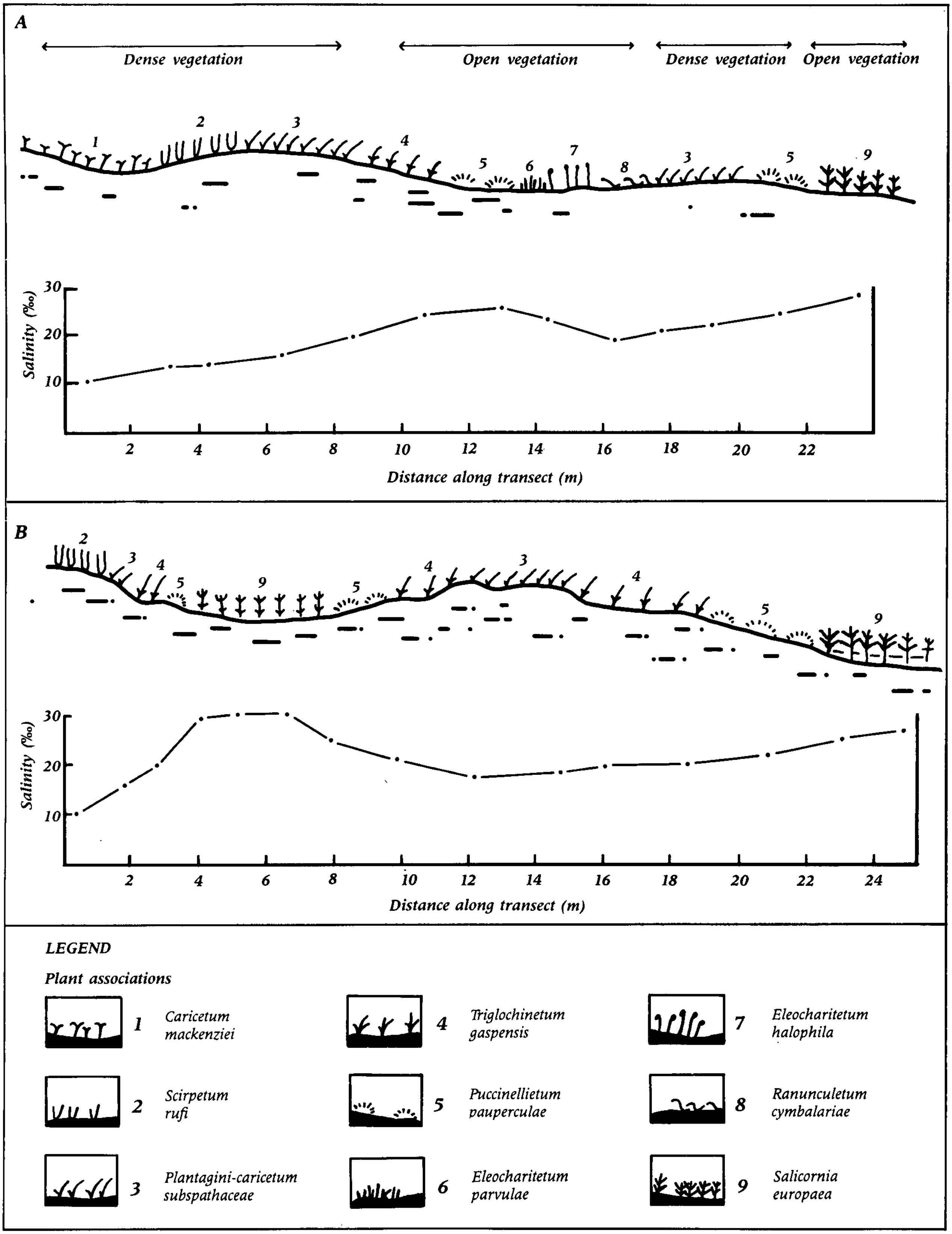
Source: Scott and Medioli (1978).

Figure 7–13.
Vegetation transect from Wolfe Inlet, Prince Edward Island. Format same as that in Figure 7–7.

Table 7–11. Distribution of shore marshes in the Quebec portions of the Gulf of St. Lawrence

Inventory area	Undifferentiated marsh	*Spartina alterniflora* marsh	*Spartina patens* marsh	Salt marsh	Total
	Area (ha)				
Estuary shores and islands	—	2 167	536	1 708	4 411
Gaspé Peninsula	—	93	37	1 090	1 220
Côte-Nord	—	88	—	1 249	1 337
Magdalen Islands	563	148	—	916	1 627
Total	563	2 496	573	4 963	8 595

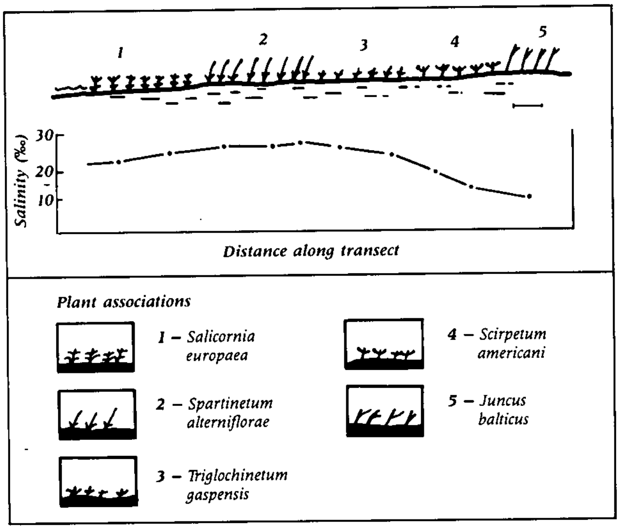
Source: Environment Canada (1986).



Source: Thannheiser (1984).

Figure 7–14.
The succession of vegetation in comparison to the distribution of salinity (percentage values in soil or water) in two salt marshes (A and B) near St. Paul's, Newfoundland.

nually. Insects use a small part of this food, but about one-half of the total is decomposed and available for detritus-eating organisms (Teal and Teal 1969). In Atlantic Canada, foraminiferal populations of up to 5 000 individuals have been observed in a 10 cm^2 marsh area (Scott and Medioli 1980b), while the number of foraminifera observed in adjacent estuarine areas is ten to a hundred times less (Scott *et al.* 1981).

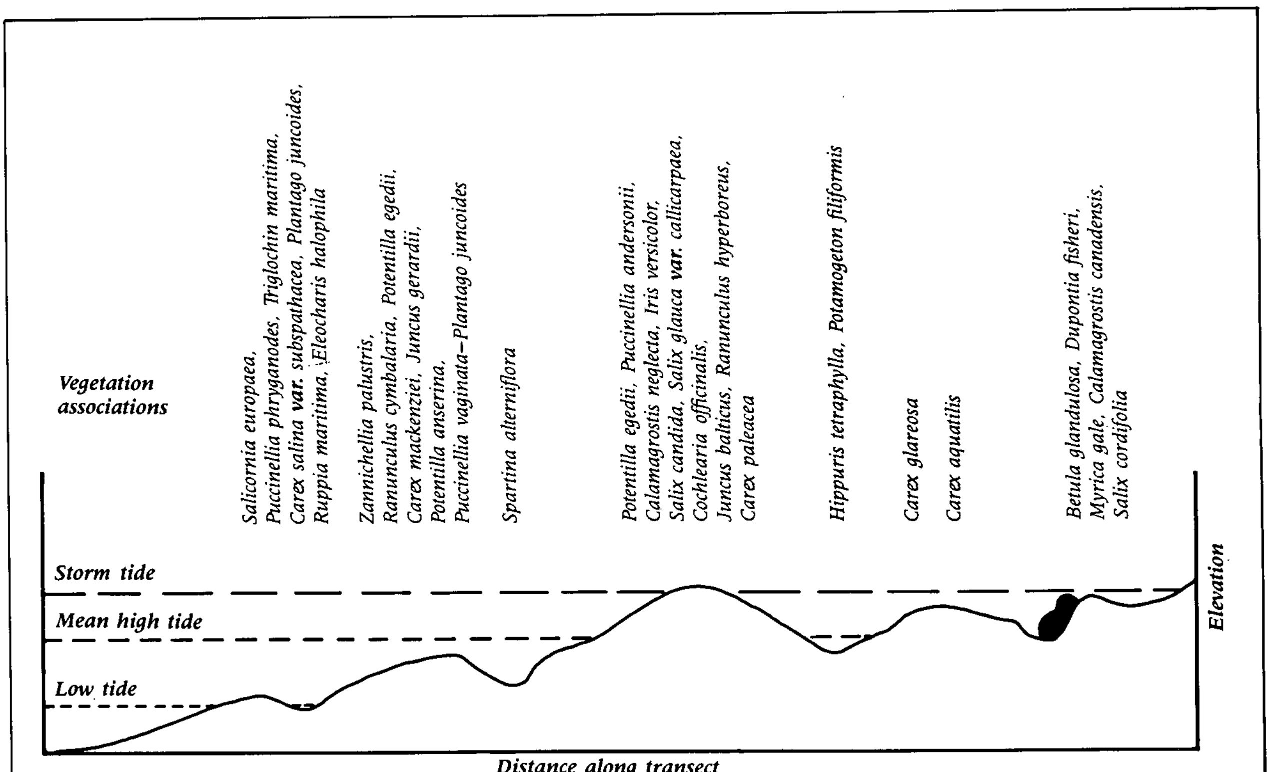


Source: Thannheiser (1984).

Figure 7–15.
Cross-sectional diagram through a salt marsh near Stephenville Crossing, Newfoundland, showing distribution of plant associations and salinity in soil or water.

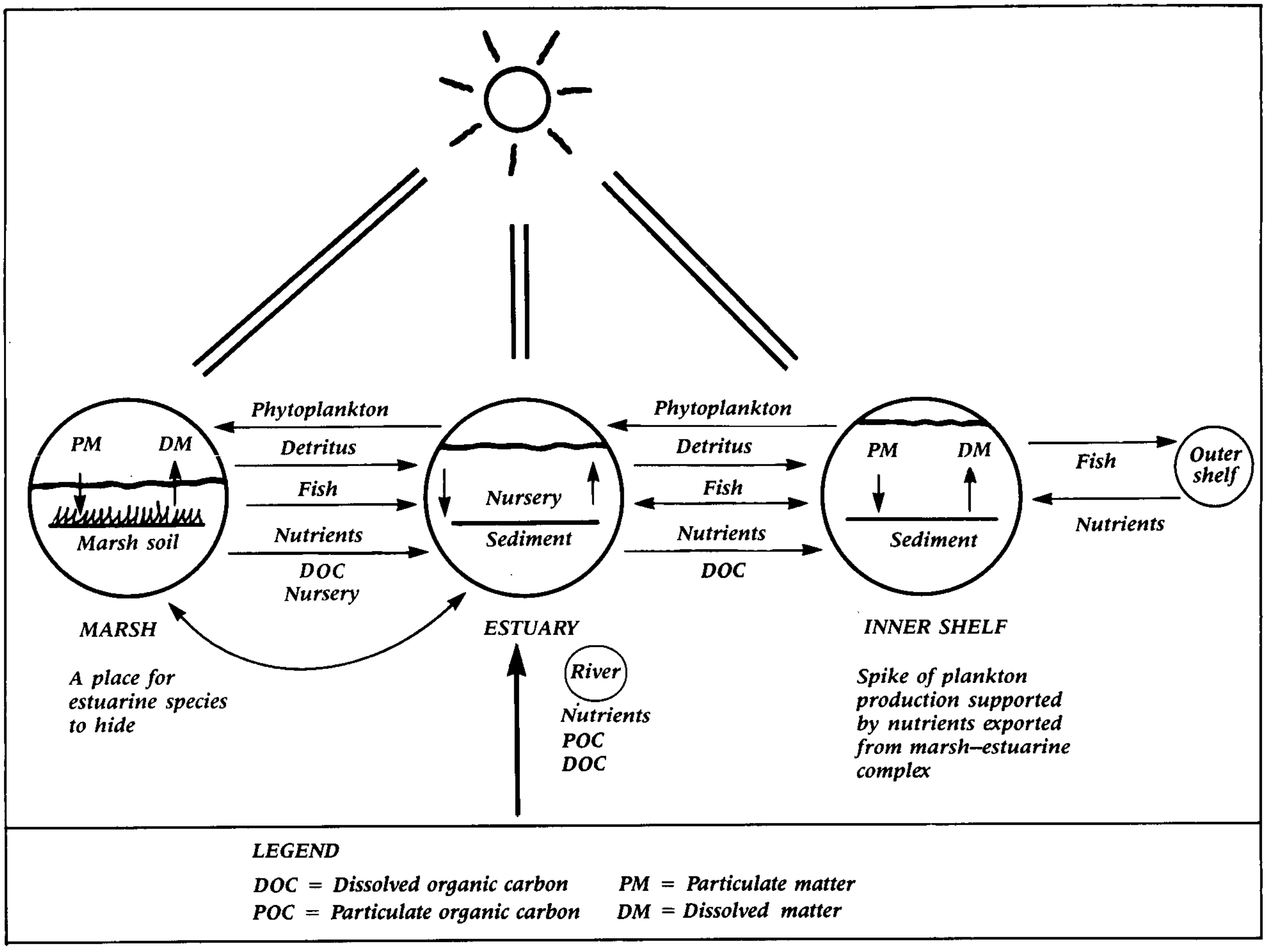
Rates of nitrogen fixation are often substantial in salt marshes. This process can occur on the mud surface in association with algae, or can be produced around plant roots by nitrogen-fixing bacteria (Hatcher *et al.* 1981). One study carried out at Conrads Beach, Nova Scotia (Hatcher *et al.* 1981), estimated annual nitrogen fixation production at 115 kg/ha/yr, of which 92 kg/ha/yr occur below the mud surface.

Studies of marshes bordering bodies of water with normal tidal ranges suggest that the amounts of combined nitrogen imported into these marshes each season are insufficient to account for observed productivity (Smith *et al.* 1979). High levels of nitrogen fixation are characteristic of these marshes (Carpenter *et al.* 1978; Patriquin and McClung 1978; Patriquin and Keddy 1978), and may supply the balance of nitrogen required. Even so, these marshes are considered to be nitrogen-limited (Valiela and Teal 1974; Broom *et al.* 1975).



Source: Roberts and Robertson (1986).

Figure 7–16.
Vegetation associations along a salt marsh profile at Groswater Bay, southeastern Labrador.



Source: Hatcher *et al.* (1981) after Haines (1979).

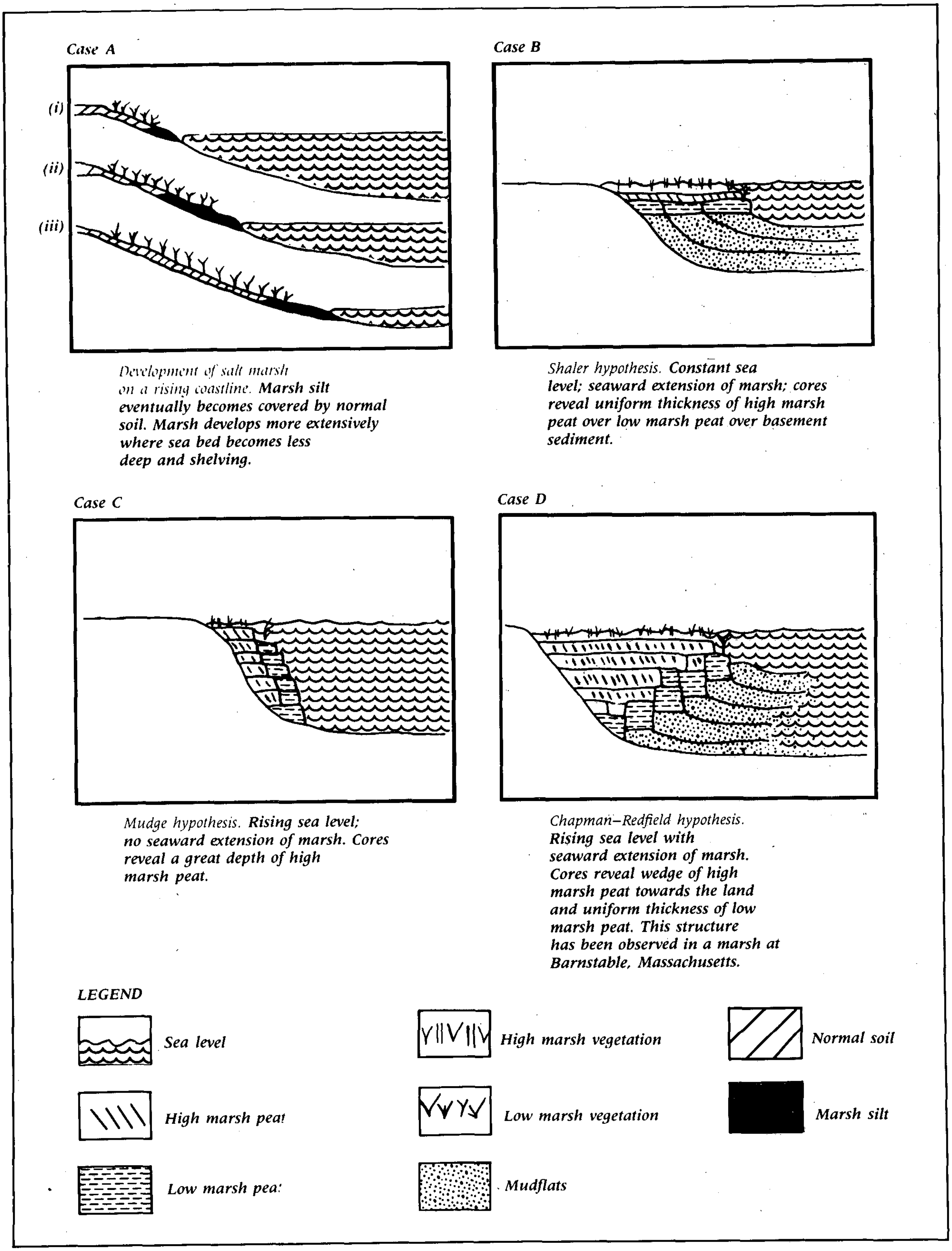
Figure 7–17.
Dynamics of nutrient movement in a marsh–estuarine system. A spike of production outside the estuary acts as a sponge for nutrients coming out of the estuary and originating in the marsh. Plankton, in turn, is carried back into the marsh–estuary, providing high-quality food for filter feeders.

The rates of below-ground nitrogen fixation in the Minas Basin marshes of Nova Scotia are much lower than those reported for other Atlantic marshes, supplying only about 7.5% of the "angiosperm requirement", indicating that the growth of angiosperms may be limited by the shortage of nitrogen (Smith *et al.* 1979). Nitrogen fixation can be inhibited by the external addition of combined nitrogen (Shanmugan and Morand 1974; Burns and Hardy 1975). The high current velocities in the Minas Basin, carrying large loads of suspended matter, may supply this additional nitrogen. Smith *et al.* (1979) suggested that Minas Basin marshes, unlike Atlantic coast marshes, are not nitrogen-limited, with high levels of soil nitrogen being supplied by the strong tidal currents.

The marshes in the John Lusby Provincial Wildlife Area at Amherst, Nova Scotia, have a lower nitrogen productivity than Northumberland Strait or Atlantic coast marshes (Morantz 1976). The Amherst area has a tidal range of 15 m, and since the marshes are restricted to the upper 4 m of this range, they receive much less tidal flooding than other marshes which are flooded at almost every high tide. Impoundments for waterfowl on the Bay of Fundy marshes impede tidal flow but actually enhance primary productivity by retaining the tidal water for a longer period (Morantz 1976).

Origin and Development of Salt Marshes in Atlantic Canada

The formation and development of salt marshes are controlled by tides, tidal ranges, sedimentation, and land submergence and/or changes in sea level (Figure 7–18). Harrison and Bloom (1977) indicated that (1) the vertical range of the marsh is controlled by the positions of higher high water and mean sea levels, and (2) higher tidal ranges increase sedimentation rates, which consequently promote faster marsh colonization. However, in the Bay of Fundy where tidal ranges are greater



Source: Hatcher *et al.* (1981) after Chapman (1974).

Figure 7–18.
Four possible ways of marsh formation.

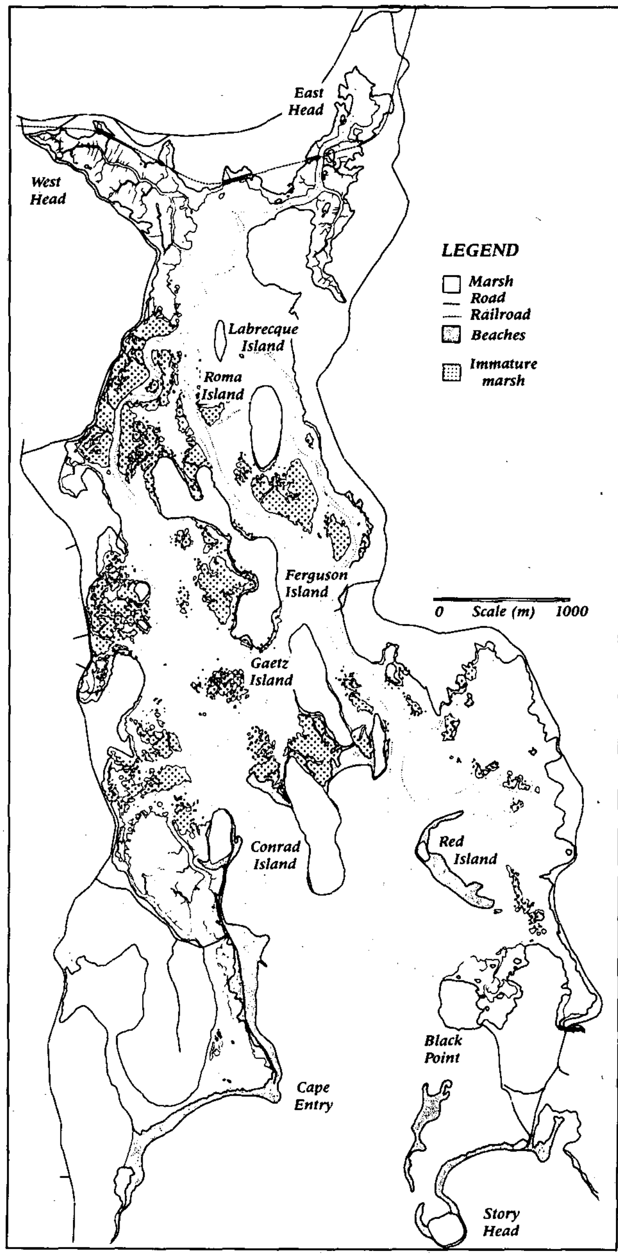
than 7 m, the vertical relationship of the marsh to tidal levels no longer exists. The largest absolute range is 3–4 m so that, in an area where the tidal range is 16 m, the marsh will occupy only the upper one-quarter rather than the upper one-half of the range (Scott and Medioli 1980a; Smith *et al.* 1984). Similarly, the rapid development since 1950 of marshes in Chezzetcook Inlet, Nova Scotia, may be attributed to an increased sediment supply directly related to road construction at that time (Figure 7–19). The high sediment load distributed over the mudflat surface raised that surface sufficiently to allow colonization by *Spartina alterniflora*.

All coastal areas in Atlantic Canada are currently submerging, except for the Labrador coast which is still emerging either because of a larger initial ice load or because of later ice retreat. The coast of Nova Scotia has been submerging for at least 7 000 years (Scott and Medioli 1982), while most areas in the Bay of Fundy have been submerging for the last 5 000–7 000 years (Scott and Greenberg 1983). On Prince Edward Island, submergence with a strong tilt from one end of the island to the other is not as great as in Nova Scotia (Scott *et al.* 1981). In Newfoundland, most areas are now submerging after experiencing significant emergence after deglaciation (Brookes *et al.* 1985). There are no specific data from Labrador but marsh soils observed there are shallow (a few centimetres), resting directly on glacial moraine or gravel, with no evidence of long-term deposition. The existence of these shallow deposits suggests that the coast is emerging.

The trend of sea-level movement directly affects how marshes form. In Quebec, where substantial emergence is still occurring, marshes are continually colonizing downslope as the water level drops. Marsh deposits are thin, usually never more than 1 m in accumulation, and basal portions consist of low marsh deposits, overlain by high marsh, and finally graduating into freshwater wetlands as the area emerges out of the marine influence.

In Newfoundland, the relatively few marshes that exist consist of thin, surficial deposits. This characteristic could be the result either of very slow sea-level rise, or of lack of sediment supply, or both. In other areas of Atlantic Canada, where submergence is occurring, marshes form in an opposite sequence: as the sea level rises, the high marsh colonizes higher on the shore, with the result that basal marsh deposits are those of high marsh, rather than low marsh, and thick accumulations of marsh occur (Scott 1980). Usually marsh growth keeps pace with rising sea level; however, if it does not, the marsh peat is buried by intertidal muds.

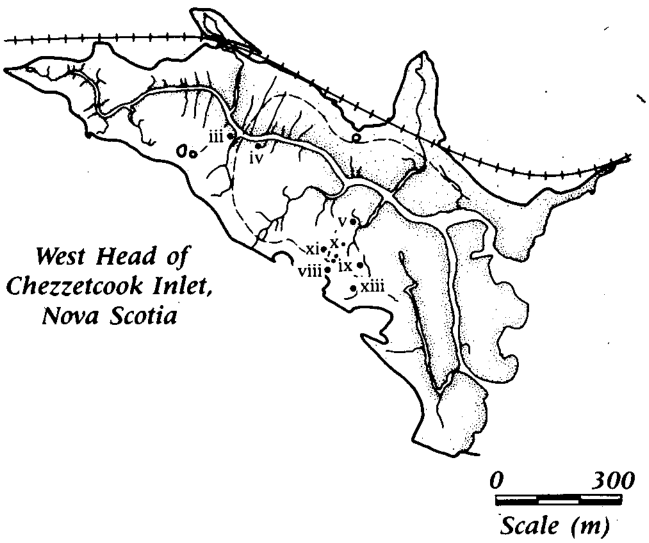
The longest marsh–estuarine sequence cored on the Atlantic coast is in a Chezzetcook Inlet marsh (Figure 7–20). It reveals a basal freshwater peat with a sharp contact to salt marsh, which



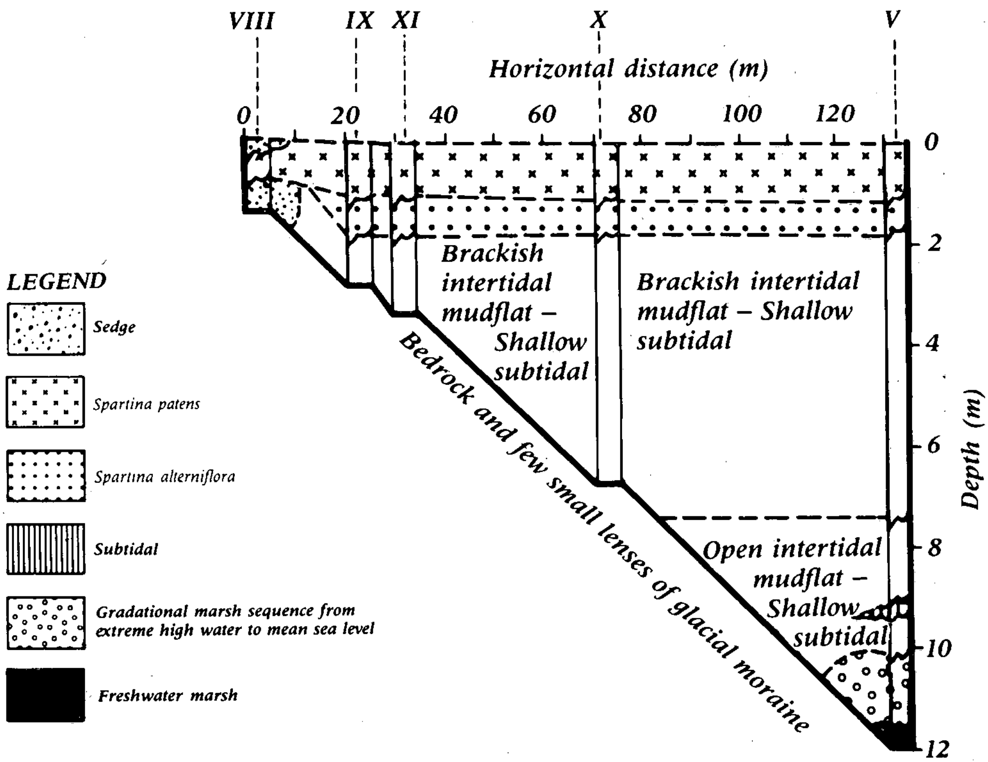
Source: Scott and Medioli (1980a).

Figure 7–19.

*A 1974 map of Chezzetcook Inlet, Nova Scotia, showing immature (*Spartina alterniflora *only) marshes and mature marsh (all zones developed).*



(A) Enlargement of the West Head at Chezzetcook Inlet, Nova Scotia, showing the position of drill holes. The dashed line represents an approximation of the maximum mudflat extent; iii–xiii are drill hole numbers.



(B) Drill hole stratigraphy from the West Head based on foraminiferal content in the sediments; V–XI are drill hole numbers.

Source: Scott (1980)

Figure 7–20.

(A) Marsh map and (B) stratigraphy from Chezzetcook Inlet, Nova Scotia. The freshwater sequence has been radiocarbon-dated at 9 600 years before present while the salt marsh overlying it is dated at 5 000 years before present and represents a sea level 11 m lower than present.

quickly grades into intertidal mudflats and only recently has reverted to marsh (Scott 1977, 1980). The advent of marsh formation 200 years ago can be directly linked to European settlement, in which clearing of adjacent land caused increased sedimentation. The increase in sedimentation rate was sufficient to raise the land surface to allow marsh colonization. Once the marsh started to form, it trapped more sediment and aided in its own extension. In the late 1940s, more marsh suddenly formed in the inner part of the estuary ("immature marsh", as indicated in Figure 7–19). This formation can be directly linked to the effects of road building, as previously described.

Several marshes around the Bay of Fundy have also been cored (Figure 7–21). Results show similar stratigraphies with basal high-marsh peats overlain either by mudflat sediments or by a long sequence of marsh deposits, as seen at Kingsport, Nova Scotia. The tidal range appears to be of little importance in the overall sequence: marshes at both Chebogue, with a tidal range of only 5 m, and Fort Beausejour, with a 16 m tidal range, do not have a continuous marsh sequence. However, Kingsport and Mary's Point, both with ranges of 16 m, have a continuous marsh sequence. On Prince Edward Island, marsh sequences are continuous but much thinner (Scott *et al.* 1981) than those observed in the Bay of Fundy and Atlantic coast areas. The thickness of sequences may, in part, be a result of local topography rather than of sea level or sedimentation rates. Estuaries on the Atlantic coast appear to be more deeply incised into bedrock than those on Prince Edward Island; hence, estuarine deposits are not as thick on Prince Edward Island.

Atlantic Freshwater Marshes

Much of the topography of Atlantic Canada is characterized by undulating lowlands and hummocky plateaus which, together with the relatively high precipitation, influence the formation of freshwater wetlands. Marshes, which account for up to 30% of the wetlands in Nova Scotia and New Brunswick, 50% in Prince Edward Island, and less than 10% in Newfoundland (National Wetlands Working Group 1979, 1986), have developed where sufficient nutrient-rich sediments have accumulated (Weller 1981). Although small in terms of total area, they are diverse and productive ecosystems that support a variety of plants and animals. Three major groups of marshes have been defined for Canada (Tarnocai 1980): (1) "catchment" basin marshes (terminal basin form); (2) "fluvial" marshes (floodplain, stream, channel, and active delta forms); and (3) "lentic" marshes (shore form). Since all these forms of marsh occur throughout Atlantic Canada, a brief description of each is presented.

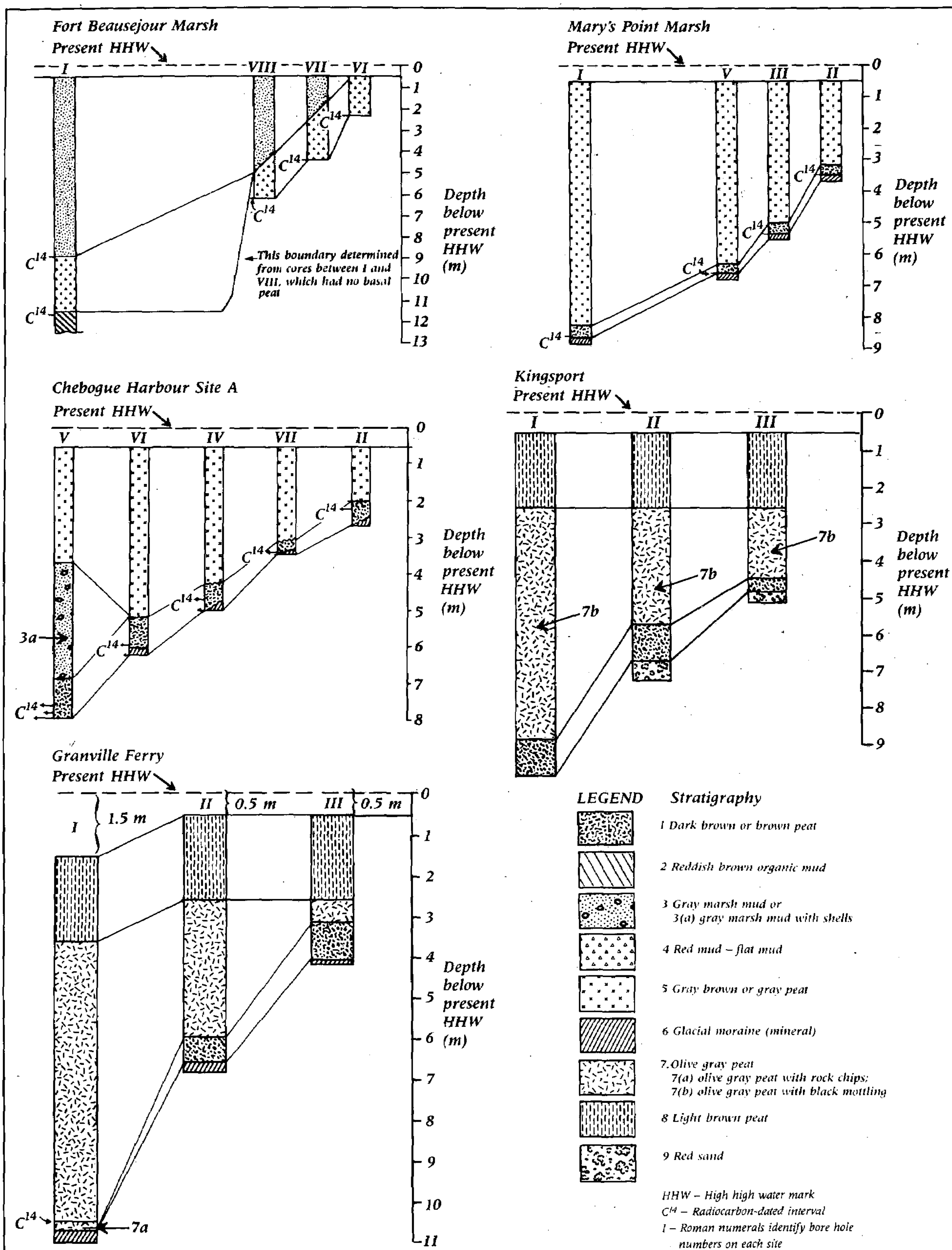
A terminal basin marsh has a well-defined basin filled with water and is usually fringed with robust emergent vegetation. Water is supplied from rainwater or snowmelt, small brooks, and occasionally through seepage from groundwater springs. The open water of the basin is generally shallow, less than 1 m deep, and a mucky organic bottom soil supports submergent and floating aquatic plants.

Fluvial marshes, usually in deltas and floodplains, are associated with rivers and are subject to seasonal flooding and deposition of silt. Portions of the marsh may dry out at times during the year; oxbow lakes are often formed during the frequent changes in river courses that occur on these dynamic sites. Fluvial marshes support a diversity of rushes, sedges, and grasses, and dry meadows may frequently predominate. Because they often drain large areas, such floodplain and delta sites constitute Canada's richest and most extensive marshes. In areas of low relief, flushings and floodings result in high rates of sedimentation on deltas, floodplains, and oxbow lakes. Frequent flooding and siltation provide a renewal of nutrients sustaining a rich, highly interspersed, and diverse marsh vegetation (Figure 7–22). The vegetation of these marshes is characteristically dominated by species such as *Equisetum fluviatile* which have a high tolerance to widely ranging water levels.

Shore marshes are formed where gravel, sand, and soil, deposited along the shores of major lakes by wave, wind, or ice action, create a marginal basin that traps water moving from the surrounding watershed. Once sufficient sediments accumulate, marsh plants can flourish. Periodic re-flooding from the lake recharges the nutrients of both marsh and lake.

Formation and Development of Freshwater Marshes

Most wetland basins are formed by tectonic activity, water movement, glacial action, or soil slip-



Source: Scott and Greenberg (1983).

Figure 7–21.

Several lithologic stratigraphies from areas around the Bay of Fundy.

page (Weller 1981). Throughout Atlantic Canada, glacial action has greatly re-formed the land surface; thus, some areas contain biologically richer wetlands than others because the productivity and location of individual marshes are influenced by climate, soil type, water depth, nutrient input, and topography.

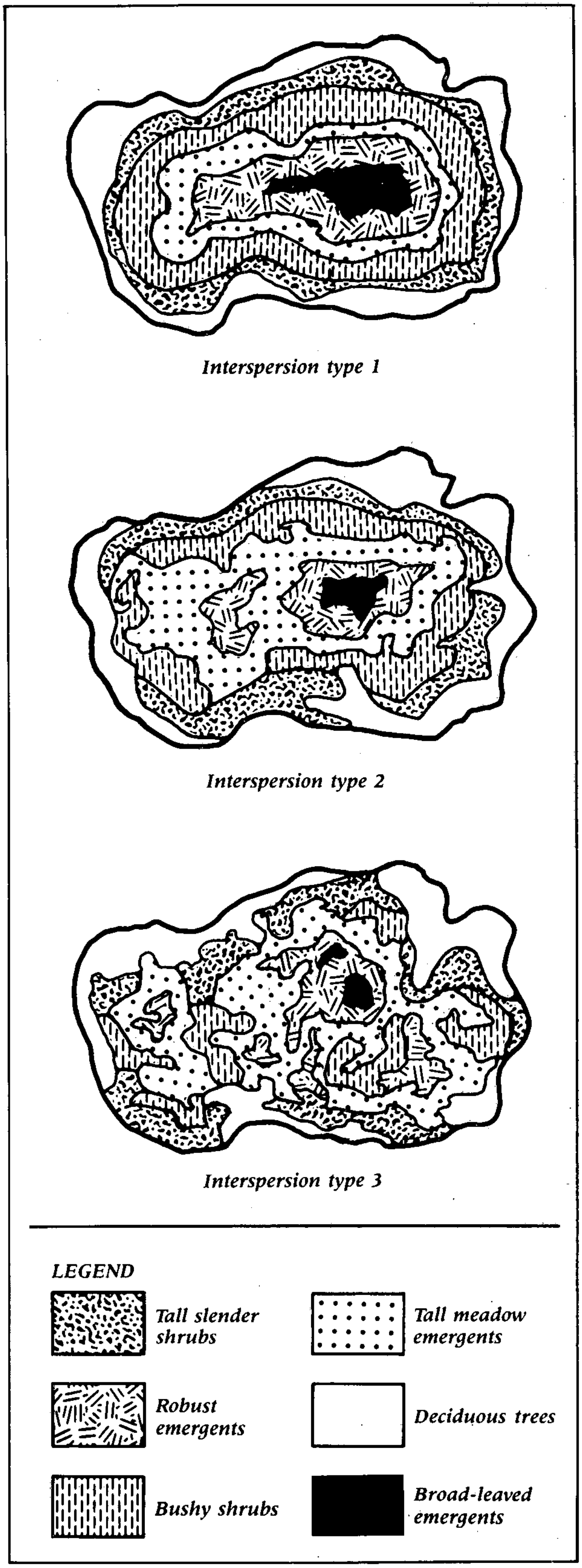
In Atlantic Canada, the beaver (*Castor canadensis*) plays an important role in terminal basin marsh formation. The flooding of backshores as a result of beaver dams causes input of organic matter and hence enrichment of the water. Furthermore, the damming of ponds, lakes, or brooks retards drainage and increases sedimentation, which provides the stratum for aquatic and semiaquatic plant growth. Development of such a wetland generally occurs from the outer edge of the basin towards the centre, producing a linear and concentric arrangement of vegetation zones. The more dissected and heterogeneous patterns are most common on fluvial marsh forms (Figure 7–22).

Decaying and non-decaying plant material adds to the rate of sedimentation, and marsh sites become progressively shallower. A hypothetical succession of open water through different marsh stages is presented in Figure 7–23. The major influencing factors are water depth and the effects of animal activities, especially those of beaver and muskrat (*Ondatra zibethicus*). The entire process requires hundreds of years to reach the local climax terrestrial vegetation stage. However, succession from open water to rich emergent marshes can occur within a decade under certain conditions, such as in a shallow catchment basin with an existing stock of marsh plants. Dynamic systems associated with fluvial marshes often display an array of marsh development stages. The hydrological influences of major river systems can result in a reversal of succession patterns, as shown in Figure 7–23. Under such conditions, high rates of vegetation decomposition can balance the rates of vegetation productivity; consequently, the sites remain as marshes indefinitely.

Distribution of Freshwater Marshes in Atlantic Canada

Nova Scotia

Bogs, shrub swamps, and fen complexes occur along streams on the Atlantic coast. These streams



Source: Golet (1972).

Figure 7–22.
Vegetation interspersion types.

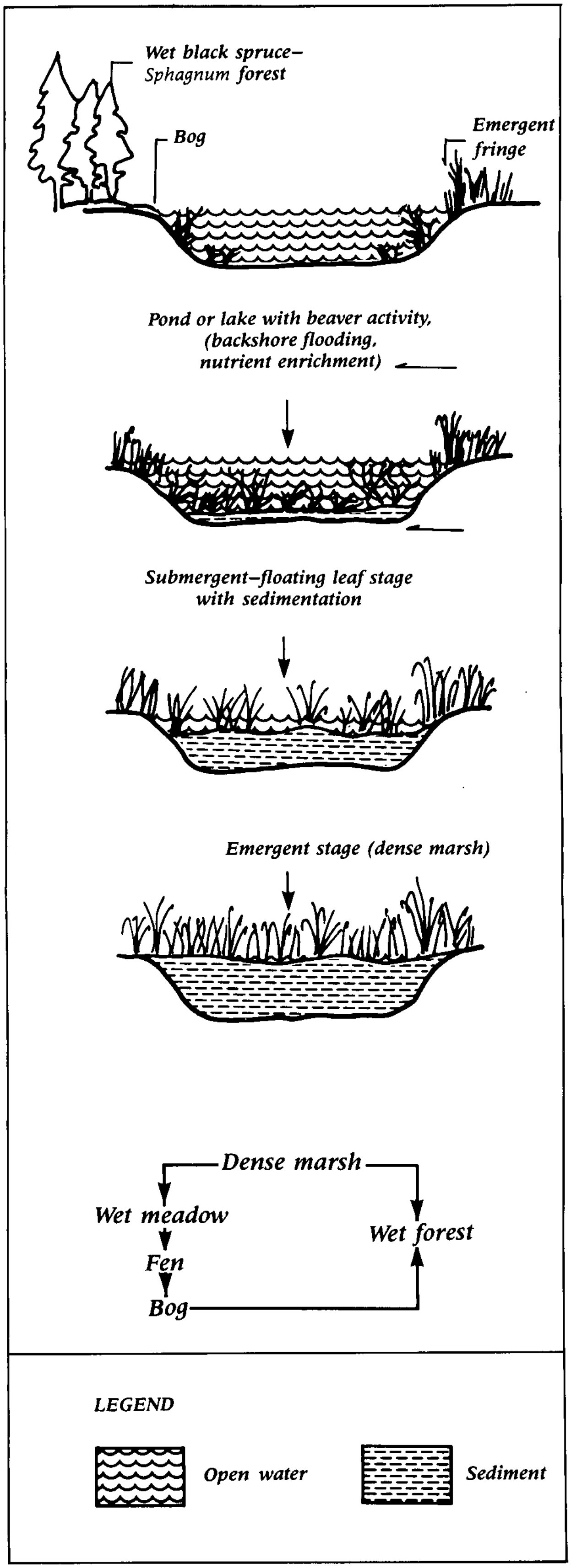


Figure 7–23.
Theoretical origin and succession of a freshwater basin marsh.

and wetland sites are generally oligotrophic with a low pH (6.5 or less) and low concentrations of minerals and nutrients. However, the largest expanse of freshwater marsh occurs in the Amherst–Sackville area linking Nova Scotia and New Brunswick. This area, the Tantramar Marshes, contains thousands of hectares of cattail marshes and abandoned diked and ditched lowlands.

Cattails and bulrushes are important components of freshwater marshes in Nova Scotia. Shallow water depressions and open water are characterized by aquatic plants such as yellow water lily (*Nuphar variegatum*), white water lily (*Nymphaea odorata*), water shield (*Brasenia schreberi*, particularly abundant in northern Nova Scotia), floating heart (*Nymphoides* spp.), pondweeds (*Potamogeton* spp.), burreeds (*Sparganium* spp.), sweet flag (*Acorus calamus*, particularly abundant in northern Nova Scotia), wild calla (*Calla palustris*), arrowhead (*Sagittaria* spp.), duckweeds (*Lemna* spp.), water smartweeds (*Polygonum* spp.), bladderworts (*Utricularia* spp.), coontail (*Ceratophyllum* spp.), water milfoils (*Myriophyllum* spp.), and pickerel weed (*Pontederia cordata*).

Rich floodplains are found along the Musquodoboit, Annapolis, and Margaree rivers. Depending on the degree of siltation and local topography, meadow and marsh emergents occur with aquatics and floating plants in slow-moving waters. Shrubs, such as alder (*Alnus rugosa*), sweet gale (*Myrica gale*), and hardhack (*Spiraea latifolia*), may form pure stands.

New Brunswick

The most significant freshwater marsh wetland sites in New Brunswick are in the floodplain that dominates the Saint John River Valley, southeast of Fredericton. This floodplain affects large areas of adjacent lakes, streams, and lowlands, seasonally resulting in a series of associated rich ponds, meadows, and shrub swamps.

In general, New Brunswick soils are relatively nutrient-poor and marshes are restricted to occasional natural terminal basins and areas of beaver activity along streams. Locally, richer bedrock in the northwest and southeast (Sussex area) increases the productivity of some wetlands found there. The eastern lowlands occupy a large triangular area from south–central New Brunswick to Chaleur Bay and along the coast to those of the Nova Scotia border. The level landforms impede drainage so that peatlands are more common.

The Bay of Fundy coastal wetlands are usually associated with poorly drained areas abandoned by agriculture and later developed as wetlands (Rowe 1972). Overall, somewhat higher pH values are found in the marshes of New Brunswick than in those of Nova Scotia; however, the vegetation is similar to that of the Nova Scotian marshes.

Prince Edward Island

Prince Edward Island consists of a fertile substrate of red, sandy loam overlying sandstone. The alkalinity and nutrient content of the waters are generally high, i.e. the waters are neutral to slightly alkaline. Marshes of limited size (20 ha or less) often contain flora indicative of rich substrates, such as *Sparganium eurycarpum*, *Lemna* spp., and *Spirodela polyrhiza*; emergent vegetation is dominated by cattails (*Typha* spp.) and bulrushes (*Scirpus* spp.). The vegetation of most marshes in Prince Edward Island is typical of the closed, emergent phase depicted in Figure 7–23, a direct result of the shallow waters and overall high fertility produced by high concentrations of nutrients such as phosphates, nitrates, and especially calcium (Ca) (R. Dibblee, personal communication).

Newfoundland and Labrador

The undulating topography of glacial deposits, typical of much of central and eastern Newfoundland, is dotted with small catchment basins where, in association with beaver activity, localized marshes have developed. The development of marshy bays on most lake systems is restricted by wave action, coarse sediments, and acid waters which are low in available nutrients, especially phosphate, which is a limiting nutrient in many wetland areas of Atlantic Canada (J. Kerekes, personal communication; Ostrofsky and Duthie 1975). Most terminal basin marsh sites contain extensive areas where *Sphagnum* mosses are infilling. In Labrador, terminal basin marshes are absent outside the more fertile Lake Melville ecoregion (Lopoukhine *et al.* 1977). The infertile backshores of spruce–lichen forest provide little substrate input for marsh development, and many terminal basin sites exhibit areas of *Sphagnum* encroachment and lack any significant emergent growth. Significant fluvial marshes occur in Labrador in the more protected river valleys, such as the delta of Snegamook Lake, and along the rivers and brooks of the Lake Melville area, such as Flatwater Brook. Beaver are scarce over much of interior Labrador.

The central plateau of interior Labrador contains extensive wetlands. In the south these are primarily string bogs (as described in Table 7–4), but there is a trend towards a predominance of the richer Atlantic ribbed fens in the north–central areas. There are extensive areas of wetland complexes in the Smallwood Reservoir ecoregion (Lopoukhine *et al.* 1977) which often show affinities to Atlantic ribbed fens, string bogs, and terminal basin marshes. The latter sites lack the strong patterning of peatlands and generally have deeper water (1–3 m). Extensive sedge-dominated shore marsh (*Carex limosa*, *Carex livida*, *Carex oligosperma*) occupies the fringes of the circular water bodies and dense emergent mats are frequently present. These sites may be in the early stages of transition to ribbed fen development.

Newfoundland and Labrador marshes consist mainly of sedges, such as *Carex rostrata*, *Carex lasiocarpa*, *Carex aquatilis*, and *Carex oligosperma*; they especially dominate marsh sites in the northern portion of these areas where water and sediments are frequently nutrient-poor and acid. Bulrush (*Scirpus acutus*) and cattail (*Typha latifolia*) are confined mainly to western Newfoundland where water and soils are more fertile. Shrubs, especially *Myrica gale*, provide major cover in conjunction with sedges on the wet meadow portions of marsh sites, which are often the most extensive and obvious. Figure 7–24 presents the distinguishing vegetation of marshes commonly encountered on the Atlantic coast. Vegetation zones are governed by moisture regimes; for example, marsh–meadow areas are at or above the water table during summer, while emergent zones are usually inundated throughout the year. Many birds are important to marshes, and the habitats of some of the marsh species that are more significant for the Atlantic coast are also indicated in Figure 7–24. Each wildlife species utilizes specific areas or zones within a marsh.

Importance of Freshwater Marshes to Wildlife

Marshes provide some of the richest wildlife habitat. In many of the vast stretches of inland barrens in Newfoundland and Labrador, a river delta or floodplain functions much like an oasis in a desert, and most species exploit the food and cover contained there. Herbivores consume the diverse array of tender herbs, grasses, and sedges that grow so abundantly on the rich mineral and

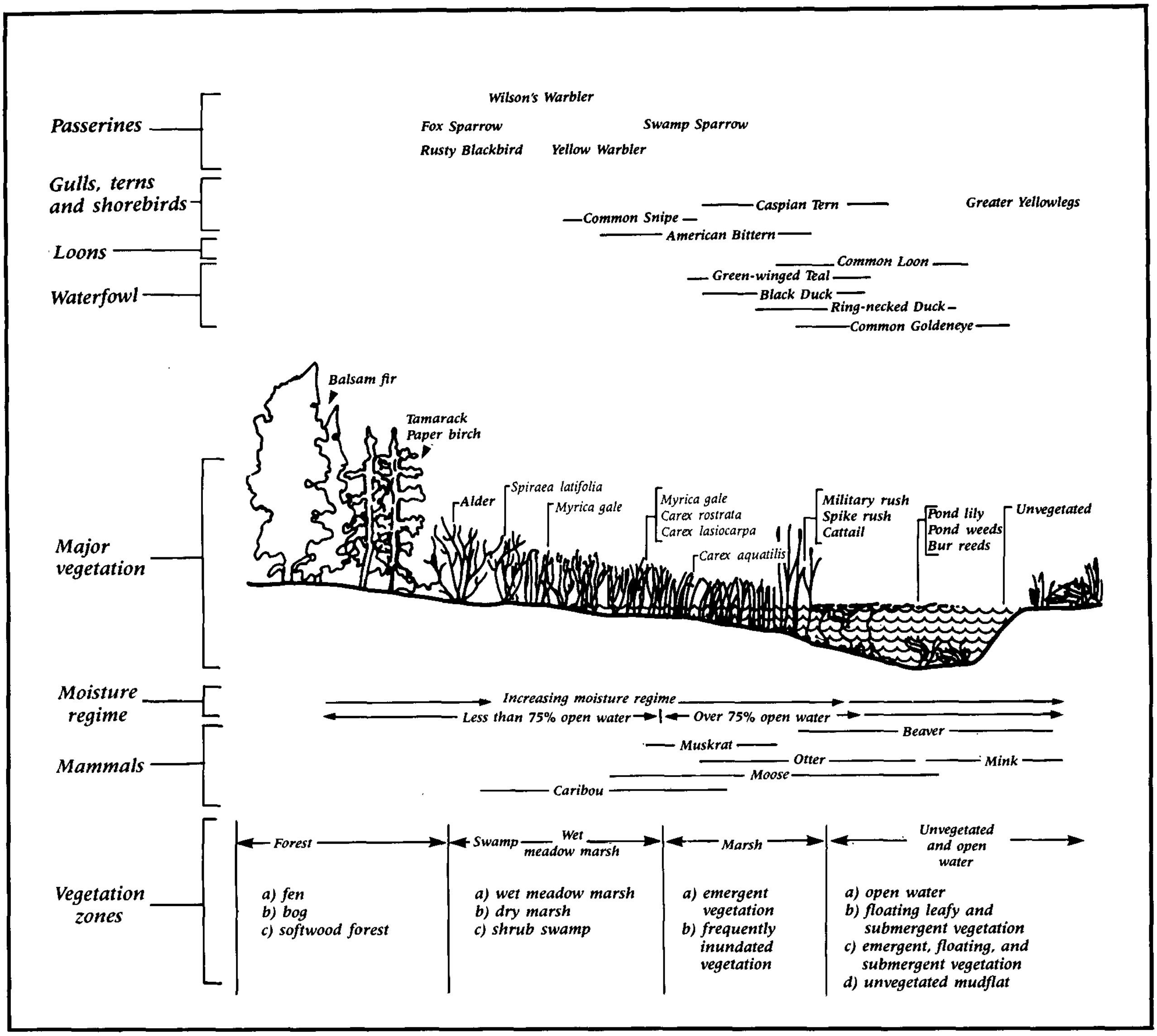


Figure 7–24.
Major vegetation zones and associated flora and fauna of a Newfoundland marsh.

organic soils. For example, in Newfoundland the floodplains of the Big Steady Marsh on the Main River (49°50′ N, 57°10′ W) are exceptional for the large numbers of moose (*Alces alces*) that browse the marsh vegetation. Other areas, such as the King George IV Lake Delta (48°10′ N, 57°53′ W), are used extensively by stag woodland caribou (*Rangifer tarandus caribou*) when they separate from the does and calves in summer.

Waterfowl are closely associated with marshes. In Atlantic Canada, they are represented primarily by four species of duck—Black Duck (*Anas rubripes*), Green-winged Teal (*Anas crecca*), Ring-necked Duck (*Aythya collaris*), and Common Goldeneye (*Bucephala clangula*)—as well as Canada Goose (*Branta canadensis*). Most waterfowl breed in marshy settings where the habitat provides not only food but also valuable escape cover from predators. Marshes can provide the seclusion and resources for the annual feather moult during which waterfowl are flightless for several weeks; examples of this are the concentrations of moulting adult male Black Ducks in a fluvial marsh at Flatwater Brook, Labrador, or moulting Canada Geese at the King George IV Lake Delta, Newfoundland.

Historically, marshes have often been viewed with distaste, and this attitude promoted rapid loss to development during the early part of this century. The value of wetlands as rich, diverse habitats is slowly being recognized by the public, and the future prospects for conserving these key ecosystems are favourable.

Atlantic Swamps

Swamps within Atlantic Canada have not received much study and are not discussed in detail in this chapter. These wetlands, however, are prevalent in Atlantic Canada and form an important constituent of the regional ecological mosaic. Hardwood treed swamps are largely restricted to the maritime provinces, although alder- and willow-dominated swamps are prevalent throughout. Red maple (*Acer rubrum*) is the dominant species on larger swamp sites. One of the few remaining such swamps falls within Prince Edward Island National Park and has thus been maintained in a relatively undisturbed state. Most other red maple swamps in the Maritimes have long since disappeared.

Swamps dominated by black ash (*Fraxinus nigra*) do occur, although in small areal extent, along the Saint John River Valley approximately from Fredericton northwards. However, within Nova Scotia, red maple predominates in existing swamps. Swamps with coniferous tree species also occur throughout Atlantic Canada, primarily covered by black spruce (*Picea mariana*) and often associated with adjacent peatlands.

Physical and chemical data on swamps within the Atlantic wetland regions are limited. Alder, willow, and associated shrubs tend to be found in stream or shore swamps. Coniferous tree species dominate peat margin swamps, while those with red maple tend towards basin or flat swamps. Gleysols, often with a peaty phase, are the predominant soils in Atlantic swamps.

Atlantic Wetland Values

The value of wetlands in Atlantic Canada is difficult to define in strictly economic terms. Estimates of financial benefits have been made for some of the well-known wetland uses, but wetlands have many special values that are often not evident to the casual observer. There is only limited knowledge of the role or function of Atlantic wetlands in their natural state and, as a consequence, the inherent values of these wetlands have been poorly documented. General observations have been made by a few authors (Wells and Pollett 1983; Lynch-Stewart 1983; Keys and Henderson, in preparation), but detailed studies are generally scarce. This section of the chapter attempts to summarize the known data on wetland values in Atlantic Canada. The following groupings have been formed to facilitate discussion: (1) wetlands in their natural state; (2) non-extractive wetland developments; and (3) peat extraction.

Values of Wetlands in their Natural State

Wetlands provide habitats for many forms of wildlife, are an integral part of the global carbon cycle, and provide numerous recreational benefits. In their natural state, they influence the hydrology of watersheds, especially in the storage of water and the regulation of its flow. A hydrologically active layer near the surface of peatlands has been reported to display substantially different characteristics from those of the deeper peat layers (Barnes 1984). During periods of high precipitation, the amount of water stored in the active layer of a peatland ecosystem is thought to increase substantially. This water is gradually released during periods of low precipitation. The result is a regulation of flow that reduces the potential for flooding in periods of high precipitation while sustaining flow in periods of lower precipitation (Barnes 1984). Wetlands also act as storage reservoirs which allow the process of evapotranspiration to return water to the atmosphere. Although little is known about the relationship between large expanses of wetlands and the atmosphere, several climatic effects have been attributed to wetlands. For example, wetlands act as heat sinks and can exhibit cooler soil temperatures and lower air temperatures than surrounding uplands (Bardecki 1984).

Wetlands also have a role in the hydrological cycle, acting as a natural filtering system. Suspended sediments and mechanically transported debris are commonly removed from the flow regime by wetlands (Bardecki 1984). In addition to this physical filtering role, wetlands have important chemical filtering characteristics. The organic matter and humic acids found in wetlands are effective in trapping metal ions, pathogens, and other toxic substances (Sparling 1966; Kadlec and Kadlec 1979; Klocking *et al.* 1976). This results in reduced concentrations of these substances in the discharge waters from the wetland system (de Jong *et al.* 1977; Hartland-Rowe 1973; Reim 1980). These natural filtering properties have encouraged studies on the potential of wetlands for wastewater treatment (e.g. Brooks *et al.* 1982).

Such studies have evaluated this potential utilization both in terms of wetlands in their natural state and in terms of the removal of peat and its emplacement in artificial systems.

Wetlands and the peat they contain represent huge accumulations of stored organic carbon. Recent concerns about the combustion of fossil fuels and the resultant "greenhouse effect" caused by the release of carbon dioxide (CO_2) into the atmosphere have led to examination of the quantities of carbon stored within the carbon cycle. Boville *et. al.* (1983) have estimated that the peatlands of Atlantic Canada contain about 2% (2 billion tonnes) of the total stored carbon reserve in Canada.

The deposition and accumulation of organic matter in wetlands, particularly peatlands, provide a stratigraphic record of many climatic and environmental events which have occurred since the retreat of the glaciers some 10 000–15 000 years ago. Pollen and other material deposited during the accumulation of peat can be identified to provide information on the plant communities which were prevalent at the time of deposition. This stratigraphic record can be correlated to time (years BP) using radiocarbon or similar dating techniques. Such studies have allowed scientists to date archaeological finds such as L'Anse aux Meadows in Newfoundland (Mott 1975) and to examine paleoclimatic events and vegetation changes at various locations in the Atlantic provinces (Auer 1930; Korpijaakko 1976; Ogden and Harvey 1975; Railton 1973; Scott and Medioli 1982).

The frequency with which wildlife uses wetlands is to some extent dependent on the wetland form and the habitat which it provides. For example, the low diversity of plant species and the infrequent open water on most bogs correspond to relatively low use by wildlife, whereas the more diverse vegetation and more frequent open water found in swamps and marshes encourage greater frequency of use. The production and support of waterfowl and fur-bearers illustrate a notable asset of wetlands. Muskrat (*Ondatra zibethicus*), beaver (*Castor canadensis*), and otter (*Lontra canadensis*) are commonly associated with wetlands, as well as moose (*Alces alces*) and various fish species. Migratory game-birds such as Black Duck (*Anas rubripes*), Teal (*Anas* spp.), and Canada Goose (*Branta canadensis*) are the most common species of waterfowl using wetlands. Wells and Pollett (1983) provide more specific information on wildlife use of peatlands in Newfoundland.

Many wetlands in Atlantic Canada are of national or international significance for waterfowl, in particular those that serve the Atlantic Flyway for migratory birds through the areas of the Bay of Fundy and the Tantramar Marshes. The North American Waterfowl Management Plan (Environment Canada and the United States Department of the Interior 1986) calls for the protection of over 4 000 ha of east coast wetland habitat for Black Ducks, noting that most of the remaining habitats are unprotected.

There are numerous recreational uses of wetlands. These include trapping and/or hunting of the many fur-bearers and game species found on the wetlands in the Atlantic wetland regions. Wetland fur-bearing species account for about one-third of the total value of the annual fur-bearer harvest in Atlantic Canada. Based on Statistics Canada figures for the period 1977–1983, the average annual value was about $850 000, with muskrat providing about 80% of the number of pelts and about 36% of the value of the harvest from wetlands. Annual harvests of sport ducks in the Atlantic provinces normally reach 250 000–270 000 birds per season (Metras 1984). The economic benefits of migratory bird hunting are difficult to estimate. Based on information from the Canadian Wildlife Service of Environment Canada (Metras 1984) and Ducks Unlimited (McAloney 1978), it can be conservatively estimated that one million dollars are spent annually by hunters.

The value of other recreational uses of wetlands is perhaps even more difficult to assess. Hiking, skiing, snowmobiling, nature study, photography, and similar pursuits are among the recreational opportunities afforded by wetlands (Figure 7–25). Other recreational uses include the picking of blueberries, cranberries, and bakeapples (cloudberries). In a few instances, these activities, as well as wild rice production, are carried out on a commercial basis.

Some wetlands in Atlantic Canada have been set aside as preservation areas. For example, Kelly's Bog at Kouchibouguac National Park in New Brunswick has a nature study area which includes a viewing tower and a 1 km boardwalk which allows visitors to participate in an interpretive study of a typical domed bog (Figure 7–26). Another boardwalk exists in Cape Breton

Figure 7–25.
"Bog Walk", a peatlands interpretation program of Terra Nova National Park, Newfoundland.

Figure 7–26.
Boardwalk at Kelly's Bog, Kouchibouguac National Park, New Brunswick. Such sites provide public education on the unique nature and role of wetland ecosystems.

Highlands National Park at French Mountain. The wetlands of Heber Meadow in Kejimkujik National Park, Nova Scotia, are also a popular hiking area, with an interpretive trail guide. Sites such as these are helping to provide public education on the unique nature of wetland ecosystems.

It is difficult to assess the value of wetlands in their natural state. Classification systems, such as those by Larson (1976) and Reid *et al.* (1980), based on methods used by Golet (1972), assign points according to various characteristics and are a useful tool in assessing the relative importance of individual wetlands on a systematic basis. Classifications of this type have been used in the production of wetland atlases for the Maritimes by the Canadian Wildlife Service (Hudgins 1983; Nova Scotia Department of Lands and Forests 1984). While these classifications are a definite advantage in a systematic study, they also have the major limitation of being two-dimensional in nature. Thus, they do not consider the depth, type, or quality of peat beneath the surface. This third dimension—peat—is also an extremely valuable resource that is gaining greater recognition. The possibility of extracting peat for horticultural or fuel purposes provided the impetus for peat and peatland inventories (Figure 7–27) which have been carried out in all Atlantic provinces in recent years (Anderson and Broughm, in preparation; Graham and Associates Ltd. 1974; Keys and Henderson, in preparation; Wells *et al.* 1983). The level of knowledge of the peat resources of Atlantic Canada is relatively high in comparison with that of many areas of North America, but it is by no means complete.

Non-Extractive Wetland Developments

The accumulated organic matter (peat) found in wetlands is often termed "organic soil" or "muck". High moisture contents and, in some cases, low nutrient availability generally preclude the utilization of these soils in their natural state. Drainage is usually required for development for agricultural purposes. Such developments are well known in Europe and other parts of Canada, including the Holland Marsh in Ontario, but they are relatively uncommon in Atlantic Canada. Experiments in growing various vegetables, cole, and forage crops on peat soils have taken place (Chipman 1954; Rayment and Penney 1980). Some vegetable production still occurs on the Caribou Bog at Aylesford, Nova Scotia, where trials were carried out in 1952.

In Newfoundland, several strategically placed demonstration plots for forage and vegetable production totalling about 400 ha were established in the late 1950s and early 1960s. An additional 800 ha of peat soil were developed as community pasture (Figure 7–28). Some of these areas were later abandoned but vegetable trials have recently been carried out at Colinet (Rayment 1985). In New Brunswick, a cooperative has operated a 20 ha site at St. Charles, near Richibucto, since the mid-1960s. Carrots constitute the principal product but other vegetables and cole crops have also been harvested (Figure 7–29). In addition to drainage, the application of lime and trace-element-enhanced fertilizers is normally required to satisfy the plants' demand for micronutrients (Mackay *et al.* 1964, 1966) and to stabilize the peat soils (Mathur and Rayment 1977). Drainage and fertilization increase the cost for production on organic soils in comparison with that on mineral soils. However, the stone-free condition of the soil contributes to a high-quality product which commands a premium price and somewhat offsets production costs (Chipman and Mackay 1960).

Information from provincial agriculture departments indicates that wild rice production occurs on an 80 ha semi-managed site near Rusagonis, New Brunswick, on a 40 ha site in Prince Edward Island, and at several locations in the Tantramar Marsh area near the New Brunswick–Nova Scotia border. Cranberry production has been carried out on a limited scale in several areas of Nova Scotia (e.g. Barrington, Pubnico, and Auburn) and abandoned drainage systems can still be found. A reclaimed salt marsh in the Amherst area is also used for the cultivation of grass for lawn sod.

Salt marshes were originally diked by the Acadians in the late 1670s so that they could grow forage, flax, vegetables, and grain for themselves and their livestock. However, the expulsion of the Acadians in 1755 resulted in a decline in salt marsh utilization (MacKinnon and Scott 1984), although the marshes became very valuable for their hay crops during the late 19th century. A hectare of good marsh could produce about 4 500 kg of hay and there were about 20 000 ha of marsh. In a world where the horse was the principal mode of transportation, hay was an important cash crop. The price of good dikeland in-

Figure 7–27.
Inventories of peat and peatland resources have been carried out in all Atlantic provinces in recent years.

Figure 7–28.
Community pasture on peat soils in Newfoundland.

Figure 7–29.
Carrot production on a domed bog at St. Charles, New Brunswick.

creased to a record $500 per hectare in 1881. The demand for drained land intensified until hay prices peaked about 1918. As the tractor and truck replaced the horse, the demand for hay declined. Over the next three decades, the dikes and dams fell into disrepair and some sections reverted to natural salt marsh. The price of dikeland had plummetted to as low as $12 per hectare by 1950. Many farmers did not raise livestock to consume the hay; other landowners were from outside the province and lost interest in the land when the cash market for their crops declined. The few people who wished to continue farming had difficulty in maintaining the entire dike system. In 1948, the federal government passed the Maritime Marshlands Rehabilitation Act to protect agricultural land on the marshes. Dikes were repaired and ditches cleaned. However, the high cost of maintaining these systems places marshland farming in a difficult economic position and many areas are reverting to natural marsh.

The pattern of settlement in Atlantic Canada has traditionally been closely associated with water courses and the sea coast. Marshes attracted early settlers because of their development potential for agriculture and their value as a source of wild game. The expansion of settlement often involved the draining and diking of wetlands or backfilling for other uses. Marshes located in the agricultural areas of central New Brunswick, the New Brunswick–Nova Scotia border area, and in the northern half of Nova Scotia have been extensively altered, whereas marshes in Prince Edward Island and Newfoundland and Labrador have been little altered by agricultural practices.

Hydroelectrical development in the upper Saint John River, New Brunswick, and in central Labrador has eliminated or modified extensive areas of freshwater wetlands over the past 20 years. More modest projects, such as the installation of industrial facilities, landfill, and sewage lagoons, have altered many small marshes throughout Atlantic Canada.

Since 1965, federal and provincial governments have acquired and protected approximately 10 000 ha of freshwater marsh habitat in the maritime provinces. These sites, generally designated as National Wildlife Areas or Provincial Wildlife Management Areas, are principally managed for inland waterfowl habitat. The federal–provincial Wetlands Protection Mapping and Designation Program, conducted in the maritime provinces (New Brunswick, Nova Scotia, and Prince Edward Island) over the period 1980–1986, has inventoried all wetlands over 0.25 ha. The information gathered is being used by researchers and planners throughout the region to ensure that developers are aware of the location, extent, and importance of specific marsh sites (Smith *et al.* 1981). Furthermore, the mandate of the newly formed Wildlife Habitat Canada Foundation is to acquire and enhance representative, threatened, and rare wildlife habitat in Canada, and various projects for wetland conservation in Atlantic Canada are being considered.

The enhancement of waterfowl habitat by the use of water control structures is another common non-extractive use of wetlands. The program of Ducks Unlimited has resulted in the development of numerous sites in many parts of Atlantic Canada (McAloney 1982). Earthen or concrete dams are often erected to raise the water table on wetlands. This increases the proportion of open water and often results in the establishment of emergent species, a combination which makes the habitat more attractive to migratory game-birds for nesting sites and contributes to increases in population numbers. Consequently, more birds are available for harvest by hunters (Figure 7–30).

Figure 7–30.
The use of water control structures to enhance waterfowl habitat is carried out by Ducks Unlimited in many areas of Atlantic Canada.

Peatland forestry is an integral part of forest management programs in countries such as Finland, Ireland, and Scotland, but only small drainage and planting trials for research have been attempted in the Atlantic provinces. A drainage trial has been carried out in New Brunswick (Wetmore 1972), but little further effort is anticipated since economic factors suggest that management priority should be given to more conventional mineral-soil sites. In Newfoundland, peat soils cover a larger portion of the land surface than they do in the other Atlantic provinces. This in part accounts for a higher level of interest in peatland forestry in Newfoundland. Between 1966 and 1976, several trials were initiated with testing of various species and ditch spacings (Figure 7–31), but only limited success was achieved (Richardson 1980; Wells 1985). In 1983, plots were established on an ombrotrophic bog and slope fen to evaluate the effects of site type, drainage intensity, surface preparation, fertilization, and various soil parameters on the survival and growth of trees. The long-term objectives of the program are to determine the potential for peatland forestry in Newfoundland and to establish guidelines for future developments (Wells 1985).

Figure 7–31.
*Lodgepole pine (*Pinus contorta *Dougl.), 14 years after planting on ditched fen in central Newfoundland.*

Peat Extraction

Bogs have long been used in the Maritimes for the commercial extraction of horticultural peat. Keys and Henderson (in preparation) report that commercial operations existed in southern New Brunswick prior to 1900, with the peat marketed in the United States for use as animal litter. Some existing operations in New Brunswick have operated continuously since the early 1940s. The principal drying and collection period is from mid-June to early September, with packaging and shipment continuing into the winter months.

New Brunswick is Canada's second-largest peat producer (after Quebec) and exports the product to markets in the United States, Europe, and Japan. In 1984, some 2 600 ha of peatland in New Brunswick were used for peat extraction by 14 companies. About 4 million bale equivalents (170 litres at a 2:1 compression) of high-quality

Figure 7–32.
Over four million bale equivalents of high-quality Sphagnum *peat are produced annually in Atlantic Canada. Exports to the United States, Europe, and Japan constitute a large share of the market.*

Sphagnum peat were produced, with a value of over $12 million (Carroll 1985). One producer in Nova Scotia ships about 170 000 bale equivalents annually, and about 100 000 bale equivalents are produced by the two operations on Prince Edward Island (Statistics Canada 1985).

While the bulk of the peat harvested is marketed as baled horticultural peat (Figure 7–32), soil mixes are also produced by several companies through the addition to the peat of lime, fertilizers, and/or materials such as vermiculite or perlite. Pressed peat pots are manufactured by one New Brunswick firm. There are also numerous other peat deposits in various parts of the Maritimes which have great potential for the extraction of horticultural peat.

Peat has been a traditional home-heating and cooking fuel for centuries. In countries such as Ireland, Finland, and the Soviet Union, large-scale operations (up to 600 megawatts) are now used to generate steam for electrical power and district heating applications. Normally the peat used for this purpose is more decomposed than that extracted for horticultural purposes and thus is a denser, more compact material when dried. Low ash and sulphur (S) contents are among the characteristics of this material. To date, peat utilization for fuel in the Atlantic provinces has been attempted only on a demonstration project basis. Industrial boilers at a paper mill in Grand Falls, Newfoundland, and a greenhouse operation at Lamèque, New Brunswick, have been used in tests of fuel peat operations. A home-heating trial has been carried out at St. Shotts, Newfoundland, and a demonstration project for industrial heating purposes has been considered for southwestern Nova Scotia.

There are large quantities of peat available in the Atlantic provinces for utilization as fuel (Anderson and Broughm, in preparation; Keys and Henderson, in preparation; Wells and Pollett 1983; Wells and Vardy 1980). However, peat must compete against other indigenous fuels for social and economic acceptance and the potential for large-scale fuel peat development is at present considered low.

Several methods of peat extraction have been used in Atlantic Canada. In the early days of the industry, blocks of peat were dug by hand using special spades and were stacked for drying. This method has since been replaced by mechanical block-cutting machines which cut and stack the blocks of peat. After several weeks, the blocks are turned for further drying, then collected and transported to the bagging plant. The blocks pass through a crusher or mill to obtain the desired size fraction prior to bagging. The peat produced by this method maintains a high fibre content and commands a premium market price. This method has low weather dependency, but it is labour-intensive and has a high unit production cost. Consequently, this method has declined in popularity and only three operations use it for portions of their production.

The milled peat method of peat collection is currently the most common. Ditching and removal of surface vegetation are required to prepare suitable deposits for production (Figure 7–33). The surface of the production field is harrowed (or milled) to allow the sun and wind to dry a thin layer of peat. Depending on weather conditions, one to three days are normally required to complete drying. The most common method of collecting the dry peat layer is by the use of a large vacuum harvester which lifts the dry peat and transports it to a stockpile (Figure 7–34). In the ridge peat method, the dry peat is ploughed into a ridge or windrow for collection and transport. These milled peat harvesting methods are commonly used in Europe for collection of both fuel and horticultural peat. In the Atlantic provinces, the vacuum method of collection is used by most peat producers. One New Brunswick producer also uses the ridge peat method.

Figure 7–33.
Ditching of production fields is required to support equipment and facilitate drying of the surface layer.

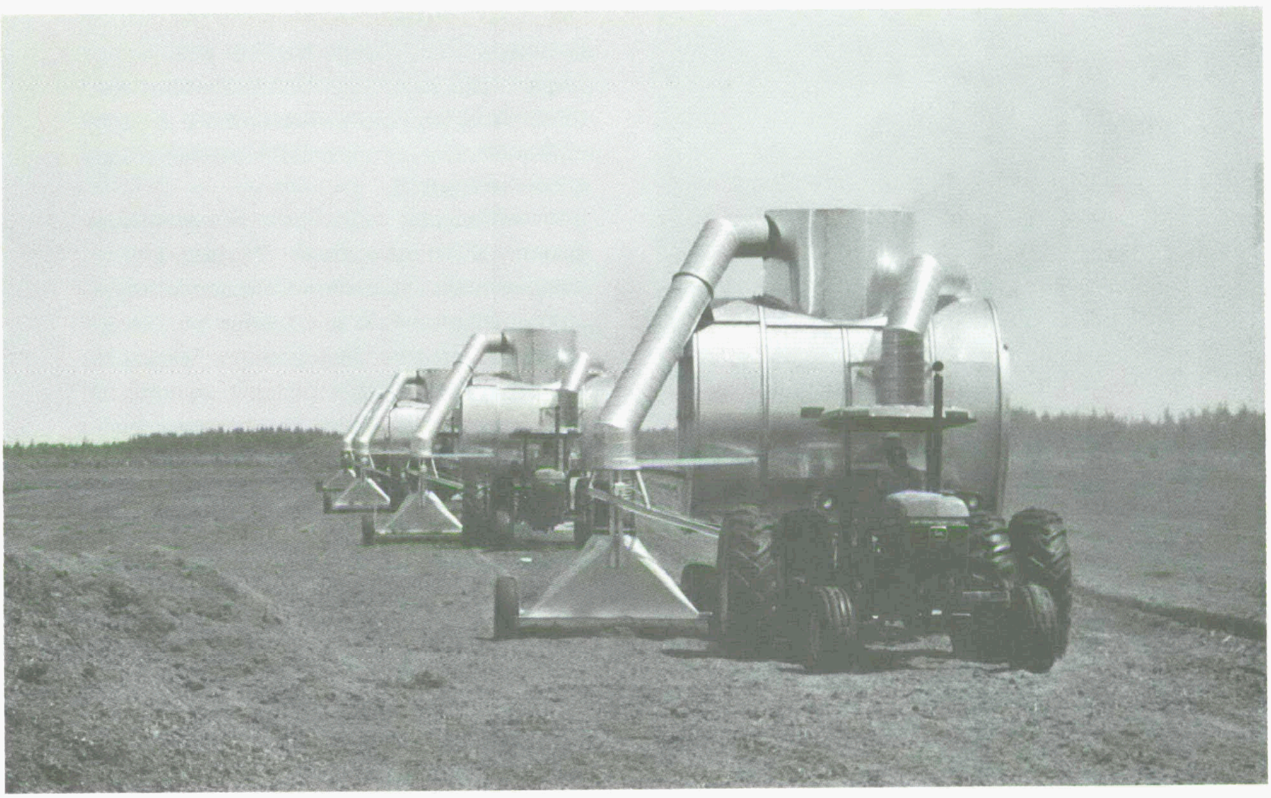


Figure 7–34.
Vacuum harvesters are commonly used to collect the dry peat.

The sod peat method is used exclusively for fuel peat harvesting. It consists of the extraction and maceration of peat by specially designed equipment and the extrusion of sods onto the peat field for drying and later collection. This method, which is less weather-dependent than milled peat methods, has been used in the demonstration project at St. Shotts, Newfoundland.

In addition to the use of peat in horticultural and fuel applications, it can be used as a source of numerous other substances. For example, studies have been completed which have investigated peat in Atlantic Canada as a source of carbon products such as metallurgical coke, carbon black, carbon filters, and activated carbon (Marsan and Associates Ltd. 1980). There is a resource base available in Atlantic Canada to support industrial utilizations of extracted peat. However, in practical applications, this resource is non-renewable and must be used prudently. Rational resource management must be exercised to ensure that this largely unknown resource makes a maximum long-term social and economic contribution.

Acknowledgements

Review comments and suggestions by the following individuals have assisted in the completion of this text: C. Rubec, S. Zoltai, C. Tarnocai, J. Pojar, and P. Grondin. Material on the coastal marshes of the Côte-Nord area of Quebec has been provided by P. Grondin. Figure 7–30 is courtesy of Ducks Unlimited (Canada). Thanks are also extended to S. Morgan of the Canadian Forestry Service for her numerous reviews of the manuscript.

References

ANDERSON, A.R., AND W. BROUGHM (in preparation). The peat resources of Nova Scotia. Nova Scotia Department of Mines and Energy. Halifax, Nova Scotia.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982a. Canadian climate normals 1951–1980. Volume 4: Degree-days; Volume 6: Frost; Volume 9: Soil temperature, lake evapotranspiration, days with . . . Environment Canada. Downsview, Ontario.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982b. Canadian climate normals 1951–1980. Temperature and precipitation: Atlantic provinces. Environment Canada. Downsview, Ontario. 136 p.

AUER, V. 1930. Peat bogs in southeastern Canada. Canada Department of Mines. Geological Survey of Canada. Memoir 162. Ottawa, Ontario. 32 p.

BARDECKI, M.J. 1984. What value are wetlands? Journal of Soil and Water Conservation, May–June 1984. p. 166.

BARNES, J.L. 1984. The hydrology and water resources of peatlands in Canada and the role of the inquiry on federal water policy. Peat News 6(3):1–18.

BEAUMONT, J.P., AND M. CHAMBERLAND. 1976. Les Îles-de-la-Madeleine: contribution à l'étude des groupements végétaux. Integrated Research Program, Direction des études biophysiques, Office of Planning and Development. Quebec, Quebec. 109 p.

BELLAMY, D.J. 1972. Templates of peat formation. *In* Proceedings, 4th International Peat Congress. Volume 1. Helsinki, Finland. pp. 7–18.

BOVILLE, R.W., R.E. HUNN, AND F.K. HARE. 1983. The storage of non-living organic carbon in boreal and arctic zones of Canada. Institute for Environmental Studies, University of Toronto, Toronto, Ontario, and United States Department of Energy, Washington, DC.

BROOKES, I.A., D.B. SCOTT, AND J.H. MCANDREWS. 1985. Postglacial relative sea-level change, Port au Port area, west Newfoundland. Canadian Journal of Earth Sciences 22:1039–1047.

BROOKS, J.L., C.A. ROCK, R.A. STRUCHTEMEYER, AND F.E. WOODWARD. 1982. The use of *Sphagnum* peat for treatment of septic tank effluent. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 442–461.

BROOM, S.W., W.W. WOODHOUSE, JR., AND E.D. SENECA. 1975. The relationships of mineral nutrients to growth of *Spartina alterniflora* in North Carolina. II. The effects of N, P, and Fe fertilizers. Proceedings, Soil Science Society of America 39:301–307.

BURNS, R.C., AND R.W.F. HARDY. 1975. Nitrogen fixation in bacteria and higher plants. Springer-Verlag Publishing Inc. Berlin, Germany.

BUTEAU, P. 1984. Tourbières de la région de Havre-Saint-Pierre. Quebec Ministry of Energy and Resources. Report No. ET 83-01. Quebec, Quebec. 47 p.

CAMERON, C.C. 1970. Peat deposits of northeastern Pennsylvania. United States Geological Survey. Bulletin No. 1317.

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication No. 1646. Ottawa, Ontario. 164 p.

CARPENTER, E.J., C. VAN RAALTE, AND I. VALIELA. 1978. Nitrogen fixation in a Massachusetts salt marsh. Limnological Oceanography 23:318–327.

CARROLL, B.M.W. 1985. New Brunswick mineral industry 1984. Mineral Resources Division, New Brunswick Department of Natural Resources. Information Circular No. 85-2. Fredericton, New Brunswick. pp. 98–107.

CHAPMAN, V.J. 1937. A note on the salt marshes of Nova Scotia. Rhodora 39:53–57.

CHAPMAN, V.J. 1960. Salt marshes and salt deserts of the world. Hill. London, UK. 392 p.

CHAPMAN, V.J. 1974. Salt marshes and salt deserts of the world. Von J. Cramer Publishing Company, Lehre, Germany. 2nd edition. 392 p.

CHIPMAN, E.W. 1954. Preliminary studies on the muck soils of Nova Scotia for vegetable production. Nova Scotia Department of Agriculture and Marketing. Unpublished.

CHIPMAN, E.W., AND D.C. MACKAY. 1960. Vegetable production on Nova Scotia peat bogs. Canada Department of Agriculture. Kentville, Nova Scotia. Unpublished.

DAMMAN, A.W.H. 1979. Geographic patterns in peatland development in eastern North America. *In* Proceedings, Symposium on Peat and Peatlands. September 17–21, 1979. Hyytiala, Finland. pp. 42–57.

DAVIS, A.M. 1984. Ombrotrophic peatlands in Newfoundland, Canada: their origins, development, and trans-Atlantic affinities. Chemical Geology 44:287–309.

DE JONG, J., T. KOK, AND A.H. KORIDON. 1977. The purification of sewage with the aid of ponds containing bulrushes or reeds in the Netherlands. Rijksdienst voor e Ijsselmeerpolders Rapp. 19 p.

DIBBLEE, R. (personal communication). 1986. Fish and Wildlife Division, Prince Edward Island Department of Community and Cultural Affairs. Charlottetown, Prince Edward Island.

DUMONT, M., AND L. GAUTHIER. 1982. Étude phyto-écologique des platières de la rivière Galiotte, Île d'Anticosti, Québec. Mémoire de fin d'études. Faculty of Forestry and Geodesy, Laval University, Quebec, Quebec. 84 p.

ENVIRONMENT CANADA. 1986. Wetlands of the St. Lawrence River region. Lands Directorate, Environment Canada. Working Paper No. 45. Ottawa, Ontario. 29 p.

ENVIRONMENT CANADA AND THE UNITED STATES DEPARTMENT OF THE INTERIOR. 1986. North American Waterfowl Management Plan. A strategy for cooperation. Canadian Wildlife Service and United States Fish and Wildlife Service. Ottawa, Ontario, and Washington, DC. 19 p.

GANONG, W.F. 1903. The vegetation of the Bay of Fundy salt and dyked marshes: an ecological study. Botanical Gazette 36(3):161–186.

GAUTHIER, R. 1981. La végétation et la flore de quelques tourbières de l'Anticosti-Minganie. Environment Directorate, Hydro-Quebec. Montreal, Quebec. 104 p.

GERARDIN, V., P. GRONDIN, AND M. LEBEL. 1984. L'inventaire du capital-nature de la Moyenne-en-Basse-Côte-Nord. Quebec Ministry of Environment. Série de l'inventaire du capital-nature No. 4. 156 p. and appendices.

GLOOSCHENKO, W.A. 1979. Coastal salt marshes in Canada. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 69–76.

GOLET, F.C. 1972. Classification and evaluation of freshwater wetlands as wildlife habitats in the glaciated northeast. Ph.D. thesis, University of Massachusetts, Amherst, Massachusetts. 179 p.

GRAHAM, R.B., AND ASSOCIATES LTD. 1974. Peat moss resources and some associated trace elements, Prince Edward Island. Department of Industry and Commerce. Charlottetown, Prince Edward Island. 164 p.

GRANDTNER, M.M. 1966a. Premières observations phytopédologiques sur la végétation des prés salés des Îles-de-la-Madeleine. Naturaliste canadien 93:361–366.

GRANDTNER, M.M. 1966b. Observations sur la végétation des marais des Îles-de-la-Madeleine. Naturaliste canadien 93:771–777.

GRONDIN, P. 1982. Brève description biophysiques et évaluation de la réserve écologique potentielle du lac Salé, Île d'Anticosti. Direction des réserves écologiques et des sites naturels. Quebec Ministry of Environment. Quebec, Quebec. 39 p.

GRONDIN, P., J-L. BLOUIN, AND D. BOUCHARD. 1980. Étude phyto-écologique de l'archipel de Mingan. Groupe Dryade Ltd., for l'Office de planification et de développement du Québec. Quebec, Quebec. 3 volumes and map atlas.

GRONDIN, P., R. CHIASSON, AND R. THÉRIAULT. 1986. La végétation de l'archipel de Mingan. Groupe Dryade Ltd., for Parks Canada, Environment Canada. Ste-Foy, Quebec. 108 p.

GRONDIN, P., L. COUILLARD, D. BOUCHARD, AND R. THÉRIAULT. 1983. Brève description et cartographie de la végétation de l'archipel de Mingan. Direction des réserves écologiques et des sites naturels, Quebec Ministry of Environment. Quebec, Quebec. 97 p. and appendices.

GRONDIN, P., AND M. MELANÇON. 1980a. La végétation du marais salé de l'Île à Samuel, archipel de Mingan, Québec. Phytocoenologia 7:336–355.

GRONDIN, P., AND M. MELANÇON. 1980b. Étude phyto-écologique de la Grosse Île au Marteau et de l'Île à Samuel, archipel de Mingan, Québec. Forest Ecology Laboratory, Laval University. Quebec, Quebec. 227 p.

GUIMOND, A., R. CHIASSON, AND P. GRONDIN. 1983. Cartographie du couvert végétal de la Moyenne-et-Basses-Côte-Nord par interprétation d'images de satellites accentuées. Hydro-Quebec. Montreal, Quebec. 2 volumes.

HAINES, E.B. 1979. Interactions between Georgia salt marshes and coastal waters: a changing paradigm. *In* Ecological processes in coastal and marine systems. R.J. Livingston, editor. Plenum Press. New York, New York. pp. 35–46.

HARRISON, E.Z., AND A.L. BLOOM. 1977. Sedimentation rates on tidal salt marshes in Connecticut. Journal of Sedimentary Petrology 47(4):1484–1490.

HARTLAND-ROWE, R. 1973. Use of swampland as a natural sink for receipt of sewage effluent. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-15. Ottawa, Ontario. 52 p.

HATCHER, A.I., D.G. PATRIQUIN, Y.F. FERN, A.J. HANSON, AND J. READE. 1981. Salt marshes in Nova Scotia. Institute of Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia. 70 p.

HIRVONEN, H.E. 1984. Atlantic region: an ecological perspective. Lands Directorate, Environment Canada. Dartmouth, Nova Scotia. 28 p.

HUDGINS, E.J. 1983. Workbook for the initiation of the New Brunswick freshwater inventory. Canadian Wildlife Service, Environment Canada. Sackville, New Brunswick. Unpublished. 84 p.

KADLEC, R.H., AND J.A. KADLEC. 1979. Wetlands and water quality. *In* Wetland functions and values: the state of our understanding. P.E. Greeson, J.R. Clark, and J.E. Clark, editors. American Water Resources Association. Minneapolis, Minnesota. pp. 436–456.

KEREKES, J. (personal communication). 1986. Canadian Wildlife Service, Environment Canada. Halifax, Nova Scotia.

KEYS, D., AND R.E. HENDERSON (in preparation). An investigation of the peatlands of New Brunswick. Mineral Resources Division, New Brunswick Department of Natural Resources. Open File Report 83-10. Fredericton, New Brunswick. 269 p.

KLOCKING R., K.D. THEIEL, AND M. SPROSSIG. 1976. Antiviral activity of humic acid from peat water. *In* Proceedings, 5th International Peat Congress. Warsaw, Poland. pp. 446–455.

KORPIJAAKKO, M.L. 1976. On the origin and geobotanical development of muskeg in New Brunswick. Ph.D. thesis, University of New Brunswick, Fredericton, New Brunswick. 154 p.

LAMB, H.F. 1980. Late quaternary vegetational history of southeastern Labrador. Arctic and Alpine Research 12:117–135.

LARSON, J.S. 1976. Models for assessment of freshwater wetlands. University of Massachusetts. Publication No. 32. Boston, Massachusetts. 91 p.

LOPOUKHINE, N., N.A. PROUT, AND H.E. HIRVONEN. 1977. Ecological land classification of Labrador. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 4. Halifax, Nova Scotia. 85 p. and map.

LYNCH-STEWART, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. Ottawa, Ontario. 115 p.

MACDOUGALL, J.I., C. VEER, AND F. WILSON (in press). Soils of Prince Edward Island. Report of soil survey. Agriculture Canada. Land Resource Research Institute Contribution No. 141. Ottawa, Ontario.

MACKAY, D.C., E.W. CHIPMAN, AND U.C. GUPTA. 1966. Copper and molybdenum nutrition of crops grown on acid *Sphagnum* peat soils. Proceedings, Soil Science Society of America 30(6):755–759.

MACKAY, D.C., E.W. CHIPMAN, AND W.M. LANGILLE. 1964. Crop response to some micronutrients and sodium on *Sphagnum* peat soils. Proceedings, Soil Science Society of America 28(1):101–104.

MACKINNON, K., AND D.B. SCOTT. 1984. An evaluation of salt marshes in Atlantic Canada. Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia, and Lands Directorate, Environment Canada. Technical Report No. 1. Dartmouth, Nova Scotia. 42 p.

MACPHERSON, J.B. 1981. The development of the vegetation of Newfoundland and climatic change during the Holocene. *In* The natural environment of Newfoundland, past and present. A.G. MacPherson and J.B. MacPherson, editors. Department of Geography, Memorial University, St. John's, Newfoundland. pp. 189–217.

MACPHERSON, J.B. 1982. Post-glacial vegetational history of the eastern Avalon Peninsula, Newfoundland, and Holocene climatic change along the eastern Canadian seaboard. Geographie physique et Quaternaire 36(1-2):175–196.

MARCOTTE, F. 1982. Étude phyto-écologique et proposition d'aménagement de la Petite Île au Marteau, archipel de Mingan. Faculty of Forestry and Geodesy, Laval University. Quebec, Quebec. 240 p.

MARSAN, A., AND ASSOCIATES LTD. 1980. Industrial uses of peat in northeast New Brunswick. Report to the Department of Commerce and Development, Fredericton, New Brunswick.

MATHUR, S.P., AND A.F. RAYMENT. 1977. Influence of trace elements fertilization on the decomposition rate and phosphate activity of a Mesic Fibrisol. Canadian Journal of Soil Science 57:397–408.

MCALONEY, R.K. 1978. Values of a managed Nova Scotia wetland. Ducks Unlimited (Canada) Ltd. Amherst, Nova Scotia. Unpublished.

MCALONEY, R.K. 1982. Wetland habitat program of Ducks Unlimited in New Brunswick. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. Canadian National Committee, International Peat Society. September 12–15, 1982. Shippagan, New Brunswick. pp. 192–197.

METRAS, L. 1984. Migratory birds killed in Canada during the 1982 season. Canadian Wildlife Service, Environment Canada. Progress Notes No. 143. Ottawa, Ontario. 39 p.

MOORE, P.D., AND D.J. BELLAMY. 1974. Peatlands. Springer-Verlag Inc. New York, New York. 221 p.

MORANTZ, D.L. 1976. Production and export from the John Lusby Marsh, Amherst, Nova Scotia. M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia. 77 p.

MOTT, R.J. 1975. Palynological studies of peat monoliths from L'Anse aux Meadows Norse site, Newfoundland. Geological Survey of Canada. Paper 75-1, Part A. Ottawa, Ontario. pp. 451–453.

NATIONAL WETLANDS WORKING GROUP. 1979. Wetlands of Canada. Map folio. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 14. Ottawa, Ontario.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NORTHLAND ASSOCIATES LTD. 1978. Peatland inventory of northeastern Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. 2 volumes (text and tables). St. John's, Newfoundland. 724 p.

NORTHLAND ASSOCIATES LTD. 1979. Peatland inventory of western Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. 2 volumes (text and tables). St. John's, Newfoundland. 339 p.

NORTHLAND ASSOCIATES LTD. 1980. Peatland inventory of eastern Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. 2 volumes (text and tables). St. John's, Newfoundland. 703 p.

NORTHLAND ASSOCIATES LTD. 1981. Peatland inventory of northern Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. 2 volumes (text and tables). St. John's, Newfoundland. 409 p.

NORTHLAND ASSOCIATES LTD. 1982. Peatland inventory of south–central Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. 2 volumes (text and tables). St. John's, Newfoundland. 641 p.

NORTHLAND ASSOCIATES LTD. 1984. Updating of existing peatland inventories and completion of peatland inventory in south–central Newfoundland. Prepared for the Newfoundland Department of Forest Research and Lands. St. John's, Newfoundland. 37 p.

NOVA SCOTIA DEPARTMENT OF LANDS AND FORESTS. 1984. Important freshwater wetlands and coastal wildlife habitats of Nova Scotia. Staff Report. Wildlife Division, Department of Lands and Forests. Halifax, Nova Scotia.

OGDEN, J.G., AND M.J. HARVEY, EDITORS. 1975. Environmental change in the Maritimes. Nova Scotia Institute of Science. Halifax, Nova Scotia. 109 p.

OSTROFSKY, M.L., AND H.C. DUTHIE. 1975. Primary productivity, phytoplankton and limiting nutrient factors in Labrador lakes. Hydrobiology 60:145–158.

PATRIQUIN, D.G., AND C. KEDDY. 1978. Nitrogenase activity (acetylene reduction) in a Nova Scotian salt marsh: its association with angiosperms and the influence of some edaphic factors. Aquatic Botany 4:227–244.

PATRIQUIN, D.G., AND C.R. MCCLUNG. 1978. Nitrogen accretion and the nature and possible significance of nitrogen fixation (acetylene reduction) in a Nova Scotian *Spartina alterniflora* stand. Marine Biology 47:227–242.

PEARCE, P.A., AND A.D. SMITH. 1974. The potential influence on waterfowl of port and power tidal development in the Bay of Fundy. *In* Waterfowl studies in eastern Canada 1969–1973. H. Boyd, editor. Canadian Wildlife Service, Environment Canada. Report Series No. 29. Ottawa, Ontario. pp. 91–100.

PHLEGER, F.B. 1971. Effect of salinity on growth of a salt marsh grass. Ecology 52:908–911.

PHLEGER, F.B., AND J.S. BRADSHAW. 1966. Sedimentary environments in a marine marsh. Science 154:1551–1553.

POLLETT, F.C. 1972a. Classification of peatlands in Newfoundland. *In* Proceedings, 4th International Peat Congress. Volume 1. Helsinki, Finland. pp. 101–110.

POLLETT, F.C. 1972b. Nutrient contents of peat soils in Newfoundland. *In* Proceedings, 4th International Peat Congress. Volume 3. Helsinki, Finland. pp. 461–468.

POLLETT, F.C., AND P.B. BRIDGEWATER. 1973. Phytosociology of peatlands in central Newfoundland. Canadian Journal of Forest Research 3:433–442.

POLLETT, F.C., AND E.D. WELLS. 1980. Peatlands of Newfoundland: an overview. *In* The diversity of peat. Proceedings, Peatland Symposium. F.C. Pollett, A.F. Rayment, and A. Robertson, editors. Newfoundland and Labrador Peat Association. St. John's, Newfoundland. pp. 39–50.

RAILTON, J.B. 1973. Vegetational and climatic history of southwestern Nova Scotia in relation to a South Mountain ice cap. Ph.D. thesis, Dalhousie University, Halifax, Nova Scotia.

RAYMENT, A.F. 1985. A new technique for vegetable–forage crop rotation on peat soils in Newfoundland. Peat News 7(2):1–6.

RAYMENT A.F., AND B.G. PENNEY. 1980. The agricultural potential of Newfoundland peat soils. *In* The diversity of peat. Proceedings, Peatland Symposium. F.C. Pollett, A.F. Rayment, and A. Robertson, editors. Newfoundland and Labrador Peat Association. St. John's, Newfoundland.

REID, R.A., N. PATTERSON, L. ARMOUR, AND A. CHAMPAGNE. 1980. A wetlands evaluation model for southern Ontario. Federation of Ontario Naturalists. Don Mills, Ontario. 140 p.

REIM, J. 1980. Sewage treatment in a *Sphagnum* peat bog. Great Lakes Focus on Water Quality 6(3):6–9.

REIMOLD, R.J. 1977. The mangals and salt marshes of eastern United States. *In* Wet coastal ecosystems. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 157–166.

RICHARDSON, J. 1980. The forestry potential of Newfoundland peatlands. *In* The diversity of peat. Proceedings, Peatland Symposium. F.C. Pollett, A.F. Rayment, and A. Robertson, editors. Newfoundland and Labrador Peat Association. St. John's, Newfoundland. pp. 59–61.

ROBERTS, B.A., AND A.W. ROBERTSON. 1986. Salt marshes of Atlantic Canada: their ecology and distribution. Canadian Journal of Botany 64(2):445–467.

ROLAND, A.E., AND E.C. SMITH. 1969. The flora of Nova Scotia. Nova Scotia Museum. Halifax, Nova Scotia. 746 p.

ROWE, J.S. 1972. Forest regions of Canada. Canadian Forestry Service, Environment Canada. Publication No. 1300. Ottawa, Ontario. 172 p.

SCOTT, D.B. 1977. Physiographic and oceanic characteristics of Chezzetcook Inlet, Nova Scotia. Maritime Sediments 13(3):73–78.

SCOTT, D.B. 1980. Morphological changes in an estuary: a historical and stratigraphical comparison. *In* The coastline of Canada. S.B. McCann, editor. Geological Survey of Canada. Paper 80-10. Ottawa, Ontario. pp. 199–205.

SCOTT, D.B., AND D.A. GREENBERG. 1983. Relative sea-level rise and tidal development in the Fundy tidal system. Canadian Journal of Earth Sciences 20(10):1554–1564.

SCOTT, D.B., AND F.S. MEDIOLI. 1978. Studies of relative sea-level changes in the Maritimes. Progress Report to Energy, Mines and Resources Canada, Research Agreement No. 2239-4-31/78. Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia. 79 p.

SCOTT, D.B., AND F.S. MEDIOLI. 1980a. Quantitative studies of marsh foraminiferal distributions in Nova Scotia: implications for sea level studies. Cushman Foundation for Foraminiferal Research. Special Publication No. 17. Washington, DC. 58 p.

SCOTT, D.B., AND F.S. MEDIOLI. 1980b. Living versus total foraminiferal populations: their relative usefulness in paleoecology. Journal of Palaeontology 54(4):814–831.

SCOTT, D.B., AND F.S. MEDIOLI. 1982. Micropaleontological documentation for early Holocene fall of relative sea level on the Atlantic coast of Nova Scotia. Geology 10:278–281.

SCOTT, D.B., M.A. WILLIAMSON, AND T.E. DUFFETT. 1981. Marsh foraminifera of Prince Edward Island: their recent distribution and application for former sea level studies. Maritime Sediments and Atlantic Geology 17:98–129.

SHANMUGAN, K.T., AND C. MORAND. 1974. Amino acids as repressors of nitrogenase biosynthesis in *Klebsiella pneumoniae*. Biochimica Biophysica Acta 437:322–332.

SIMARD, A. 1976. Tourbières du canton de Manicouagan. Service des gîtes minéraux. Quebec Ministry of Natural Resources. Report No. ES-17. Quebec, Quebec. 211 p.

SJÖRS, H. 1976. Successional trends in boreal peatlands. *In* Proceedings, 5th International Peat Congress. Warsaw, Poland. pp. 22–28.

SMITH, A.D., E.J. HUDGINS, AND M. SPENCE. 1981. Wetlands inventory and evaluation in the Maritimes. Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 116–119.

SMITH, A.D., D.B. SCOTT, AND F.S. MEDIOLI. 1984. Marsh foraminifera in the Bay of Fundy: modern distribution and application to sea-level determinations. Maritime Sediments and Atlantic Geology 20:127–142.

SMITH, D.L., J. MCLACHLAN, AND D.G. PATRIQUIN. 1979. Nitrogen fixation as determined by acetylene reduction in two salt marshes of Minas Basin. Proceedings, Nova Scotia Institute of Science 29:381–392.

SPARLING, J.H. 1966. Studies on the relationship between water movement and water chemistry in mires. Canadian Journal of Botany 44:548–549.

STATISTICS CANADA. 1985. Domestic exports by province. Data Book No. 65004. Unpublished.

TANSLEY, A.G. 1953. The British Isles and their vegetation. 2 volumes. Cambridge University Press. Cambridge, UK. 930 p.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–39.

TARNOCAI, C. 1984. Peat resources of Canada. National Research Council of Canada. Publication No. 24140. Ottawa, Ontario. 17 p.

TAYLOR, J.A., AND R.T. SMITH. 1972. Climatic peat—a misnomer? *In* Proceedings, 4th International Peat Congress. Volume 1. Helsinki, Finland. pp. 471–484.

TEAL, J., AND M. TEAL. 1969. Life and death of the salt marsh. Little, Brown, Publishers. Boston, Massachusetts. 278 p.

TERASMAE, J. 1963. Three C-14 dated pollen diagrams from Newfoundland, Canada. Advances in Frontiers of Plant Science (New Delhi) 6:149–162.

THANNHEISER, D. 1984. The coastal vegetation of eastern Canada. Memorial University of Newfoundland. Occasional Papers in Biology No. 8. St. John's, Newfoundland. 212 p.

UGOLINI, F.C., AND D.H. MANN. 1979. Biopedological origin of peatlands in southeast Alaska. Nature 281:366–368.

VALIELA, I., AND J.M. TEAL. 1974. Nutrient limitation in salt marsh vegetation. *In* Ecology of halophytes. E.J. Reimold and W.H. Queen, editors. Academic Press. New York, New York. pp. 547–563.

WALKER, D. 1970. Direction and rate in some British post-glacial hydroseres. *In* Studies in the vegetational history of the British Isles. D. Walker and R.G. West, editors. Cambridge Publishers. Cambridge, UK. 117 p.

WELLER, M.W. 1981. Freshwater marshes: ecology and wildlife management. University of Minnesota Press. Minneapolis, Minnesota. 146 p.

WELLS, E.D. 1981. Peatlands of eastern Newfoundland: distribution, morphology, vegetation, and nutrient status. Canadian Journal of Botany 59(11):1978–1997.

WELLS, E.D. 1985. État de la sylviculture des tourbières à Terre-Neuve. (The status of peatland forestry in Newfoundland.) *In* Proceedings, Colloquium on Forest Drainage. September 10–11, 1985. Ste-Foy, Quebec. pp. 85–111.

WELLS, E.D. (in preparation). Morphology and phytosociology of peatlands in Atlantic Canada. Canadian Forestry Service. St. John's, Newfoundland.

WELLS, E.D., AND F.C. POLLETT. 1983. Peatlands. *In* Biogeography and ecology of the Island of Newfoundland. G.R. South, editor. Dr. W. Junk Publishers. The Hague, The Netherlands. pp. 207–266.

WELLS, E.D., AND R.B. VARDY. 1980. Peat resources of Newfoundland with emphasis on its use for fuel. *In* Proceedings, Symposium on Peat as an Energy Alternative. Institute of Gas Technology. December 1–3, 1980. Arlington, Virginia. pp. 679–698.

WELLS, E.D., F.C. POLLETT, AND E.R. DAWE. 1983. Peatland inventories for Newfoundland: methodology and application. *In* Proceedings, Peatland Inventory Methodology Workshop. S.M. Morgan and F.C. Pollett, editors. Land Resource Research Institute, Agriculture Canada, Ottawa, Ontario, and Canadian Forestry Service, Environment Canada, St. John's, Newfoundland. pp. 25–34.

WETMORE, M.P. 1972. Swamp drainage in New Brunswick. Forestry Branch, New Brunswick Department of Natural Resources. Report No. TR-2. Fredericton, New Brunswick. 6 p.

ZOLTAI, S.C. 1972. Palsas and peat plateaus in central Manitoba and Saskatchewan. Canadian Journal of Forest Research 2(3):291–302.

ZOLTAI, S.C., AND C. TARNOCAI. 1971. Properties of a wooded palsa in northern Manitoba. Arctic and Alpine Research 3(2):115–129.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12(1):28–43.

8 Wetlands of Pacific Canada

A. Banner
R.J. Hebda
E.T. Oswald
J. Pojar
R. Trowbridge

Wetlands of Pacific Canada

The Pacific coast of Canada, as a setting for wetlands, consists of the lower slopes of the Coast and Insular mountain ranges, the coastal lowlands, the fiords and estuaries, and the adjacent islands (Figure 8–1). The region abuts the Alaska panhandle to the north and the northwest corner of Washington State to the south. The Coast Mountains form the eastern boundary, and the Insular Mountains occur on Vancouver Island and the Queen Charlotte Islands (Holland 1976). These mountains are part of the Mountain Complex Wetland Region, which is not specifically dealt with in this book. The tidal marshes and estuaries are integral parts of the Pacific coast wetlands but are considered in Chapter 9.

The maritime climate of the Pacific coast promotes relatively lush growth of vegetation, but retards the decomposition of

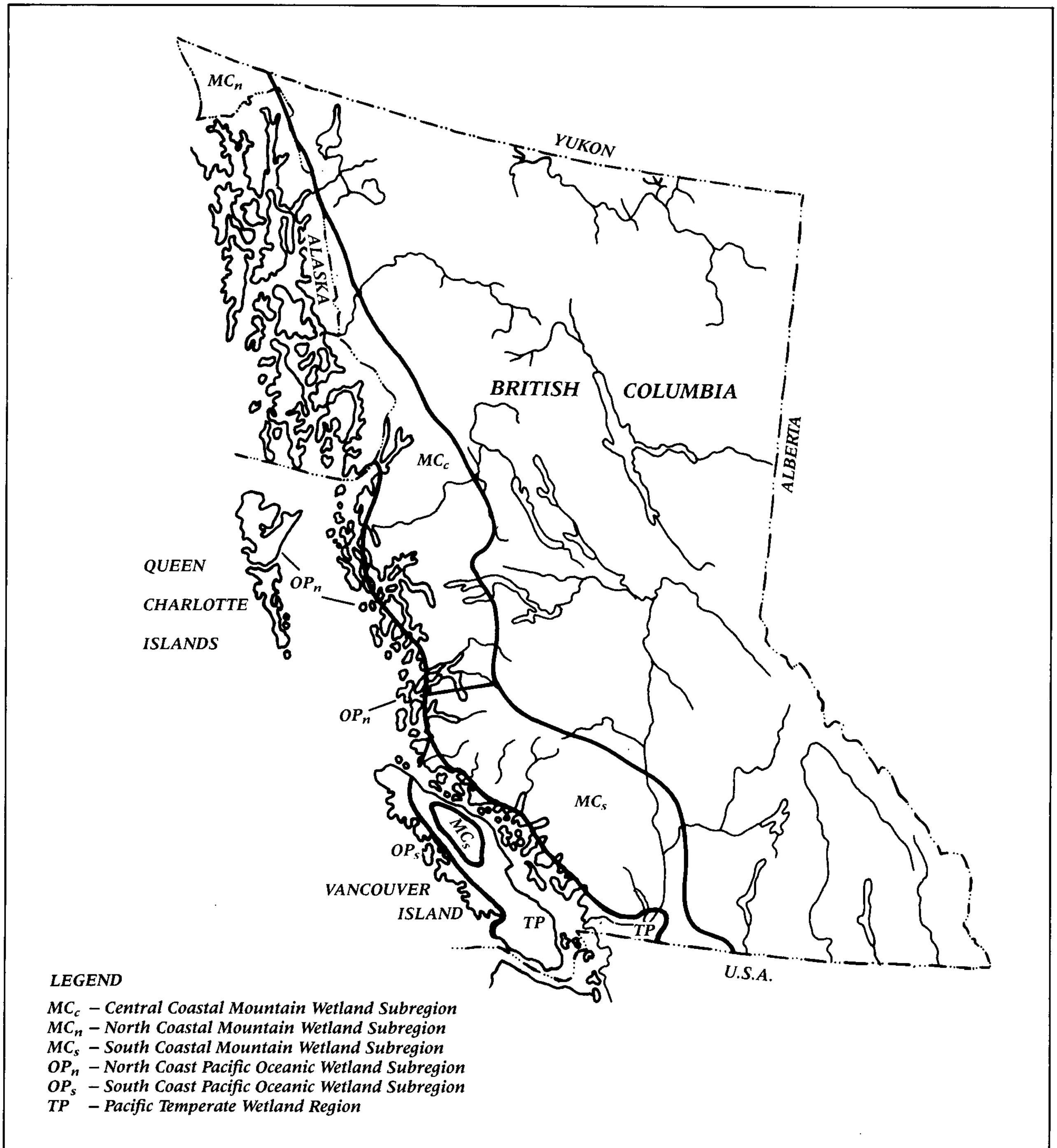


Figure 8–1.
Pacific coast wetland regions and subregions.

organic matter. Consequently, organic matter tends to accumulate, particularly in wet sites where free water reduces the aeration necessary for rapid decomposition. Peat accumulates in poorly drained depressions, as well as on moderate to steep slopes (Rigg 1914, 1922, 1937; Lawrence 1958; Neiland 1971; Reiners *et al.* 1971).

The Pacific coastal wetlands are divided into two wetland regions and two subregions (National Wetlands Working Group 1986; Figure 8–1). The Pacific Temperate Wetland Region (TP) occurs on southern Vancouver Island and the Fraser Lowland, and extends northwards along both sides of the Strait of Georgia, including the Gulf Islands. This area is relatively dry and wetlands constitute less than 5% of the terrain. The characteristic wetlands of this region are swamps, basin and domed bogs, and flat, mostly stream or shore fens, and marshes. The Pacific Oceanic Wetland Region (OP) consists of the South Coast (OPs) and North Coast (OPn)

Wetland Subregions. The South Coast Pacific Oceanic Wetland Subregion (OPs) occurs on western and northern Vancouver Island with characteristic flat or basin bogs, stream fens, basin swamps, and marshes along the coast and estuaries. The mainland along Queen Charlotte Strait to the boundary with Alaska and the Queen Charlotte Islands is within the North Coast Pacific Oceanic Wetland Subregion (OPn). This area receives the most precipitation in Canada and wetlands cover up to 75% of the terrain. Characteristic wetlands of the north coast are slope, basin, and shore bogs, and localized stream fens, basin swamps, and estuaries or coastal marshes.

Most west coast wetlands are relatively small in comparison with those in many other parts of Canada, largely due to constraining topographic features. Some of the larger wetlands of the Pacific Temperate Wetland Region occur in the Fraser Delta, which consists of a fairly large expanse of essentially flat fluvial material. Most other non-tidal wetlands in this region have formed in depressions where drainage is impeded by bedrock, compact glacial moraine, or marine clay. In the Pacific Oceanic Wetland Region, relatively large wetlands occur on flat terrain and gentle to moderate slopes, and reflect the high rainfall of the region. Impermeable soil horizons restrict drainage and thereby play a role in wetland development. Sloping bogs sometimes coalesce with wetlands formed in basins. However, even these wetlands are interrupted by bedrock outcrops.

This chapter describes the common wetland forms of the Pacific coast and gives an overview of the geology, climate, ecology, and criteria for wetlands in the west coast environment. A discussion of the dynamics and values of coastal wetlands concludes the chapter.

Environmental Setting

Geography

The west coast of Canada consists primarily of the glacially abraded, Mesozoic, igneous-intrusive Coast Mountain Range and the volcanic or sedimentary Insular Mountain Range. Along much of its length the coast is dissected by fiords, and many lowlands occur near the contact with the Pacific Ocean (Holland 1976). The two mountain ranges are separated by an ocean-filled depression some 30 km (south end of Vancouver Island) to 75 km (Queen Charlotte Islands) wide, blocked by several islands near north–central Vancouver Island. Several peaks over 3 000 m above sea level occur in the Coast Mountain Range and over 2 000 m above sea level in the Insular Mountain Range; however, this chapter focuses on the terrain below 600 m above sea level.

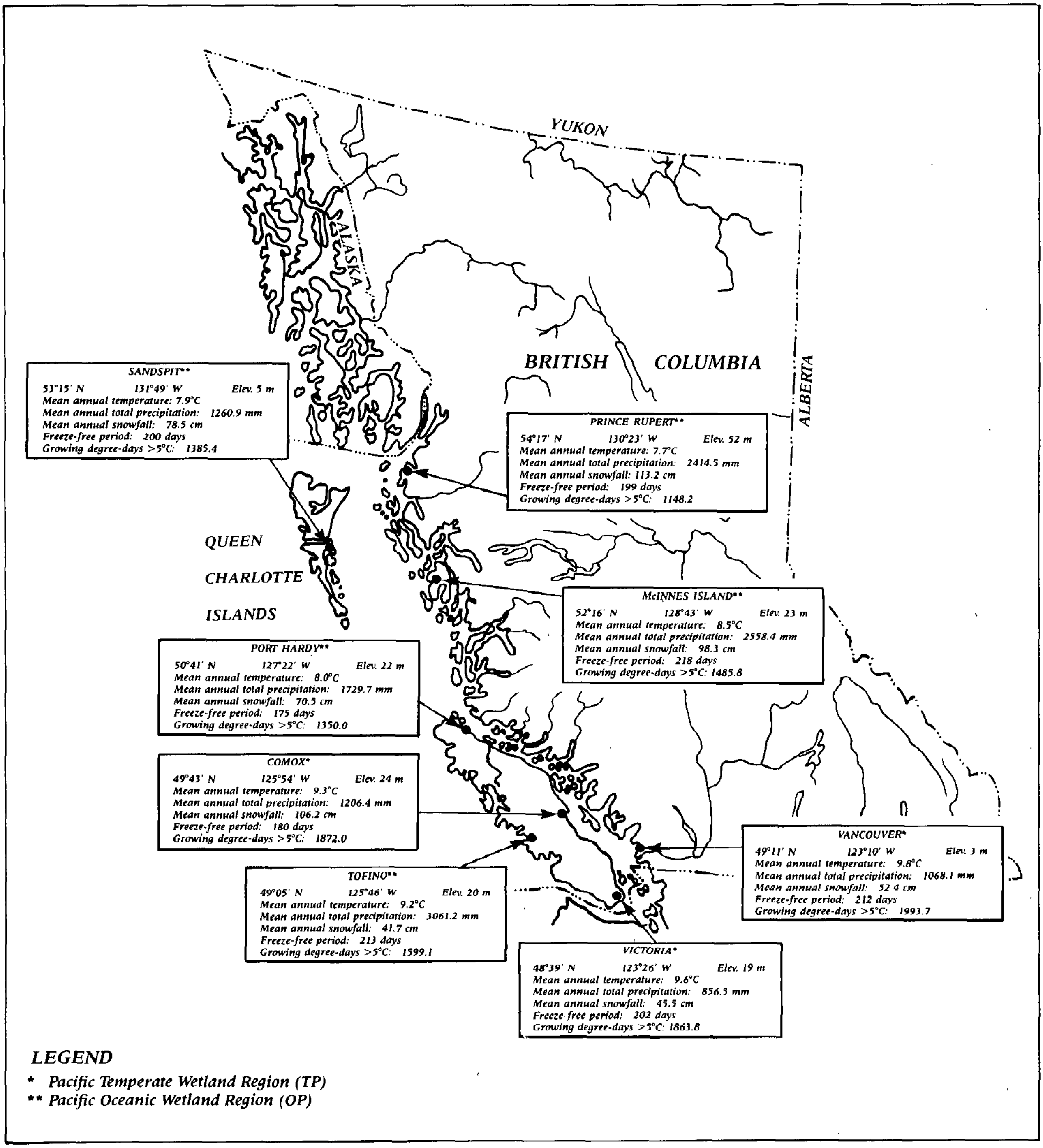
The lowlands are geologically and geomorphologically separated into three sections: the Estevan Coastal Plain along the west coast of Vancouver Island, underlain by tertiary sandstones and harder rocks of the Vancouver Group; the Hecate Depression, which includes the north end of Vancouver Island, the Queen Charlotte Lowland, and the western lowland fringe of the mainland, underlain by late Mesozoic and early Cenozoic basaltic and sedimentary rocks; and the Georgia Depression, which extends southwards from central Vancouver Island to include the Fraser Delta, underlain on the east side by granitic rocks and on the west side by Upper Cretaceous sedimentary rocks (Holland 1976).

Surficial materials largely originate from and reflect the major glacial episodes that occurred during the Tertiary (Miocene and Pliocene epochs) and Quaternary (Pleistocene epoch) periods (Fyles 1963). The last glaciation occurred during the late Pleistocene period, and modified or obliterated deposits of previous glacial periods. During part of this glaciation, much of the current coastal area was submerged to about 150 m above current sea levels (Clague 1981). This resulted in accumulations of marine clays and sands on previous glacial sediments or bedrock. During glaciation and subsequent deglaciation, some land surfaces were scoured to bedrock whereas others received various deposits of glacio-fluvial, mass-wasting, or morainal materials. Some of these have been and continue to be modified by recent water and wind action.

Peat accumulations have developed since deglaciation, about 13 500 to 10 500 years before the present (BP), although peat about 40 000 years old has been found (Fyles 1963; Howes 1981; Clague 1981). Peat accretion continues where disturbance or forest encroachment have not altered peat-forming processes.

Climate

The Pacific maritime climate is characterized by cool, wet winters and warm, moist to dry summers. Mean monthly temperatures among eight climatic stations near the coast range from 1.7°C in January to 17.4°C in July but the range may be less at any given station (Figure 8–2). The Pacific Temperate



Source: Chilton (1981) and Atmospheric Environment Service (1982).

Figure 8–2.
Climatological data from selected stations on the Pacific coast.

Wetland Region lies for the most part in the rain shadow of the Olympic and Vancouver Island mountains, resulting in slightly warmer and much drier conditions than in the Pacific Oceanic Wetland Region.

The mean annual precipitation in the Pacific Temperate Wetland Region, based on measurements from three climatic stations, ranges from 856 to 1 206 mm (mean = 1 044 mm). December is the wettest month and July the driest. Snow falls mostly from December through February, with traces in November and March. Mean annual temperatures in this region range from 9.3 to 9.8°C (mean = 9.6°C), with January being the coldest month and July the warmest. The freeze-free period ranges from 180 to 212 days (mean = 198 days) and the growing degree-days above 5°C range from 1 864 to 1 994 (mean = 1 910).

In the Pacific Oceanic Wetland Region, the mean annual precipitation, based on measurements from five climatic stations, ranges from 1 261 to 3 061 mm (mean = 2 117 mm), although some localities receive more. The wettest period extends from October through January and the driest period from May through August. Snow can be expected from November through March, but is ephemeral except at higher elevations. Mean annual temperatures range from 7.7 to 9.2°C (mean = 8.2°C). January is the coldest month and August the warmest. The freeze-free period ranges from 175 to 213 days (mean = 197 days) and the degree-days above 5°C range from 1 148 to 1 599 (mean = 1 371). Fog and cloud are more common in this region than in the Pacific Temperate Wetland Region, resulting in less sunshine and lower evapotranspiration rates.

Ecology

The Pacific coastal area contains the most productive forests in Canada. The principal tree species vary from south to north primarily in response to differences in precipitation and evapotranspiration. On the driest parts of southeastern Vancouver Island and the adjacent mainland, Garry oak (*Quercus garryana*), arbutus (*Arbutus menziesii*), western flowering dogwood (*Cornus nuttallii*), and grand fir (*Abies grandis*) occur with Douglas-fir (*Pseudotsuga menziesii*), shore pine (*Pinus contorta* var. *contorta*), western red cedar (*Thuja plicata*), and bigleaf maple (*Acer macrophyllum*), among others. As the moisture increases, Douglas-fir, western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*), western red cedar, and red alder (*Alnus rubra*) become more prominent. In the wetter areas along the west coast of Vancouver Island and northwards, amabilis fir, western red cedar, western hemlock, and Sitka spruce (*Picea sitchensis*) constitute the primary tree species. Yellow cypress (*Chamaecyparis nootkatensis*) and mountain hemlock (*Tsuga mertensiana*) are subalpine species in the south, but extend down to sea level in the north and may be major components of forest stands.

Soils in the drier parts of the Pacific coast are mainly Eutric and Dystric Brunisols (Canada Soil Survey Committee 1978). These soils are relatively warm and well drained, and organic material accumulates rather slowly. Gleysolic soils occur in poorly drained areas, and Organic soils may occur in basins that have restricted water discharge. As precipitation increases, Humo-Ferric Podzols and Ferro-Humic Podzols develop. Impermeable placic horizons, commonly at a depth of 45–60 cm, occur in the Ferro-Humic Podzols. However, the Humo-Ferric Podzols also can be underlain by bedrock, compacted glacial material, and duric horizons that are equally effective in inhibiting water and root penetration. In either case, water penetrates to the impermeable layer and is discharged downslope. Particularly in the wetter environments, a layer of folic organic material on bedrock can form a substrate capable of supporting vegetation (Trowbridge 1981). Although these Folisols are organic soils, they seldom constitute wetland substrates. Where drainage is restricted largely by fine-textured soils, gleyed subgroups and/or peaty phases of Humo-Ferric and Ferro-Humic Podzols are prominent.

Black-tailed deer (*Odocoileus hemionus columbianus*), ranging throughout the area, are probably the most influential large herbivorous animals of the Pacific coast. Roosevelt elk (*Cervus elaphus roosevelti*) occur mainly in central Vancouver Island. Red squirrels (*Tamiasciurus hudsonicus*), cottontail rabbits (*Sylvilagus nuttallii*), porcupines (*Erethizon dorsatum*), and a variety of mice, voles, and birds are also herbivorous and can have direct influences on vegetation. Black bears (*Ursus americanus*) and several species of birds are omnivorous and, along with the carnivorous species such as timber wolves (*Canis lupus*), cougars (*Felis concolor*), and eagles (*Haliaeetus* spp.), have a less direct influence on vegetation.

Criteria for Wetlands

Most criteria for wetlands discussed in the introductory chapter apply to the Pacific coast regions as well. However, some situations pertinent to wetland formation are unique to or more pronounced in coastal environments.

The heavy precipitation of the Pacific coast climate maintains a high water flux, not only in basins but on slopes as well. Particularly in the Pacific Oceanic Wetland Region, which receives the highest precipitation in Canada, the soils rarely, if ever, become dry even during summer. Wetlands form where the movement of soil water is impeded, such as by bedrock, restrictive horizons, or surface organic horizons (Neiland 1971; Ugolini and Mann 1979; Banner *et al.* 1983). The wetlands may or may not have a concomitant accumulation of peat. Frequently, however, sedges become prominent in what formerly may have been normal forest vegetation, and sedge peat may be formed. Low nutrient flux and lowering of the pH value can provide conditions for *Sphagnum* invasion. A dense blanket of *Sphagnum* spp. tends to lower the soil temperature and reduce oxygen (O), thereby promoting peat accumulation. Where peat does not form, wetland soils can be identified by gleyed horizons (Canada, Soil Survey Committee 1978).

Fog is an important climatic factor associated with coastal environments. It not only provides moisture, but reduces insolation, thereby reducing evapotranspiration. The reduction in insolation tends to lower the air and soil temperatures, and this in turn reduces the rate of decomposition. The combined effects of fog, high precipitation, and low temperatures promote wetland development on sites that would not otherwise support wetlands.

Pacific Wetland Forms and Types

Wetlands are relatively abundant along the coast of British Columbia (Figure 8–3, a, b, c, and d) and the principal wetland classes found here are bogs and swamps. Fens and marshes are associated primarily with riverine–estuarine systems. Bogs constitute the most abundant wetland class, especially in the oceanic and hyperoceanic climates. There are differences in form and vegetation between the bogs of the Pacific Oceanic Wetland Region and those of the Pacific Temperate Wetland Region which are described here in the discussion of each form. Swamps occur more frequently in the relatively drier and warmer climate of the east side of Vancouver Island and the adjacent mainland. However, the wetlands of coastal British Columbia have not been thoroughly studied and thus our knowledge of some wetland forms is limited.

Pacific Coast Bogs

Basin Bogs

Basin bogs along the southern part of the coast are usually small, ranging in size from less than 1 ha (Rigg and Richardson 1938) to 100 ha. Their shape is variable and depends on the constraining landforms. Many are circular to subcircular, whereas others are subrectangular to lobed. In vertical section, the organic deposits are more or less lenticular or saucer-shaped with the greatest thickness corresponding to the deepest portion of the basin. Basin bogs occur in sites where relatively small basins have filled with organic deposits to create a substrate for primary peat accumulation and bog development, exemplifying the classic model of hydrosere succession or basin infilling (Rigg 1925; Moore and Bellamy 1974).

The surface patterns of Pacific basin bogs vary considerably. Those located in the drier, warmer climate of the Pacific Temperate Wetland Region are characterized by a peripheral lagg (Rigg 1925). In the oceanic regime, dendritic drainage patterns associated with an outlet develop (Figure 8–4). In one case, on the hyperoceanic Brooks Peninsula, terraced ponds formed on the surface of a small basin bog. In some areas, such as the north end of Vancouver Island (Hebda 1983) and around Prince Rupert (Banner 1983), basin bogs have expanded and become parts of slope bog complexes. The concept of the "blanket mire complex" of Moore and Bellamy (1974) applies to bog development and relationships in the Pacific Oceanic Wetland Region.

Some bogs, such as one near Bear Cove (Hebda 1983), have a complex history of peat accumulation, making it difficult to decide where to begin measuring peat depth in the stratigraphic column. Organic thickness in basin bogs varies from about 1 to 10 m (Table 8–1). Usually limnic peat predominates, although occasionally sedge peat ("Rithets Bog") or *Sphagnum* peat ("Nettle Island Bog") can be dominant. Four representative sections (Figure 8–5) from basin bogs show that these bogs typically begin as lakes, pass through a sedge-dominated phase, and finally end up as *Sphagnum* bogs. In artificially drained basins, the *Sphagnum* phase is succeeded by shrub and tree vegetation, producing a fibrous, humic, litter-dominated sediment.

Few basin bogs in southwest British Columbia have been studied for chemical characteristics, although recent analyses reveal the chemical characteristics of organic sediments (Tables 8–2 and 8–3, a and b). Typically, pH (3.5–4.5) and nutrient concentrations are low, even for bogs that are becoming forested because of historic drainage and water table modifications (Pearson 1985).

Two types of basin bogs can be recognized on the basis of vegetation: coniferous treed and moss.

Coniferous treed type: Shore pine or shore pine–western hemlock stands are known from two basin bogs, Camosun Bog in Vancouver and Rithets Bog in Victoria. Shore pine and/or western hemlock dominate over a shrub layer that consists predominantly of *Gaultheria shallon* and *Ledum groenlandicum*. The herb and bryophyte layers are poorly developed except in openings. *Oxycoccus microcarpus*, *Sphagnum* spp. (mostly *Sphagnum rubellum*), and other bryophytes cover much of the ground. This vegetation is most likely a product of drainage and disturbance. The original vegetation is difficult to determine; however, it probably consisted of typical

Table 8–1. Peat depths of Pacific coast basin bogs

Bog	Location	Peat depth	Source
Camosun Bog	Vancouver	4.0–5.5 m	Pearson (1985), Rouse*
Rithets Bog	Victoria	8.5–9.9 m	Zirul (1967)
Tyee Bog	Duncan	ca. 10.0 m	Rigg and Richardson (1938)
Effingham Island Bog	Barkley Sound Vancouver Island	8.0 m	Hebda*
Nettle Island Bog	Barkley Sound Vancouver Island	8.0 m	Hebda*
Gold Creek Bog	Brooks Peninsula Vancouver Island	4.0 m	Hebda*
Bear Cove Bog	Near Port Hardy Vancouver Island	2.0 m	Hebda (1983)
Several	Prince Rupert area	1.0–4.0 m	Banner *et al.**

**Data from unpublished file reports.*

Sphagnum-dominated bog communities, because *Sphagnum* peat underlies much of the surface and the shore pine trees are all less than 100 years old.

Moss type: The oceanic climate combined with lack of disturbance leads to a different vegetation in a basin bog. The peripheral drainage ditch usually surrounding a basin bog is lacking. Bog vegetation often extends onto the base of surrounding slopes where it is shaded out by the forest, usually under a dense band of shrubs and small trees (Figure 8–6).

Typically, the vegetation of this type of basin bog (Table 8–4) consists of a hummocky carpet of *Sphagnum* spp. supporting a diversity of herbaceous species, and zones of shrubby red cedar or, less frequently, yellow cypress. The most common low shrubs and herbaceous plants include *Ledum groenlandicum, Kalmia polifolia, Oxycoccus microcarpus, Rhynchospora alba, Drosera rotundifolia, Drosera anglica, Blechnum spicant, Hypericum anagalloides,* and *Lycopodium inundatum. Sphagnum rubellum* and *Sphagnum imbricatum* usually cover 80–100% of the ground. *Nuphar polysepalum* occupies shallow pools of water courses (Figure 8–7).

Table 8–2. Average annual pH, nutrient concentrations, and specific conductivity in soil water from Camosun Bog, Vancouver, British Columbia

pH	3.5–4.5
Ca^{++}	1–3 mg/L
Mg^{++}	1–2 mg/L
K^+	ca. 1–2 mg/L
Na^+	ca. 3–4 mg/L
NO_3	1 mg/L
NH_4^+	1–4 mg/L
PO_4^{3-}	1–2 mg/L
Specific conductivity	40–70 µS/cm

Source: Pearson (1985).

Shore Bogs and Floating Bogs

Two similar forms of bogs occur at the margins of small lakes: floating bogs and shore bogs. However, as there are insufficient field data to describe them separately, they are combined into one class: shore bogs.

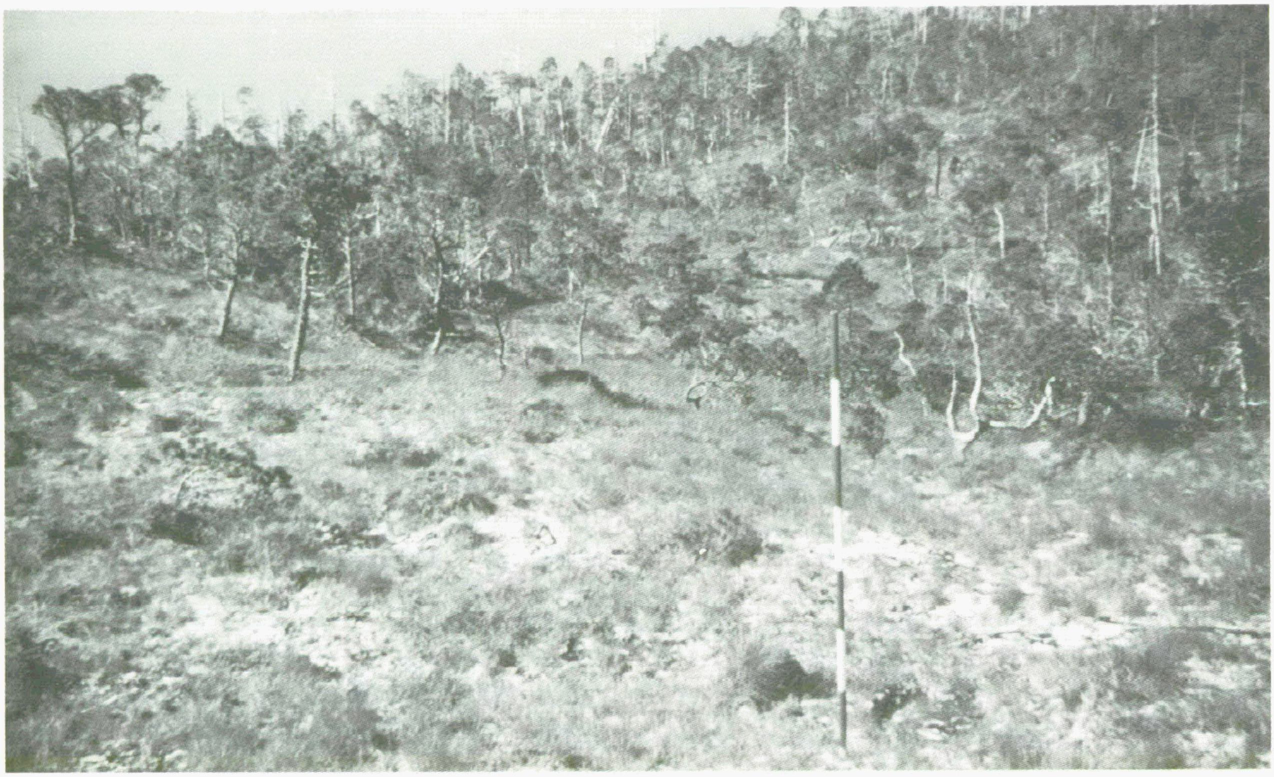
Shore bogs (Figures 8–8 and 8–9) occur along the margins of dystrophic lakes. On the west coast of Vancouver Island, almost every small lake with a gently sloping shoreline has a shore bog, but such bogs are less abundant along the dry and warm east side of Vancouver Island and the adjacent mainland. These bogs may be floating or grounded on the shore and, indeed, a lake in the Broken Group Islands on the west coast of Vancouver Island has both types. Shore bogs usually form a narrow (2–20 m wide) fringe or band along a gently sloping or nearly flat portion of the shore, or completely cover a small bay or corner of the lake. Most of these bogs are less than 0.1 ha, although some may reach 5 ha.

The surface of shore bogs is usually uniform and consists of moss mat–hummock complexes. Typically, there are no bodies of water within the bog. Stratigraphy and peat thickness are extremely variable. Floating bogs may be up to 13 m deep (as observed by R. Hebda at the "Tzartus Island Bog", Vancouver Island) but usually are less than 10 m deep. Grounded shore bogs are shallower with typical depths ranging from a few decimetres to 3 m.

(a)

(b)

(c)



(d)

Figure 8–3.

(A) A slope bog complex on northern Banks Island in the central coastal lowland of British Columbia. (B) A slope bog, deep phase, at 80 m elevation near Rainbow Lake southeast of Prince Rupert, British Columbia, supporting a Myrica gale/Scirpus caespitosus – Rhynchospora alba/Cladina impexa – Sphagnum rubellum, Sphagnum papillosum *association. Range rod interval is 25 cm. (C) Slope bog complex: shrub type, shallow phase in foreground and coniferous treed type in background. Littlejohns Point, Pitt Island, British Columbia, 50 m elevation. Range rod interval is 25 cm. (D) Slope fen in upper Williams Creek, southeast of Terrace, British Columbia, at 600 m elevation. Surrounding forest is mostly* Tsuga heterophylla *and* Abies amabilis.

Figure 8–4.
Dendritic drainage in a basin bog.

Peat thickness increases gradually from a few centimetres at the landward edge to more than 2 m at the water's edge. Large rocks or bedrock occasionally protrude through the peat surface.

Stratigraphic studies of floating bogs indicate that the upper part of the sequence (approximately 1 m) consists of fibrous *Sphagnum* peat (Figure 8–9). Below this, there is usually watery fibrous peat that may contain *Sphagnum* spp., sedge, and aquatic macrophyte remains, often bound together by living and dead roots. Water zones occur within the peat above the limnic sediment on the lake bottom.

Deposits of grounded shore bogs may occasionally be dominated by *Sphagnum* spp., but more often consist of slightly to very humified fibrous peat strata with infrequent water lenses that in turn overlie limnic organic sediments and gyttja (Figure 8–10). The nature of the peat and vegetation (Table 8–5) in grounded shore bogs depends on the position of the bog with respect to the outlet of the basin. Bogs distal to the outlet are *Sphagnum*-dominated, usually species-poor, and produce predominantly *Sphagnum* peat. Bogs near the outlet receive a regular input of nutrients, are herb-dominated, and species-rich. Slightly fibrous, humic peat usually results.

A common occurrence of shore or floating bogs is the moss–forb type.

Moss–forb type: The largest known floating bog is located on Village Lake in the Hesquiat Peninsula, British Columbia, but no vegetation data are available. Grounded shore bogs at Whyac Lake and Bamfield on the west coast of Vancouver Island are

Table 8–3a. Chemical data* of a Pacific basin bog with peripheral drainage near Campbell River, British Columbia

Horizon	Depth (cm)	pH 1:2 .01 M $CaCl_2$	C (%)	H (%)	N (%)	Pyro-phosphate soluble (%)	Ash (%)	Fibre content		Exchangeable cations (me/100 g)					Calorific value (cal/g)
								Unrubbed (%)	Rubbed (%)	Ca	Mg	K	Na	CEC	
Of	0–28	3.0	—	—	—	5.0	1.9	100	82	9.2	7.4	0.76	0.68	132.8	5 374
Om1	28–106	3.1	59.7	5.83	1.62	30.0	3.0	60	10	5.1	2.8	0.36	0.52	126.8	5 668
Om2	106–225	3.6	54.0	5.15	1.64	15.0	2.5	70	28	9.7	4.3	0.12	0.61	124.8	5 524
Om3	225–315	4.2	52.7	4.64	1.23	17.0	4.2	24	Tr**	—	—	—	—	140.8	5 833
Om4	315–523	4.6	25.5	2.27	0.94	8.0	5.3	88	18	29.7	10.7	0.15	1.55	102.6	5 849
Oco	523–545	—	30.6	3.31	2.00	13.5	—	82	Tr	—	—	—	—	90.5	4 458
IICg	545 +	—	6.2	0.86	0.69	—	—	—	—	—	—	—	—	—	—

Table 8–3b. Chemical data* of a Pacific basin bog without peripheral drainage near Prince Rupert, British Columbia

Horizon	pH 1:2 .01 M $CaCl_2$	C (%)	H (%)	N (%)	Pyro-phosphate soluble (%)	Ash (%)	Fibre content		Exchangeable cations (me/100 g)				Calorific value (cal/g)
							Unrubbed (%)	Rubbed (%)	Ca	Mg	K	Al	
Of1	3.0	46.8	5.59	1.02	8.0	5.8	100	80	5.10	10.36	0.59	3.33	4 868
Om	2.9	50.5	5.56	1.14	9.0	5.4	80	46	—	—	—	—	5 340
Of2	3.0	47.2	5.98	0.88	6.8	2.0	100	100	4.62	10.36	0.44	1.67	5 223

**Analyses conducted under guidance of C. Tarnocai, Land Resources Research Centre, Ottawa.*
***Tr—trace.*

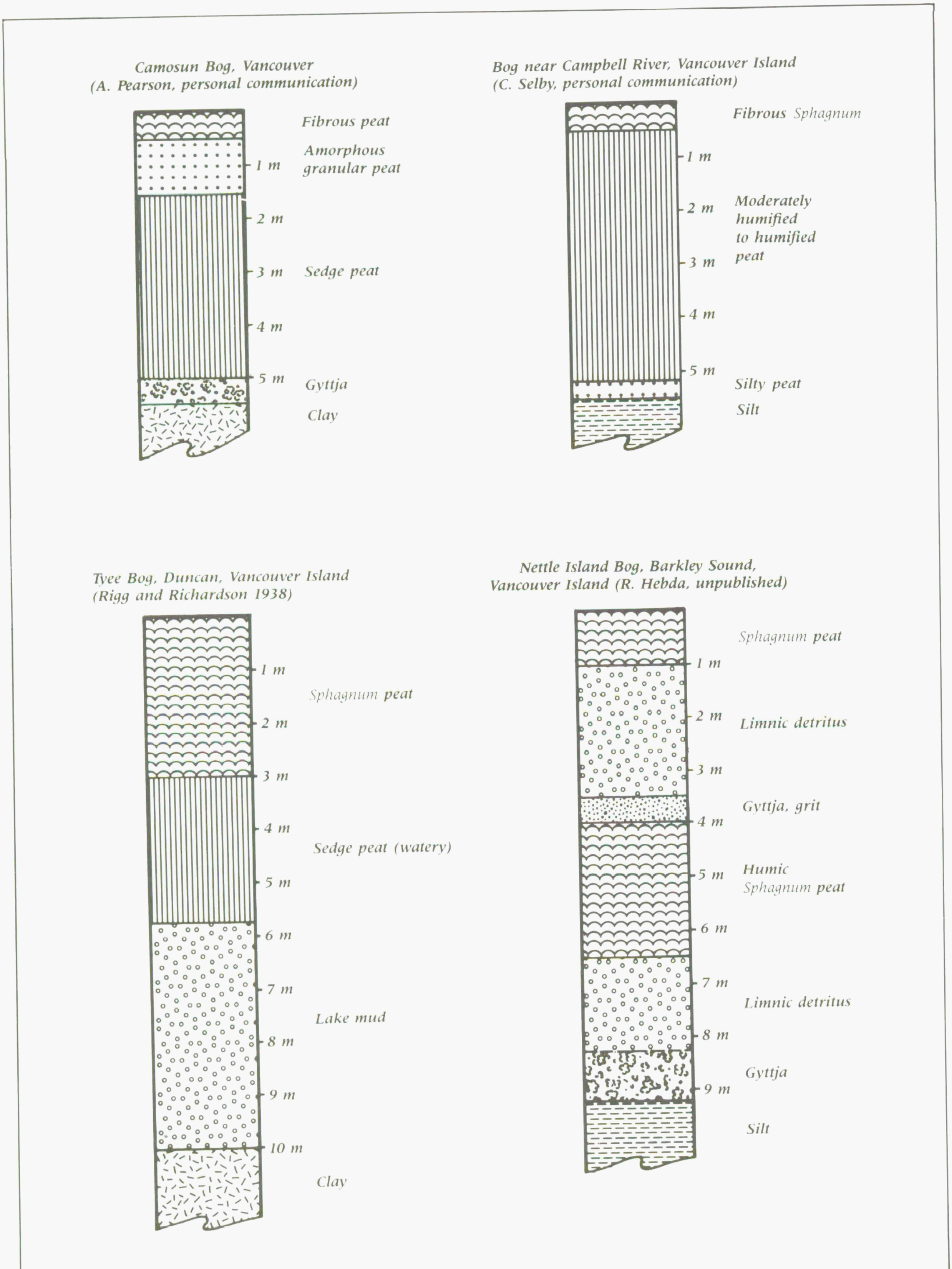


Figure 8–5.
Stratigraphy of selected Pacific coast basin bogs.

Figure 8–6.
Basin bog, moss type at Rainbow Lake southeast of Prince Rupert, British Columbia, at 50 m elevation supporting Carex pluriflora – Trientalis europaea – Kalmia polifolia/Sphagnum rubellum, *and* Sphagnum papillosum.

Figure 8–7.
Nuphar lutea *in a bog on Nettle Island, British Columbia.*

dominated by mosses and forbs (Table 8–5; Figure 8–10). Trees are absent and shrub cover is sparse, consisting primarily of dwarfed western red cedar, *Myrica gale,* and *Ledum groenlandicum.* The herb and bryophyte strata are rich in species. The plant associations closely resemble those on shallow peat at the margins of some basin bogs. The basin bog associations probably began in a similar setting before terrestrialization of lake or bog by peat accumulation took place. Chemical analyses of peat from the Bamfield Bog are presented in Tables 8–6a and 8–6b.

Table 8–4. ***Major species and percent cover of a Pacific basin bog with peripheral drainage near Campbell River, British Columbia***

Strata and species	*Cover (%)* Near edge	*Cover (%)* Middle of bog
Shrub stratum		
Kalmia microphylla	2	30
Ledum groenlandicum	3	50
Oxycoccus microcarpus	—	70
Salix spp.	5	—
Spiraea douglasii	90	—
Herb stratum		
Carex rostrata	15	—
Carex sitchensis	10	—
Drosera rotundifolia	—	1
Bryophyte stratum		
Aulacomnium palustre	40	5
Polytrichum juniperinum	—	2
Sphagnum spp.	20	90

Source: C. Selby, Agriculture Canada, Vancouver.

Slope Bogs

Slope bogs (Figures 8–11 and 8–12) constitute a common wetland form in the Pacific Oceanic Wetland Region but are lacking in the Pacific Temperate Wetland Region. They occur on virtually all slope positions from gentle to very steep (up to 70%) and extend onto level terrain, hence resembling blanket bogs. The underlying materials can be bedrock, morainal, colluvial, or fluvial deposits. The peat depth reflects the underlying topography and ranges from discontinuous accumulations less than 50 cm deep to continuous blankets over 2 m deep (Stephens *et al.* 1970). Vegetation varies from nearly closed forest to shrublands, but in all cases productivity is low.

Soils are mostly Mesisols, with Humisols, Fibrisols, Gleysols, and Folisols being less common, and Humic or Ferro-Humic Podzols and Humic Regosols sometimes occurring in areas of shallow peat. Sedge peat dominates the lower horizons and *Sphagnum* with other moss peat predominates in the upper horizons; woody material is present throughout. The peat is extremely acid, with pH values of 2.9–3.2 at the surface increasing to 3.7–4.5 near the bottom (Table 8–7). The ash content is generally low (less than 5%) at the surface, but increases with depth. Exchangeable calcium (Ca) and magnesium (Mg) decrease with depth where trees are present, but are highest in the middle horizons under shrubs.

Figure 8–8.
A grounded shore bog community on Nettle Island, British Columbia, and surrounding forest.

Within the slope bog complex, two wetland types, each with two phases, can be identified: coniferous treed (forest and woodland phases) and tall shrub (deep and shallow phases). The shallow phase of the tall shrub type represents sloping wetlands that are transitional between bog and fen.

Coniferous treed type, forest phase: In this phase, the tree canopy is open, unevenly aged, seldom over 20 m in height, and is dominated by western red cedar, yellow cypress, and shore pine (Figure 8–13). Western hemlock is common as a suppressed tree but is of minor importance in the upper canopy (Table 8–8). Dead snags are common and the cedar and cypress are usually "spike-topped".

Shrub layers are well developed, except where deer have overbrowsed, as on the Queen Charlotte Islands. Tree regeneration dominates the tall shrub layer. *Gaultheria shallon* is the dominant shrub species. A diverse array of both bog and forest species comprises the well-developed (except where overbrowsed) herb and dwarf shrub layer. The well-developed ground cover also reflects the transitional nature of coniferous forest slope bogs. Upland forest

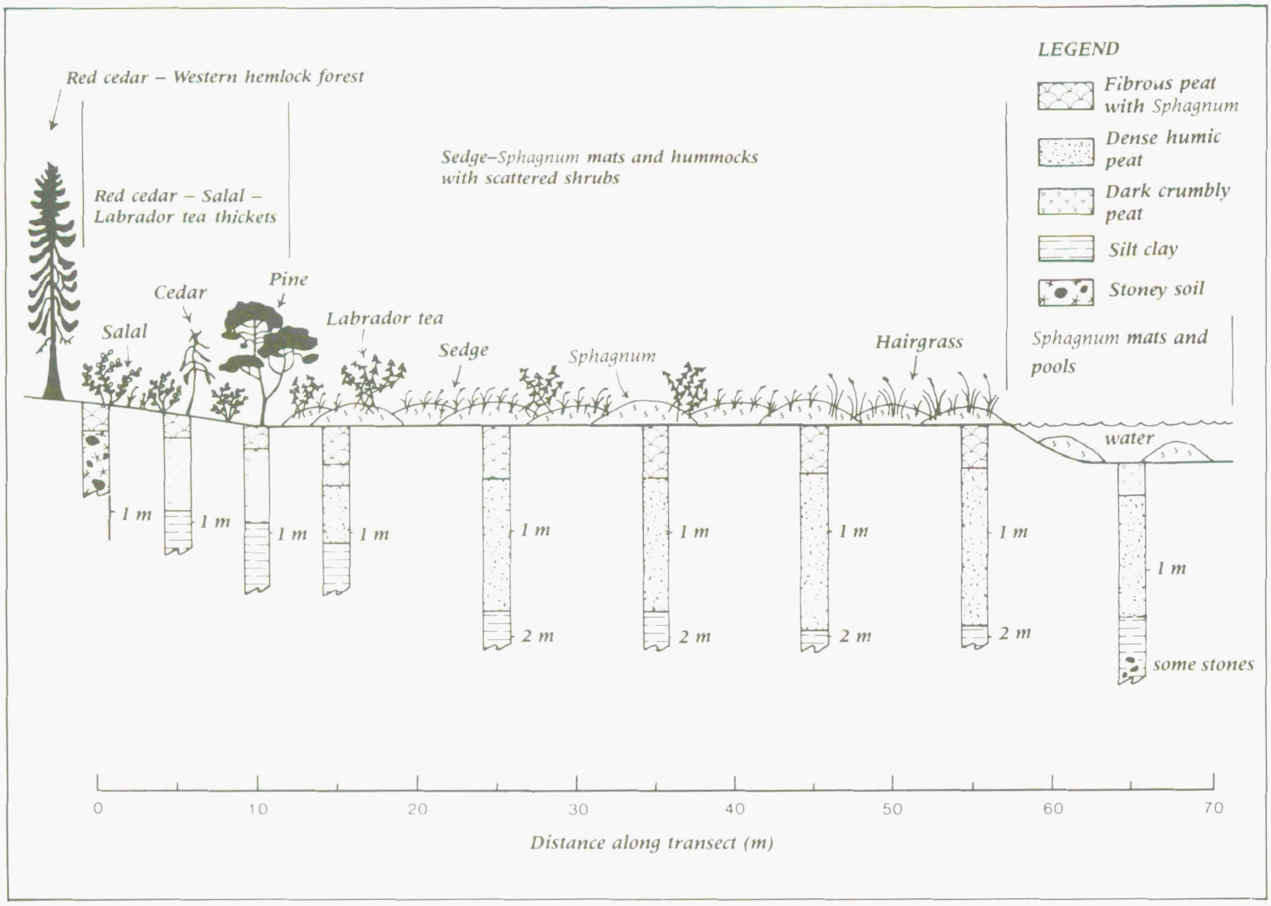


Figure 8–9.
Vegetation and stratigraphy of a shore bog, Bamfield Bog, British Columbia.

species such as *Rhytidiadelphus loreus, Hylocomium splendens, Sphagnum girgensohnii, Rhizomnium glabrescens,* and *Plagiothecium undulatum* occur together with several open or coniferous woodland slope bog species such as *Sphagnum papillosum, Sphagnum rubellum, Cladina rangiferina,* and *Cladina impexa.*

Though most common on gentle to moderate slopes, coniferous forest slope bogs may occur on slopes of up to 70%. Principal soils are Mesisols and Humisols, but Gleysols, Humic Gleysols, and Folisols with surface organic horizons 10–55 cm thick also occur. Table 8–7 contains selected chemical and physical soil data for coniferous treed and tall shrub slope bogs in the Prince Rupert area.

Coniferous treed type, woodland phase: Shore pine, yellow cypress, and western red cedar are the most abundant trees in coniferous woodland slope bogs, but western and mountain hemlock are also common (Figure 8–14, a and b). However, the trees are often stunted and are rarely taller than 12 m. Much of the variation in tree height is due to microsite growing conditions rather than to age differences. A characteristic feature is the large number of standing

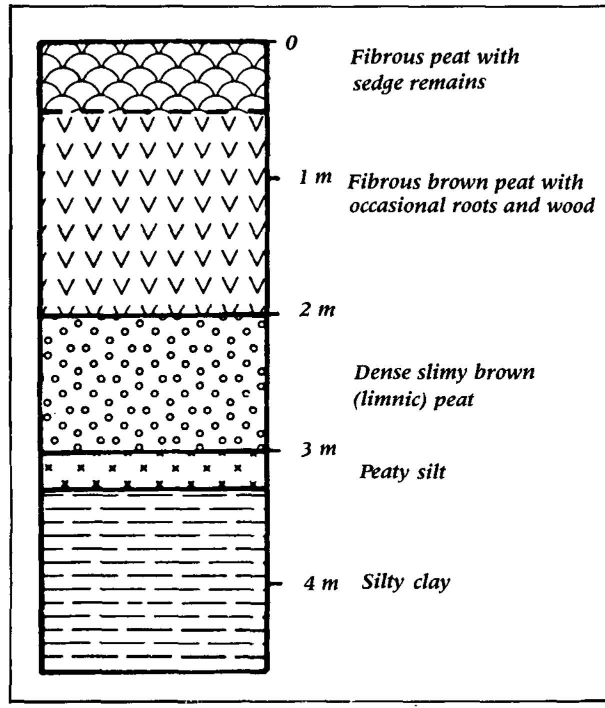


Figure 8–10.
Stratigraphy of a shore bog, Whyac Lake, west coast, Vancouver Island.

Table 8–5. Major species and percent cover in two Pacific shore bogs on the west coast of Vancouver Island

Strata and species	Cover (%)			
	Bamfield Bog			Whyac Lake
	Edge	Middle	Near centre	
Tree stratum				
Pinus monticola	5	—	—	—
Thuja plicata	5	—	—	—
Shrub stratum				
Gaultheria shallon	25	3	—	—
Ledum groenlandicum	25	15	—	—
Thuja plicata	40	1	—	—
Myrica gale	—	—	—	30
Oxycoccus microcarpus	*	8	1	5
Herb stratum				
Blechnum spicant	20	10	—	—
Carex livida	—	*	—	20
Carex phyllomanica	—	5	—	—
Carex rostrata	12	30	8	20
Hypericum anagalloides	—	10	—	2
Lycopodium inundatum	—	—	2	5
Nuphar polysepalum	—	—	—	5
Panicum occidentale	—	—	—	5
Plantago macrocarpa	—	—	—	10
Rhynchospora alba	—	—	5	—
Sanguisorba officinalis	—	—	—	30
Bryophyte stratum				
Dicranum spp.	5	—	—	—
Sphagnum imbricatum	—	5	—	—
Sphagnum papillosum	10	70	50	—
Sphagnum rubellum	35	15	—	—
Sphagnum tenellum	—	—	10	—
Sphagnum spp.	—	—	—	50
Gymnocolea inflata	—	—	15	—

**Trace occurrence.*

Table 8–6a. Analyses of samples collected at selected sites at Bamfield Bog, British Columbia*

Station no.**	Depth (cm)	pH ($CaCl_2$)	CEC (me/100 g)	Base saturation (%)	Exchangeable cations (me/100 g)			
					Ca	Mg	K	Na
1	0–15	3.80	25.95	21	4.12	0.91	0.27	0.15
2	0–15	3.90	88.02	19	10.86	4.27	0.92	0.46
3	40–60	4.73	105.83	24	20.42	3.74	0.30	0.75
4	0–15	4.08	98.73	25	16.90	6.25	0.58	0.53
5	—	4.17	98.24	21	13.25	6.38	0.70	0.65
6	0–15	3.95	101.45	23	16.09	6.57	0.51	0.60
7	0–20	3.63	103.74	20	13.32	6.03	0.61	0.65
8	0–20	4.30	74.60	23	14.91	2.15	0.14	0.26
8a	0–20	5.20	61.09	56	29.10	3.42	0.34	1.39
9	0–20	4.86	57.03	82	20.70	3.26	0.21	0.32
10	0–20	4.85	55.61	36	17.31	2.08	0.14	0.33
11	10–30	3.60	105.21	14	8.23	4.06	0.88	1.02

Table 8–6b. Total element analyses at selected sites at Bamfield Bog, British Columbia*

Station no.**	Element (mg/kg)													
	Ca	Mg	Na	K	Al	Ti	Pb	Cu	Fe	Mn	Zn	Ni	S	P
1	393.7	588.94	213.72	813.57	6 455.0	76.66	13.18	6.50	2 984.3	48.01	15.40	5.92	172.33	133.54
2	2 011.4	660.04	201.00	555.46	6 777.6	73.26	15.39	7.39	3 215.7	21.44	9.07	3.40	1 176.40	1 046.50
3	5 321.1	791.05	277.72	573.16	19 014.2	135.80	23.99	17.83	9 373.1	133.39	14.48	31.32	2 568.80	800.45
4	4 086.1	1 805.20	264.74	737.98	10 916.3	199.70	37.98	16.27	6 756.5	108.05	23.56	5.07	1 503.80	914.06
5	3 702.1	3 606.70	386.78	1 386.50	18 097.2	291.72	64.88	23.66	17 668.7	247.47	39.09	8.42	990.26	726.10
6	3 986.0	2 947.30	357.76	1 117.30	15 869.5	288.71	51.02	17.10	12 567.5	152.21	29.95	6.55	762.94	618.11
7	2 714.3	1 009.40	239.62	373.70	6 182.0	83.98	161.29	7.50	5 415.2	23.21	18.64	3.76	695.73	525.78
8	3 548.4	500.53	153.30	415.43	13 220.2	103.16	19.50	6.07	3 011.4	14.90	7.15	5.52	1 412.20	486.39
8a	7 329.5	827.60	394.90	426.25	10 353.9	163.57	20.57	7.20	4 056.3	84.91	15.50	5.26	2 618.70	535.19
9	4 759.1	743.58	177.24	383.06	10 002.6	147.10	19.67	5.24	2 955.7	16.98	15.56	5.16	1 499.60	547.11
10	3 925.7	607.37	191.14	438.20	11 393.2	154.62	16.76	5.31	50 002.6	27.53	15.49	5.47	1 321.70	480.59
11	1 420.4	694.14	304.52	518.62	8 555.4	77.22	18.74	6.35	5 228.6	49.50	19.08	3.99	1 128.10	1 002.00

*Analyses conducted under guidance of S.C. Zoltai, Northern Forestry Centre, Edmonton.
**Stations are numbered from the edge (no.1) to the centre (no.11) of the bog.

Table 8–7. Chemical data* from Pacific slope bogs near Prince Rupert, British Columbia

Bog type/ phase	Horizon	pH 1:2 .01 M $CaCl_2$	C (%)	H (%)	N (%)	Pyro-phosphate soluble (%)	Ash (%)	Fibre content		Exchangeable cations (me/100 g)				Calorific value (cal/g)
								Unrubbed (%)	Rubbed (%)	Ca	Mg	K	Al	
Coniferous treed/ forest	F**	3.0	48.8	5.74	1.26	18.6	5.0	—	—	6.24	5.43	2.96	10.30	5 343
	H**	3.0	45.7	5.91	1.54	30.0	12.3	70	22	3.84	3.36	1.65	10.70	5 400
	Oh1	3.0	43.7	5.71	1.54	51.0	15.6	80	2	2.04	1.97	1.02	9.99	4 856
	Oh2	3.0	38.1	5.91	1.07	84.0	26.0	80	2	1.26	0.99	0.62	8.99	4 903
	Oh3	3.2	27.8	3.36	0.76	90.3	19.6	54	2	1.02	0.30	0.40	16.70	3 232
	Bhf	3.7	7.7	0.94	0.18	—	—	—	—	0.84	0.20	0.38	6.32	—
Coniferous treed/ woodland	F**	2.9	49.6	5.73	0.91	8.2	3.4	—	—	10.50	11.84	1.82	1.00	4 455
	Om	3.0	42.6	7.35	1.51	28.8	9.4	48	4	1.80	2.76	1.08	3.33	5 781
	Oh1	3.2	46.0	8.11	1.50	58.4	6.6	42	4	1.44	1.28	0.54	7.33	4 573
	Oh2	3.7	47.7	5.98	0.77	65.7	28.3	8	1	1.14	0.39	0.42	6.99	5 712
	Oh3	—	22.0	2.78	0.45	74.4	65.5	10	2	—	—	—	—	2 539
Tall shrub/ deep	Of	3.2	47.5	6.04	0.43	4.6	1.1	100	100	—	—	—	—	4 988
	Om	3.3	50.2	6.85	1.95	22.9	4.1	66	14	7.32	2.66	0.52	2.99	6 040
	Oh1	4.0	47.4	7.16	1.11	41.6	6.1	76	6	21.30	3.75	0.39	2.00	4 484
	Oh2	4.5	33.7	3.98	0.73	90.3	44.0	12	2	11.04	1.88	0.26	1.67	3 810

*Analyses conducted under guidance of C. Tarnocai, Land Resources Research Centre, Ottawa.
**See Klinka et al. (1981).

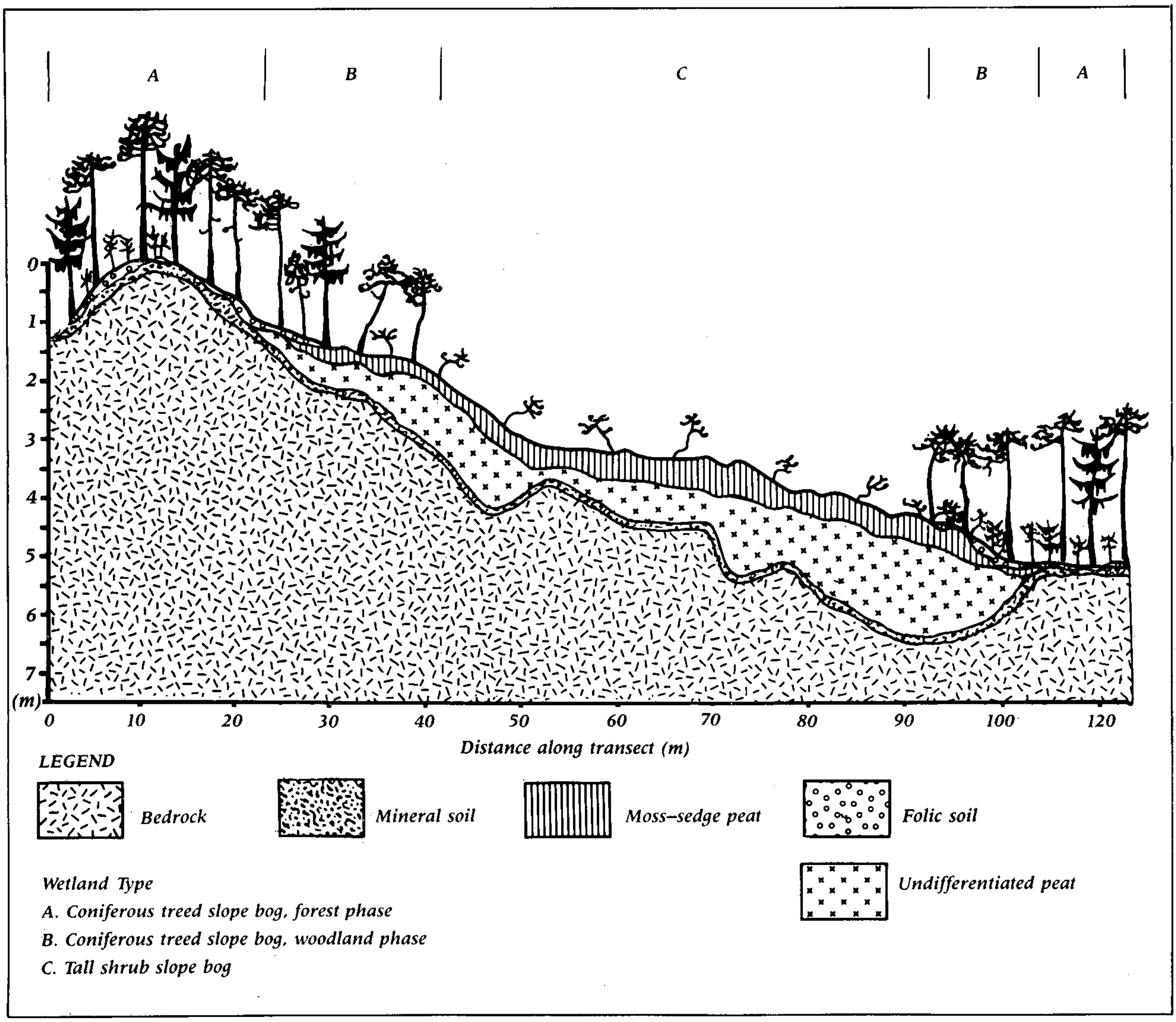


Figure 8–11.
Schematic profile of a slope bog landscape near Rainbow Lake, southeast of Prince Rupert, British Columbia.

dead and dead-topped trees; larger red cedar and yellow cypress often have dead spike-tops.

The well-developed shrub layers are dominated by young or stunted older trees and by *Gaultheria shallon. Fauria crista-galli, Coptis asplenifolia, Empetrum nigrum*, and *Cornus canadensis* are characteristic of the moderately developed dwarf shrub and herb layers. Browsing by deer has depleted the shrub and herb layers of woodland slope bogs on the Queen Charlotte Islands. *Rhytidiadelphus loreus* and *Hylocomium splendens* dominate the well-developed moss layer. *Pleurozium schreberi* occupies higher, drier microsites, and *Sphagnum* spp. grow in wet depressions (Table 8–8).

Woodland slope bogs occur on most slope positions, from valley bottoms to upper slopes and ridge crests. Slopes usually range from 5 to 30%, but may reach 65%. Such slopes in the hyperoceanic climate are sufficient to prevent water from stagnating, but are insufficient to overcome the generally poor drainage. Thus, water, dissolved oxygen, and nutrients move through the soil slowly. The predominant soils are Mesisols, but Folisols and folic phases of Gleysols are also common.

Tall shrub type, deep phase: These ombrotrophic slope bogs support a mosaic of plant communities that develop in response to, or bring about, heterogeneous surface topography and moisture conditions (Figure 8–15). Dwarf, contorted shore pine is dominant, and yellow cypress and western red cedar are less frequent. Shrub development is best in the driest habitats. Common shrubs include *Juniperus communis, Ledum groenlandicum*, and *Vaccinium uliginosum. Myrica gale* is usually restricted to the edges of streamlets meandering through these bogs.

The dwarf shrub/herb layer is usually well developed, although generally less diverse than in shal-

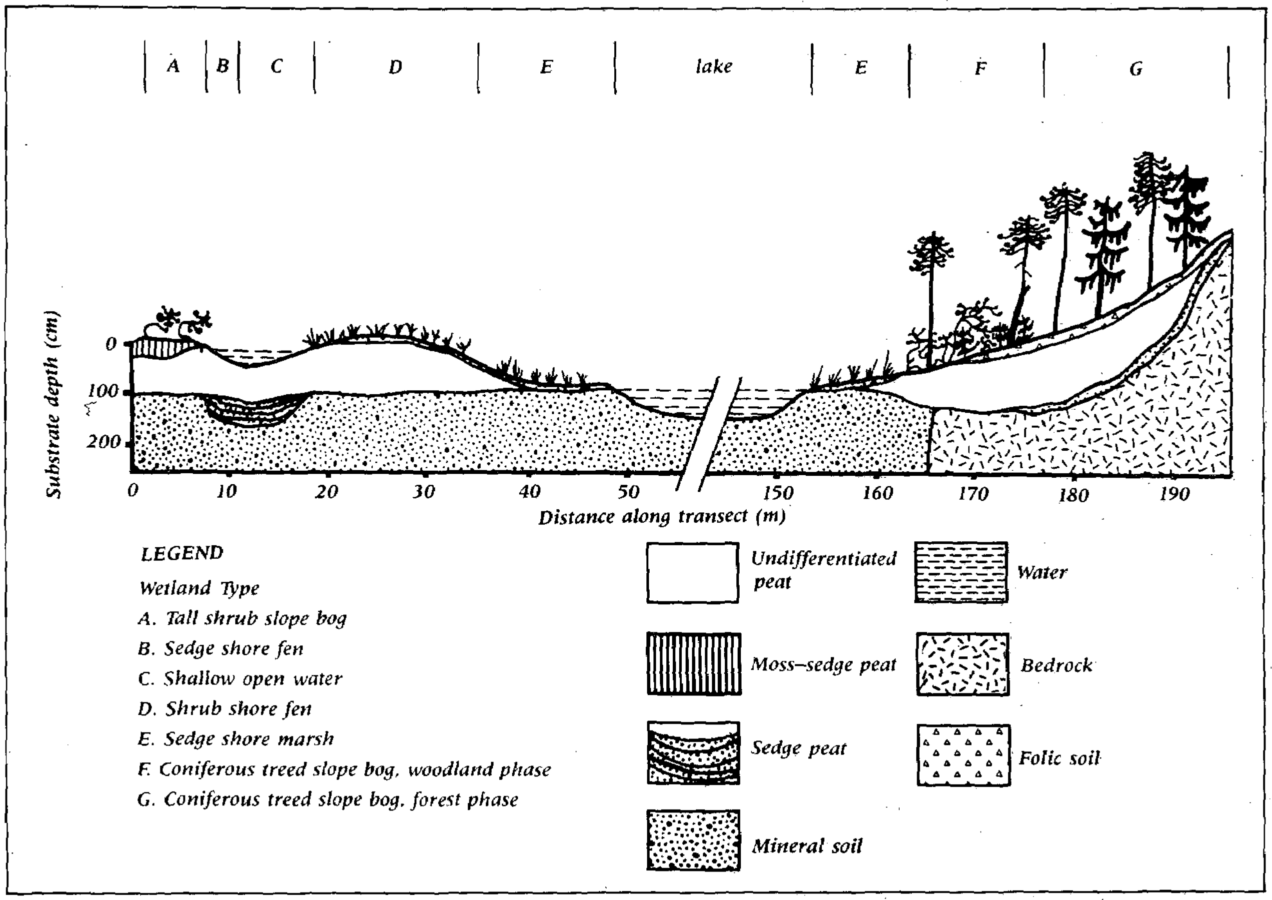


Figure 8–12.
Schematic profile of a wetland landscape (including marsh, fen, and bog forms) near Prudhomme Lake, southeast of Prince Rupert, British Columbia.

low slope bogs (Table 8–8). Drier sites, especially in the North Coast Pacific Oceanic Wetland Subregion, are characterized by *Empetrum nigrum*, *Loiseleuria procumbens*, and *Vaccinium vitis-idaea*. Herbaceous species, of which *Scirpus caespitosus* is usually dominant, form a major component of all except the wettest communities. *Rhynchospora alba*, *Carex livida*, *Eriophorum angustifolium*, *Drosera rotundifolia*, *Drosera anglica*, and *Lycopodium inundatum* colonize wet depressional areas, which in many cases appear to have originated through succession from open ponds. *Menyanthes trifoliata* commonly occurs in the smaller ponds and may be joined by *Nuphar polysepalum* in the larger, deeper pools.

Bryophytes and lichens are abundant throughout, and are largely responsible for the irregular bog surfaces. Dry hummocks or mounds typically consist of *Sphagnum rubellum*, *Sphagnum fuscum*, *Rhacomitrium lanuginosum*, *Cladina impexa*, and *Cladina rangiferina*. *Sphagnum papillosum* and *Sphagnum imbricatum* form wetter hummocks, and *Sphagnum tenellum*, *Sphagnum compactum*, and *Sphagnum lindbergii* occur in the wettest depressions, often submerged at the edges of ponds. Although the *Siphula ceratites–Gymnocolea inflata* association commonly occurs in low wet areas, it is usually not as well developed and striking as in bogs that have a shallow peat cover.

Small, shallow pools 1–4 m² in area and 10–50 cm deep are distributed throughout these deep slope bogs. The pools often form a series of circular to teardrop-shaped terraces held by dams of *Sphagnum* spp. and *Scirpus caespitosus* growing in fibric peat.

Ombrotrophic slope bogs with relatively deep (more than 1–2 m) accumulations of *Sphagnum* peat are common on more gently sloping and generally less exposed terrain than the shallow, minerotrophic slope bogs. Soils are commonly Mesisols; Fibrisols and Humisols are less common. They are usually underlain by bedrock, less commonly by glacial moraine or fluvial deposits. Peat depth can vary considerably (from 50 to over 400 cm) over short distances in deeper slope bogs. The large variability in peat depth suggests that wet depressions in the underlying bedrock may have acted originally as templates or nuclei for peat accumulation and bog formation. The underlying to-

*Table 8–8. Major floristic and plant community features of bog types and phases in the northern part of the Pacific Oceanic Wetland Region**

	Pacific slope bogs				*Pacific basin bogs (4)*	*Pacific domed bogs (1)*
			Tall shrub (27)			
Strata and species	*Coniferous treed, forest (32)***	*Coniferous treed, woodland (28)*	*Shallow (16)*	*Deep (11)*		
Overstory trees						
Thuja plicata	164	28	—	—	—	—
Chamaecyparis nootkatensis	118	33	—	—	—	—
Pinus contorta	88	75	—	—	—	—
Tsuga heterophylla	25	T	—	—	—	—
Tsuga mertensiana	8	2	—	—	—	—
Understory trees						
Thuja plicata	80	16	—	—	—	—
Chamaecyparis nootkatensis	50	19	—	—	—	—
Tsuga heterophylla	28	T	—	—	—	—
Pinus contorta	23	10	—	—	—	—
Tsuga mertensiana	7	T	—	—	—	—
Tree saplings and seedlings/ stunted trees						
Tsuga heterophylla	293	68	6	1	T	T
Thuja plicata	197	159	39	19	T	2
Chamaecyparis nootkatensis	95	407	137	44	T	—
Pinus contorta	36	185	188	100	T	175
Tsuga mertensiana	28	34	9	—	—	—
Shrubs						
Gaultheria shallon	240	177	6	3	—	—
Menziesia ferruginea	51	20	T	—	—	—
Vaccinium parvifolium	26	11	1	—	—	—
Ledum groenlandicum	12	41	23	54	7	75
Kalmia polifolia	T	23	14	63	87	15
Myrica gale	T	23	72	91	—	—
Juniperus communis	—	8	73	125	4	75
Dwarf shrubs/herbs						
Blechnum spicant	77	17	10	1	—	—
Carex anthoxanthea	69	11	T	—	—	—
Cornus canadensis	53	60	11	33	123	2
Veratrum viride	50	12	T	1	—	—
Calamagrostis nutkaensis	41	11	12	—	—	—
Lysichitum americanum	26	20	T	1	7	—
Coptis asplenifolia	18	29	3	7	4	—
Fauria crista-galli	11	123	51	5	87	—
Empetrum nigrum	8	43	45	107	11	75
Gentiana douglasiana	6	2	16	25	16	2
Agrostis aequivalvis	3	2	33	18	2	10
Drosera rotundifolia	2	5	21	40	53	2
Carex pluriflora	4	18	—	4	35	15
Trientalis europaea	3	13	12	29	40	2
Coptis trifolia	1	6	8	32	36	—
Eriophorum angustifolium	T	10	42	206	22	15
Carex livida	T	2	29	46	22	7
Andromeda polifolia	T	T	19	55	80	—
Scirpus caespitosus	T	91	480	293	427	—
Sanguisorba officinalis	T	15	51	201	71	2
Rhynchospora alba	—	1	56	116	—	—
Rubus chamaemorus	—	1	T	4	—	—
Vaccinium oxycoccus	—	3	T	23	20	35
Deschampsia caespitosa	—	1	27	1	—	—
Carex obnupta	—	—	—	—	—	75
Carex pauciflora	—	—	—	—	—	175

Table 8–8. (continued)

Strata and species	Pacific slope bogs: Coniferous treed, forest (32)**	Pacific slope bogs: Coniferous treed, woodland (28)	Pacific slope bogs: Tall shrub (27): Shallow (16)	Pacific slope bogs: Tall shrub (27): Deep (11)	Pacific basin bogs (4)	Pacific domed bogs (1)
Mosses, liverworts, and lichens						
Rhytidiadelphus loreus	265	145	2	T	—	2
Hylocomium splendens	163	108	T	—	—	35
Sphagnum girgensohnii	103	65	1	—	—	15
Sphagnum rubellum	89	128	18	73	320	75
Sphagnum papillosum	73	45	26	106	643	—
Rhizomnium glabrescens	27	5	—	—	—	—
Herbertus aduncus	16	15	26	1	—	—
Sphagnum fuscum	11	20	7	50	6	—
Pleurozium schreberi	5	57	2	37	T	75
Cladina rangiferina	2	5	9	40	T	2
Cladina impexa	1	18	25	59	4	—
Sphagnum compactum	2	T	57	28	T	—
Sphagnum fallax	T	T	T	3	116	35
Campylopus atrovirens	—	—	47	T	—	—
Cladonia pseudostellata	—	T	2	49	T	—
Rhacomitrium lanuginosum	—	14	133	126	1	—
Siphula ceratites	—	T	75	65	2	—
Sphagnum lindbergii	T	—	T	26	47	—
Sphagnum tenellum	—	T	18	102	17	—
Sphagnum imbricatum	—	—	—	—	625	—
Average cover (%) of strata						
Tree	51	36	—	—	—	—
Shrub	74	75	53	53	27	38
Dwarf shrub/herb	43	57	75	78	35	40
Bryophyte/lichen	85	83	67	93	99	95

**Species data are prominence values = (mean cover) ($\sqrt{\text{frequency}}$). Only species with a prominence value of 25 or more, in at least one form, are included in this table. T (trace) indicates a prominence value of less than 1.*
***Number of sites sampled appears in parentheses.*

pography was masked as the bogs expanded and coalesced over the higher and better-drained areas through the accumulation of secondary and tertiary peat. Soil and water chemistry data for tall shrub slope bogs are presented in Tables 8–7 and 8–9.

Tall shrub type, shallow phase: This type of wetland is transitional between bog to fen, and is characterized by tree species occurring as shrubs (less than 2 m tall) and lichens (Figure 8–16). Shore pine, yellow cypress, and western red cedar dominate, whereas western and mountain hemlock are of minor importance. Shrubs which occur frequently are *Myrica gale, Juniperus communis, Ledum groenlandicum, Kalmia polifolia, Vaccinium uliginosum,* and *Vaccinium caespitosum.*

Sedges and rushes dominate the herb layer (Table 8–8). *Scirpus caespitosus* is by far the most dominant species. The presence or relative abundance of several herb species, including *Plantago macrocarpa, Geum calthifolium, Erigeron peregrinus, Apargidium boreale, Dodecatheon jeffreyi,* and *Deschampsia caespitosa,* suggests a more enriched nutrient regime in shallow slope bogs than in deeper ombrotrophic slope bogs. *Menyanthes trifoliata, Nuphar polysepalum, Scheuchzeria palustris,* and *Juncus oreganus* are common aquatic species in larger ponds.

The relative scarcity of *Sphagnum* spp. in these shallow slope bogs is another feature distinguishing them from deeper bogs. The same species occur (Table 8–8), but usually only in small localized patches or hummocks. Characteristic bryophytes include *Campylopus atrovirens, Rhacomitrium lanuginosum, Pleurozia purpurea, Herberta aduncus,* and *Mylia taylori.* Lichens are abundant throughout; some common species are *Cladina impexa, Cladina rangiferina, Cladonia gracilis, Cladonia pseudostellata,* and *Siphula ceratites.* Extensive white mats of *Siphula ceratites* (often in association with the liverwort *Gymnocolea inflata*), in wet depressions and at edges of ponds, are characteristic of most slope bogs.

These wetlands occupy extensive areas along the exposed outer coast, over flat to sometimes steeply sloping mineral terrain where little or no peat has

Table 8–9. Water chemistry of some tall shrub slope bogs, deep and shallow phases, in the Pacific Oceanic Wetland Region*

Bog type	Bedrock type**	No. of samples***	Mean pH	Analyses (ppm)								
				O_2	NH_4	NO_3	PO_4	Ca	Mg	K	SiO_2	Cl
Deep slope bog	I	9	4.7	2.4	0.57	0.45	0.06	0.3	0.14	0.7	0.9	2.6
Deep slope bog	I	9	4.5	4.3	0.45	0.99	0.11	0.2	0.15	0.8	1.3	1.6
Deep slope bog	I	9	4.6	1.9	0.26	0.58	0.07	0.2	0.12	0.05	1.3	1.5
Shallow slope bog	M	2	5.6	—	0.37	2.94	0.09	3.4	0.43	1.6	2.3	1.8

Water samples were collected from piezometers (perforated plastic pipes) installed to a depth of 40–80 cm in the bog soils. The data are presented as means of samples taken from each piezometer at intervals between May 21 and October 12, 1979 (see footnote*). Samples were collected by the senior author. Analyses were done in the forest ecology laboratory at the Faculty of Forestry, University of British Columbia.*

***Bedrock types are as follows: I, igneous (mainly quartz diorite rock); M, metamorphic rocks containing hornblende, biotite, biotite garnet, amphibolite shist and gneiss, layered quartz feldspar shist, and impure quartzite.*

****Samples represent repeated collections from one piezometer installed in each of the sample bogs. Samples were taken from the bogs over igneous bedrock approximately every two weeks between May 21 and September 6 with a final collection on October 10, 1979. Samples were collected from the woodland bog and flat topogenous bog over metamorphic bedrock on June 22, August 3, and October 12, 1979, and from the shallow bog on June 22 and August 9, 1979.*

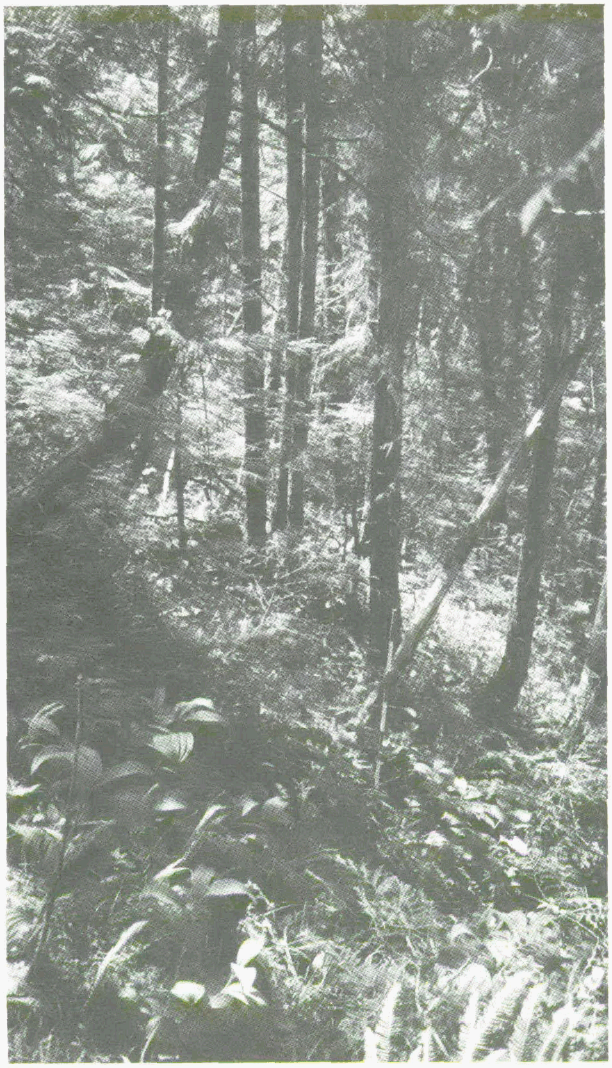


Figure 8–13.
Coniferous treed slope bog, forest phase on McCauley Island, British Columbia, supporting Chamaecyparis nootkatensis – Thuja plicata/Gaultheria shallon/Blechnum spicant – Veratrum viride/Sphagnum *spp. Range rod interval is 25 cm.*

accumulated. Patches of exposed mineral soil are common, and bedrock outcrops, rocks, and large boulders dot the surface of shallow slope bogs. Free water is concentrated in a network of rivulets and small, shallow, often terraced ponds.

Soils are a complex of poorly drained Gleysols and Humic Gleysols, Humic and Ferro-Humic Podzols (often gleyed), Folisols, Humic Regosols, and shallow Humisols and Mesisols. Mineral parent materials are most often derived from bedrock either weathered *in situ* (saprolite) or slope-washed. Organic accumulations are discontinuous and range from shallow (5 cm) L, F, or H horizons to deeper (50 cm) Om and Oh horizons. Ahg horizons derived from abundant sedge roots (mostly *Scirpus caespitosus*) are common (soil horizons as per Canada Soil Survey Committee 1978).

It is difficult to generalize about the successional relationships between the two phases of tall shrub slope bog. Some shallow minerotrophic bogs show tendencies, such as increased cover of *Sphagnum* spp. and deeper peat accumulation, that suggest succession towards deep, ombrotrophic bogs. Others show no such tendencies and appear to have been maintained in their present state for thousands of years, perhaps by severe wind and water erosion common to exposed outer coastal localities.

Flat Bogs

Sphagnum bogs with level or nearly level surfaces cover extensive areas on the poorly drained Queen Charlotte Lowland. Although treated here as flat bogs, their surfaces are slightly raised above the level of the surrounding terrain; hence, many of these bogs appear to be developing towards domed bogs

(a)

(b)

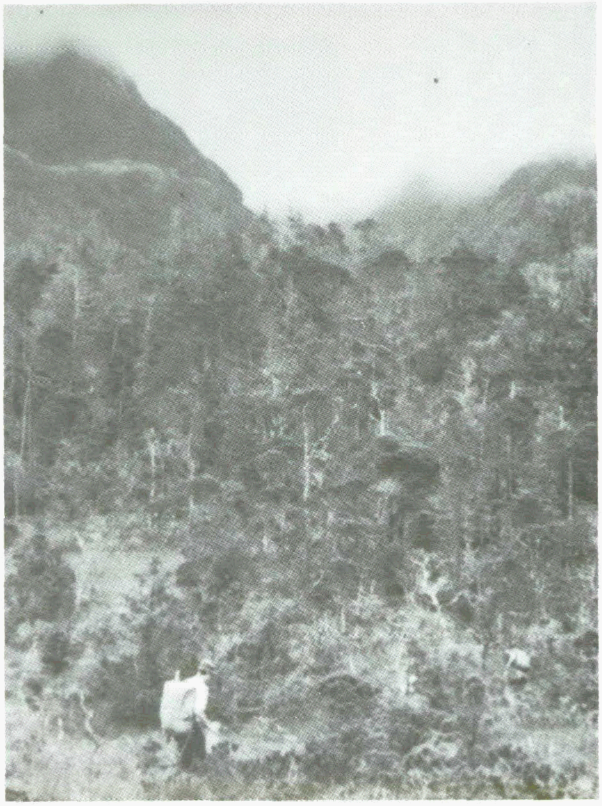


Figure 8–14.

(A) Coniferous treed slope bog, woodland phase at Gunboat Passage near Bella Coola, British Columbia, supporting Pinus contorta – Chamaecyparis nootkatensis/Gaultheria shallon/ Fauria crista-galli – Scirpus caespitosus/Sphagnum rubellum. *Range rod interval is 25 cm. (B) Slope bog with shore pine, Brooks Peninsula, British Columbia.*

and thus have the hummock/hollow microtopography more typical of the latter bog form. Conceivably, this could be related to age or stage of development.

Mesisols, with fibric *Sphagnum* peat at the surface grading into more decomposed mesic and humic sedge peat at greater depth, are the characteristic soils of these bogs. Peat depth is about 1.5 m and consists of fibrous *Sphagnum* peat grading into mesic and humic sedge peat, although at Masset, British Columbia, the peat is up to 8 m deep (Heusser 1960). Mineral materials of variable textures and origin (glacial moraine, outwash, alluvium, and marine deposits) underlie the peat. The organic mantle varies in depth, but is commonly 100–150 cm thick. An irregular surface results from abundant *Sphagnum* hummocks, and small pools are common.

Shore pine and red cedar are characteristic tree species and occur as shrubs or stunted trees. Yellow cypress, a common species in the slope bogs, is absent or rare in the bogs of the Queen Charlotte Lowland. Other common shrubs include *Juniperus communis, Ledum groenlandicum, Kalmia microphylla* ssp. *occidentalis,* and *Gaultheria shallon* (Table 8–8).

Herbs and dwarf shrubs are abundant. *Carex pauciflora, Carex obnupta, Carex pluriflora, Eriophorum angustifolium,* and *Podagrostis aeguivalvis* are common. Several species of *Sphagnum* dominate the bryophyte layer, including *Sphagnum recurvum, Sphagnum girgensohnii, Sphagnum fuscum,* and *Sphagnum capillaceum. Pleurozium schreberi* is also common.

Domed Bogs

Domed bogs (Figure 8–17) occur extensively on the Fraser Lowland, but also occur locally in other lowland areas including the Queen Charlotte Lowland. They occur in defined depressions or on flat terrain, consist of *Sphagnum* peat overlying sedge peat, and have raised centres surrounded at least in

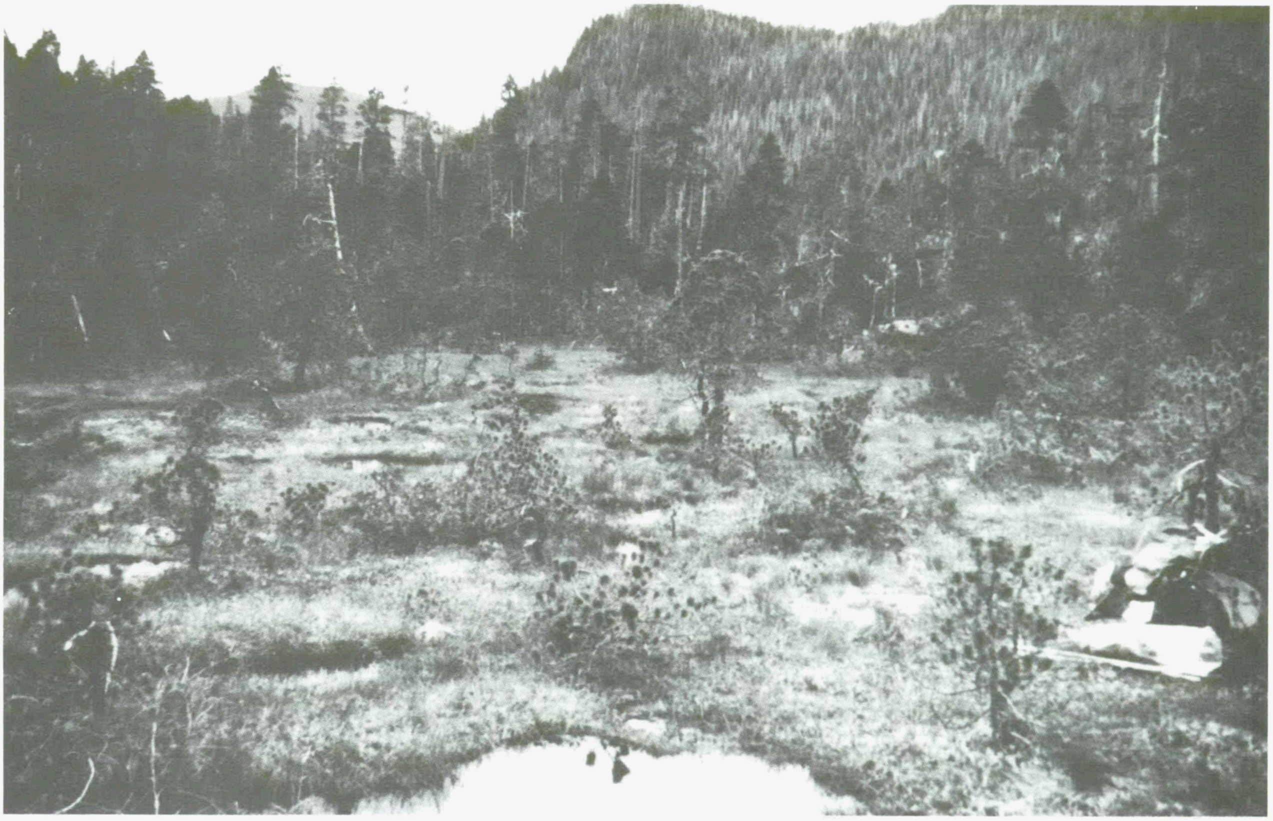


Figure 8–15.
Tall shrub slope bog, deep phase surrounded by coniferous treed slope bog near Prince Rupert, British Columbia, at 60 m elevation supporting Pinus contorta – *ericaceous shrub/*Scirpus caespitosus/Sphagnum *spp. – lichen spp.*

Figure 8–16.
Tall shrub slope bog, shallow phase near Monk Bay, Princess Royal Island, British Columbia, at 40 m elevation supporting Juniperus communis – Myrica gale/Scirpus caespitosus/Campylopus atrovirens – Siphula ceratites – Rhacomitrium lanuginosum. *Note exposed rock.*

part by a lagg. According to their peat stratigraphy, these domed bogs appear to have originated from basin or flat bogs through secondary peat accumulation that raised the surface above the water table. However, many domed bogs, particularly along the north coast, gradually blend into other wetland forms, such as slope and basin bogs, and require detailed stratigraphic analysis for their recognition.

Although peat depths are variable, they appear to be greater in the south than in the north. Burns Bog, representative of the Fraser Lowland bogs, consists of about 2 m of fibrous *Sphagnum* peat over 1 m of woody peat and 1.2 m of sedge peat (Hebda 1977; Figure 8–18). The fibrous *Sphagnum* peat often thins out at the perimeter of domed bogs. The lower surface of the underlying sedge peat follows the contours of the basin, but the relatively flat upper surface is controlled by the water table. The surface of these bogs is covered with *Sphagnum* hummocks and hollows. The bogs are generally featureless in the south, although small, irregular ponds 2–20 m long may occur.

These bogs are extremely acid (pH 2.6–4.1), low in nutrients especially in the upper peat layers, and high in organic content (Table 8–10). Total nitrogen (N) is higher in the more humified marginal peat,

Figure 8–17.
A domed bog supporting Sphagnum *spp. and heathland with scrub pine in background, in Burns Bog, Fraser Lowland, British Columbia.*

thus reducing the ratio of carbon (C) to nitrogen. This factor may be associated with the vegetation differences between the marginal peat and the actual bog itself.

Domed bogs are of the low shrub type, with *Ledum groenlandicum* and stunted shore pine the most characteristic species (Figure 8–19). Associated species usually include *Vaccinium myrtilloides* and *Gaultheria shallon* in the south and *Juniperus communis, Kalmia polifolia, Empetrum nigrum,* and *Gaultheria shallon* in the north. Herbs are sparse in domed bogs in the south, but *Carex pauciflora, Carex obnupta, Carex pluriflora, Eriophorum angustifolium,* and *Podagrostis aequivalvis* are common in the north, attesting to an earlier stage of development. Bryophytes are abundant, with *Sphagnum rubellum, Sphagnum girgensohnii, Sphagnum fuscum,* and *Sphagnum fallax* prominent. *Pleurozium schreberi* is common in bogs in the north and *Polytrichum juniperinum, Dicranum scoparium, Rhytidiadelphus*

Figure 8–18.
Vegetation and stratigraphy of a domed bog, Burns Bog, Fraser Lowland, British Columbia.

Table 8–10. Chemical soil data from three domed bogs in the Pacific Temperate Wetland Region

Organic soil type and horizon	Depth (cm)	Texture	pH		Conductivity (mS/cm)	Total N (%)	C/N ratio	Phosphorus*		Exchangeable cations (me/100 g)					Base saturation (%)
			H_2O	0.01 M $CaCl_2$				P1 (ppm)	P2 (ppm)	Ca	Mg	K	Na	CEC	
Sphagno–Fibrisol															
Of1	0–20	fibric	4.0	2.8	0.2	0.63	106.1	17.2	—	12.26	5.39	2.16	0.78	158.5	13.0
Of2	20–33	fibric	3.7	2.7	0.1	0.92	74.6	7.2	7.2	5.30	7.71	0.39	0.46	163.2	8.5
Of3	33–63	fibric	3.6	2.6	0.1	0.80	84.8	2.4	2.4	3.55	7.33	0.09	0.57	172.6	6.7
Of4	63–86	fibric	3.8	2.8	0.9	0.68	100.1	7.8	10.4	5.73	9.90	0.16	0.89	178.5	9.4
Of5	86–119	fibric	4.1	2.9	—	0.70	84.5	5.0	5.0	—	—	—	—	—	—
Of6	119–165	fibric	4.2	3.0	—	1.04	70.7	1.3	7.8	—	—	—	—	—	—
Terric Mesisol															
Omp	0–15	mesic	4.3	3.9	1.2	2.97	24.9	114.7	134.7	42.39	8.23	0.32	0.17	146.4	34.9
Om1	15–41	mesic	4.0	3.7	0.9	3.13	24.6	22.4	28.7	27.43	4.74	0.15	0.22	139.2	23.4
Om2	41–61	mesic	4.3	3.8	0.2	2.75	27.3	10.0	14.3	12.53	2.38	0.05	0.13	60.6	41.4
Om3	61–89	mesic	4.6	4.1	0.5	2.08	33.1	3.8	6.3	—	—	—	—	—	—
Cg	89+	silty clay	4.3	4.1	1.6	0.13	24.3	0.5	111.1	—	—	—	—	—	—
Typic Mesisol															
Of	0–23	fibric	3.3	2.8	0.3	1.28	54.5	35.1	40.0	5.43	16.30	0.69	0.77	178.5	13.0
Om1	23–41	mesic	3.4	2.8	0.3	1.25	59.8	8.8	13.2	2.87	10.77	0.19	1.04	173.9	14.3
Om2	41–74	mesic	3.3	2.9	0.3	1.16	66.3	9.7	17.0	2.91	9.47	0.17	0.97	164.7	8.2
Om3	74–97	mesic	3.6	3.0	0.3	1.13	65.6	0	0	—	—	—	—	—	—
Om4	97–127	mesic	4.2	3.7	0.7	2.27	31.3	0	0	—	—	—	—	—	—
Om5	127–165	mesic	4.5	4.2	2.6	1.87	32.9	14.4	18.0	—	—	—	—	—	—

Source: Luttmerding (1980).

**P1 and P2 correspond to available phosphorus by standard method by Bray and an ascorbic acid reduction modified version of the method by Bray, respectively.*

spp., and *Stokesiella oregana* are common in the south. Lichens, mostly *Cladina* spp. and *Cladonia* spp., are also common on the drier southern bogs.

A wet phase of the domed bogs in the south has *Vaccinium uliginosum, Kalmia polifolia, Andromeda polifolia, Rhynchospora alba,* and *Eriophorum chamissonis* growing among *Sphagnum* hummocks. *Sphagnum rubellum* or *Sphagnum fuscum* form the hummocks and *Sphagnum tenellum, Sphagnum fallax,* and *Sphagnum papillosum* dominate the wetter sides and depressions between hummocks. *Oxycoccus microcarpus, Rubus chamaemorus, Drosera rotundifolia, Cladina impexa,* and *Cladina rangiferina* occur on hummocks. This wet phase of the domed bogs was very common in the Fraser Lowland prior to drainage, fires, and peat mining (Hebda and Biggs 1981).

Two varieties of woodland occur on the periphery of the domed bogs. Both are considered to be of recent origin (Hebda and Biggs 1981). One has shore pine over 4 m tall and an understory dominated by *Ledum groenlandicum, Gaultheria shallon,* and *Pteridium aquilinum. Trientalis europaea, Cornus canadensis, Sphagnum rubellum, Stokesiella oregana, Dicranum scoparium,* and *Polytrichum juniperinum* are common constituents of the ground cover. The other is a birch woodland consisting of dense to open stands of paper birch (*Betula papyrifera*) over a shrub layer of *Spiraea douglasii* mixed with profuse *Pteridium aquilinum*. The lagg area surrounding domed bogs often supports thickets of *Spiraea douglasii* intermingled with patches of *Carex* spp.

Figure 8–19.
Domed bog, Burns Bog on Fraser Lowland, British Columbia, supporting Ledum groenlandicum *heathland.*

Pacific Coast Swamps

Basin Swamps

Swamps are common wetlands throughout the Pacific Oceanic Wetland Region, but generally are quite localized and never dominate the landscape as do bogs. In the Pacific Temperate Wetland Region, swamps are mostly confined to small basins. Many of the swamps seem to be progressing or degrading towards the transitional forest bog type as, with increasing age, stagnation, and humification, tree productivity declines and Organic soils develop (Figure 8–20).

Swamps with skunk cabbage (*Lysichitum americanum*) range from moderately poor to rich in nutrients. Skunk cabbage (if it has not been overbrowsed) indicates, by its abundance and vigour, the nutrient status of the swamp. The most vigorous swamps have a virtually solid cover of waist-high skunk cabbage growing in a dark, rich, mucky, mineral and organic substrate. The poorest swamps are predominantly mounds of decaying wood and other organic matter that support *Rhytidiadelphus loreus*, *Hylocomium splendens*, some *Sphagnum* spp., stunted trees, and shrubs and herbs; small skunk cabbage plants are found in wet hollows between the mounds.

Tree growth also corresponds well with the nutrient status of the swamp, although productivity is severely restricted by the high water table and poor soil aeration. The best stands are dominated by spruce or cedar of moderate size, whereas the nutrient-poor swamps are dominated by stunted hemlock. Over time, productive cedar–spruce/skunk cabbage swamps gradually fill in with decayed wood and other organic matter until they support poor-quality hemlock/blueberry/moss associations elevated above the water table.

The most common type of basin swamp in the Pacific coast wetland regions is the tall shrub type.

Tall shrub type: Shrub swamps are more abundant in the Pacific Temperate Wetland Region than in the Pacific Oceanic Wetland Region largely because the summer drawdown of the water table allows for increased decomposition of organic matter. Typical dominant tall shrubs include *Pyrus fusca*, *Spiraea douglasii*, *Rosa nutkana*, *Cornus stolonifera*, *Lonicera involucrata*, *Crataegus douglasii*, and several species of *Salix*. These swamps often occur at the margins of basin bogs where there is a plentiful nutrient supply from adjacent slopes (Moore and Bellamy 1974). The extent of these swamps has been greatly reduced by diking, drainage, and agriculture. *Spiraea* or *Salix–Spiraea* thickets occur in the lagg around domed bogs in the Fraser Delta where groundwater flows during the wet season, but the water table is low during the dry season (Hebda and Biggs 1981).

Stream Swamps

Stream swamps are common along meandering streams on level to gently sloping terrain, in valley bottoms, shallow depressions, and on toe slopes (Figure 8–21). Characteristic soils are Gleysols and Mesisols. Chemical data for the organic materials in a stream swamp near Prince Rupert, British Columbia, are presented in Table 8–11.

Western red cedar is usually the dominant species, but western hemlock, Sitka spruce, grand fir (in the Pacific Temperate Wetland Region), and red alder are frequent but usually minor associates. Tree growth is relatively poor, but red cedar, spruce, and grand fir tolerate the semi-stagnant conditions and grow much better than hemlock. Hemlock occurs mostly on raised, organic hummocks.

Shrubs are generally not abundant (Table 8–12), but typically include *Rubus spectabilis*, *Vaccinium alaskaense*, *Vaccinium parvifolium*, *Menziesia ferruginea*, and *Gaultheria shallon*. All but *Rubus spectabilis* are usually associated with decaying wood and organic hummocks. In its typical development, this form of swamp has a vigorous cover of *Lysichitum americanum*, often with *Athyrium filix-femina* in the herb layer. Heavy browsing by deer has greatly reduced the herb cover (especially *Lysichitum americanum*) of swamps in some areas, most noticeably on the Queen Charlotte Islands. Degraded or more humified swamps also show a decline in the abundance and vigour of herbs.

The typical bryophytes segregate into two communities. *Conocephalum conicum*, *Pellia neesiana*, *Leucolepis menziesii*, and *Sphagnum* spp. (such as *Sphagnum girgensohnii* and *Sphagnum papillosum*) dominate in mucky depressions, whereas *Rhizomnium glabrescens*, *Rhizomnium perssonii*, *Hylocomium splendens*, *Rhytidiadelphus loreus*, *Stokesiella oregana*, and *Stokesiella praelonga* occupy the better-drained organic hummocks.

Floodplain Swamps

Floodplain swamps are restricted to poorly drained fluvial terraces and fans, and hence develop on level or very gently sloping valley-bottom terrain (Figure 8–22). They seem to have a less stagnant hydrology than the other swamp forms, resulting in better soil aeration, higher nutrient status, and better tree productivity. Typical soils are Gleysols and Humic Reg-

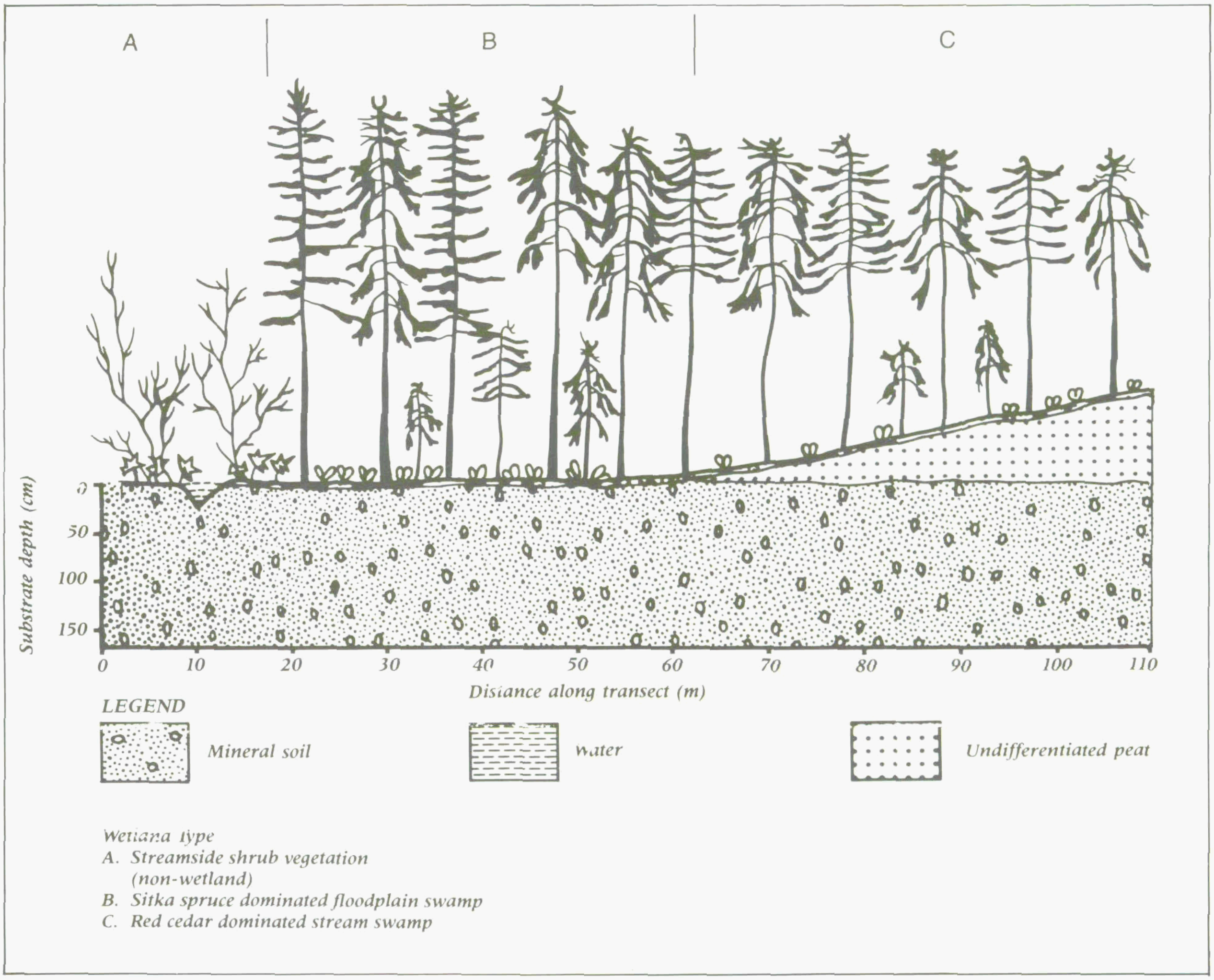


Figure 8–20.
Schematic profile of a swamp landscape at the foot of Mt. Hayes, Prince Rupert, British Columbia.

osols. Chemical data for soil in a floodplain swamp near Prince Rupert, British Columbia, are included in Table 8–11.

Forest stands in these floodplain swamps are typically patchy, with irregular and uneven canopies and frequent windthrow. Sitka spruce and western red cedar dominate, whereas western hemlock and sometimes amabilis fir form a subcanopy layer (Table 8–12). Red alder typically occurs in canopy openings. Sitka spruce has greater dominance and much better growth in these swamps than in stream swamps.

A moderately well-developed shrub layer typically has abundant tree regeneration (dominated by western hemlock) and scattered clumps of *Vaccinium alaskaense, Menziesia ferruginea, Rubus spectabilis, Cornus stolonifera*, and *Oplopanax horridus. Lysichitum americanum* and *Maianthemum dilatatum* characterize the moderately developed herb layer.

The patchy to well-developed bryophyte layer includes *Pellia neesiana, Conocephalum conicum, Leucolepis menziesii, Sphagnum girgensohnii, Sphagnum squarrosum*, and *Rhizomnium glabrescens* in wetter, periodically flooded depressions, and *Rhytidiadelphus loreus, Hylocomium splendens, Stokesiella oregana*, and *Stokesiella praelonga* on drier, elevated microsites.

Spring Swamps

Spring swamps are typical of higher elevations (usually above 500 m) in the Pacific Oceanic Wetland Region. They are analogous to the stream swamp form of lower elevations, but tree productivity is lower and forest stands have a scrubby aspect. The forests are mixtures of species of all ages, including yellow cypress, western hemlock, Sitka spruce, mountain hemlock, amabilis fir, and western red cedar (Table 8–12).

The sparse shrub layer of spring swamps consists of scrubby or regenerating trees, scattered *Vaccinium* spp., *Ribes* spp., and *Menziesia ferruginea*. The poorly

Figure 8–21.
Stream swamp near Prince Rupert, British Columbia, at 10 m elevation supporting Thuja plicata – Tsuga heterophylla/Lysichitum americanum. *Range rod interval is 25 cm.*

Table 8–11. Chemical data from a stream and a floodplain swamp near Prince Rupert, British Columbia*

Wetland form	Horizon	pH 1:2 .01 M $CaCl_2$	C (%)	H (%)	N (%)	Pyro-phosphate soluble (%)	Ash (%)	Fibre content		Exchangeable cations (me/100 g)				Calorific value (cal/g)
								Unrubbed (%)	Rubbed (%)	Ca	Mg	K	Al	
Stream swamp	F**	4.2	19.7	2.68	0.67	19.0	60.9	—	—	15.54	3.36	1.98	1.67	2 166
	Om1	3.6	41.7	4.93	1.54	41.8	24.2	60	28	7.08	2.07	0.58	8.33	5 063
	Om2	3.3	48.3	5.33	1.41	33.9	10.7	50	10	11.16	2.76	0.48	7.66	5 427
	Om3	3.6	38.9	4.45	1.26	47.9	26.9	64	36	7.25	3.36	0.39	9.32	4 443
	Ahg	3.9	4.7	0.77	0.14	—	—	—	—	1.50	0.30	0.37	3.33	—
Floodplain swamp	F**	4.0	19.1	2.63	0.80	18.9	65.4	—	—	9.00	1.58	1.36	2.99	2 064
	Ahg	4.0	8.4	1.38	0.48	—	—	—	—	3.78	0.69	0.60	4.66	—

*Analysis conducted under guidance of C. Tarnocai, Land Resources Research Centre, Ottawa.
**See Klinka et al. (1981).

developed herb layer typically includes *Veratrum viride, Coptis asplenifolia, Blechnum spicant,* and *Carex anthoxanthea. Lysichitum americanum* occurs sporadically. The well-developed bryophyte layer is characterized by large patches of liverworts (*Conocephalum conicum, Pellia neesiana*) among *Leucolepis menziesii, Sphagnum girgensohnii, Sphagnum squarrosum,* and *Rhizomnium* spp. in wet depressions. Drier, higher microsites are dominated by *Rhytidiadelphus loreus* and *Hylocomium splendens.*

Figure 8–22.
Floodplain swamp near Prince Rupert, British Columbia, at 10 m elevation supporting Picea sitchensis/Lysichitum americanum. *Range rod interval is 25 cm.*

These spring swamps are usually quite small and local, occurring on steep, mountainous terrain in seepage pockets and on gentler, concave slopes, where fine-textured, slope-washed sediments have accumulated in depressions or behind ridges or logs. Typical soils are very poorly drained Gleysols.

Pacific Coast Fens

Stream and Shore Fens

Fens are infrequent and localized along flowing water and lake margins (Figure 8–23). It appears that most fen soils are Mesisols or Humisols and in some cases (usually in tall shrub fens) Humic Regosols. Chemical data from four fens near Prince Rupert, British Columbia, are presented in Table 8–13. Two fen types (sedge and tall shrub) have been identified (based primarily on vegetation) along the north coast subregion in the Pacific Oceanic Wetland Region.

Sedge type: *Carex*-dominated fens have several vegetation associations depending on their dominant species. A *Carex sitchensis* association is common and often consists of monotypic stands of *Carex sitchensis*. Mixed with this, *Carex sitchensis–Deschampsia caespitosa* and *Carex sitchensis–Carex obnupta* associations often occur. A *Carex pluriflora–Menyanthes trifoliata* association is fairly common, not only in the few sizeable sedge fen complexes that do exist, but also in the bog pool–rivulet system that punctuates extensive slope bog complexes. This association occupies the mucky bottoms or sides of pools and rivulets. A *Carex obnupta–Carex sitchensis–Calamagrostis nutkaensis* association occasionally forms a dense

*Table 8–12. Major floristic and plant community features of swamp forms in the northern part of the Pacific Oceanic Wetland Region**

Strata and species	Stream swamps: Red cedar–western hemlock coniferous forest (20)**	Floodplain swamps: Sitka spruce–red cedar coniferous forest (9)	Spring swamps: Yellow cypress–western hemlock coniferous forest (4)
Overstory trees			
Thuja plicata	211	150	4
Tsuga heterophylla	61	211	198
Chamaecyparis nootkatensis	48	—	142
Picea sitchensis	39	306	80
Alnus rubra	—	30	—
Tsuga mertensiana	—	—	103
Understory trees			
Thuja plicata	70	28	2
Tsuga heterophylla	83	178	107
Chamaecyparis nootkatensis	32	—	11
Picea sitchensis	5	11	12
Alnus rubra	2	17	—
Tsuga mertensiana	—	—	28
Tree saplings and seedlings/ stunted trees			
Tsuga heterophylla	198	220	112
Thuja plicata	45	25	10
Chamaecyparis nootkatensis	20	—	27
Picea sitchensis	20	30	10
Tsuga mertensiana	—	—	49
Shrubs			
Menziesia ferruginea	51	102	5
Gaultheria shallon	47	10	—
Vaccinium alaskaense	45	37	87
Vaccinium ovalifolium	30	12	8
Vaccinium parvifolium	18	97	16
Herbs/dwarf shrubs			
Lysichitum americanum	73	108	T
Blechnum spicant	35	54	8
Cornus canadensis	30	46	1
Coptis asplenifolia	20	10	25
Rubus pedatus	17	28	1
Maianthemum dilatatum	11	25	—
Veratrum viride	6	2	33
Mosses, liverworts, and lichens			
Rhytidiadelphus loreus	212	191	283
Hylocomium splendens	191	180	99
Sphagnum girgensohnii	100	65	108
Pellia neesiana	60	22	37
Rhizomnium glabrescens	57	61	95
Stokesiella oregana	9	45	1
Leucolepis menziesii	7	29	22
Conocephalum conicum	7	26	44
Scapania bolanderi	6	34	41
Pogonatum alpinum	2	32	13
Average cover (%) of strata			
Tree	65	75	58
Shrub	48	27	15
Herb/dwarf	59	40	14
Bryophyte/lichen	90	85	88

*Species data are prominence values = (mean cover) ($\sqrt{\text{frequency}}$). Only species with a prominence value of 25 or more, in at least one form, are included in this table. T (trace) indicates a prominence value of less than 1.
**Number of sites sampled appears in parentheses.

Figure 8–23.
Stream fen complex along upper Tlell River, Graham Island, British Columbia, at 60 m elevation; dark areas along river are mostly Spiraea douglasii *and* Pyrus fusca *shrub fens and lighter areas are* Carex sitchensis – Deschampsia caespitosa *fens.*

band along the upper beaches of larger lakes. A *Carex canescens–Carex exsiccata–Carex phyllomanica–Eriophorum chamissonis* association characterizes fens in elongated depressions between old beach ridges on the Queen Charlotte Lowland.

Tall shrub type: Three main tall shrub fen vegetation associations occur. The *Pyrus fusca–Salix* spp./*Carex obnupta* association has open shrub cover (including *Spiraea douglasii*) with scattered Sitka spruce and shore pine trees. These fens typically border sluggish creeks and sometimes occur along alluvial backwaters and sloughs, particularly on river deltas. The *Spiraea douglasii/Carex sitchensis* association represents a shrub fen that develops along sloughs and slow-moving streams. A *Myrica gale/Carex sitchensis* association occupies similar habitats and occurs in an upper, shrub-dominated belt of some brackish, tidal wetlands.

Slope Fens

The sloping, terraced slope fen wetland that typically occurs at higher elevations (usually greater than 500 m), and mostly in the Pacific Oceanic Wetland Region, is designated primarily on the basis of floristics, although it has some characteristics of a slope bog (see Tables 8–7 and 8–13). The slope fen often develops a reticulate or ladder-like pattern of terraces stepped down moderate to steep slopes (Figure 8–24). On the terraces, small pools form behind peat dams surmounted primarily by *Scirpus caespitosus*. The vegetation matrix that contains the pools is also dominated by *Scirpus caespitosus*, accompanied by variable amounts of *Sphagnum* spp. (particularly *Sphagnum compactum*, *Sphagnum papillosum*, and *Sphagnum imbricatum*). Some other typical species are *Fauria crista-galli*, *Eriophorum angustifolium*, *Vaccinium uliginosum*, *Kalmia polifolia*, *Cladothamnus pyrolaeflorus*, *Podagrostis aequivalvis*, *Lycopodium sabinaefolium* var. *sitchense*, *Lycopodium inundatum*, *Geum calthifolium*, *Dodecatheon jeffreyi*, *Drosera anglica*, *Drosera rotundifolia*, and *Coptis trifolia*. Slope fens lack the stunted trees and shrubs typical of slope bogs. The shallow pools often contain *Menyanthes trifoliata*, *Juncus oreganus*, and (along the pool margins) *Sphagnum tenellum*.

Typical soils are Mesisols consisting mainly of dense sedge peat. Slope-wash and limnic deposition have resulted in a detrital type of peat on the

Table 8–13. Chemical data from four Pacific coast fens near Prince Rupert, British Columbia*

Wetland type	Horizon	pH 1:2 .01 M $CaCl_2$	C (%)	H (%)	N (%)	Pyro-phosphate soluble (%)	Ash (%)	Fibre content		Exchangeable cations (me/100 g)				Calorific value (cal/g)
								Unrubbed (%)	Rubbed (%)	Ca	Mg	K	Al	
Sedge fen	Om	3.9	12.9	1.88	0.58	17.7	77.2	56	28	5.28	1.48	0.74	3.66	2 147
	Ahg	3.9	2.9	0.50	0.07	—	94.2	—	—	1.98	0.49	0.40	1.33	—
	II Ahg	3.8	6.7	0.99	0.22	—	86.8	—	—	3.60	0.79	0.42	3.33	—
Sedge fen	Om1	4.2	31.1	4.06	1.33	33.8	35.9	50	32	6.96	4.05	1.53	2.00	3 676
	Om2	3.0	49.6	5.94	1.70	30.4	4.7	72	30	3.18	2.66	0.59	5.66	5 718
	Oh	3.1	36.6	6.43	1.29	63.2	14.0	52	10	2.88	1.18	0.56	10.70	3 972
	Om3	3.6	29.8	3.75	1.25	90.3	44.3	68	34	2.10	0.30	0.38	9.66	3 708
Shrub fen	Om1	3.7	30.8	4.83	1.30	24.0	33.0	80	20	12.60	4.44	1.05	6.99	2 598
	Of	3.2	47.0	5.93	1.15	7.3	4.2	94	54	23.40	9.87	0.89	5.00	5 185
	Om2	3.0	40.8	6.97	1.30	15.7	4.5	50	20	6.60	5.43	0.12	4.00	5 391
	Om3	3.0	46.4	5.85	1.27	28.3	10.6	48	20	—	—	—	—	5 199
	Oh1	3.0	36.9	6.65	1.09	30.0	11.0	18	6	3.72	2.66	0.42	8.66	4 038
	Oh2	3.5	37.0	4.02	0.99	90.3	31.7	42	10	2.46	0.99	0.43	13.65	3 439
Slope rush fen	Of	3.4	42.5	5.84	0.89	12.1	7.9	100	92	—	—	—	—	5 142
	Om	3.1	46.8	5.88	1.96	28.8	12.5	68	20	1.62	1.18	0.64	5.66	5 341
	Oh1	—	54.7	7.68	2.15	63.2	4.3	70	14	—	—	—	—	5 532
	Oh2	—	44.0	5.20	1.28	300.0	20.8	46	2	3.30	0.89	0.44	11.30	5 611
	Cg	4.0	5.2	0.87	0.17	—	—	—	—	0.56	0.16	0.09	2.61	—

**Analyses conducted under guidance of C. Tarnocai, Land Resources Research Centre, Ottawa.*

bottom of the pools. This sedimentary peat is amorphous, greasy, and undergoes dramatic (up to 60%) shrinkage when the pools dry up during infrequent, sunny summer spells.

Dynamics of Pacific Coast Wetlands

Hydrological Gradient

The dynamic processes of wetland development and succession can be viewed within the framework of three interdependent aspects of the associated water. These are: (a) water source, which influences anion and cation content and concentration including pH; (b) water flow rate, which is directly related to nutrient flux; and (c) water table depth, which is related to the degree of aeration and decomposition at the wetland surface.

A simple model of wetland interrelationships and succession can be based on changes in ionic dominance (Moore and Bellamy 1974). Wetland forms are related to a hydrological gradient as follows:

(1) "rheophilous": fed by regional groundwater, typically with bicarbonate as the predominant anion and calcium the predominant cation;

(2) "transition": fed by local groundwater and surface runoff, typically with sulphate and calcium as the predominant anion and cation, respectively;

(3) "ombrophilous": fed entirely by rainwater, typically with sulphate and hydrogen as the predominant ions.

This gradient leads from a nutrient-rich sedge fen to a nutrient-poor bog, and can be viewed as a gradient in relative hydrogen ion and cation concentration. Most wetlands of the Pacific coast are

Figure 8–24.

Slope fen near Mt. Hayes, Prince Rupert, British Columbia, at 580 m elevation supporting Scirpus caespitosus/Sphagnum compactum; *terrace probably is a filled-in pool. Range rod interval is 25 cm.*

at the low end of the pH and cation concentration gradients, and have water flow rates from rapid to stagnant.

The position of the water table relates directly to the amount of organic matter that can accumulate. The degree to which the water table is lowered during dry summer months and how much decomposition occurs in the aerated layer are of importance. These are primarily controlled by climate; consequently, the water table fluctuates much more in the warm, dry Pacific Temperate Wetland Region than in the cool, moist Pacific Oceanic Wetland Region.

Successional Relationships

Succession in coastal wetlands (excluding salt marshes) appears to be proceeding towards *Sphagnum* bogs. In the normal hydrosere succession, organic matter accumulates below the water table, gradually separating the wetland surface from groundwater influence and favouring local water derived from organic terrain high in hydrogen ions. This acidification process further favours the accumulation of organic matter and, in this moist, cool climate, the eventual growth of *Sphagnum* bogs. The accumulation of organic matter may also begin at the water table surface under conditions of poor drainage in moist climates, or on the forest floor in moderately well-drained areas under the influence of extremely nutrient-poor, acid conditions and moist climate (the process called "paludification").

Basin and shore bogs, to some extent, are products of hydrosere succession. Shore bogs floating at the margin of a lake are often precursors of basin bogs. Here, organic matter accumulates at the edge and bog vegetation grows outwards into the basin, eventually covering it (Thompson *et al.* 1927; Osvald 1933; Wetzel 1975). In terms of hydrological gradients, floating bogs usually occur in water of moderate to low pH, have little water flow, and have a high water table. Bog associations could advance directly onto open water without other pioneering vegetation, or could advance on floating pioneers such as *Potentilla palustris*, *Menyanthes trifoliata*, and *Polygonum* spp. (Rigg 1925). If the conditions for growth of *Sphagnum* mosses and formation of peat remained unchanged, the floating shore bog would eventually become a basin bog.

Basin bogs can also form by filling from the bottom up rather than from the margins inwards (Rigg 1925). This process evidently has occurred between old dunes on northeastern Graham Island, British Columbia, and may still be occurring in some shallow ponds located between dunes on the west coast of Vancouver Island. At one site, *Potamogeton* spp. and *Nuphar polysepalum* grow in 0.7–1 m of water and contribute to the fibrous organic muck forming in the ponds. At the margins of the shallow water, *Carex* spp., *Oenanthe sarmentosa*, *Veronica* sp., and shrubs are contributing to the formation of primary peat. There is no recognizable floating mat. The hydrological setting is slightly acid to acid, with a moderate water flow and a permanent high water table. Presumably, once the basin fills in with debris of aquatic macrophytes, sedges cover the surface and eventually bog species take over.

Basin bogs can form as a result of factors other than natural hydrosere succession, such as decreases in the water table of shallow pools. Lowering of the water table can be caused by downcutting of an effluent stream, for example. Hebda (1983) believes that a bog near Bear Cove on the north end of Vancouver Island formed as a result of a climatic change towards warmer and drier conditions about 8 500 years BP, followed by a return to a moist climate about 7 000 years BP.

The stratigraphic sequence expected in a floating bog hydrosere succession would be *Sphagnum* peat over aquatic macrophyte peat over limnic detritus peat. No clear example of such a sequence has been found in coastal British Columbia, although some sequences, such as that in Rithets Bog (Zirul 1967), approximate it. Thick zones of sedge peat occur in several basin bogs and are believed to have formed during sedge or swamp stages between the aquatic macrophyte and *Sphagnum* peat stages. Such sequences have been observed in both the Pacific Temperate Wetland Region at Tyee Bog (Rigg and Richardson 1938) and the Pacific Oceanic Wetland Region at Bear Cove Bog (Hebda 1983). The sedge and swamp stages may result from factors, such as climatic changes, extraneous to natural hydrosere succession.

Another sequence that may lead to bog development begins on poorly drained, flat to gently sloping terrain (Hebda 1977). In this case, wetland succession depends on particular geomorphic circumstances in an appropriate climatic setting. Unlike the classic basin hydrosere which begins with limnic vegetation, this succession begins on a poorly drained mineral surface which may be subject to seasonal inundation. Initially the pH is probably neutral to slightly acid depending on parent material, the water flow is sluggish, and the water table fluctuates periodically from above to just below the ground surface. These conditions favour the growth of sedges and other fen species and, because of the relatively high water table, also favour the accumulation of organic matter. The wetland surface gradually rises above the original plane and becomes progressively removed from the nutrients in the original mineral substrate, the pH declines, and the water table may be lowered. Wetland shrubs and shrubby trees succeed the sedges. Eventually, with the increase in acidification and the accumulation of organic matter, and the relative lowering of the water table, *Sphagnum* spp., especially *Sphagnum rubellum*, gain dominance. The water flow or nutrient flux is curtailed and the primary water source is precipitation. Hebda (1977) observed this sequence in the Pitt River area of the Fraser Lowland, where the vegetation progression along a transect from newly emergent terrain to the centre of a small incipient bog is: sedges and grass, to shrubs over sedges and grass, to shrubs over advancing *Sphagnum* mats and hummocks, to continuous *Sphagnum* bog. The first shrubs in the sequence are *Myrica gale*, *Spiraea douglasii*, and occasionally *Pyrus fusca*. In later shrub stages, *Ledum groenlandicum* becomes important. This sequence of vegetation is noticeable in the stratigraphy of Burns Bog in the Fraser Lowland (Figure 8–25), and on the Queen Charlotte Lowland. Sedge peat occurs below woody peat which precedes heath peat and is topped by *Sphagnum* peat. In the Burns Bog near Delta, British Columbia, this sequence spans less than 5 000 years.

Shore bogs may have a similar stratigraphic sequence if they occur along poorly drained lake margins; however, there is a difference in water flow. Domed bogs are only rain-fed, while shore bogs receive water from the lake and from adjacent upland areas. In the hydrological gradient scheme, the pH would be low, flowing water would create a relatively high nutrient flux, and the water table would fluctuate. In comparison with floating bogs, non-floating shore bogs begin in a relatively nutrient-rich regime and may continue there because of water flow and elevation above the water table. Two such bogs (one on Tzartus Island and one at Whyac Lake) on the west coast of Vancouver Island are species-rich and do not possess much *Sphagnum* growth, thus indicating high nutrient flux.

Paludification, the process by which non-wetland terrain is converted into wetlands, has played a major role on the Pacific coast where productive forests on well-drained flat or sloping terrain have been degraded to scrub forest growing on poorly drained peat (Banner *et al.* 1983). Most Pacific slope bogs probably formed through paludification, either by marginal expansion of extant wetlands or by *in situ* development. Because of the very moist climate, placic mineral-soil horizons may form that impede drainage and prevent root penetration. Ugolini and Mann (1979) described an 8 000-year chronosequence from Sitka spruce forests to peatland on marine terraces in southeast Alaska that was apparently triggered by the formation of cemented horizons. A similar age (8 140 years BP) was obtained by Heusser (1960) for a 3.1 m peat bog overlying an upper marine terrace in southeast Alaska. Bedrock close to the soil surface may also restrict drainage internally. With impeded drainage, organic matter accumulates on the forest floor to the point where the resultant peat forms a self-sustaining and water-retaining mass upon which bog vegetation develops. In the hydrological gradient model, a forested slope would at first be subject to groundwater with moderate pH, high nutrient flux, and a low water table. But where placic or other restricting mineral-soil horizons occur, precipitation is forced to flow on or near the soil surface, the water table is perched, and the pH and nutrient flux tend to decline. These conditions enhance the accumulation of organic matter, and *Sphagnum* spp. become prominent, whereas trees decline. However, during these stages, the downslope and overland water flow and nutrient flux remain higher than those in domed bogs, and eventually the growth of *Sphagnum* mosses becomes inhibited and the accumulation of organic matter declines. On gentle slopes and level terrain, however, bog formation may continue indefinitely.

Using pollen analysis, peat stratigraphy, and radiocarbon dating, Banner *et al.* (1983) reconstructed the historical development of a woodland bog near Prince Rupert over 8 700±210 years. The following successional sequence was revealed: *Pinus contorta–Alnus rubra*/ferns (pioneer alluvial forest); *Picea sitchensis–Alnus rubra–Tsuga heterophylla–Thuja plicata*/*Lysichitum americanum*–ferns (moist productive alluvial forest on Rego-

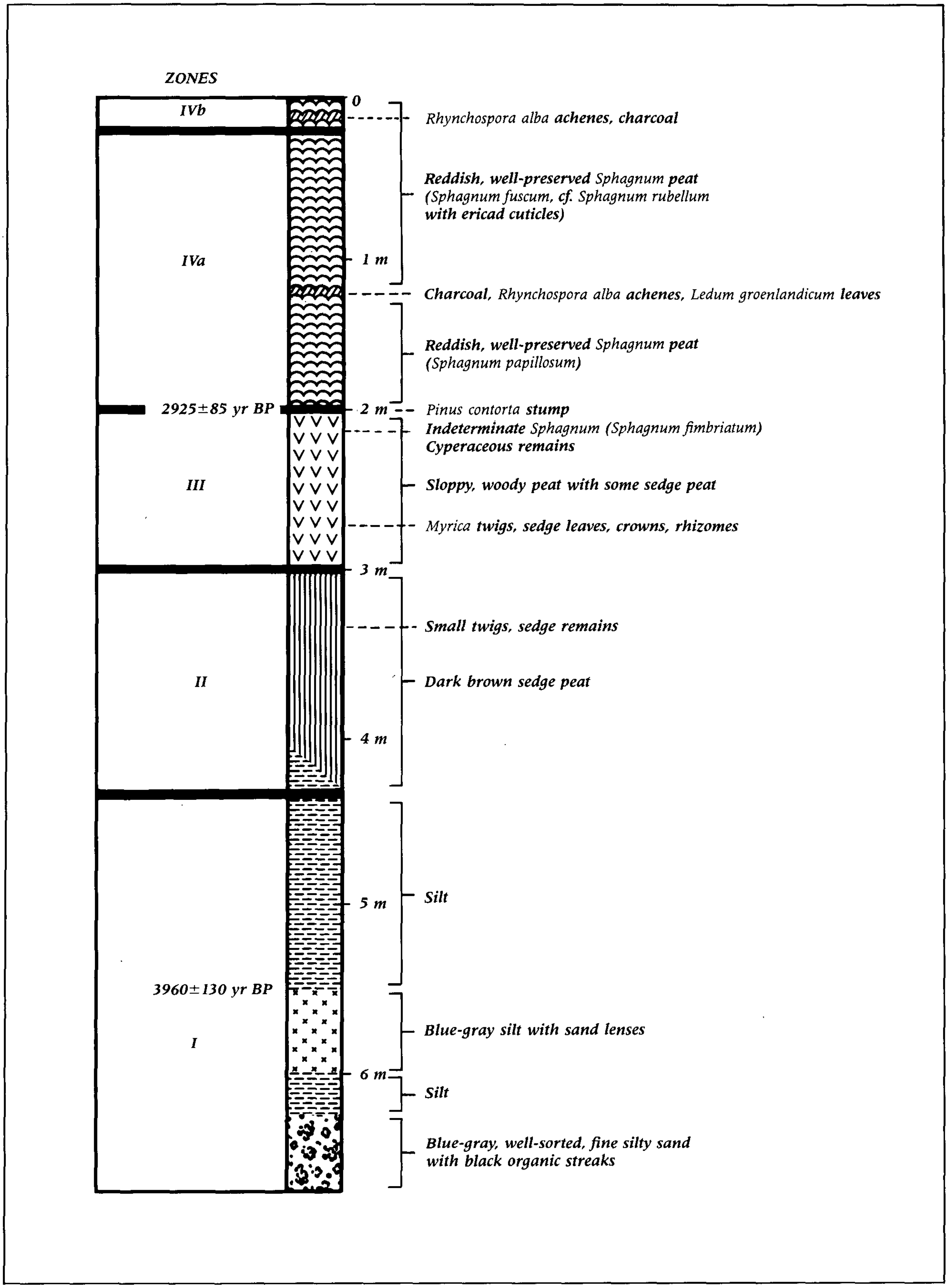


Figure 8–25.
Stratigraphy and macrofossils of core no. CBB, Burns Bog, Fraser River Delta, British Columbia.

sols); *Thuja plicata–Chamaecyparis nootkatensis–Tsuga heterophylla–Pinus contorta* (scrub forest on peaty mineral soils); *Pinus contorta–Chamaecyparis nootkatensis*/ericaceous shrubs/*Sphagnum* spp. (woodland bog on organic soils 2 m deep). This sequence is correlated with changes in the paleoclimate of southwestern British Columbia (Mathewes and Heusser 1981), and may also be associated with edaphic factors such as changing drainage patterns, formation of cemented soil horizons, and the accumulation of thick organic surface horizons.

Swamps are situated in sites of higher nutrient flux or greater water table fluctuation than bogs. Even if the substrate is acid, there are sufficient nutrients available for the growth of coniferous trees or shrubs such as *Salix* spp. and *Spiraea* spp. Water table lowering during the summer encourages decomposition of organic matter. Consequently, the increase in acidity, reduction in available nutrients, and accumulation of tertiary peat necessary for bog development are curtailed. Shade provided by trees and dense shrubs may further inhibit the growth of *Sphagnum* spp.

Coniferous treed swamps develop on sites of moderate acidity, moderate to high nutrient flux, and with a moderate to high water table; they frequently occur on floodplain and seepage sites. The apparent stability of these swamps is probably due both to the continually high nutrient flux and to the heavy shade provided by trees, which effectively inhibits encroachment of fen and bog species.

The end point or climax stage of succession, particularly in coniferous forest bogs, has been a point of controversy (Zach 1950; Stephens *et al.* 1970). Some consider the bog stage to be the climax, whereas others believe that the bog surface eventually rises sufficiently above the water table to allow the return of more productive forests. Support for the forest climax hypothesis comes from the incidence of forest peat overlying *Sphagnum* and sedge peat. Such stratigraphic sequences are common in southeast Alaska (Stephens *et al.* 1970) and have also been found in coastal British Columbia, but only where some disturbance or climatic change has lowered the water table (Hebda and Biggs 1981; Banner *et al.* 1983). Apparently, under extant climatic conditions, most *Sphagnum* bogs are still growing and have not attained a point dry enough to curtail the growth of *Sphagnum* mosses. Burns Bog has been disturbed by peat mining, drainage, and agriculture, yet there are extensive areas where *Sphagnum rubellum* is actively expanding into pine forest. This bog is in an area with almost the warmest and driest climate along the coast.

Role of Climate and Geomorphology in Wetland Succession

Throughout this discussion on wetland dynamics, reference has been made to the role of climate and geomorphology in the genesis and character of wetlands. Since deglaciation there have been three broad climatic regimes in the Pacific Northwest (Heusser 1952, 1960; Lawrence 1958). The climate was generally cool and moist from 11 500 to 10 500 years BP; this period was followed by amelioration to warmer and drier conditions, during what is known as the xerothermic period from about 10 000 to 6 600 years BP, and since then the climate has been relatively moist and cool, similar to current conditions (Hebda 1983). Conditions for bog formation were generally not favourable during the xerothermic period, but the moister and cooler periods were conducive to wetland development (Banner *et al.* 1983; Hebda 1983).

The major geomorphic changes affecting the evolution of wetlands were glaciation and fluctuations in relative sea levels. During the early Holocene epoch, the land of the southern coast of British Columbia was considerably depressed relative to sea level, but subsequently rose to levels higher than at present before declining to current levels (Clague *et al.* 1982). Most coastal lowland wetlands are on surfaces dating to the mid- to late-Holocene; for example, domed bogs of the Fraser Delta are less than 5 000 years old (Hebda 1977) and slope bogs on Hesquiat Peninsula on the west coast of Vancouver Island are about 1 000 years old (Hebda and Rouse 1979). One bog near sea level on Barkley Sound contains a marine transgression within *Sphagnum* bog peat. The developmental history and current successional status of Pacific coast wetlands have been shaped by these fluctuations.

Carbon dates for bogs along north coastal British Columbia and southeast Alaska, obtained by Heusser (1960), range from 1 210 years BP for a 2 m deep bog formed in a coastal lagoon near Grand Plateau Glacier, southeast Alaska, to 10 850 years BP for a 6.6 m deep bog on southern Langara Island, British Columbia.

Recent Disturbances Affecting Wetland Dynamics

Fire has played an important role in the wetland dynamics of the drier south coast. The pine woodland and dry heathland of domed bogs on the Fraser Lowland are prone to fire in summer (Hebda 1977; Hebda and Biggs 1981). Many hectares have burned, providing a seedbed for shore pine and paper birch regeneration. The fires have disrupted *Sphagnum* growth and peat accumulation, and have served as a mechanism for the creation of hummocks and hollows (Figure 8–26).

Disturbances by humans are perhaps the most devastating factors affecting wetlands. These disturbances are more prominent in the Pacific Temperate Wetland Region than in the Pacific Oceanic Wetland Region, not only because of the type of wetlands and associated climates, but also because of demographic factors. Agriculture, peat mining, landfill, and construction have been, and still are, occurring, particularly in the basin and domed bogs and swamps of the Pacific Temperate Wetland Region.

Altered drainage has the most widespread effects. A lowering of the water table allows shore pine, western hemlock, and paper birch to expand at the expense of *Sphagnum* spp. and other bog species in basin and domed bogs (Hebda and Biggs 1981). Often associated with drainage is the introduction of mineral-rich waters from surrounding uplands. This combination of disturbances increases the nutrient flux and decomposition of organic matter, particularly along drainage channels. Flora characteristic of bogs are replaced by fen and swamp plants such as *Spiraea* spp., *Salix* spp., *Pyrus* spp., *Juncus* spp., and *Carex* spp.

Peat mining has resulted in the flooding of large areas of former domed bogs on the Fraser Lowland. The nature of vegetation that recolonizes mined areas depends on the degree of humification of the remaining substrate and on the degree of drainage. On unhumified moss peat, bog species such as *Sphagnum* spp., *Drosera rotundifolia*, *Rubus chamaemorus*, and *Ledum groenlandicum* regenerate. New *Sphagnum* peat accumulation in pits and pools after mining may amount to over 8 mm/yr (Hebda and Biggs 1981). *Spiraea douglasii* thickets intermingle with patches of *Carex* spp. or *Juncus effusus* on well-humified or thoroughly cultivated peat. If the thickets are peripheral to a main bog where the hydrology has not been drastically altered, they are eventually invaded by *Sphagnum rubellum* and presumably return to bog vegetation. Paper birch and shore pine invade areas where the water table remains low. However, where the underlying mineral substrate is exposed, *Juncus* spp., *Carex* spp., and *Typha latifolia* appear in temporary fen stages.

Pacific Wetland Values

The wetlands of Pacific Canada have significant ecological, economic, educational, and aesthetic values. In their natural state, wetlands serve as water absorption and storage reservoirs that aid in reducing flood hazards. Their absorptive capacity, related to the type and depth of organic material, reduces the amount of free-flowing water and improves water quality by filtering nutrient, sediment, and pollutant loads. Filtering is perhaps most significant when the wetlands are associated with larger bodies of water used for water supply systems for domestic, industrial, or irrigation purposes. However, of particular national and international importance are wildlife and fisheries values. The region is in the western flyway of a large variety of migratory birds, and the estuaries and water channels support a large number of salmonid and other fish populations.

Many of the wetlands have been modified to accommodate urban and industrial pursuits. On the Fraser Delta, for example, many wetlands have been diked and drained or filled for the purpose of agriculture, urbanization, and industrial activity. Some of the most productive market gardens in Canada for growing vegetables and small fruits are located here. Peat is harvested for horticulture. Forage crops, which are essential to a large dairy industry, are produced in areas unsuitable for more intensive uses. Many wetlands along the east coast of Vancouver Island have undergone similar development, although diking and peat extraction are rare, mostly because of the relatively small size of the wetlands and the low-lying position they occupy in relation to the surrounding topography. These smaller wetlands, most of which were bogs, have been converted to seasonal pastures or forage crop production.

Wetlands are also used as recreational and greenbelt areas. Some recreational activities have necessitated drastic modifications, as in the case of golf courses, for example, which have been constructed entirely or in part on wetlands. Wetlands

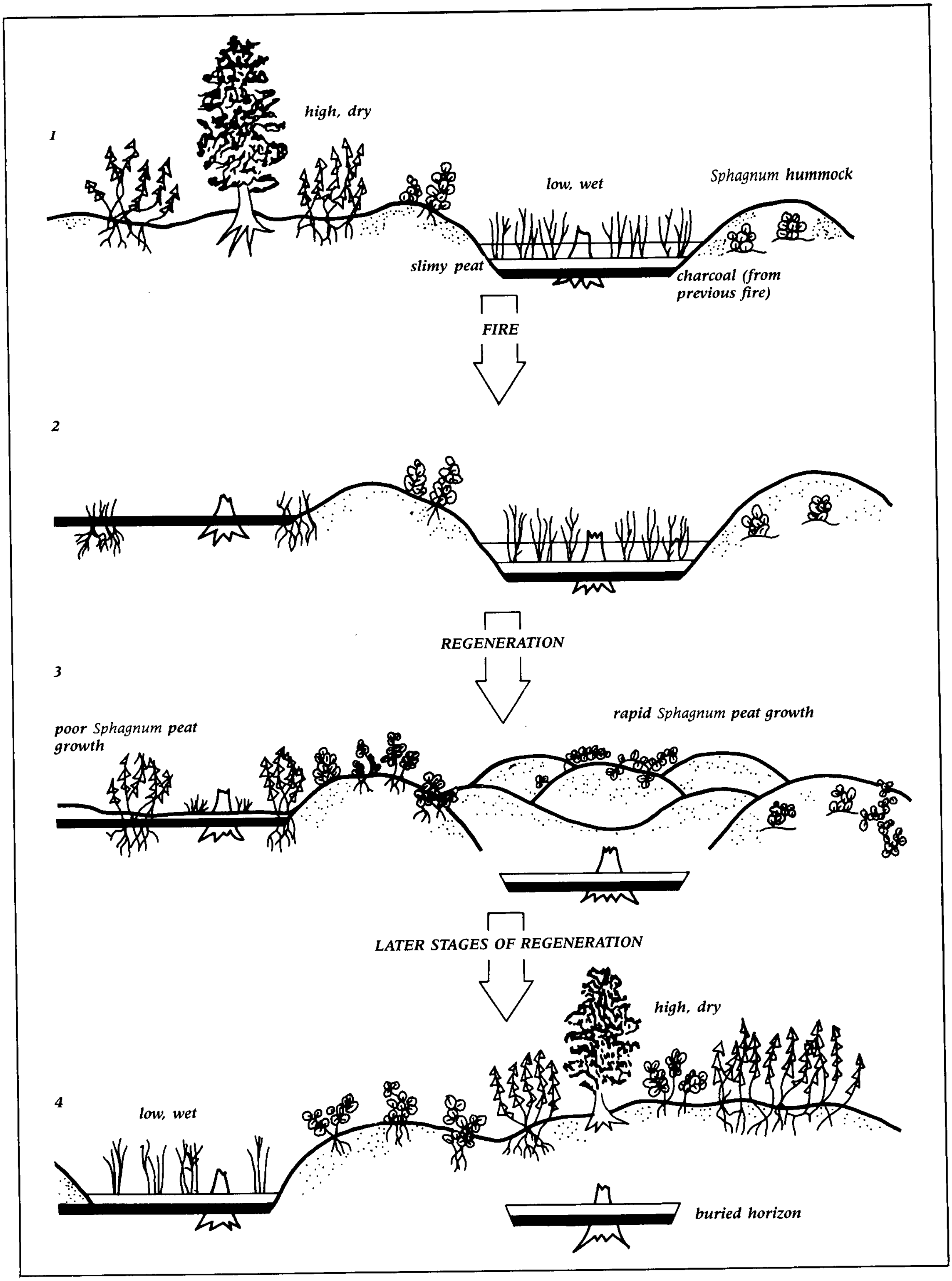


Figure 8–26.
Fire-induced hummock-hollow cycling, Burns Bog, Fraser River Delta, British Columbia.

are enjoyed by naturalists, as outdoor classrooms for student field trips and for scientific studies. When left as greenbelts, they serve to modify the climate associated with the urban setting by influencing wind patterns and temperature regimes; they also enhance visual values within subdivisions and provide habitat for local wildlife populations. Several provincial parks and nature reserves in coastal areas of British Columbia include wetlands. Some of these are used intensively for nature trails and picnic and leisure areas near urban centres; those in more remote areas are used as heritage and wildlife preserves for scientific studies.

The wetlands of the North Coast Pacific Oceanic Wetland Subregion and those along the west coast of Vancouver Island are not usually drastically disturbed except by forestry operations and, rarely, by industrial developments. For the most part, tree growth is poor in these wetlands unless they are drained, with the exception of areas associated with flowing water which provide some of the best sites for tree growth. Bogs in their natural state support extremely limited or no tree growth because of the high water table, lack of oxygen, and low nutrient availability.

People have had a major impact on wetlands. Residential and industrial complexes have been built on wetlands, following modifications such as drainage, diking, surface material removal, landfill, and dumping of garbage (Figure 8–27). Linear developments, such as roads and power lines, have also been built across wetlands. Most of these developments result in the total, irreversible loss of the wetland habitat. One study of the southwest Fraser Lowland has documented the nature and amount of land use changes influencing wetlands in this area of intensive, conflicting demands for land (Pilon and Kerr 1984). From 1967 to 1982, for example, 7% of the riparian, salt, and intertidal marsh wetlands were converted to other land uses, a trend which is continuing but only to a minor degree.

Figure 8–27.
Garbage dump in shore pine woodland, Burns Bog, Fraser Lowland, British Columbia.

Major efforts in recent years by provincial and federal agencies have been directed at the development of regionally significant wetland evaluation tools and monitoring systems. These are focusing on a commitment to wetland conservation and wise, sustainable use of the resource.

Acknowledgements

The following have provided comments and reviews during the preparation of this text: H. Hirvonen, S. Zoltai, C. Tarnocai, C. Rubec, C. Selby, and A. Pearson. A. Smith collected samples and J. Kimmins and M. Tsze provided advice and assistance as well as laboratory facilities at the University of British Columbia for data in Table 8–9. Drafting for original figures was undertaken by B. Brown, M. Williams, and P. Nystedt.

References

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals, 1951–1980. Volume 4: Degree-days. Environment Canada. Downsview, Ontario. 280 p.

BANNER, A. 1983. Classification and successional relationships of some bog and forest ecosystems near Prince Rupert, British Columbia. M.Sc. thesis, Faculty of Forestry, University of British Columbia, Vancouver, British Columbia. 235 p.

BANNER, A., J. POJAR, AND G.E. ROUSE. 1983. Postglacial paleoecology and successional relationships of a bog woodland near Prince Rupert, British Columbia. Canadian Journal of Forest Research 13:938–947.

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication No. 1646. Ottawa, Ontario. 164 p.

CHILTON, R.R.H. 1981. A summary of climatic regimes of British Columbia. Assessment and Planning Division, Ministry of the Environment, Province of British Columbia. 46 p.

CLAGUE, J.J. 1981. Late Quaternary geology and geochronology of British Columbia, Part 2. Geological Survey of Canada. Paper 80-35. Ottawa, Ontario.

CLAGUE, J.J., J.R. HARPER, R.J. HEBDA, AND D.E. HOWES. 1982. Late Quaternary sea levels and crustal movements, coastal British Columbia. Canadian Journal of Earth Sciences 19:597–618.

FYLES, J.G. 1963. Surficial geology of Horne Lake and Parksville map areas, Vancouver Island, British Columbia, 92 F/7, 92 F/8. Geological Survey of Canada. Memoir 318. Ottawa, Ontario. 142 p.

HEBDA, R.J. 1977. The paleoecology of a raised bog and associated deltaic sediments of the Fraser River Delta. Ph.D. thesis, Department of Botany, University of British Columbia, Vancouver, British Columbia. 202 p.

HEBDA, R.J. 1983. Late-glacial and postglacial vegetation history at Bear Cove Bog, northeast Vancouver Island, British Columbia. Canadian Journal of Botany 61:3172–3192.

HEBDA, R.J., AND W.E. BIGGS. 1981. The vegetation of Burns Bog, Fraser Delta, southwestern British Columbia. Syesis 14: 1–20.

HEBDA, R.J., AND G.E. ROUSE. 1979. Palynology of two Holocene cores from Hesquiat Peninsula, Vancouver Island, British Columbia. Syesis 12:121–129.

HEUSSER, C.J. 1952. Pollen profiles from southeastern Alaska. Ecological Monographs 22:331–352.

HEUSSER, C.J. 1960. Late-Pleistocene environments of North Pacific North America. American Geographical Society. Special Publication No. 35. pp. 177–265.

HOLLAND, S.S. 1976. Landforms of British Columbia. A physiographic outline. British Columbia Ministry of Mines and Petroleum Resources. Bulletin No. 48. 138 p.

HOWES, D.E. 1981. Late Quaternary sediments and geomorphic history of north–central Vancouver Island. Canadian Journal of Earth Sciences 18:1–12.

KLINKA, K., R.N. GREEN, R.L. TROWBRIDGE, AND L.E. LOWE. 1981. Taxonomic classification of humus forms in ecosystems of British Columbia. Ministry of Forests, Province of British Columbia. Land Management Report No. 8. 54 p.

LAWRENCE, D.B. 1958. Glaciers and vegetation in southeastern Alaska. American Scientist 46:89–122.

LUTTMERDING, H.A. 1980. Soils of the Langley–Vancouver map area. Resource Analysis Branch, Ministry of the Environment, Province of British Columbia. Bulletin 18. 6 volumes.

MATHEWES, R.W., AND L.E. HEUSSER. 1981. A 12 000 year palynological record of temperature and precipitation trends in southwestern British Columbia. Canadian Journal of Botany 59:707–710.

MOORE, P.D., AND D.J. BELLAMY. 1974. Peatlands. Springer-Verlag New York Inc. New York, New York. 221 p.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada and Wetland distribution in Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NEILAND, B.J. 1971. The forest-bog complex of southeast Alaska. Vegetatio 22:1–64.

OSVALD, H. 1933. Vegetation of the Pacific coast bogs of North America. Acta Phytogeographica Suecica 5:1–32.

PEARSON, A.F. 1985. Ecology of Camosun Bog and recommendations for restoration. University Endowment Lands, Forest Park Research. Greater Vancouver Regional District Parks Department. Technical Paper No. 3. 202 p.

PILON, P., AND M.A. KERR. 1984. Land use monitoring on wetlands in the southwestern Fraser Lowland, British Columbia. Lands Directorate, Environment Canada. Working Paper No. 34. Vancouver, British Columbia. 31 p. and map.

REINERS, W.A., I.A. WORLEY, AND D.B. LAWRENCE. 1971. Plant diversity in a chronosequence at Glacier Bay, Alaska. Ecology 52:55–69.

RIGG, G.B. 1914. Notes on the flora of some Alaskan sphagnum bogs. The Plant World 17:167–182.

RIGG, G.B. 1922. A bog forest. Ecology 3: 207–213.

RIGG, G.B. 1925. Some sphagnum bogs of the north Pacific coast of North America. Ecology 6:260–278.

RIGG, G.B. 1937. Some raised bogs of southeastern Alaska with notes on flat bogs and muskegs. American Journal of Botany 24: 194–198.

RIGG, G.B., AND C.T. RICHARDSON. 1938. Profiles of some sphagnum bogs of the Pacific coast of North America. Ecology 19:408–434.

SELBY, C. (personal communication). February 1986. Canada Soil Survey, Agriculture Canada, Vancouver, British Columbia.

STEPHENS, F.R., C.R. GASS, AND R.F. BILLINGS. 1970. The muskegs of southeast Alaska and their diminished extent. Northwest Science 44:123–130.

THOMPSON, T.G., J.R. LORSH, AND G.B. RIGG. 1927. The acidity of the waters of some Puget Sound bogs. Journal of the American Chemical Society 49:2981–2988.

TROWBRIDGE, R., EDITOR. 1981. Second progress report of the working group on organic horizons, Folisols, and humus form classification. Land Resource Research Institute, Agriculture Canada. Ottawa, Ontario. Unpublished.

UGOLINI, F.C., AND D.H. MANN. 1979. Biopedological origin of peatlands in southeast Alaska. Nature 281:366–368.

WETZEL, R.G. 1975. Limnology. W.B. Saunders Company. Philadelphia, Pennsylvania. 743 p.

ZACH, L.W. 1950. A northern climax, forest or muskeg? Ecology 31:304–306.

ZIRUL, D.L. 1967. Pollen analysis of a bog in the Garry oak zone of southern Vancouver Island, BC. B.Sc. thesis, Department of Biology, University of Victoria, Victoria, British Columbia. 38 p.

ZOLTAI, S.C., AND F.C. POLLETT. 1983. Wetlands in Canada: their classification, distribution, and use. *In* Mires: swamp, bog, fen and moor. B. Regional Studies. A.J.P. Gore, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 245–268.

9 Salt Marshes of Canada

W.A. Glooschenko
I.P. Martini
K. Clarke-Whistler

Salt Marshes of Canada

Salt marshes are important coastal ecosystems that represent a complex interaction between oceanographic, biological, geological, chemical, and hydrological processes. They constitute an area of transition from marine to freshwater terrestrial environments which have been described as, in reality, several ecosystems with complex ecotones, ranging from wet to dry, from aerobic to anaerobic, and from saline to freshwater (Pomeroy and Wiegert 1981).

Canada can be divided into three main salt marsh areas; these are depicted in Figure 9–1 and described below. The Pacific salt marshes *of British Columbia are restricted in extent as a result of the active tectonic, geological, and geomorphological nature of the western coast of Canada which is characterized by deep fiords. This coast has only limited pro-*

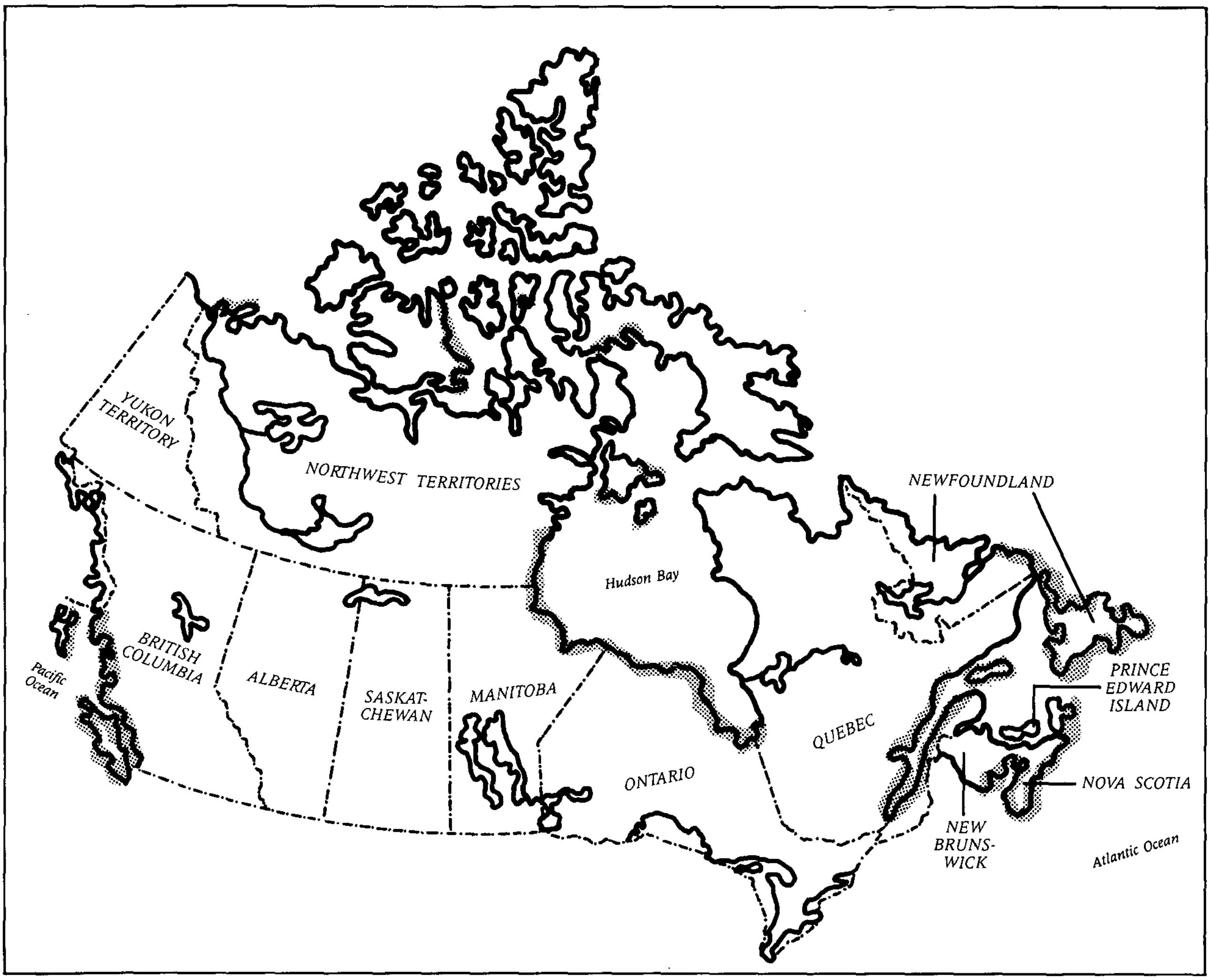


Figure 9–1.
Map of Canada showing important salt marsh areas assuming proper environmental conditions for development.

tected embayments which favour salt marsh development. *Atlantic salt marshes* are concentrated in the lower St. Lawrence River of Quebec, the southern shores of the Gulf of St. Lawrence in New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland, and the southern tip of Labrador. *Subarctic and arctic salt marshes* occur in James Bay and Hudson Bay, the arctic coasts and islands of Foxe Basin, and restricted locations throughout the Arctic Archipelago.

This chapter includes discussions of (1) geological factors that have influenced the formation of salt marshes and their vegetation ecology in Canada; (2) the effects of climate on such marshes; (3) similarities between Canadian salt marshes and those in other parts of the world; (4) the ecological significance of marshes for coastal fisheries and wildlife; and (5) human influences that have led to losses of salt marsh ecosystems.

Environmental Setting

What is a Salt Marsh?

The term "salt marsh" is commonly used to describe grass-dominated coastal ecosystems subject to the inundation of saline tidal waters. Chapman (1974) defined salt marshes as "areas of land bordering the sea, more or less covered by vegetation, and subject to periodic inundation by the tide". Beeftink (1977) used the following definition: "natural or semi-natural halophytic grassland and dwarf brushwood on alluvial sediments bordering saline water bodies whose water level fluctuates either tidally or non-tidally". Frey and Basan (1978) defined salt marshes as "well-vegetated saline intertidal flats". Zedler (1984) has used a more comprehensive, ecologically oriented definition for a salt marsh: "A community of organisms dominated by plants that are tolerant of wet, saline soils: generally found in low-lying coastal habitats which are periodically wet and usually saline to hypersaline". She uses the term to include both the saline condition of the habitat and the emergent vegetation that grows on it. Thus, salt marsh vegetation must tolerate both waterlogged and saline conditions, but this does not mean that salt marsh species have to be obligate halophytes. Barbour (1970) has pointed out that, in fact, very few species in salt marshes are obligate halophytes. He feels that the ultimate criterion for salt tolerance is the ability to reproduce under saline conditions (Glooschenko and Clarke 1982).

Classification of Salt Marshes

In this chapter, the definition of marsh used is that of Tarnocai (1980): "a marsh is a mineral or peat-filled wetland which is periodically inundated by standing or slowly moving waters". Often associated with marshes is another wetland class—shallow open water—which Tarnocai defined as "semi-permanent to permanent standing or flowing water with relatively large and stable expanses of open water . . . distinguished from deep waters by the upper 2 m limit, although depths may occasionally exceed this during periods of abnormal flooding". The term "salt marsh" refers to marshes that are inundated by saline or brackish water from tidal marine sources, as opposed to interior salt marshes which are discussed in Chapter 5 on the wetlands of the Prairies.

Normal sea water has a salinity level of 33.5 parts per thousand (often abbreviated as ‰ or ppt). Waters of lower salinity (brackish waters) can be transported onto tidal flats or marshes and then evaporate there, resulting in elevated soil salinities (Chapman 1974). Thus, a salt marsh can occur adjacent to a water body of quite low salinity such as James Bay (Glooschenko and Clarke 1982). It is difficult to relate the presence of different salt marsh plant species to a given level of soil salinity as this level can fluctuate over a year as a result of the flushing of salts during periods of increased rainfall or the build-up of salinity in soils in drier periods due to increased evapotranspiration (Glooschenko and Clarke 1982).

Another important and relevant concept that must be considered is that of an estuary. A classical definition is that of Pritchard (1967): "a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage". These estuarine systems are of four geomorphic origins: drowned river valleys, bar-built estuaries, fiords, and estuaries built by tectonic processes. Ketchum (1983a, 1983b) has criticized this definition because he believes that an estuary does not have to be semi-enclosed; for example, offshore coastal waters that are diluted by terrestrial-derived fresh water can be estuarine. Thus, in Canada, James Bay could be considered an estuary of Hudson Bay.

Fairbridge (1980) stresses that the estuarine concept must be qualified by inclusion of both tidal and river influences. He uses the following definition: "An estuary is an inlet of the sea reaching into a river valley as far as the upper limit of tidal rise, usually being divisible into three sectors: (a) a marine or lower estuary in free connection with the open sea, (b) a middle estuary, subject to strong salt and fresh water mixing, and (c) an upper or fluvial estuary, characterized by fresh water but subject to daily tidal action". Thus, he feels that the concept of an estuary requires the notion of enclosure as defined by Pritchard (1967). In the classification scheme employed in this chapter, Fairbridge's concept of an estuary is used.

In this chapter, the classification of salt marshes in Canada as a wetland form is that of Tarnocai (1980), presented in Table 9–1. This classification includes four wetland forms: estuarine high and low marshes, and coastal high and low marshes.

Table 9–1. Classification of Canadian salt marshes

Estuarine Marsh: Wetlands influenced by marine tidal water in river estuaries or connecting bays where tidal flats, channels, and pools are periodically inundated by water of varying salinity.
High – Located above mean high-water levels; inundated only at highest tides and/or storm surges
Low – Located below mean high-water levels; frequently inundated
Coastal Marsh: Wetlands on marine terraces, flats, embayments, or lagoons behind barrier beaches, remote from estuaries, where there is periodic inundation by tidal brackish or salt water, including salt spray.
High – Located above mean high-tide levels; inundated only at flood tides
Low – Located below mean high-tide levels

Source: Tarnocai (1980).

Geological and Physiographical Conditions for the Development of Salt Marshes

Salt marshes develop in low-lying areas protected from direct reworking by large, open sea waves and in areas where a relatively large amount of sediment is available and can be trapped along the shore. As Phleger (1977) has noted, the sediment grain size of an area depends largely upon what sizes are available. Marshes, however, accumulate the finest sediment available in the system because of the low current velocities in very shallow water. Salt marsh plants can also trap finer sediment. These fine sediments carry abundant exchangeable ions, thus fertilizing and enhancing the productivity of marshes. Fine sediments may be transported from inland areas to the sea by rivers, or may be derived from the erosion of shorelines. In either case, they are redistributed by marine agents and transported on to marshes by tides.

A sandy substratum is not ideal for the development of marshes. However, it may support marsh development in tectonically stable, sheltered areas and along slowly emerging shores where, as in southeast England, Wales, and Denmark, "increasing exposure of sand flats, and drying winds at low tide blow onto marshes", thus mixing sand with tidal silts (Chapman 1977). From the geological–physiographical point of view, development of marshes is thus favoured primarily by (1) flat, sheltered coastal areas; (2) extensive availability and accumulation of fine silty and clayey sediments; (3) tectonically stable or slowly emerging shores; and (4) a suitable climate for plant growth.

The physiography of Canada reflects the complex geological history of the continent (Douglas 1970; Bostock 1970). Accordingly, Atlantic Canada is affected by the relatively old but still sizeable Paleozoic Appalachian Mountains to the south and the older Precambrian Shield along the Labrador coast. Locally, the mountainous areas are fronted by the relatively wide sediment wedge of the Mesozoic and Pleistocene continental shelf. Many of the Arctic Islands and their coasts are similarly affected by mountainous regions alternating with flat-lying areas primarily associated with an ancient Precambrian peneplained surface. The Pacific coast differs because it is undergoing a mountain-building episode; thus, except where the large Fraser River Delta has formed, the coast is characterized by steep rocky shores. Finally, the large inland sea of Canada (James Bay, Hudson Bay, and Foxe Basin) occupies a cratonic basin which has persisted from Precambrian times and has been partially filled by flat-lying Paleozoic and Mesozoic sedimentary rocks.

As a result of factors which favour the formation of extensive marshes and in accordance with the physiography and climatic conditions of Canada, the most extensive salt marshes have developed in southwestern Hudson and James bays; the next most extensive, in order, are the salt marshes of embayments along the Atlantic coast, those in some areas of flat-lying Prince Edward Island in the Gulf of St. Lawrence, the marshes of the Fraser River Delta, and those of the coasts of the Arctic Ocean.

Climatic Aspects of Canadian Salt Marshes—The Wetland Region Concept

Canada's salt marshes occur in a variety of different climates ranging from temperate to arctic. In this chapter, the climatic aspects of salt marsh areas are discussed in conformity with the wetland regions of Canada (National Wetlands Working Group 1986). Temperature and precipitation data for each of these wetland regions are presented in Chapter 1 (Table 1–3).

On the Pacific coast, the area from the Alaska–British Columbia border to the northern portion and western coast of Vancouver Island is characterized by the Pacific Oceanic Wetland Region (OP). The main portion of the Island and the adjacent mainland are part of the Pacific Temperate Wetland Region (TP). The vegetation of the salt marshes along the entire British Columbia coast is fairly uniform, but shows little floristic similarity to other Canadian salt marshes. However, similarities to marshes in southern Alaska and the Pacific northwestern states including Washington, Oregon, and the northern part of California do exist (Macdonald 1977).

The salt marshes on the Atlantic coast of Canada mainly occur in the Atlantic Boreal Wetland Region (BA). This wetland region includes the lower Gulf of St. Lawrence (Quebec), the maritime provinces (New Brunswick, Prince Edward Island, and Nova Scotia), and the western and northern coastline of insular Newfoundland. The southern coast of Newfoundland and the coasts of Labrador are mainly included in the Atlantic Subarctic Wetland Region (SA), and the extreme southeastern tip of Newfoundland is in the Atlantic Oceanic Wetland Region (OA). Most of the salt marshes on the Atlantic coast of Canada are characterized by similar vegetation, dominated by the low marsh species *Spartina alterniflora.*

The other main salt marsh area of Canada is in the area of James and Hudson bays and the southern Arctic Islands. The coast between the Alaska–Yukon Territory border and Bathurst Inlet is in the Low Arctic Wetland Region (AL); to the east, most of the marshes are found in the Mid-Arctic Wetland Region (AM). The Arctic Islands are in the Mid- and High Arctic Wetland Regions (AM; AH) but salt marshes are rare here. Notable areas of coastal salt marsh occurrence in the Arctic Islands include Prince Charles, North and South Spicer, Air Force, Southampton, Mansel, and Coats islands of Foxe Basin and their associated shores bordering Melville Peninsula and the Great Plain of the Koukdjuak on southwestern Baffin Island. Creswell Bay on Somerset Island and limited coastal areas of the Somerset–Boothia arch, Queen Maud Gulf Lowlands, northern and eastern Victoria Island, and Truelove Lowland of Devon Island are also characterized by occurrences of coastal and estuarine marshes (C.D.A. Rubec, personal communication). In Hudson Bay, the major salt marsh area occurs along the Hudson Bay Lowland (Glooschenko and Martini 1978) which lies in the High Subarctic Wetland Region (SH); it extends from Cape Henrietta Maria north to the Manitoba–Northwest Territories border. North of this, some salt marshes are found in the Low and Mid-Arctic Wetland Regions but are of limited areal extent.

Most salt marsh areas in James Bay occur mainly in the Low Subarctic Wetland Region (SL). The Humid Mid-Boreal Wetland Subregion (BMh) occurs peripherally from the southern end of James Bay extending into Quebec to a point north of the Opinaca River. The rocky east coast of James Bay is predominantly in the Humid High Boreal Wetland Subregion (BHh). Salt marshes here are fairly similar, dominated by *Puccinellia phryganodes* as the low marsh colonizing species. The salt marshes of this entire area are similar to circumpolar salt marshes in Greenland, northern Europe, and Alaska (Chapman 1974; Beeftink 1977).

The Pacific Oceanic and Pacific Temperate Wetland Regions are similar in salt marsh species composition. The same holds true for the wetland regions of the Atlantic area and those of James and Hudson bays. The wetland regions in the Arctic, particularly the Low and Mid-Arctic Wetland Regions, are similar in salt marsh species composition to those in Hudson and James bays but with fewer species present. They have also been subjected to fewer studies because of their remoteness. Few studies of salt marshes in Labrador and northern Quebec exist and therefore analyses of changes in salt marsh vegetation north from the Island of Newfoundland to Labrador are limited.

Canadian Salt Marshes

Salt Marshes of the Pacific Coast

The following three major areas of Pacific coastal salt marshes are found in British Columbia: (1) the Queen Charlotte Islands; (2) the mainland of British Columbia, especially the southern portion adjacent to the Canada–United States border; and (3) Vancouver Island. The mainland can be further divided into two subareas: southern British Columbia including the Fraser River Delta and Boundary Bay, and the area dominated by fiords extending from Squamish, north of Vancouver, to the Alaskan border.

The Pacific coast is more tectonically active than the Atlantic seaboard. "Mountain building has left little room for coastal lowlands. Estuaries and lagoons make up only 10–20% of the shoreline, a marked contrast with the comparable figure of 80–90% for the Atlantic and Gulf coasts" (Macdonald 1977). Most of the Pacific coast is characterized by a relatively narrow shelf. Numerous deep fiords and islands are present (Owens 1977; Clague and Bornhold 1980). Sediment carried locally to the coasts is dispersed in deep waters and no widespread longshore drift and coastal accumulations develop to encourage the formation of extensive marshes.

Narrow, marshy terrain rims the deltas at the head of fiords. There are examples of such marshes in the Squamish River Delta which has developed at the head of Howe Sound (Clague and Luternauer 1982). Two relatively small, narrow marshes, which flank two distributaries, are affected by a sedimentation rate ranging from 0.5 to 1.5 cm/yr (Pomeroy and Stockner 1976). These marshes as well as the whole environment of the area are to some degree influenced by industrial activities including mercury contamination in at least one isolated portion.

Some marshes have developed in the Queen Charlotte Islands where "high-salinity marshes, fronted by shingle beaches or mudflats, are deeply dissected by tidal creeks. Between the creeks the marshland forms a vegetative terrace that is only flooded by extreme tides and storms" (Macdonald 1977).

Extensive marshes have formed on the Fraser River Delta. This Delta has been growing in area since approximately 11 000 years before the present (BP). During the early growth periods, the sea level was higher than at present, and intruded into the lower reaches of the mountain valleys. The sea level dropped until approximately 8 000 years BP when it was about 12 m lower than at present. The Delta adjusted accordingly and prograded into emerging lowlands. By about 5 000 years BP, transgression had brought the sea level almost to that of the present day. Since that time, the Delta has prograded regularly into the Strait of Georgia while the sea may have risen about 1–2 m (Luternauer and Murray 1973). In recent times, the natural environment has been greatly affected by human activities such as the diking of distributary channels and shores, and the building of causeways and jetties for ships terminals on tidal flats. These human activities have changed the sediment dispersal pattern in front of the Delta, leading to more rapid rates of sedimentation locally and to reduced influence of freshwater plume on some marshes protected by artificial jetties (Clague and Luternauer 1982).

South of the Fraser River Delta, and separated from it by a Pleistocene promontory (Point Roberts), is a wide embayment, Boundary Bay, which has well-developed salt marshes along its coasts. The relative steepness of the coast and the relatively high tides (maximum spring tides of 4.1 m) cause dissection of the tidal flat–marsh complexes by tidal creeks (Swinbanks and Murray 1981).

The southern mainland of British Columbia contains the greatest extent of salt marshes. This area extends northwards from the Canada–United States border around Boundary Bay, past Point Roberts, and to the mouth of the Fraser River. The area of salt marsh is approximately 27 km^2 (Kistritz 1978). Coastal salt marshes are limited to those areas beyond the influence of the freshwater discharge of the Fraser River, which include the Tsawwassen area south of the Roberts Bank coal terminal causeway and the Boundary Bay salt marshes.

Boundary Bay, isolated from the plume of the Fraser River, is characterized by coastal low and high marsh forms. The salt marshes are located here seaward of an artificial dike (Kellerhals and Murray 1969). The marshes are characterized by meandering tidal creeks and ponds with freshwater species. Some peat is accumulating. Major plant species in the low marsh include *Spergularia marina*, *Triglochin maritima*, *Salicornia europaea*, *Distichlis spicata*, *Plantago maritima*, *Cotula coronopifolia*, and *Atriplex patula*. High marsh species include *Hordeum jubatum*, *Elymus mollis*, *Aster* sp., *Achillea millefolium*, and *Rumex crispus*. Yamanaka (1975) found that 237 ha of Boundary Bay marshes were dominated by *Distichlis spicata*, *Salicornia virginica*, and *Triglochin maritima*. Parsons (1975) has also described vegetation at Boundary Bay. Boundary Bay marshes started as freshwater marshes which gradually became inundated as a result of the rising sea level (Shepperd 1981). A typical Boundary Bay marsh is presented in Figure 9–2.

Figure 9–2.
Coastal low salt marsh at Boundary Bay, British Columbia, with tidal creek in left foreground.

The other area of coastal salt marsh occurs in the Tsawwassen area, located on the mainland south of the mouth of the Fraser River. Yamanaka (1975) documented the presence of salt marsh species similar to those in Boundary Bay. Minor species included *Atriplex patula* and *Hordeum jubatum*. In areas of recent sedimentation, *Triglochin maritima* was the main colonizing species (Figure 9–3). Hillaby and Barrett (1976) described the succession of vegetation in this marsh. The tidal flats have been colonized by *Salicornia virginica* and *Distichlis spicata*. On the high marsh, *Grindelia integrifolia* and *Atriplex patula* were abundant. Hillaby and Barrett (1976)

Figure 9–3.
Colonization of sediments seaward of dike by Triglochin maritima, *near Roberts Bank coal terminal, south of Vancouver, British Columbia.*

felt that marsh development would cease if sedimentation were reduced, and erosion by wave activity would occur, thus destroying the marsh. They also pointed out that diking could reduce the influence of tidal inundations and the salt marsh could become a freshwater marsh. Olmstead and Fink (1982) conducted another study on this marsh in 1982, resampling plots of the earlier study by Hillaby and Barrett (1976). The main species in the low marsh still consisted of *Distichlis spicata*, *Atriplex patula*, *Salicornia virginica*, and *Grindelia integrifolia*. Little change was noted except for *Atriplex patula* which was more abundant, possibly due to a decline of *Salicornia virginica* caused by insect damage. Three species were found to be more abundant—*Cuscuta salina*, *Hordeum jubatum* var. *breviaristatum*, and *Triglochin maritima*. The grass *Festuca rubra*, indicative of a later stage of succession, was also more abundant. Hillaby and Barrett concluded that the dike enclosing the marsh had little effect on primary species and, in fact, may have protected the marsh from retreat by erosion. They also stated that any diking must allow for free exchange of sea water.

The major occurrence of tidal marshes in British Columbia is found at the mouth of the Fraser River. These marshes can be classified as estuarine. Burgess (1970) described marshes from Iona Island south to Brunswick Point and found an estuarine low marsh characterized by *Scirpus americanus* and *Carex lyngbyei*. Other important species included *Scirpus maritimus*, *Scirpus lacustris* var. *validus*, and *Eleocharis palustris*. Important factors controlling the distribution of species included water salinity, degree of tidal flooding, and drainage. In the estuarine high marsh areas subjected to freshwater influence, *Typha latifolia* and *Scirpus validus* were more abundant. Forbes (1972) and McLaren (1972) have described the distribution of vegetation in this area. Yamanaka (1975) pointed out that the major low marsh plant species were *Scirpus americanus*, *Scirpus maritimus* (=*paludosus*), and *Carex lyngbyei*, while *Typha latifolia* was an estuarine high marsh species.

Moody (1978) studied the vegetation of Brunswick Point and described the marsh as brackish, with major species being *Scirpus americanus*, *Scirpus maritimus*, and *Carex lyngbyei*. She found that marsh elevation in relation to tidal level was an important factor in the control of vegetation distribution.

Kistritz (1978) carried out a major study of the role of detritus and nutrient cycling in the Fraser River marshes. He discussed the role of these marshes in marine food chains in exporting nutrients and organic matter to offshore waters. Kistritz and Yesaki (1979) also studied primary production, detritus flux, and nutrient cycling in a *Carex lyngbyei* marsh.

A study of vegetation community structure at the Ladner Marsh on a small island in the Fraser River has been carried out by Bradfield and Porter (1982). They found three major vegetation zones. In regularly flooded and drained areas, especially along tidal creeks, *Carex lyngbyei* occurred. Along levees, a grass–willow zone dominated by *Scolochloa festucacea* (=*Festuca arundinacea*), *Lathyrus palustris*, and *Salix lasiandra* was found. These areas were flooded only by the highest winter storm tides. Where drainage was found to be restricted, a mixed-forb zone dominated by *Menyanthes trifoliata* occurred. The marsh terminated at a floodplain forest. No typical brackish species were found to be present on the island. Bradfield and Porter concluded that the vegetation pattern was controlled by physiography and drainage, and that elevation was not a good predictor of marsh vegetation. Hutchinson (1982) studied the interactions between vegetation and environment in the foreshore marshes of Lulu Island. He found three distinct elevational zones: a low marsh dominated by *Scirpus americanus* and *Scirpus maritimus*, a middle marsh with *Carex lyngbyei*, *Triglochin maritima*, and *Scirpus maritimus*, and a high marsh consisting of *Agrostis exarata*, *Potentilla egedii* (=*pacifica*), *Distichlis spicata*, and *Typha* *latifolia*. Each of these three zones varied in its exposure to water by tidal action. The low marsh experienced a submergence of 16–21 hours and the middle marsh a maximum submergence of 8 hours. The upper marsh had a maximum continuous exposure of over 200 hours. Elevation and elevation–salinity interactions were the primary factors in the control of plant distribution, while substrate texture and moisture were associated with variations in species abundance.

There have been several studies of the vegetation of the coastal marshes of Vancouver Island. Bell and Kallman (1976a) studied the flora of the deltas on the Cowichan and Chemainus river estuaries. In those areas of the Chemainus River Estuary under freshwater influence, *Carex* sp. and *Juncus* sp. were present. Where elevated salinities occurred, the dominant species included *Salicornia virginica, Distichlis spicata, Hordeum jubatum, Potentilla egedii* (= *pacifica*), *Triglochin maritima, Atriplex patula*, and *Achillea millefolium*. The mouth of the Cowichan River Estuary has been more disturbed by industry and agriculture, and exhibits more freshwater influence, than the Chemainus River Estuary. The two main species there are *Carex lyngbyei* and *Juncus arcticus*. The Nanaimo River Estuary is more brackish in nature (Bell and Kallman 1976b). Major species there are *Juncus gerardii* and *Carex lyngbyei*. Bell and Thompson (1977) described the Campbell River Estuary. Five saline-influenced communities were found: (1) *Carex lyngbyei*; (2) *Potentilla pacifica –Eleocharis palustris*; (3) *Deschampsia caespitosa*; (4) *Potentilla pacifica–Deschampsia caespitosa*; and (5) *Ruppia maritima*. Similar vegetation was described for the Courtenay River Estuary (Morris *et al.* 1979) and for the Somass River Estuary (Morris and Leaney 1980).

The vegetation of the Tsitika River Estuary, also on Vancouver Island, was described by Ceska (1981). In the lower part of the Estuary, a *Carex lyngbyei* community is present; it is fairly uniform in composition except for the rare occurrence of *Festuca rubra*. The largest part of the Estuary is covered by a *Deschampsia beringensis* community. This species is accompanied by *Festuca rubra, Potentilla egedii* (= *pacifica*), and *Hordeum brachyantherum*. Higher up, on gravelly ridges, is a community dominated by *Plantago maritima* and *Glaux maritima*. This would suggest an estuarine high marsh as these two species are typically salt-tolerant.

The estuarine plant communities of 18 river mouths on Vancouver Island have been reviewed by Kennedy (1982). She determined that 11 groups of estuarine vegetation occurred; these were based upon the following 6 principal physical factors: (1) time of maximum river discharge; (2) relationship between the river's average April to September mean discharge and the size of the river delta; (3) mean annual total precipitation; (4) relative protection of the river delta from wind and wave energy; (5) substrate particle size; and (6) frequency and duration of tidal inundation. Kennedy also produced a key to the different estuary types.

A comprehensive study of an estuarine marsh in the Little Qualicum River Estuary on Vancouver Island was completed by Dawe and White (1982). They identified nine plant communities related to increased elevation from the river mouth:

(1) *Glaux*–pioneer community: a community dominated by almost pure stands of *Glaux maritima* with some *Salicornia virginica* and *Puccinellia* sp.
(2) *Ruppia*–aquatic community: *Ruppia maritima* occurring in channel bottoms and pools with standing water.
(3) *Carex*–channel edge community: a community occurring at the edge of tidal channels. The dominant species was *Carex lyngbyei* with a scattered occurrence of *Eleocharis palustris, Potentilla egedii* (= *pacifica*), and *Agrostis* sp. A minor additional phase was found with *Scirpus cernuus* on open anoxic mud, and *Typha latifolia* was found in the extreme eastern reach of the Estuary.
(4) *Ranunculus*–low pasture community: an estuarine low marsh community grazed by cattle, with the dominant species being *Agrostis* sp., *Carex lyngbyei*, and *Distichlis spicata*. Other species here included *Ranunculus cymbalaria, Lilaeopsis occidentalis*, and *Triglochin maritima*.
(5) *Carex–Agrostis*–slope community: a community occurring at the slope between the channel edge and the flats community. Dominant species included *Agrostis* sp. and *Carex lyngbyei*, with such others as *Potentilla egedii* (= *pacifica*), *Eleocharis palustris, Triglochin maritima*, and *Glaux maritima*.
(6) *Ranunculus–Juncus*–high pasture community: a community next to the *Ranunculus*–low pasture community and with similar species plus *Juncus balticus, Agrostis* sp., and *Carex lyngbyei*.
(7) *Deschampsia*–flats community: a community occupying the largest area of the study site with dominant species being *Potentilla egedii* (= *pacifica*), *Juncus balticus*, and *Carex lyngbyei*. *Deschampsia caespitosa* and *Trifolium wormskjoldii* appeared here, and *Triglochin maritima* and *Glaux maritima* were present.

(8) *Juncus*–high marsh community: a community occurring at the upper reaches of the Estuary with *Juncus balticus*, *Potentilla egedii* (= *pacifica*), *Agrostis* sp., and *Poa pratensis*. Other forbs and grasses that were not present in the estuarine low marsh occurred here. This community gave way to forest.

(9) *Rosa*–gravel bar community: a community on fluvial gravel bars without wetland vegetation.

Dawe and White (1982) also studied physical and chemical factors influencing marsh communities and measured aerial peak primary production of these salt marshes. Major factors influencing vegetation included elevation, soil type and texture, and the salinity of inundating waters. Soil conductivity had little influence.

Dawe and White (1986) further studied the Nanoose–Bonell Estuary near Nanaimo, on the east coast of Vancouver Island. Eight plant communities were described, ranging from a *Salicornia*–pioneer community, with *Salicornia virginica*, *Glaux maritima*, *Spergularia canadensis*, and *Plantago maritima*, to an *Agropyron*–high grass community. Elevations ranged from 2.79–3.82 m ACD (above chart datum) to 4.85–5.26 m ACD for the highest marsh community. Salinity was an important controlling factor. Salt marsh communities were found to occur where salinities were greater than 20 ppt. Below this, brackish or freshwater communities were present. Elevation controlled exposure/inundation of plants and therefore was also an important controlling factor. Salinity was found to control what species were present and their horizontal distribution, while texture determined what species occurred in terms of vertical gradients on the marsh. For coarser soil textures, pioneer communities were found higher on the marsh.

There have been limited studies of the coastal marshes of the mainland of British Columbia north of the Fraser River, with an emphasis on the wetlands of the Squamish River Delta. Lim and Levings (1973) reported 24 species of vegetation on tidal flats, with *Carex lyngbyei* being the dominant species. Other common species included *Eleocharis palustris*, the grasses *Deschampsia caespitosa*, *Festuca rubra*, *Hordeum jubatum* (= *brachyantherum*), *Phalaris arundinacea*, and *Agropyron repens*, and forbs such as *Potentilla egedii* (= *pacifica*). Other major species were *Typha latifolia*, *Scirpus lacustris* var. *validus*, *Triglochin maritima*, *Sium suave*, and *Cicuta maculata*. These latter species appear to indicate freshwater conditions. Lim and Levings (1973) and Levings (1980a, 1980b) also reported considerable disturbance of these estuarine marshes by such activities as port development, logging operations, industrial effluents, and construction activities. Levings and Moody (1976) also studied the Squamish River Delta. They assessed the primary production of vegetation and noted the recovery of vegetation from siltation caused by hydraulic dredging operations. They noted that recovery could take place within one year if the silt layer was thin, but they noted no recovery in other areas.

The Bella Coola River Estuary, north of the Squamish River, was examined by Leaney and Morris (1981). The lowest part of the intertidal zone was colonized by *Hippuris tetraphylla* and *Plantago maritima*. Next, there was a zone dominated by *Eleocharis palustris*, which in turn gave way to a higher zone with *Carex* sp., *Potentilla* sp., and *Trifolium* sp. The Kitimat River Estuary was described by Bell and Kallman (1976c). In the intertidal zone, the lower portions were characterized by *Typha latifolia*, *Eleocharis* sp., *Scirpus cyperinus*, *Scirpus microcarpus*, *Scirpus lacustris* var. *validus*, *Carex obnupta*, and *Carex lyngbyei*. The higher parts of the marsh contained *Triglochin maritima*, *Salicornia virginica*, *Cuscuta salina*, *Suaeda maritima*, and *Spergularia marina*.

The Queen Charlotte Islands also have salt marshes which occur in inlets. Calder and Taylor (1968) found that the marshes with the highest salinity occur in areas protected by shingle beaches or mudflats. Major species here include *Deschampsia caespitosa*, *Hordeum jubatum* var. *breviaristatum* (= *brachyantherum*), *Festuca rubra*, *Triglochin maritima*, *Carex lyngbyei*, *Plantago macrocarpa*, and *Stellaria humifusa*. In estuarine marshes more exposed to brackish water, important species include *Triglochin maritima*, *Puccinellia angustata* (= *pumila*), *Scirpus cernuus*, and *Lilaeopsis occidentalis*. Figure 9–4 shows a typical *Carex lyngbyei* marsh.

The coastal marshes of British Columbia show similarities in vegetation species composition to marshes both to the south in Oregon and Washington and to the north in Alaska (Macdonald 1977). The marshes in parts of Washington are mainly estuarine and dominated by *Carex lyngbyei*; they also have other species in common with British Columbia, such as *Distichlis spicata* and *Salicornia virginica* (Disraeli and Fonda 1979; Burg *et al.* 1980; Ewing 1983). Similar vegetation is found in Oregon marshes which also tend to be estuarine (Jefferson 1975; Seliskar and Gallagher 1983). In northern

Figure 9–4.
Carex lyngbyei *estuarine low salt marsh located in the Queen Charlotte Islands, British Columbia.*

California, *Carex lyngbyei* disappears, and *Spartina foliosa* becomes the main colonizing species (Macdonald 1977).

To the north, similarities exist between southern Alaskan marshes and those of coastal British Columbia. Again, *Carex lyngbyei* is the dominant species in marshes located between Juneau and Cook Inlet near Anchorage, Alaska (Crow 1977; Macdonald 1977). At Cook Inlet, species more typical of Canadian subarctic and arctic salt marshes begin to appear (Snow and Vince 1984; Vince and Snow 1984). Also of interest is the fact that, in the Pacific coastal marshes, *Carex lyngbyei* appears to occupy the same ecological position as *Carex paleacea* does in subarctic Canadian marshes; this will be discussed later.

Salt Marshes of the Atlantic Coast

The Atlantic coastline of North America is characterized by salt marshes dominated by the marine angiosperm *Spartina alterniflora*. This low salt marsh colonizing species occurs from the Gulf of Mexico, around Florida, and northwards to Newfoundland. Another species, *Spartina patens*, is a dominant high marsh plant in these marshes and is also found only in such Atlantic salt marshes (Chapman 1974; Reimold 1977). This type of marsh can be considered typical of the temperate to subarctic Atlantic coastline in North America. *Spartina alterniflora* does not occur in any other part of Canada. The only other *Spartina* species found in salt marshes is *Spartina foliosa*, which is found on the Pacific coast in California (Macdonald 1977).

Along the Atlantic coast of North America, the most extensive marshes have developed in the lowlands of the central and southern coasts of the United States, particularly in North and South Carolina and Georgia. In Canada, sizeable marshes have formed only in embayments affected by very high tides, such as the vast Bay of Fundy, some pocket embayments along the Nova Scotia and southern Newfoundland coasts, in areas protected by coastal barriers in the southwestern Gulf of St. Lawrence in New Brunswick and particularly in the flat-lying areas of Prince Edward Island, as well as locally along the coast of Labrador. No extensive marshes have formed along the Atlantic seaboard of Baffin Island, nor in the Arctic Islands. The prime geological–physiographical reasons for this distribution relate to the predominance of rocky steep shores associated with the Appalachians and associated mountains. Marshes develop only in those protected embayments which have served as sediment traps since the Pleistocene epoch. The extensive marshes of the Bay of Fundy and Prince Edward Island have also been favoured by readily available fine sediments derived, respectively, from the easily erodible Triassic and Paleozoic clastic bedrock.

The Bay of Fundy experiences some of the highest tides of the northern hemisphere, locally up to 16 m. In the sheltered head parts of embayments, steep muddy tidal flats develop locally, backed by salt marshes (Yeo and Risk 1981). The high tidal range and subsiding land levels lead to marsh deposits up to several metres in thickness (Scott and Greenberg 1983). The marshes develop sediments ranging in texture from clay to silt, as deposited during regular or extreme tidal cycles, to boulders, usually carried in by ice rafting (Yeo and Risk 1981). The impact of ice on Atlantic salt marshes is discussed in the work of Roberts and Robertson (1986).

Scott and Medioli (1978a, 1978b, 1979) and Scott and Greenberg (1983) have carried out extensive studies of the relative change in sea level in the maritime provinces. They utilized a combination of radiocarbon-14 dating of marsh deposits and the identification of ancient sea levels in cores by observing the variation between species of foraminifera living in salt marshes and those living in freshwater marshes. The maritime areas underwent a relatively rapid lowering of sea level due to a combination of isostatic rebound and increased quantities of water in the oceans as glaciers melted. Since approximately 3 000 years BP, however, there has been a relatively slow but steady sea-level rise varying between 13 and 19 cm per century (Scott and Greenberg 1983). The variations depend on several factors such as local rates of sedimentation, tidal ranges, and differential rates of land subsidence either because of residual post-glacial isostatic adjustments or, in other parts of Canada, because of neotectonic movements. For instance, Scott *et al.* (1981) confirmed the earlier Holocene eastward tilting of Prince Edward Island originally suggested by Kranck (1972).

In this chapter, the Atlantic coast of Canada is considered briefly in the context of three separate areas: (1) the St. Lawrence Estuary of Quebec; (2) Nova Scotia, New Brunswick, and Prince Edward Island; and (3) Newfoundland and Labrador. In Chapter 7 these areas are discussed in more detail with emphasis upon the evolution of Atlantic salt marshes.

Salt Marshes of the St. Lawrence Estuary

Salinity in the salt marshes of the St. Lawrence Estuary varies from 0.2 ppt at the most western extreme (near Montreal) to over 25 ppt downstream (Gauthier 1979; Gauthier *et al.* 1980). This extreme variation in salinity, coupled with the harsh climate and the influence of ice action during the winter months, limits species composition, abundance, and distribution across salt marshes. In the Gaspé region, salt marsh development is limited by the steep, rocky, and abrupt shoreline. Along the open shore, marshes are narrow and restricted to small sheltered embayments and estuaries. Upstream, individual marshes cover larger areas, but are floristically different. *Scirpus americanus* replaces *Spartina alterniflora* at lower marsh levels, while *Zizania aquatica* and *Sagittaria* spp. are found at higher elevations. Under the circumstances, it is difficult to establish or identify a "typical" marsh profile for this area.

Reed and Moisan (1971) described five zonal marsh communities typical of the shoreline between St. Roche des Aulnaies and Trois-Pistoles, Quebec. At the lowest marsh level, *Spartina alterniflora* dominates the marsh, and is often found with *Zostera marina* and *Salicornia europaea*. This zone is regularly flooded (except by weak tides) and creek levees are often associated with more luxuriant growth of *Spartina alterniflora*. The second zone is dominated by *Spartina patens* and characterized by frequent, deep, water-filled pools with *Ruppia* spp. Overlapping and admixing with this zone is one dominated by a diverse mixture of forbs, including *Limonium carolinianum* (= *nashii*), *Spergularia* spp., *Triglochin* spp., *Glaux maritima*, *Plantago* spp., *Ranunculus cymbalaria*, and *Suaeda maritima* towards the seaward edge. Landwards, *Atriplex* spp., *Potentilla anserina*, and *Hordeum jubatum* are common. Further upslope, *Carex paleacea*, *Juncus gerardii*, *Juncus balticus*, and *Scirpus maritimus* are flooded only by higher tides. Although there are some ponds within this marsh zone, they are less frequent than at lower elevations. Where freshwater seepage is common, *Typha angustifolia* and *Sparganium eurycarpum* may be found. Highly saline conditions may exist where ponded tidal waters have undergone considerable evaporation. *Salicornia europaea* and stunted *Spartina alterniflora* may grow at the edges of these former ponds. The centre of these denuded patches is characterized by bare mud and algal mats. The highest marsh level or border is characterized by shrubs and grasses, including *Myrica gale*, *Spartina pectinata*, *Carex* spp., *Calamagrostis* spp., and *Juncus balticus*. Figure 9–5 shows a typical marsh in the lower St. Lawrence River.

Figure 9–5.
Spartina alterniflora *low salt marsh located near Rivière-du-Loup, Quebec, lower St. Lawrence River Estuary.*

Gauthier (1982) defined three zonal marsh communities within the lower marsh ("slikke") on Isle-Verte, Quebec. At the lowest levels, dense *Zostera marina* covers the substrate. At slightly higher elevations, *Spartina alterniflora* constitutes the "typical" marsh community and, at higher elevations, a subgroup of *Spartina alterniflora* has been identified. This area is characterized by *Salicornia europaea*, with minor occurrences of *Spergularia canadensis*, *Spergularia marina*, and *Atriplex* spp. All three communities identified occurred below the mean high-water mark.

Gauthier *et al.* (1980) described the coastal vegetation for a series of marshes from Montreal to Cap-Chat, Quebec. Typical marsh species on the lowest marsh include *Spartina alterniflora* with *Carex paleacea*, *Scirpus maritimus*, *Triglochin maritima*, *Ranunculus cymbalaria*, and *Eleocharis* spp. *Spartina patens* is at the second level of the marsh, with *Juncus gerardii* at the subsequent level. *Limonium carolinianum* (= *nashii*) and *Glaux maritima* are frequently found at the eastern end of the St. Lawrence Estuary.

Marsh communities on the south shore of Anticosti Island, Quebec, include *Spartina alterniflora* in saline "pan" depressions near the coast. Above these pans, *Juncus balticus* and *Festuca rubra* form a fringe community. Associated species include *Triglochin maritima*, *Potentilla anserina*, *Potentilla palustris*, *Spartina pectinata*, *Myrica gale*, *Iris versicolor*, *Carex lasiocarpa*, and *Hierochloë odorata*. Salt marshes on the Magdalen Islands, Quebec, in the Gulf of St. Lawrence are dominated by *Spartina alterniflora* and are quite similar in species composition to salt marshes in the maritime provinces (Grandtner 1966; Thannheiser 1981).

Salt Marshes of Nova Scotia, New Brunswick, and Prince Edward Island

A classic study of Atlantic salt marshes in the Bay of Fundy, Nova Scotia, was carried out by Ganong (1903). He described a halophytic division of low salt marshes, which are subjected to tidal inundations and have tidal creeks. The low marsh is dominated by *Spartina alterniflora*, which he called *Spartina stricta*. In the high marsh, major species include *Spartina patens*, *Limonium carolinianum*, *Salicornia europaea*, *Atriplex patula*, *Hordeum jubatum*, *Glaux maritima*, *Triglochin maritima*, *Suaeda maritima* (= *linearis*), *Plantago maritima*, and *Puccinellia maritima* (probably *Puccinellia americana*, according to Scoggan (1978)). These high marsh species represent a mixture of temperate salt marsh species and those more typical of the boreal to subarctic wetland regions. Ganong also described a mesophytic division which consisted of salt marshes influenced by land use activities such as grazing and cultivation. His hydrophytic division consisted of freshwater marshes and bogs located landward of the salt marshes.

An early study of salt marshes located on Cape Breton Island, Nova Scotia, was carried out by Nicolas (1918). The vegetation species composition which he described was quite similar to that of the Bay of Fundy, but he identified two different species—*Scirpus maritimus* and *Stellaria humifusa*. The former is found in boreal and Pacific coast salt marshes while the latter is found in boreal and arctic coastal marshes. Thus, the salt marshes of Cape Breton Island appear to represent a transition to more northerly salt marshes. Further studies of salt marshes in Nova Scotia were made by Chapman (1937). He described the landward area of a high salt marsh as being characterized by *Juncus gerardii* and *Juncus balticus*, the latter also being typical of boreal salt marshes. He also described the successional patterns found in such marshes, especially in relation to human harvesting of marsh grasses. Chapman (1974) further summarized the vegetation of such salt marshes and compared it with that of typical New England salt marshes (Nixon 1982).

A more recent discussion of the salt marshes of Nova Scotia has been provided by Patriquin (1981). He described the following three major areas of salt marsh. (1) Fundy marshes are limited to the upper third of the intertidal zone and are typically characterized by *Spartina alterniflora* in the low marsh and *Spartina patens* in the high marsh. These have been extensively reclaimed and contribute little to marine food chains because of their relatively high elevation. (2) Atlantic marshes are mainly low marshes and are of importance to marine food chains. A typical Atlantic low marsh is shown in Figure 9–6 and a high marsh in Figure 9–7. (3) Northumberland salt marshes are of major importance to marine food chains. They are quite similar to the marshes of the eastern coastline of the United States and are extremely productive for fish and carnivorous birds. Several studies have been made of primary productivity and nutrient cycling in Nova Scotian marshes (Hatcher and Mann 1975; Morantz 1976).

Along the coasts of both Prince Edward Island and New Brunswick in the southern Gulf of St. Lawrence, salt marshes are present. In terms of their geomorphology, they are found in the lee of

Figure 9–6.
Spartina alterniflora *low salt marsh, Negro Harbour, Nova Scotia.*

Figure 9–7.
Spartina patens-*dominated high salt marsh on creek near Yarmouth, Nova Scotia.*

barrier islands. Substrates are usually sandy (Lucas 1980; Thannheiser 1981). These marshes have a low marsh area typically dominated by *Spartina alterniflora*, with highest production along tidal creeks. In highly saline substrates such as pans, typical species are *Salicornia europaea*, *Atriplex patula*, and *Suaeda* spp. *Triglochin maritima* and *Plantago maritima* may also occur on somewhat higher areas of the low marsh and extend into the high marsh. The high marsh is typically dominated by *Spartina patens*, which is found above the level of daily tidal flooding. Other species that may occur here include *Potentilla anserina* (probably *Potentilla egedii*), *Eleocharis* spp., *Glaux maritima*, *Carex paleacea*, *Scirpus maritimus* (in pans filled with water), and *Scirpus americanus*. At slightly higher elevations, this association gives way to a meadow-like community, with the main species being *Juncus gerardii*, *Agrostis stolonifera* (=*alba*), *Festuca rubra*, *Poa palustris*, *Puccinellia americana* (*Puccinellia maritima*), *Limonium carolinianum*, and *Solidago sempervirens*. *Juncus balticus* may also be present at the edge of meadows with assorted species of forbs. In wetter areas, freshwater marsh species include *Spartina pectinata*, *Typha latifolia*, and *Scirpus lacustris* var. *validus*.

Salt Marshes of Newfoundland and Labrador

Studies of the vegetation of the salt marshes, dunes, and beaches of insular Newfoundland and the tip of southern Labrador have been conducted by Thannheiser (1981). The Island of Newfoundland has several marshes characterized by *Spartina alterniflora* on the western and northeastern coasts. Occasionally, *Salicornia europaea* is found to colonize tidal flats seaward of *Spartina alterniflora*. Thannheiser reported that *Triglochin maritima* (=*gaspense*), *Scirpus americanus*, and *Juncus balticus* occur in the high marsh. In salt marshes on other parts of the Island, *Spartina alterniflora* was absent. He also described a characteristic Newfoundland salt marsh as having the following vegetation zonation in terms of dominants from the sea landwards: (1) *Eleocharis parvula*; (2) *Puccinellia ambigua* (=*paupercula*); (3) *Triglochin maritima* (*Triglochin gaspense*); (4) *Plantago maritima–Carex subspathacea*; (5) *Ruppia maritima* (in shallow ponds); (6) a *Plantago maritima* association with other species including several species of forbs; (7) *Ranunculus cymbalaria*; (8) *Eleocharis halophila*; (9) *Scirpus rufus*; (10) *Carex mackenziei*; and (11) *Carex paleacea*. This represents a unique marsh and it would appear to occur in more brackish waters. Many of these species are also found in boreal salt marshes such as those along the coast of James Bay. In Labrador, salt marshes are limited in the number and width of vegetation zones. Thannheiser described a marsh at

Pinware Bay in Labrador with *Eleocharis parvula* as the colonizing species and with bands of *Triglochin maritima* and *Carex paleacea* landwards. Another marsh at Red Bay, Labrador, was colonized by *Puccinellia ambigua* with *Carex paleacea* landward of it. Both of these marshes occur at the southern tip of Labrador.

Roberts and Robertson (1986) discussed the salt marshes of Kaipokok Bay and Groswater Bay in Labrador. Kaipokok Bay is located on the central Labrador coast, northeast of Makkovik. The marshes there are described as brackish and are characterized by such salt-tolerant species as *Triglochin maritima*, *Carex paleacea*, *Glaux maritima*, and *Potentilla egedii*. These plants are also typical of the Hudson Bay Lowland, within both the boreal and subarctic wetland regions. The salt marshes of Groswater Bay have three main vegetation zones: intertidal mudflats, pan communities, and sward communities. Again, the vegetation consists of salt marsh species similar to those found in the Hudson Bay Lowland. Roberts and Robertson reported the presence of *Spartina alterniflora*; this is the most northern occurrence of that species reported in the literature. Major factors influencing these salt marshes are the extent of sedimentation, salinity distribution, extent of wracks, and waterfowl grazing.

Salt Marshes of Northern Canada

The majority of Canada's northernmost salt marshes occur in coastal areas of Yukon and the Northwest Territories, along the Hudson Bay and James Bay coastlines of Ontario and Manitoba, and along the northern edges of Quebec and Labrador. The largest and most diverse marshes occur along the western coasts of Hudson Bay and James Bay. That area, known as the Hudson Bay Lowland, extends some 1 700 km from the southern end of James Bay to Churchill, Manitoba, and constitutes the longest stretch of low-gradient emergent shoreline in the world. Salt marshes cover 85–90% of the coast of the Lowland.

The arctic environment ". . . is extreme, especially in winter, and the marshes appear to be somewhat fragmentary" (Chapman 1977). In this harsh environment, only restricted floristic associations can develop (Walter 1977). Furthermore, the coasts of the arctic seas are heavily reworked by ice action. "Well-developed salt marsh communities are absent—rather there is a mosaic of plant species, the extent and age of which is determined by the frequency of disruptive ice action" (Macdonald 1977). Open coastal marshes, often only a few metres in extent, occur frequently along flat, rocky shores. Somewhat more extensive, but still restricted, are the marshes that develop in deltaic areas, most notably the Mackenzie River Delta, and in areas where conditions are more sheltered and the action of pack ice is reduced.

Finally, the development of marshes in most arctic areas is hampered by the lack of abundant silt and clay trapped along the coast. This is the result of two main factors. First, much of the fine detritus transported by the northward-flowing rivers is dispersed offshore either by fluvial plumes during the brief summer season when the sea is not covered by ice, or by ice rafting during the spring break-up. During the remainder of the year, even if river flow exists, little sediment is carried to the sea, and if it is, it is dispersed under the pack ice. In any case, only a small portion of the fine sediment can be resuspended and made available for dispersal by the generally low tides of the northern seas. The second factor relates to the predominance of physical weathering mostly associated with frost processes. Although sedimentary rocks, as well as igneous and metamorphic rocks, are present in these northern areas, boulders, pebbles, and sand grains rather than abundant silt and clay are produced by the prevalent physical weathering.

Extensive marshes occur along the southwestern coasts of James Bay, Hudson Bay, and Foxe Basin, an area of large cratonic basins which have persisted since Precambrian times. Paleozoic carbonate rocks, calcareous shales, and sandstones lie almost flat or gently dipping towards these basins. They cover most of the basin floor and form the southwestern shores of James Bay and Hudson Bay, the southern shores of Southampton Island and neighbouring islands to the north, such as Prince Charles Island, the Spicer Islands, and Air Force Island, and the eastern shores of Foxe Basin (Heywood and Sanford 1976). Most of the other coasts in this area are underlain by more rugged Precambrian terrain, generally scraped clean by Pleistocene glaciers which formed and flowed from them.

The largest marshes have developed on the flat-lying coasts underlain by Paleozoic sedimentary rocks. A considerable amount of silt is present, primarily generated by the comminution of bedrock material by glaciers and redistributed by semi-diurnal tides ranging in amplitude from 1 to 3 m. Wide marshes develop in embayments, where they are fronted by extensive tidal mudflats, or behind the protection of beach ridges (Martini 1981a, 1982). Some marshes, more restricted in extent, develop along the Precambrian coasts, primarily in estuarine embayments and in areas where major deltas occur (Dionne 1980). The marshes of Hudson Bay and James Bay are affected by and retain erosional scars and rafted sediments associated with sea ice (Martini 1981b). However, the fact that much of the sea is ice-free for up to six months of the year and no permafrost develops alongshore in the southern areas allows for the regular and vast development of coastal marshes. The coastal plains of Foxe Basin and their southeastern shores are covered by wide extensions of mudflats and marshes, heavily utilized by migratory avifauna. Several national migratory bird sanctuaries, including Dewey Soper, Harry Gibbons, East Bay, and McConnell River, are located in this area.

Arctic Salt Marshes

The arctic coastline of Canada is extensive, yet salt marshes cover less than 5% of the total coastal area. Ice scour and erosion, low tidal amplitudes, and adverse climate and soil conditions limit salt marsh development to protected inlets and river estuaries. Even in such sheltered areas, vegetation is sparse, species diversity is low, and there is little evidence of the floristic community zonation typical of more southerly areas. Vegetation generally consists of low-growing perennial grass species capable of reproducing by vegetative means.

Studies of Canadian arctic salt marshes are limited to floristic inventories of selected areas. Polunin (1948) described the salt marshes of the eastern Arctic and the islands of the Arctic Archipelago. Porsild (1955) and Jefferies (1977) have described the flora of the western Canadian Arctic.

The islands of the Arctic Archipelago, which fall mainly within the Mid-Arctic Wetland Region, contain the most northerly salt marshes in Canada. The most northerly salt marshes described to date are found on Ellesmere Island. Polunin (1948) found sparse areas of salt marsh vegetation at stream mouths and on muddy tidal flats. *Puccinellia phryganodes* and *Stellaria humifusa* are present in the wettest areas, while *Cochlearia officinalis* and *Carex maritima* occur on slightly elevated mounds. Polunin (1948) found up to 13 plant species in sheltered coastal areas of Devon, Cornwall, and Somerset islands. Algal mats, present in the most seaward shore areas, were gradually colonized by *Puccinellia phryganodes*. Jefferies (1977) found *Puccinellia phryganodes* growth to be significantly increased in the presence of decaying algae, suggesting that nutrient deficiencies limit growth. Other species found in sandy or muddy areas of the lower marsh include *Stellaria humifusa*, *Carex salina*, and *Carex ursina*. *Mertensia maritima* occurs in dry areas above the high-water mark. On Bylot Island, *Puccinellia langeana* forms continuous "lawns" along the shores of lagoons, which are closely grazed by Canada Geese (*Branta canadensis*) (S.C. Zoltai, personal communication). Jefferies (1977) described a 50 m coastal transect along the Truelove Lowland on northern Devon Island. Here, the presence of species such as *Dupontia fisheri*, *Carex aquatilis*, and the moss *Drepanocladus uncinatus* reflects the influence of freshwater drainage from inland areas on the upper reaches of the marsh. Porsild (1955) described a well-developed salt marsh complex at Minto Inlet, Victoria Island, where vegetation has developed along a series of ridges and swales running parallel to the shore. In the swales, *Puccinellia phryganodes* is the dominant species. Also present are *Equisetum variegatum*, *Eriophorum scheuchzeri*, *Juncus biglumis*, *Melandrium apetalum*, *Cochlearia officinalis*, and *Epilobium palustre* (= *arcticum*). Several of these species are more commonly found in freshwater environments, and their presence here reflects the low salinity (about 10 ppt) of the arctic waters which results from the melting of sea ice during the summer months.

The area around the outer Mackenzie River Delta contains the most diverse vegetation along the Canadian arctic coast (Porsild 1955). The reasons for this are twofold: first, large areas of Yukon escaped glaciation, and thus alpine species from the cordilleran areas of British Columbia were able to migrate northwards, and, second, freshwater input from the Mackenzie River produces a freshwater to saltwater gradient in the coastal waters. Jefferies (1977) found such species as *Hippuris tetraphylla*, *Dupontia fisheri*, and *Arctophila fulva* growing in sea water at Tuktoyaktuk, Northwest Territories, a site within the influence of the Mackenzie River Delta. At this location, *Carex ramenskii* forms lush swards from the lower marsh to the upper marsh.

Subarctic Salt Marshes of Hudson Bay and Northwestern James Bay

Salt marsh vegetation similar to that of the arctic wetland regions occurs in both the Low Subarctic and High Subarctic Wetland Regions. The primary locality of salt marshes in the Low Subarctic Wetland Region extends from the mouth of the Attawapiskat River on the James Bay coast northwards to Cape Henrietta Maria in Ontario. The salt marshes of the High Subarctic Wetland Region extend further northwards along the Hudson Bay coast of Ontario approximately to the Manitoba–Northwest Territories border. Some coastal areas of the Island of Newfoundland are included in the Oceanic Atlantic Subarctic Wetland Subregion (SAo) and some areas of Labrador are in the Coastal Atlantic Subarctic Wetland Subregion (SAc) which are described in Chapter 7. The vegetation composition of salt marshes in these latter two areas is similar to that of Atlantic salt marshes, as discussed in a previous section of this chapter.

The coastal lowlands of Hudson and James bays have been extensively studied. Multidisciplinary studies combining elements of soil science, sedimentology, geomorphology, vegetation composition and productivity, and shorebird habitat use have provided an overall picture of coastal ecology in these areas (Glooschenko and Martini 1978; Martini and Protz 1978; Martini *et al.* 1979; Glooschenko 1980; Martini *et al.* 1980a; Martini *et al.* 1980b). Based on these studies, four coastal ecosystems along the boreal and subarctic coasts of Hudson and James bays have been identified (Glooschenko 1980): (1) salt marsh; (2) brackish marsh; (3) estuarine marsh; and (4) high-energy coastlines with limited marsh development.

The first studies of salt marsh vegetation in this area included a brief, descriptive study of the mouth of the Churchill River in Manitoba by Ritchie (1957) and a more detailed study of salt marsh vegetation by Schofield (1959). The dominant species of these salt marshes were *Carex subspathacea* and *Puccinellia phryganodes*. A much more detailed study was conducted at La Pérouse Bay near Churchill, Manitoba, by Jefferies *et al.* (1979). The main colonizing species on tidal flats exposed to waters of higher salinity is *Puccinellia phryganodes*. This species occurs with *Carex subspathacea*, *Potentilla egedii*, and *Cochlearia officinalis* var. *groenlandica*. In the high marsh, several species of forbs are present, including *Stellaria humifusa*, *Chrysanthemum arcticum*, *Senecio congestus*, *Plantago maritima*, and *Ranunculus cymbalaria*. Where waters are of low salinity, such as at the mouth of the Mast River, *Hippuris tetraphylla* is the dominant species. These coastal marshes are replaced inland by fens. The area is quite important as a summer feeding ground for Snow Geese (*Anser caerulescens*) (Jefferies *et al.* 1979).

A detailed study of coastal marshes occurring on East Pen Island at the Ontario–Manitoba border was conducted by Kershaw (1976). Vegetation is similar to that previously described as occurring in the Churchill area. Kershaw described a mid-marsh area dominated by *Dupontia fisheri* and *Calamagrostis neglecta*. This gives way to a wide fen dominated by *Carex aquatilis*.

Glooschenko and Martini (1981) studied salt marsh vegetation succession at four sites on the Ontario coast of Hudson Bay (Figure 9–8). The colonizing species is *Puccinellia phryganodes*, except near areas of high river discharge where *Hippuris tetraphylla* is dominant (Figure 9–9). The low coastal marsh gives way to a high coastal marsh with *Carex subspathacea*, *Potentilla egedii*, and various forb species of limited cover. Unvegetated pans of high substrate salinity may be present. Landward of the high marsh is a saline upland with *Festuca rubra*, several species of *Salix*, and several species of forbs. This area receives saline waters only during the highest spring tides or storm surges; it is not wet enough to be considered a marsh. This association gives way to fens with such species as *Calamagrostis neglecta*, *Carex aquatilis*, *Carex glareosa*, and several species of *Salix*.

Glooschenko (1983) described salt marsh vegetation on 22 transects located on the Ontario shores of

Figure 9–8.
Beach ridge–salt marsh complex looking landward, Hudson Bay coast of Ontario.

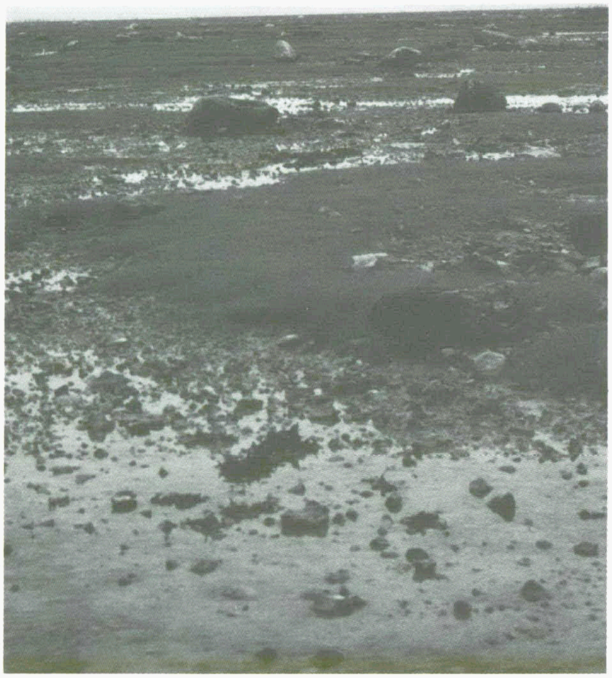


Figure 9–9.
Colonization of sediments by Puccinellia phryganodes, *located north of mouth of Winisk River, Hudson Bay, Ontario.*

Figure 9–10.
Salt marsh zonation seaward of beach ridge, north of Ekwan Point, James Bay, Ontario.

Hudson and James bays in the High and Low Subarctic Wetland Regions. Again, all have *Puccinellia phryganodes*–low marshes and *Carex subspathacea*–high marshes with *Hippuris tetraphylla* located at river mouths (Figure 9–10).

The salt marshes of subarctic and arctic Canada are similar to those found in northern Alaska. Taylor (1981) studied the marsh vegetation of the Chukchi Sea and Beaufort Sea coasts of arctic Alaska and found *Puccinellia phryganodes* and *Carex subspathacea* dominating the low marsh and *Carex ramenskii* and *Dupontia fisheri* dominating the high marsh. The salt marshes of Disko Bay in Greenland are also similar to those in subarctic and arctic Canada (Vestergaard 1978). In addition, there are similarities to northern European salt marshes (Chapman 1974; Beeftink 1977).

Boreal Salt Marshes of James Bay

Salt marshes develop in the protected coastal areas of James Bay that are not directly influenced by freshwater input from river mouths. Characteristic vegetation formations occur in the low and high marsh, and even small elevational changes (8 cm) can cause transition from one vegetation formation to another. Salt marshes are most highly developed in southern James Bay where a number of distinct vegetational communities, dominated by one or two species, occur in broad bands running parallel to the coast. The upper and lower limits of a salt marsh are a function of maximum tidal range, but the location of vegetational communities within a marsh is the result of complex interactions between the tide-related physicochemical properties of the sediments, marsh topography, and local drainage patterns.

The vegetational composition of the boreal salt marshes of the Hudson Bay Lowland is similar to that of the arctic and subarctic areas of Canada, Alaska, Greenland, and northern Europe (Chapman 1974), and is characterized by low-growing perennials, most of which undergo vegetative reproduction. Species richness generally increases landwards. A number of detailed floristic studies of the coastal marshes of James Bay have been conducted (Glooschenko and Martini 1978; Riley and McKay 1980; Martini *et al.* 1980b). *Puccinellia phryganodes* dominates the lower marsh (Figure 9–11). *Puccinellia* spp. grow best in sandy waterlogged sediments, and reproduce by stolons which are broken off by tidal action and may become re-established in intertidal areas which have been colonized by algal mats. Nearshore sediments are reworked extensively by ice and, as a result, the lower marsh takes on a pitted-pool appearance. Glacial scour features,

Figure 9–11.
Low salt marsh with Puccinellia phryganodes *and* Carex subspathacea *seaward of beach ridge, Longridge Point, James Bay, Ontario.*

such as longitudinal furrows and irregularly shaped ice-pan depressions, occur in all marsh zones, and many remain water-filled throughout the spring and summer (Dionne 1972, 1976, 1978; Martini and Protz 1978; Martini *et al.* 1980b). *Ruppia maritima, Zannichellia palustris,* and scattered *Scirpus maritimus* occur in pools in the lower marsh (Glooschenko and Martini 1978), while *Puccinellia lucida* often grows at the edges of such ponds.

In some marshes, particularly in northwestern James Bay, the low marsh *Puccinellia phryganodes* zone gives way directly to a high marsh *Carex subspathacea* community. However, in more southern salt marshes, *Puccinellia* sp. is succeeded by a *Plantago maritima–Puccinellia lucida* association at approximately 0.5 m above the mean high-water marsh limit. A saline community characterized by species such as *Triglochin maritima, Potentilla egedii, Festuca rubra,* and *Hordeum jubatum* may be dominant in the middle reaches of the marsh, where tidal inundation is restricted to storm periods. Subsequent evaporation may produce elevated soil salinities and salt pans. The obligate halophyte *Salicornia europaea* is a common pan colonizer (Kershaw 1976; Glooschenko and Martini 1978). Figure 9–12 depicts such a marsh.

This transition zone, which is presumably formed by freshwater runoff, is unique to North American subarctic and arctic salt marshes. Inland drainage systems may be poorly to well developed. *Carex*

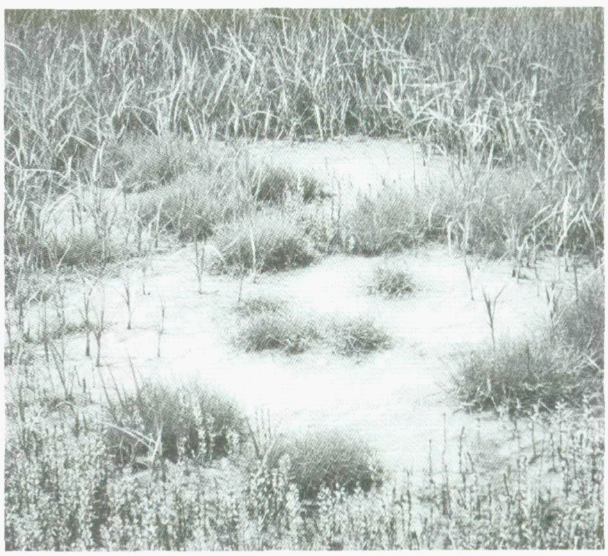


Figure 9–12.
Close-up of low salt marsh vegetation surrounding pan with Hippuris tetraphylla *in foreground, near Hannah Bay, southwestern James Bay, Ontario. Low* Puccinellia phryganodes *tufts in pan. Tall plant in background is* Scirpus maritimus.

paleacea is usually the dominant marsh species; it colonizes bare non-saline sediments and can withstand occasional tidal flooding. Fen indicator species such as *Menyanthes trifoliata* are often present in this zone. Where pools are present, *Scirpus maritimus* rapidly becomes established in the soft bottom sediments. In some areas, *Hippuris vulgaris* and *Zannichellia palustris* are codominant. There is evidence that intensive feeding and trampling by Canada Geese and Lesser Snow Geese can modify pond size and drainage patterns in the upper marsh (Martini and Protz 1978; Jefferies *et al.* 1979).

The freshwater fen–marsh zone, which delimits the landward extent of the salt marsh, often grades into old beach ridge communities dominated by a *Juncus balticus–Salix* spp. association. Freshwater marshes and fens occur landward of these ridges.

A study of the coastal geology, geomorphology, and vegetation of Akimiski Island, James Bay, Northwest Territories, was made by Martini and Glooschenko (1983/1984). Marshes on the Island were similar to those on the mainland, with a *Puccinellia phryganodes* low marsh and a high marsh with *Carex subspathacea* and *Festuca rubra*. Various forbs were also present. Ponds had several salt-tolerant species such as *Senecio congestus*, *Hippuris tetraphylla*, and *Potamogeton filiformis*. The low marsh was actively grazed by Canada Geese. Riley (1981) has described the vegetation on the Island.

Brackish marshes are found down current from major river mouths. Since nearshore currents in James Bay are predominantly counterclockwise, brackish marshes occur south of major rivers, such as the Attawapiskat and the Harricanaw, and in Hannah Bay at the south end of James Bay (Glooschenko 1980; Glooschenko and Martini 1986). The vegetation of the seaward end of such marshes reflects the freshwater influence. Major species include *Eleocharis palustris*, *Carex paleacea*, *Hippuris tetraphylla*, and *Scirpus maritimus*. Typical salt marsh species may occur inland as a result of storm surges which transport brackish water to the upper reaches of the marsh. Such water can evaporate there, possibly leading to elevated salinities. However, Ewing and Kershaw (1986) felt that other hydrological factors may explain this phenomenon.

Estuarine marshes occur within, or immediately adjacent to, river mouths. Vegetation is more typical of inland freshwater marshes. Typical dominant species include *Eleocharis palustris*, *Scirpus lacustris* var. *validus*, *Scirpus americanus*, and several species of *Carex*, *Juncus*, and *Potamogeton*. An example of an estuarine marsh at the mouth of the Attawapiskat River was studied by Glooschenko and Martini (1983). Here, the wetlands of the lower 12 km of the river were studied, and marshes ranging from saline/brackish to freshwater riverine were found. The river mouth vegetation is dominated by submergent *Potamogeton richardsonii* and emergent *Sagittaria latifolia*, both typical freshwater riverine species. At the river bank, two brackish species, *Carex paleacea* and *Hippuris tetraphylla*, are abundant. Somewhat farther from the river, salt marsh species including *Puccinellia phryganodes*, *Puccinellia lucida*, *Triglochin maritima*, and *Scirpus maritimus* occur. Farther upstream from the river mouth, marshes are dominated by *Eleocharis* spp., *Hippuris tetraphylla*, *Carex paleacea*, and *Carex aquatilis*. Ringius (1980) described the marshes at the mouth of the Kapiskau River, located to the south of the Attawapiskat River. He found colonization by *Hippuris tetraphylla*, indicative of brackish conditions. Ewing and Kershaw (1986) have also discussed the estuarine wetlands of the Harricanaw River in southern James Bay.

Several other small areas of brackish and estuarine marsh occur on the Quebec coastline of James Bay. The Canadian Shield on this eastern coast of James Bay tends to lack development of wide tidal flats compared with the western coast of the Bay. Marshes are located on river mouths and bays such as Rupert Bay (Lamoureux and de Repentigny 1972; Lamoureux and Zarnovican 1972; Laverdière and Guimont 1975) and the Baie aux Oies (Lamoureux and Zarnovican 1974). Because of large river inputs of fresh water, such marshes are not salt marshes. Estuarine marshes occur where river influence is limited, and the main species include *Carex paleacea*, *Scirpus maritimus*, and *Hippuris tetraphylla*. The freshwater marshes are dominated by *Eleocharis* sp., *Scirpus lacustris* var. *validus*, *Scirpus americanus*, *Calamagrostis neglecta*, *Potamogeton* sp., *Deschampsia caespitosa*, *Carex glareosa*, and others. Species tolerant of higher salinities, such as *Salicornia europaea*, *Puccinellia lucida*, *Atriplex patula*, and *Suaeda maritima*, are limited to areas where evaporation of trapped saline water may occur, such as in the Cabbage Willow Bay area. The authors are not aware of data for the Hudson Bay, Hudson Strait, or Ungava Bay coasts of Quebec.

The Ecological Significance of Salt Marshes

Salt marshes are considered to be extremely important ecosystems and much public concern has arisen over threats to their existence from drainage for agricultural purposes, urban and industrial pressures, and energy developments. These factors are discussed in the next section. Among the many ecological values attributed to salt marshes are the following: nutrient and organic export to adjacent coastal waters, use as spawning grounds for fish and invertebrates of commercial importance, nesting and staging areas for waterfowl and shorebirds, areas of waste and toxic substance assimilation, and sites of aesthetic importance. In this section, the importance of salt marshes for coastal fisheries and bird utilization is considered.

The Importance of Salt Marshes for Coastal Fisheries

Much of the research on *Spartina alterniflora* salt marshes has emphasized their contribution to marine coastal fisheries (Odum 1980; Pomeroy and Wiegert 1981; Mann 1982). Salt marshes are characterized by high primary productivity. The organic matter produced is exported to estuaries and adjacent offshore waters, a process described by Odum (1980) as "outwelling". Little direct grazing on living salt marsh vegetation takes place. The dead plant remains are converted to detritus, which becomes associated with a living complex of bacteria, algae, protozoans, and fungi. This in turn is eaten by detritus consumers such as invertebrates and small fish which are then eaten by carnivorous fish, birds, and mammals.

Even though much of the detritus research has been concerned with the marshes of the southeastern United States, there is evidence for such a mechanism operating in Canada. Kistritz (1978) and Kistritz and Yesaki (1979) demonstrated the importance of detritus production in the Fraser River marshes of the Pacific coast. Naiman and Sibert (1979) felt that detritus derived in part from *Carex lyngbyei* is important as a food source for juvenile salmon in the Nanaimo Estuary. Simenstad (1983) and Seliskar and Gallagher (1983) also showed the importance of coastal wetlands to fish in the adjacent Pacific northwestern states of the United States.

Coastal wetlands have also been shown to be important to fisheries on the Atlantic coast of Canada. High primary productivity and subsequent export of organic matter and nutrients in Nova Scotian salt marshes were demonstrated by Hatcher and Mann (1975), Hatcher (1977), and Morantz (1976). Such marshes were also shown to be important for approximately 20 species of fish, including eel, flounder, and striped bass, and also for molluscs (Hatcher *et al.* 1981). Tidal pools and creeks located in marshes of the lower St. Lawrence River are also utilized by fish (Dutil and Fortin 1983; Ward and Fitzgerald 1983a, 1983b).

A major ecological question is the exact nature of the relationship between coastal and estuarine marshes and fisheries. Dorcey *et al.* (1978) have reviewed the role of the Fraser River marshes with regard to salmon. They noted that all marshes in estuaries are utilized by young salmon and that these marshes provide or regulate nutrients, are utilized by all salmon species, and provide areas to salmon for temporary residence, sea-water adaptation, rich feeding, refuge from predators, and staging. They pointed out that there is evidence for all these roles, but stated that many questions still exist and more research needs to be done in this critical area of fisheries research in British Columbia.

A very important paper on the relationship between salt marshes and coastal fisheries was written by Nixon (1980). He critically reviewed previously published papers on this theme and concluded that wetlands *per se* may not be the cause of increased fisheries productivity offshore of such ecosystems. He stated that wetlands may serve as protection for fish, but that other factors may be more important in explaining enhanced productivity in estuarine and coastal waters. He cautioned, however, that the question of organic matter and nutrient cycling in salt marshes is complex and more research is needed in this area in Canadian coastal and estuarine wetlands.

Bird Utilization of Canadian Salt Marshes

Atlantic coast salt marshes dominated by *Spartina alterniflora* are important to aquatic birds. Reed and Moisan (1971) studied the lower St. Lawrence salt marshes and found them to be an important breeding ground for Black Duck (*Anas rubripes*) in the spring and summer. Other ducks that use such marshes include the Northern Pintail (*Anas acuta*), Green-winged Teal (*Anas crecca*), Mallard (*Anas platyrhynchos*), and Common Eider (*Somateria mollissima*). Other common aquatic birds include the Great Blue Heron (*Ardea herodias*), Black-crowned

Night Heron (*Nycticorax nycticorax*), Common Snipe (*Gallinago gallinago*), Killdeer (*Charadrius vociferus*), and Spotted Sandpiper (*Actitis macularia*). The Canada Goose (*Branta canadensis*) is an important spring migrant. Shorebirds and non-aquatic birds also utilize these marshes. Nova Scotian salt marshes are also important for waterfowl. McAloney (1981) showed that, during spring migration, the same waterfowl species found in the St. Lawrence marshes used salt marshes in Nova Scotia. The marshes served as important staging areas from August through November for the fall migration. Labrador salt marshes are also heavily used by some 75 species of migratory birds, mainly ducks (Roberts and Robertson 1986).

Pacific coast marshes are also critically important for birds. Important species include ducks, geese, shorebirds, and other aquatic and non-aquatic birds (Burgess 1970). The Fraser Delta, in particular, is of major significance to Canadian waterfowl as over 50% of the ducks that overwinter in Canada do so here. Pacific coast marsh habitats in estuaries are also internationally recognized as important for migratory birds (R. McKelvey, personal communication).

The coastal marshes of Hudson and James bays provide breeding grounds and staging areas for a number of migratory waterfowl and shorebirds. The most common waterfowl species include the Canada Goose, Snow Goose (*Anser caerulescens*), Brant (*Branta bernicla*), Pintail, Black Duck, Green-winged Teal, and Mallard (Martini *et al.* 1980b; Ross 1982). Waterfowl prefer wide coastal marsh areas containing diverse vegetation. Important foods include grasses and sedges, rushes, and horsetail (*Equisetum* spp.) (Prevett *et al.* 1979; Thomas and Prevett 1982).

The coastal area of the Hudson Bay Lowland is an internationally recognized staging area for several species of shorebirds breeding in the Arctic and Subarctic. These include the Semipalmated Sandpiper (*Calidris pusilla*), Greater Yellowlegs (*Tringa melanoleuca*) and Lesser Yellowlegs (*Tringa flavipes*), Hudsonian Godwit (*Limosa haemastica*), and a number of other species. Shorebird feeding habitat appears to change seasonally in response to food supply. For example, at North Point on the southwestern coast of James Bay, north of the mouth of the Moose River in Ontario, the distribution of Semipalmated Sandpiper shows a net seaward movement over the summer months. During the northward migration in June, the majority of birds are observed in the salt marsh, but by late August, they are distributed evenly between the tidal flats and the salt marsh, feeding in the former during low tide and in the latter during high tide (Clarke 1980).

The *Carex–Scirpus* upper marsh is used for feeding and roosting during the spring migration by a number of species including the Black-bellied Plover (*Pluvialis squatarola*), Red Knot (*Calidris canutus*), Ruddy Turnstone (*Arenaria interpres*), Pectoral Sandpiper (*Calidris melanotos*), Semipalmated Plover (*Charadrius semipalmatus*), and Lesser Yellowlegs, but it is seldom visited during the fall migration by these species. However, large flocks (500–1 000) of Whimbrel (*Numenius phaeopus*), White-rumped Sandpiper (*Calidris fuscicollis*), and Pectoral Sandpiper roost in the tall grasses of the *Triglochin–Potentilla* upland when feeding grounds in the lower tidal flats are covered.

Within the salt marsh, the shallow ponds are a favoured feeding habitat for most species. Chironomid midge larvae, found in high densities in the muddy bottom sediments of the ponds, are a favoured prey of most shorebird species (Clarke 1980). Some species exploit different habitats or prey found within the marsh. For example, the Lesser Yellowlegs commonly feeds on adult shoreflies (Ephydridae) commonly found in *Puccinellia phryganodes* in the lower marsh. Small stickleback fish which become trapped in the salt marsh after tidal inundation are also taken by the Lesser Yellowlegs.

Losses of Canadian Salt Marshes due to Human Activities

The areal extent of Canadian salt marshes is not known; however, limited information is available for some areas of Canada, such as the maritime provinces and parts of British Columbia. There is almost no available distribution information for the more remote parts of the country, such as the Arctic. Lynch-Stewart (1983) has summarized the available data on salt marsh losses in Canada and Lynch-Stewart *et al.* (1984) provide limited synthesis data for portions of the Arctic Islands and Beaufort Sea coastal wetlands. The greatest threat to salt marshes is agricultural reclamation. In British Columbia, diking of coastal marshes for agriculture in the Fraser River Delta has led to salt marsh loss which has potentially detrimental effects for fisheries and wildlife habitat. Along the lower St. Lawrence River in Quebec, agricultural land reclamation has led to a loss of some 32% of tidal marshes (Reed and Moisan 1971). A 5.8% loss occurred between 1950 and 1978 alone (Lands Directorate 1986). Remaining marshes are often subjected to deleterious land use activities such as grazing.

Lynch-Stewart (1983) and MacKinnon and Scott (1984) reported that 65% of coastal salt marshes in Atlantic Canada have been diked for agricultural reclamation since settlement. In Nova Scotia, 11 600 ha of salt marsh remain, one-third of the original acreage. In New Brunswick, 13 000 ha of marsh have been lost to agriculture. The famous Tantramar Marshes on the Bay of Fundy had been so extensively diked that, by 1920, only 20% remained in a natural, tidal-influenced state. However, since 1920, a significant proportion of this diked area has reverted to natural salt marshes as a result of the abandonment of dikes with the decline of the hay harvesting industry.

Another land use activity affecting salt marshes is grazing by domestic animals such as cattle, sheep, and horses. Roberts and Robertson (1986) reported that salt marshes in Newfoundland are heavily grazed by domestic animals. Such grazing has also been observed in salt marshes in the Queen Charlotte Islands.

A major threat to salt marshes stems from urbanization and industrialization. In British Columbia, the Fraser River marshes have been subjected to residential, shipping, and industrial development. Pilon and Kerr (1984) noted that, in a study area in the southwestern Fraser Lowland, salt, intertidal brackish, and freshwater riparian marshes occupied 6% of all wetlands present in 1967. From 1967 to 1982, about 7% of these marshes were lost to urban and agricultural cropland uses, while another 51% were protected as conservation and recreational lands. Further north, port development at Prince Rupert and at the Kitimat Estuary have led to wetland loss. On the Atlantic coast, in the areas of Halifax, Nova Scotia, and St. John, New Brunswick, there has been salt marsh loss due to residential and industrial developments. Energy developments also threaten marshes, and the Bay of Fundy tidal power project is a particular threat to salt marshes. Along the entire Canadian coastline, potential oil spills from oil tanker activities pose a threat to salt marshes (Roberts and Robertson 1986). Road building can also lead to marsh destruction through the construction of causeways and infilling.

Conclusions

Salt marsh studies in Canada have been limited in the past, mainly because of limited access, relatively short field seasons, and high travel costs. Thus, salt marsh research has been concentrated on accessible areas such as southern British Columbia and parts of Atlantic Canada. The economic importance of particular wetlands has also determined where research occurs. Important waterfowl and shorebird habitats in the James Bay and Hudson Bay areas have been the focus of significant salt marsh research. Coastal marshes in British Columbia have received greater attention than those in other parts of Canada due to their importance as spawning areas for salmon, a major commercial species. Salt marsh research in Atlantic Canada has concentrated on the areas of fisheries and migratory bird usage.

Priorities for further salt marsh research are:

(1) Salt marsh dynamics—vegetation succession, on both a short- and a long-term basis, is an important ecological process meriting research. It is necessary to understand how salt marshes respond to various natural events and human disturbances in order to predict the ecological impact of possible management schemes. The development of predictive models related to succession is needed.

(2) Hydrology—little is known about the hydrology of Canadian salt marshes as related to the control of vegetation. Salt marshes represent the zone of saline and freshwater interaction and this merits more research.

(3) Fish and wildlife habitat—limited research has been carried out on the ecology and role of Canadian salt marshes. Such marshes can only be assumed to serve the same critical functions as the well-studied coastal marshes of the southeastern United States.

(4) The impact of contaminants on salt marshes—little research has been done on the influence of contaminants on the ecology of salt marshes. Also, research is needed on the role of such wetlands as sinks for nutrients and contaminants.

The management of salt marshes in Canada is quite complex. The country consists of many political jurisdictions at federal, provincial, and local government levels. This is not the place to discuss needs related to protective legislation for salt marshes. However, there are several ways in which government agencies can be helped in improving salt marsh protection:

(5) Inventories—detailed salt marsh inventories are needed for many areas of Canada, especially in the Arctic. These will serve to assist managers in identifying specific salt marshes or salt marsh areas that require conservation. Inventories of portions of the Atlantic provinces of New Brunswick, Prince Edward Island, and Nova Scotia have now been completed by the Canadian Wildlife Service.

(6) Wetland evaluation—improved methodologies are necessary to determine which salt marshes must be preserved and which ones are not the most ecologically significant. These evaluations should, for example, include considerations such as wildlife and fish habitat, hydrological role, and prevalence or rarity of a particular wetland type in a locality.

(7) Impact of human activities on wetlands—research on how various agricultural and industrial activities affect salt marshes is needed. For example, how can grazing practices be made more compatible with protection of salt marshes in Atlantic Canada? How do river modifications such as dams affect coastal wetlands? The latter is especially important for James Bay where new macroscale hydro projects are being considered.

(8) Regional needs—there is little available information on some geographical localities in Canada, including Labrador and the Arctic Islands. This needs to be remedied.

Acknowledgements

The authors wish to thank A. Lucas for her assistance on the Atlantic coast salt marshes and also E. McCurdy for her typing of the manuscript. Reviews and comments by H. Hirvonen, C. Tarnocai, S. Zoltai, D. Scott, D. Kelly, E. Oswald, R. McKelvey, and C. Rubec have assisted in the finalization of this chapter.

References

BARBOUR, M.G. 1970. Is any angiosperm an obligate halophyte? America Midland Naturalist 84:105–120.

BEEFTINK, W.G. 1977. Salt marshes. *In* The coastline. R.S.K. Barnes, editor. J. Wiley and Sons. London, UK. pp. 93–121.

BEEFTINK, W.G. 1979. The coastal salt marshes of western and northern Europe: an ecological and phytosociological review. *In* Wet coastal ecosystems. Ecosystems of the World 1. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 109–155.

BELL, L.M., AND R.J. KALLMAN. 1976a. The Cowichan-Chemainus River estuaries—Status of environmental knowledge to 1975. Pacific Environmental Institute, Fisheries and Marine Service, Environment Canada. Special Estuary Series No. 4. 328 p.

BELL, L.M., AND R.J. KALLMAN. 1976b. The Nanaimo River estuary—Status of environmental knowledge to 1976. Pacific Environmental Institute, Fisheries and Marine Service, Environment Canada. Special Estuary Series No. 5. 298 p.

BELL, L.M., AND R.J. KALLMAN. 1976c. The Kitimat River estuary—Status of environmental knowledge to 1976. Pacific Environmental Institute, Fisheries and Marine Service, Environment Canada. Special Estuary Series No. 6. 296 p.

BELL, L.M., AND J.M. THOMPSON. 1977. The Campbell River estuary—Status of environmental knowledge to 1977. Pacific Environmental Institute, Fisheries and Marine Service, Environment Canada. Special Estuary Series No. 7. 346 p.

BOSTOCK, H.S. 1970. Physiographic subdivisions of Canada. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. 5th edition. Ottawa, Ontario. pp. 9–30.

BRADFIELD, G.E., AND G.L. PORTER. 1982. Vegetation structure and diversity components of a Fraser estuary tidal marsh. Canadian Journal of Botany 60:440–451.

BURG, M.E., D.R. TRIPP, AND E.S. ROSENBERG. 1980. Plant associations and primary productivity of the Nisqually salt marsh in southern Puget Sound, Washington. Northwest Science 54:222–236.

BURGESS, T.E. 1970. Foods and habitat of four Anatids wintering on the Fraser Delta marshes. M.Sc. thesis, University of British Columbia, Vancouver, British Columbia.

CALDER, J.A., AND R.L. TAYLOR. 1968. Flora of the Queen Charlotte Islands. I. Systematics of the vascular plants. Research Branch, Canada Department of Agriculture. Monograph No. 4, Part I. 659 p.

CESKA, A. 1981. Vegetation of the Tsitka River estuary. Report to Ecological Reserves Unit, Ministry of Lands, Parks and Housing, Victoria, British Columbia. 28 p.

CHAPMAN, V.J. 1937. A note on the salt marshes of Nova Scotia. Rhodora 39:53–57.

CHAPMAN, V.J. 1974. Salt marshes and salt deserts of the world. 2nd edition. Verlag von J. Cramer Publishing Company. Lehre, Germany. 392 p.

CHAPMAN, V.J. 1977. Introduction. *In* Wet coastal ecosystems. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 1–29.

CLAGUE, J.J., AND B.D. BORNHOLD. 1980. Morphology and littoral processes of the Pacific coast of Canada. *In* The coastline of Canada. S.B. McCann, editor. Geological Survey of Canada. Paper 80-10. pp. 339–380.

CLAGUE, J.J., AND J.L. LUTERNAUER. 1982. Late Quaternary sedimentary environments, southwestern British Columbia. Guidebook 30A, 11th International Congress on Sedimentology. McMaster University, Hamilton, Ontario. 167 p.

CLARKE, K.E. 1980. Ecology of a subarctic coastal system, North Point, James Bay, Ontario. M.Sc. thesis, University of Guelph, Guelph, Ontario. 232 p.

CROW, J.H. 1977. Salt marshes of the Alaska Pacific coast. *In* Proceedings, Symposium on Terrestrial and Aquatic Studies in the Northwest. R.D. Andrews III, R.L. Carr, F. Gibson, B.Z. Lang, R.A. Soltero, and K.C. Swedberg, editors. EWSC Press. Cheneg, Washington. pp. 103–110.

DAWE, N.K., AND E.R. WHITE. 1982. Some aspects of the vegetation ecology of the Little Qualicum River estuary, British Columbia. Canadian Journal of Botany 60:1447–1460.

DAWE, N.K., AND E.R. WHITE. 1986. Some aspects of the vegetation ecology of the Nanoose-Bonell estuary, Vancouver Island, British Columbia. Canadian Journal of Botany 64:27–34.

DIONNE, J.C. 1972. Caractéristiques des accores des régions froides en particulier de l'estuaire du Saint-Laurent. Zeitschrift Für Geomorphologie, N.F. Supplement Bands 13:131–162.

DIONNE, J.C. 1976. The effects of drift ice in tidal marshes on the eastern shore of James Bay. Cahiers de géographie de Québec 20:303–326.

DIONNE, J.C. 1978. Le glaciel en Jamesie et en Hudsonie. Québec, Subarctique, Geographie physique et Quaternaire 32:3–20.

DIONNE, J.C. 1980. An outline of the eastern James Bay coastal environments. *In* The coastline of Canada. S.B. McCann, editor. Geological Survey of Canada. Paper 80-10. pp. 311–338.

DISRAELI, D.J., AND R.W. FONDA. 1979. Gradient analysis of the vegetation in a brackish marsh in Bellingham Bay, Washington. Canadian Journal of Botany 57:465–475.

DORCEY, A.H.J., T.G. NORTHCOTE, AND D.V. WARD. 1978. Are the Fraser marshes essential to salmon? Westwater Lectures, University of British Columbia, No. 1, July 1978. 29 p.

DOUGLAS, R.J.W. 1970. Introduction. *In* Geology and economic minerals of Canada. R.J.W. Douglas, editor. Geological Survey of Canada. Economic Geology Report No. 1. pp. 2–6.

DUTIL, J.-D., AND M. FORTIN. 1983. La communauté de poissons d'un marécage intertidal de l'estuaire du Saint-Laurent. Naturaliste canadien (Revue d'écologie systématique) 110:397–410.

EWING, K. 1983. Environmental controls in Pacific Northwest intertidal marsh plant communities. Canadian Journal of Botany 61:1105–1116.

EWING, K., AND K.A. KERSHAW. 1986. Vegetation patterns in James Bay coastal marshes. I. Environmental factors on the south coast. Canadian Journal of Botany 64:217–226.

FAIRBRIDGE, R.W. 1980. The estuary: its definition and geodynamic cycle. *In* Chemistry and biogeochemistry of estuaries. E. Olavsson and I. Cato, editors. J. Wiley and Sons. New York, New York. pp. 1–35.

FORBES, R.D. 1972. A floral description of the Fraser River estuary and Boundary and Mud bays, BC. British Columbia Fish and Wildlife Branch, Department of Recreation and Conservation. Victoria, British Columbia.

FREY, R.W., AND P.B. BASAN. 1978. Coastal salt marshes. *In* Coastal sedimentary environments. R.A. Davis, Jr., editor. Springer-Verlag. Berlin, Germany. pp. 101–169.

GANONG, W.F. 1903. The vegetation of the Bay of Fundy salt and diked marshes: an ecological study. Botanical Gazette 36:161–186, 208–302, 340–367, 429–455.

GAUTHIER, B. 1979. Recherches sur les limites biologiques du Saint-Laurent. Ph.D. thesis, Laval University, Quebec, Quebec.

GAUTHIER, B. 1982. L'étagement des plantes vascuclaires en milieu saumâtre, estuaire du Saint-Laurent. Naturaliste canadien 109:189-203.

GAUTHIER, J., D. LEHOUX, AND J. ROSA. 1980. Les marécages intertidaux dans l'estuaire du Saint-Laurent. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. 91 p.

GLOOSCHENKO, W.A. 1980. Coastal ecosystems of the James/Hudson Bay area of Ontario, Canada. Zeitschrift Für Geomorphologie, N.F. Supplement Bands 34:214–224.

GLOOSCHENKO, W.A. 1983. Salt marsh vegetation of the Ontario coast of Hudson and James Bay. Part 1. Transect descriptions. National Water Research Institute, Environment Canada. Publication 82-23. 56 p.

GLOOSCHENKO, W.A., AND K. CLARKE. 1982. The salinity cycle of a subarctic salt marsh. Naturaliste canadien 109:483–490.

GLOOSCHENKO, W.A., AND I.P. MARTINI. 1978. Hudson Bay Lowlands Baseline Study. Proceedings, Symposium on Technical, Environmental, and Socio-Economic Regulatory Aspects for Coastal Zone Management. American Society of Civil Engineers. pp. 663–679.

GLOOSCHENKO, W.A., AND I.P. MARTINI. 1981. Salt marshes of the Ontario coast of Hudson Bay, Canada. Wetlands 1:9–18.

GLOOSCHENKO, W.A., AND I.P. MARTINI. 1983. Wetlands of the Attawapiskat River mouth, James Bay, Ontario, Canada. Wetlands 3:64–76.

GLOOSCHENKO, W.A., AND I.P. MARTINI. 1986. Vegetation of river-influenced coastal marshes of the southwestern end of James Bay, Ontario. Wetlands: In press.

GRANDTNER, M.M. 1966. Première observation phytopedologiques sur les pies sales des Îles-de-la-Madeleine. Naturaliste canadien 93:361–366.

HATCHER, A.I. 1977. Aspects of carbon and nitrogen cycling in a *Spartina* dominated salt marsh on the Northumberland Strait, Nova Scotia; and the effects of impoundment. M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia. 110 p.

HATCHER, A.I., D.G. PATRIQUIN, Y.F. FERN, A.J. HANSON, AND J. READE. 1981. Salt marshes in Nova Scotia. Institute of Resource and Environmental Studies, Dalhousie University, Halifax, Nova Scotia. 70 p.

HATCHER, B.G., AND K.H. MANN. 1975. Above-ground production of marsh cordgrass (*Spartina alterniflora*) near the northern end of its range. Journal Fisheries Research Board of Canada 32:83–87.

HEYWOOD, W.W., AND B.V. SANFORD. 1976. Geology of Southampton, Coats and Mansel Islands, District of Keewatin, Northwest Territories. Geological Survey of Canada. Memoir 382. 35 p.

HILLABY, F.B., AND D.T. BARRETT. 1976. Vegetation communities of a Fraser River salt marsh. Fisheries and Marine Service, Habitat Protection Directorate, Environment Canada. Technical Report Pac/T-76-14. Vancouver, British Columbia. 19 p.

HUTCHINSON, I. 1982. Vegetation-environment relations in a brackish marsh, Lulu Island, Richmond, BC. Canadian Journal of Botany 60:452–462.

JEFFERIES, R.L. 1977. The vegetation of salt marshes at some coastal sites in arctic North America. Journal of Ecology 65:661–672.

JEFFERIES, R.L., A. JENSEN, AND K.F. ABRAHAM. 1979. Vegetational development and the effect of geese on vegetation at La Perouse Bay, Manitoba. Canadian Journal of Botany 57:1439–1450.

JEFFERSON, C.A. 1975. Plant communities and succession in Oregon coastal salt marshes. Ph.D. thesis, Oregon State University, Corvallis, Oregon. 144 p.

KELLERHALS, P., AND J.W. MURRAY. 1969. Tidal flats at Boundary Bay, Fraser River delta, British Columbia. Bulletin of Canadian Petroleum Geology 17:67–91.

KENNEDY, K.A. 1982. Plant communities and their standing crop on estuaries of the east coast of Vancouver Island. M.Sc. thesis, University of British Columbia, Vancouver, British Columbia.

KERSHAW, K. 1976. The vegetation zonation of the East Pen Island salt marshes, Hudson Bay. Canadian Journal of Botany 54:5–13.

KETCHUM, B.H. 1983a. Estuarine characteristics. *In* Estuaries and enclosed seas. B.H. Ketchum, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 1–14.

KETCHUM, B.H. 1983b. Enclosed seas—Introduction. *In* Estuaries and enclosed seas. B.H. Ketchum, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 209–218.

KISTRITZ, R.U. 1978. An ecological evaluation of Fraser estuary tidal marshes: the role of detritus and the cycling of elements. Westwater Research Centre, University of British Columbia. Technical Report No. 15. Vancouver, British Columbia. 59 p.

KISTRITZ, R.U., AND I. YESAKI. 1979. Primary production, detritus flux, and nutrient cycling in a sedge marsh, Fraser River estuary. Westwater Research Centre, University of British Columbia. Technical Report No. 17. Vancouver, British Columbia. 53 p.

KRANCK, K. 1972. Geomorphological development of post-pleistocene sea-level changes, Northumberland Strait, maritime provinces. Canadian Journal of Earth Sciences 9:835–844.

LAMOUREUX, J.P., AND L.G. DE REPENTIGNY. 1972. Contribution à la flore des marécages intertideaux de la Baie de Rupert, Québec. Report to Canadian Wildlife Service, Valleyfield, Quebec. 14 p.

LAMOUREUX, J.P., AND R. ZARNOVICAN. 1972. Approximation relative à la vegetation riparienne de la Baie de Rupert, Québec. Report to Canadian Wildlife Service, Valleyfield, Quebec. 126 p.

LAMOUREUX, J.P., AND R. ZARNOVICAN. 1974. Les marécages côtiers de la Baie aux Oies, Québec. Canadian Wildlife Service, Environment Canada. James Bay Report Series No. 13. Ste-Foy, Quebec. 99 p.

LANDS DIRECTORATE. 1986. Wetlands of the St. Lawrence River Region 1950–1978. Lands Directorate, Environment Canada. Working Paper No. 45. Ottawa, Ontario. 29 p.

LAVERDIÈRE, C., AND P. GUIMONT. 1975. Le milieu biophysique de la Baie de Rupert. Environment Directorate, James Bay Development Corporation. Reconnaissance Report. Montreal, Quebec. 157 p.

LEANEY, A.J., AND S. MORRIS. 1981. The Bella Coola river estuary. Status of environmental knowledge to 1981. Fisheries and Oceans. Canada Special Estuary Series No. 9. Vancouver, British Columbia. 266 p.

LEVINGS, C.D. 1980a. An account of a workshop on restoration of estuarine habitats. Fisheries and Aquatic Sciences, Environment Canada. Manuscript Report No. 1571. Vancouver, British Columbia. 29 p.

LEVINGS, C.D. 1980b. Consequences of retaining walls and jetties for aquatic habitats at two British Columbia estuaries. Coastal Engineering 4:111–136.

LEVINGS, C.D., AND A.I. MOODY. 1976. Studies of intertidal vascular plants, especially sedge (*Carex lyngbyei*) on the disrupted Squamish River delta, British Columbia. Fisheries and Marine Service, Environment Canada. Technical Report No. 606. 51 p.

LIM, P.G., AND C.D. LEVINGS. 1973. Distribution and biomass of intertidal vascular plants on the Squamish delta. Fisheries Research Board of Canada. Miscellaneous Report No. 1219. 26 p.

LUCAS, A.E. 1980. Phytogeomorphic sequences on barrier coastlines within the southern Gulf of St. Lawrence. M.Sc. thesis, McMaster University, Hamilton, Ontario.

LUTERNAUER, J.L., AND J.W. MURRAY. 1973. Sedimentation in the western delta-front of the Fraser River, British Columbia. Canadian Journal of Earth Sciences 10:1642–1663.

LYNCH-STEWART, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. Ottawa, Ontario. 115 p.

LYNCH-STEWART, P., R.G. HÉLIE, AND D. OUIMET. 1984. Northern wetlands research project: procedures, results and guidelines. Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 53 p.

MACDONALD, K.B. 1977. Plant and animal communities of Pacific North American salt marshes. *In* Wet coastal ecosystems. Ecosystems of the World 1. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 167–191.

MACKINNON, K., AND D.B. SCOTT. 1984. An evaluation of salt marshes in Atlantic Canada. Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia, and Lands Directorate, Environment Canada. Technical Report No. 1. Dartmouth, Nova Scotia. 37 p. and appendices.

MANN, K.H. 1982. Ecology of coastal waters. University of California Press. Berkeley, California. 322 p.

MARTINI, I.P. 1981a. Morphology and sediments of the emergent Ontario coast of James Bay, Canada. Geographische Annaler 63A:81–94.

MARTINI, I.P. 1981b. Ice effect of erosion and sedimentation on the Ontario shores of James Bay, Canada. Zeitschrift Für Geomorphologie, N.F. 25:1–16.

MARTINI, I.P. 1982. Geomorphological features of the Ontario coast. Naturaliste canadien 109:415–429.

MARTINI, I.P., D.W. COWELL, AND G.M. WICKWARE. 1980a. Geomorphology of southern James Bay: a low energy, emergent coast. *In* The coastline of Canada. S.B. McCann, editor. Geological Survey of Canada. Paper 80-10.

MARTINI, I.P., AND W.A. GLOOSCHENKO. 1983/1984. Emergent coasts of Akimiski Island, James Bay, Northwest Territories, Canada: geology, geomorphology, and vegetation. Sedimentary Geology 37:229–250.

MARTINI, I.P., R.I.G. MORRISON, W.A. GLOOSCHENKO, AND R. PROTZ. 1980b. Coastal studies in James Bay, Ontario. Geoscience Canada 7:11–20.

MARTINI, I.P., AND R. PROTZ. 1978. Coastal geomorphology, sedimentology, and pedology of southern James Bay, Ontario, Canada. Department of Land Resource Sciences, University of Guelph, Guelph, Ontario. 118 p.

MARTINI, I.P., R. PROTZ, D. GRINHAM, W.A. KING, AND K. CLARKE. 1979. Studies of coastal sediments, soils, and biota, James Bay, Ontario, Canada. Department of Land Resource Science, University of Guelph. Technical Memorandum 79-1. Guelph, Ontario. 290 p.

MCALONEY, R.K. 1981. Waterfowl use of Nova Scotian salt marshes. *In* Salt marshes in Nova Scotia. A. Hatcher and D.G. Patriquin, editors. Institute for Resource and Environmental Studies and Department of Biology, Dalhousie University, Halifax, Nova Scotia. pp. 60–66.

MCKELVEY, R. (personal communication). December 1986. Canadian Wildlife Service, Environment Canada. Delta, British Columbia.

MCLAREN, K.A. 1972. A vegetation study of the islands and associated marshes in the south arm of the Fraser River, BC, from the Deas Island Tunnel to Westham Island foreshore. Report to Fish and Wildlife Branch, Ministry of Environment, Victoria, British Columbia.

MOODY, A.I. 1978. Growth and distribution of the vegetation of a southern Fraser delta marsh. M.Sc. thesis, University of British Columbia, Vancouver, British Columbia. 153 p.

MORANTZ, D.L. 1976. Productivity and export from the John Lusby Marsh, Amherst, Nova Scotia. M.Sc. thesis, Dalhousie University, Halifax, Nova Scotia. 77 p.

MORRIS, S., AND A.J. LEANEY. 1980. The Somass River estuary. Status of environmental knowledge to 1980. Fisheries and Oceans Canada. Special Estuary Series No. 9. Vancouver, British Columbia. 374 p.

MORRIS, S., A.J. LEANEY, L.M. BELL, AND J.M. THOMPSON. 1979. The Courtenay River estuary. Status of environmental knowledge to 1978. Research and Services Branch, Fisheries and Environment Canada. Special Estuary Series No. 8. 355 p.

NAIMAN, R.J., AND J.R. SIBERT. 1979. Detritus and juvenile salmon production in the Nanaimo estuary: III. Importance of detrital carbon to the estuarine ecosystem. Journal Fisheries Research Board of Canada 36:504–520.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

NICOLAS, G.E. 1918. The vegetation of northern Cape Breton Island, Nova Scotia. Transactions. Connecticut Academy of Arts and Sciences 22:249–467.

NIXON, S.W. 1980. Between coastal marshes and coastal waters—a review of 20 years of speculation and research on the role of salt marshes in estuarine productivity and water chemistry. *In* Estuarine and wetland processes with emphasis on modeling. P. Hamilton and K.B. Macdonald, editors. Plenum Press. New York, New York. 437 p.

NIXON, S.W. 1982. The ecology of New England high salt marshes: a community profile. Office of Biological Services, United States Fish and Wildlife Service. FWS/OBS-81/55. Washington, DC. 70 p.

ODUM, E.P. 1980. The status of three ecosystem-level hypotheses regarding salt marsh estuaries: tidal subsidy, outselling, and detritus-based food chains. *In* Estuarine perspectives. V.S. Kennedy, editor. Academic Press. New York, New York. pp. 485–495.

OLMSTEAD, W.R., AND R.P. FINK. 1982. Environmental evaluation of the Tsawwassen salt marsh in relation to flood control diking. Report to Research and Management Division, Indian and Northern Affairs Canada, Vancouver, British Columbia. 21 p.

OWENS, E.H. 1977. Coastal environments of Canada: the impact and cleanup of oil spills. Fisheries and Environment Canada. Economic Technical Review Report EPS-3-EC-77-13. Ottawa, Ontario. 413 p.

PARSONS, C.O. 1975. Vegetation pattern in a salt marsh at Boundary Bay, BC. Lambda 1:45–52.

PATRIQUIN, D.G. 1981. The general biology of salt marshes. *In* Salt marshes in Nova Scotia. A. Hatcher and D.G. Patriquin, editors. Dalhousie University, Halifax, Nova Scotia. pp. 4–27.

PHLEGER, F.B. 1977. Soils of marine marshes. *In* Wet coastal ecosystems. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 69–77.

PILON, P., AND M.A. KERR. 1984. Land use monitoring on wetlands in the southwestern Fraser Lowland, British Columbia. Lands Directorate, Environment Canada. Working Paper No. 34. Vancouver, British Columbia. 31 p. and map.

POLUNIN, N. 1948. Botany of the Canadian Eastern Arctic. III. Vegetation and ecology. National Museums of Canada. Bulletin No. 104. 304 p.

POMEROY, L.R., AND R.G. WIEGERT. 1981. The ecology of a salt marsh. Springer-Verlag. New York, New York. 271 p.

POMEROY, W.M., AND J.G. STOCKNER. 1976. Effects of environmental disturbance on the distribution and primary production of benthic algae on a British Columbia estuary. Journal Fisheries Research Board of Canada 33:1175–1187.

PORSILD, A.E. 1955. The vascular plants of the western Canadian Arctic Archipelago. National Museums of Canada. Bulletin No. 135. 276 p.

PREVETT, J.R., I.F. MARSHALL, AND V.G. THOMAS. 1979. Fall foods of Lesser Snow Geese in the James Bay region. Journal of Wildlife Management 43:736–742.

PRITCHARD, D.W. 1967. What is an estuary: physical viewpoint. *In* Estuaries. G.H. Lauff, editor. American Association for the Advancement of Science. Publication No. 83. Washington, DC. pp. 3–5.

REED, A., AND G. MOISAN. 1971. The *Spartina* tidal marshes of the St. Lawrence Estuary and their importance to aquatic birds. Naturaliste canadien 98:905–922.

REIMOLD, R.J. 1977. Mangals and salt marshes of eastern United States. *In* Wet coastal ecosystems. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 157–166.

RILEY, J.L. 1981. The vascular flora of Akimiski Island, James Bay, NWT. Naturaliste canadien 108:229–235.

RILEY, J.L., AND S.M. MCKAY. 1980. The vegetation and phytogeography of coastal southwestern James Bay. Contributions of the Royal Ontario Museum, Life Sciences Report No. 124. 86 p.

RINGIUS, G.S. 1980. Vegetation survey of a James Bay coastal marsh. Canadian Field-Naturalist 94:110–120.

RITCHIE, J.C. 1957. The vegetation of Manitoba. II. A prisere on the Hudson Bay Lowlands. Ecology 38:429–435.

ROBERTS, B.A., AND A.W. ROBERTSON. 1986. Salt marshes of Atlantic Canada: their ecology and distribution. Canadian Journal of Botany 64:455–467.

ROSS, R.K. 1982. Duck distribution along the James and Hudson Bay coasts of Ontario. Naturaliste canadien 109:927–932.

RUBEC, C.D.A. (personal communication). 1986. Lands Directorate, Environment Canada. Ottawa, Ontario.

SCHOFIELD, W.B. 1959. The salt marsh vegetation of Churchill, Manitoba and its phytogeographic implications. National Museums of Canada. Bulletin No. 160. pp. 107–132.

SCOGGAN, H.J. 1978. The flora of Canada. Parts 1, 2, 3, 4. National Museum of Natural Sciences. Publications in Botany No. 7. Ottawa, Ontario. 1711 p.

SCOTT, D.B., AND D.A. GREENBERG. 1983. Relative sea-level use and tidal development in the Fundy tidal system. Canadian Journal of Earth Sciences 20:1554–1564.

SCOTT, D.B., AND F.S. MEDIOLI. 1978a. Vertical zonation of marsh foraminifera as accurate indicators of former sea levels. Nature 272:528–531.

SCOTT, D.B., AND F.S. MEDIOLI. 1978b. Studies of relative sea-level changes in the Maritimes. Department of Geology, Dalhousie University. Progress Report No. EMR 2239-4-31/78. Halifax, Nova Scotia. 79 p.

SCOTT, D.B., AND F.S. MEDIOLI. 1979. Marine emergence and submergence in the Maritimes. Department of Geology, Dalhousie University. Progress Report No. EMR 45-4-79. Halifax, Nova Scotia. 69 p.

SCOTT, D.B., M.A. WILLIAMSON, AND T.E. DUFFET. 1981. Marsh foraminifera of Prince Edward Island: their recent distribution and application for former sea-level studies. Maritime Sediments and Atlantic Geology 17:98–129.

SELISKAR, D.M., AND J.L. GALLAGHER. 1983. The ecology of tidal marshes of the Pacific northwest coast: a community profile. Division of Biological Services, United States Fish and Wildlife Service. FWS/OBS-82/32. Washington, DC. 65 p.

SHEPPERD, J.E. 1981. Development of a salt marsh on the Fraser Delta at Boundary Bay, British Columbia, Canada. M.Sc. thesis, University of British Columbia, Vancouver, British Columbia. 62 p.

SIMENSTAD, C.A. 1983. The ecology of estuarine channels of the Pacific northwest coast: a community profile. Fish and Wildlife Service, United States Department of the Interior. Report No. FWS/OBS-83/03. 181 p.

SNOW, A.A., AND S.W. VINCE. 1984. Plant zonation in an Alaskan salt marsh. II. An experimental study of the role of edaphic conditions. Journal of Ecology 72:669–684.

SWINBANKS, D.D., AND J.W. MURRAY. 1981. Biosedimentological zonation of Boundary Bay tidal flats, Fraser River delta, British Columbia. Sedimentology 28:201–237.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–39.

TAYLOR, R.J. 1981. Shoreline vegetation of the Arctic Alaska coast. Arctic 34:37–42.

THANNHEISER, D. 1981. Die kustenvegetation Ost Kanadas. A. Mayr, editor. Munster Geographical Series No. 10. Paderborn, Germany. 202 p.

THOMAS, V.G., AND J.P. PREVETT. 1982. The roles of the James and Hudson Bay Lowlands in the annual cycle of geese. Naturaliste canadien 109:913–925.

VESTERGAARD, P. 1978. Studies in vegetation and soil of coastal salt marshes in the Oisko area, west Greenland. Meddelelser Om Gronland 204:1–51.

VINCE, S.W., AND A.A. SNOW. 1984. Plant zonation in an Alaskan salt marsh. I. Distribution, abundance and environmental factors. Journal of Ecology 72:651–663.

WALTER, H. 1977. Climate. *In* Wet coastal ecosystems. Ecosystems of the World 1. V.J. Chapman, editor. Elsevier Scientific Publishing Company. Amsterdam, The Netherlands. pp. 61–67.

WARD, G., AND G.J. FITZGERALD. 1983a. Macrobenthic abundance and distribution in tidal pools of a Quebec salt marsh. Canadian Journal of Zoology 61:1071–1085.

WARD, G., AND G.J. FITZGERALD. 1983b. Fish predation on the macrobenthos of tidal salt marsh pools. Canadian Journal of Zoology 61:1358–1361.

YAMANAKA, K. 1975. Primary productivity of the Fraser River delta foreshore: yield estimates of emergent vegetation. M.Sc. thesis, Department of Plant Science, University of British Columbia, Vancouver, British Columbia. 134 p.

YEO, R.K., AND M.J. RISK. 1981. The sedimentology, stratigraphy, and preservation of intertidal deposits in the Minas Basin system, Bay of Fundy. Journal Sedimentary Petrology 51:245–260.

ZEDLER, J.B. 1984. *Salt marsh restoration. A guidebook for southern California*. California Sea Grant Corporation. Report No. T-CSGCP-009. 46 p.

ZOLTAI, S.C. 1980. An outline of the wetland regions of Canada. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–38.

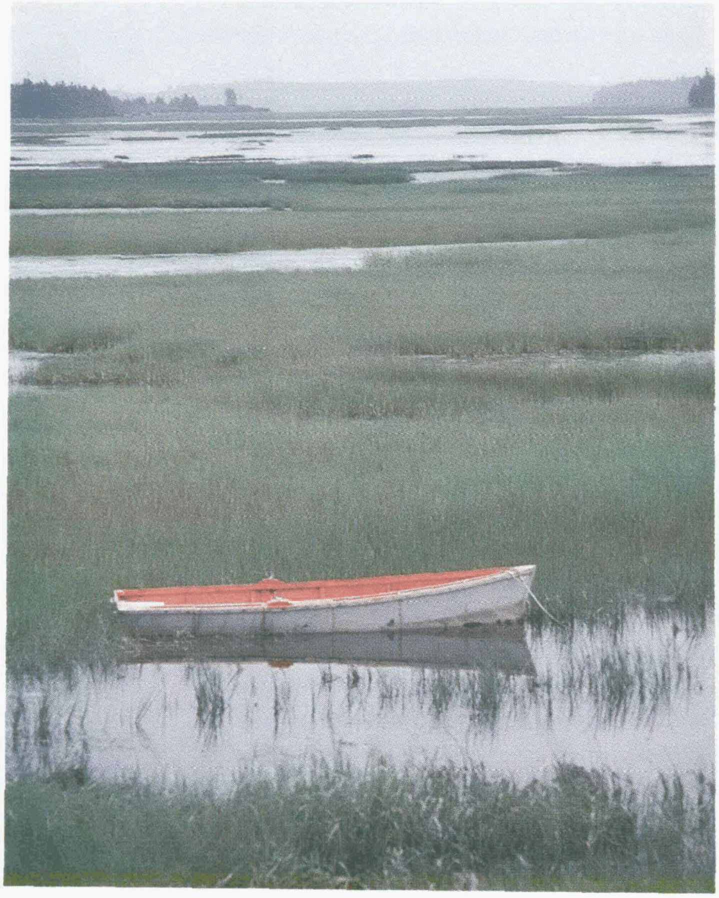
ZOLTAI, S.C. (personal communication). 1985. Canadian Forestry Service. Edmonton, Alberta.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

10 Wetland Utilization in Canada

C.D.A. Rubec
P. Lynch-Stewart
G.M. Wickware
I. Kessel-Taylor

Wetland Utilization in Canada



In their natural state, wetlands provide hydrological, ecological, recreational, and other functions vital to the well-being of Canadians. However, wetlands are increasingly being converted from their natural state to support alternative land uses such as agriculture, urbanization, industrial development, and recreation. The diversity of competing uses and resource values associated with wetlands, and the environmental implications of disrupting wetland functions, have resulted in a conflict of national scale and concern.

Wetlands have traditionally been regarded as unexploited wastelands and obstacles to development and production. Their perceived value has depended primarily on their potential for conversion to more "productive" uses. However, knowledge of wetland functions and values has grown considerably in the last decade, and is beginning to be recognized in political and economic spheres, as well as in the scientific world. Having been primarily associated with waterfowl wildlife in the past, wetlands are now credited for their important role in supporting coastal and estuary fishery resources, their capacity to protect shorelines from erosive wave action and watersheds from flood surges, their contribution to improved water quality in many of the nation's watersheds, their utility as outdoor educational exhibits and scientific laboratories, their value for recreational pursuits, and their harvesting importance for wild rice, forests, game animals, and peat itself. As presented in this chapter, the economic value to Canada of this national wetland resource may exceed $5–10 billion per year.

Conservation efforts related to the nation's wetland resource have been plagued by a number of constraints. Fragmented jurisdiction, spreading responsibility for wetlands among many federal, provincial, and municipal agencies, has complicated and reduced the possibility of wise management. Protective measures until recently had been largely reactive, providing only *ad hoc* responses to development threats. The very nature of land use change on wetlands across the country, with significant amounts of conversion occurring incrementally, makes sound management of the wetland resource even more difficult. The primary obstacles to rational decisions regarding wetland use relate to the nature of their intrinsic functions and values.

First, there still persists a serious lack of knowledge and experience in expressing wetland benefits in meaningful terms within the present systems of resource allocation. Failure to quantify wetland values for comparison with competing or alternative land uses has resulted in significant losses of wetland area. To date, only a few economic valuation investigations of wetland benefits and services have been completed.

Jaworski and Raphael (1978) calculated the gross annual income per hectare of wetlands in the Great Lakes region. This methodology involved user-day values as well as wholesale value of wetland products, and concluded that the cultural values of wetlands generate a gross return of $1 610 per hectare per year. Tilton (1978) employed an "ecosystem replacement value" methodology to determine the 30-year cost of replacing natural wetland functions (Table 10–1). Jaworski (1981) combined the results of Tilton (1978) with those of Jaworski and Raphael (1978) to obtain the data presented here in Table 10–2. A further study by Thibodeau and Ostro (1981) employed a cost–benefit analysis and calculated that the benefits of an acre of wetland in the Charles River Watershed, Massachusetts, range from $153 000 to $190 000 per year. Further development and application of economic valuation techniques such as these are among the most pressing research needs related to wetland conservation in Canada.

A second major obstacle to wetland conservation efforts results from the fact that the majority of wetland benefits accrue to the public in general, and not exclusively to the private landowner. As decisions regarding wetlands in private ownership are usually, and understandably, based on personal benefit, wetland preservation generally loses out to economic development. This reality has resulted in

Table 10–1. Cost of replacing wetland functions

Wetland function	*Cost of natural function ($/ha)*	*Cost of replacement ($/ha)*	*Net value ($/ha)*
1. Shoreline protection	functions unknown	—	—
2. Floodwater retention	functions unknown	—	—
3. Sedimentation control	functions unknown	—	—
4. Fish production			
Purchased replacement	0	31 100	31 100
Constructed replacement	0	65 500	65 500
5. Waterfowl breeding/feeding			
Purchased replacement	0	21 500	21 500
Constructed replacement	0	59 000	59 000
6. Nutrient removal (wastewater renovation)			
Purchased replacement	—	—	—
Constructed replacement	32 400	74 100	41 700
Upland spray irrigation	32 400	55 300	22 900
Chemical treatment	32 400	62 200	29 800
7. Runoff nutrient control			
Purchased replacement	0	50 400	50 400
Constructed replacement	0	85 500	85 500
Upland spray irrigation	0	72 900	72 900
Chemical treatment	0	75 100	75 100
8. Water supply	150	—	—
Total	97 350	652 600	555 400

Source: Modified from Tilton (1978).

Table 10–2. Combined user-day and wetland replacement values

Benefit	*1980 value ($/ha/yr)*
Runoff nutrient control	1 680
Sport fishing	1 054
Fish production	1 040
Waterfowl breeding/feeding	720
Waterfowl hunting	103
Trapping of fur-bearers	74
Water supply	16
Commercial fishing	13
Total	4 700

Source: Jaworski (1981).

the conversion of many privately owned wetland areas across Canada to urban, industrial, agricultural, recreational, and other uses, to the detriment of natural functions. The wide-reaching nature of wetland benefits and services requires broad public support, in concert with appropriate legislation and government programs aimed at preserving these natural systems. Such programs and policies are now beginning to be implemented in some Canadian provinces and at the federal level.

This chapter provides an overview of wetland uses across Canada. It initially presents a conservation perspective, outlining the inherent functions and sustainable uses for which wetlands are valued. This includes those uses which do not alter or which enhance the ecological balance of wetlands. Wetland conversion issues are then reviewed, with identification and description of those uses made of wetlands which reclaim, alter, or destroy their physical structure, water regime, soils, or biota. A discussion on quantitative studies of wetland conversion follows, organized into seven geographic areas and referenced to the wetland regions of the country as defined by the National Wetlands Working Group (1986). Finally, conclusions are presented concerning the state of wetlands across Canada and wetland uses which are essential to wise management of the nation's remaining wetland resource base.

The Conservation Perspective

Major achievements towards wetland conservation have occurred in recent years in Canada. Under the RAMSAR Convention, acceded to by Canada in 1981, some 28 sites have been declared wetlands of international importance by virtue of their vital significance to migratory birds. In 1984, the Wildlife Habitat Canada Foundation was established as a private, non-profit organization to preserve all types of wildlife habitat, but in particular wetlands for migratory waterfowl. This foundation provides an important bridge between federal, provincial, and non-governmental conservation interests. The North American Waterfowl Management Plan, which was jointly signed by Canada and the United States in mid-1986, calls for the protection and rehabilitation of over 1.5 million ha of wetlands, mainly in western Canada and the Great Lakes region during the 1986–2000 period. It also provides for ongoing monitoring and inventory efforts (Environment Canada and United States Department of the Interior 1986).

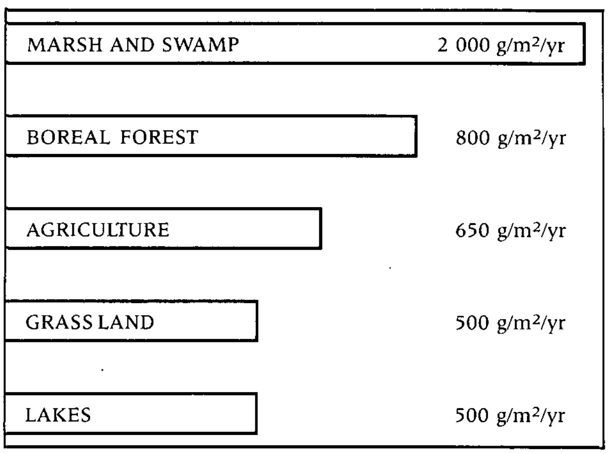
At the provincial level, significant achievements are notable. Key to conservation efforts are inventory and evaluation programs that provide monitoring and baseline data allowing the development of strategies and policies. Major wetland programs undertaken to date in Canada include: (1) the Wetland Protection Mapping and Designation Program, a joint federal–provincial effort in Prince Edward Island, Nova Scotia, and New Brunswick; (2) the New Brunswick, Newfoundland, and Nova Scotia Peat Resources Evaluation programs; (3) the Ontario Peat Resources Inventory Program and the Ontario Wetland Evaluation Program; (4) the Northern Resources Information Program in Manitoba; (5) the Wetland Inventory Program in Saskatchewan; and (6) the British Columbia Estuary Habitat Mapping and Classification Program. Ducks Unlimited has also been instrumental in protecting or rehabilitating over 1.4 million ha of wetlands in Canada through private funding.

The province of Ontario has set a particularly important example towards wetland conservation by drafting wetland management guidelines in 1984 which are leading to a provincial wetlands policy. In 1986, Quebec announced new regulations to be implemented in 1987 to protect the bulk of riverine and shoreline wetlands in that province. In British Columbia, wetland evaluations are leading directly to protection of an array of estuarine wetlands.

These developments augur well for wetland conservation in Canada. Wetlands were identified as a priority national conservation issue by Canada, with provincial, territorial, and stakeholder support, at the International World Conservation Strategy Conference in Ottawa in 1986. This was a major recognition of the critical need for coordinated, cooperative action (Environment Canada 1986).

Productivity and Habitat Diversity

Occupying a unique position in the transitional zone between aquatic and terrestrial environments, wetland marshes, swamps, and shallow water areas are often highly productive or "fertile" environments, which provide habitat for a diverse range of plants and animals and support a complex web of energy transfers. Over 45 species of waterfowl, 155 other species of birds, 50 types of mammal, and an extensive flora depend on wetlands (S. Price, personal communication). Their biotic density and diversity are frequently higher than that in the adjacent uplands (Shay 1981) (Figure 10–1). However, nutrient-poor wetlands, such as bogs and some types of fens, are floristically simple, with limited faunal diversity.



Source: Shay (1981).

Figure 10–1.
Net primary productivity of selected ecosystems (dry grams per square metre per year).

Wildlife values have been the prime reason for the recognition and protection of wetlands (Figure 10–2). This is mainly because of their highly visible nature, substantial public interest and support, and the possibility of quantifying potential impacts on habitat more readily. Since these natural systems are maintained for fish and wildlife habitat, they continue to support a wide range of inherent functions.

Canadian wetland habitat is especially noted for support of the continent's waterfowl species and is the focus of the North American Waterfowl Management Plan. Prairie potholes provide habitat for the production of roughly 50% of the North American waterfowl population. Every year, waterfowl migrate along four major flyways (the Pacific, Central, Mississippi, and Atlantic) using wetlands for feeding, staging, breeding, and nesting. In addition to waterfowl, the main groups of birds which use freshwater and saline wetlands include raptors, shorebirds, and songbirds. The Red-winged Blackbird (*Agelaius phoeniceus*), for instance, is among the most well-known inhabitants of the cattails and shrubs of wet areas. Herons, Bald Eagle (*Haliaeetus leucocephalus*), and Osprey (*Pandion haliaetus*) are commonly seen in wetland environments as they prey on fish. Hawks, in search of smaller birds and mice, are also typically associated with wetland habitat. In Quebec, Greater Snow Geese (*Anser caerulescens atlantica*) are major users of the *Scirpus* wetlands at the Cap Tourmente National Wildlife Area. In northern regions, major migratory bird sanctuaries dominated by wetlands and used by waterfowl and migratory birds include the Great Plain of the Koukdjuak on Baffin Island and the Anderson River Delta. Both of these areas support a major percentage of North America's Snow Geese (*Anser caerulescens*) and duck populations in certain summer months.

Numerous mammals are adapted to the water and hydrophytic vegetation of the wetland habitat, while other upland species use wetlands for food, escape cover, and reproductive habitat. The widely distributed muskrat (*Ondatra zibethicus*) and beaver (*Castor canadensis*) are the most common in Canada, occurring in a variety of wetland types. Other small and large mammals such as mice, voles, water shrews, weasels, mink, raccoons, rabbits and hares, moose, deer, caribou, and bears are common beneficiaries of the wetland environment. Estuaries support marine mammals such as harbour seals (*Phoca vitulina*), sea lions (*Eumetopias jubata*), and otters (*Lontra canadensis*).

Wetlands in estuarine or coastal areas are essential to the maintenance of various fish and invertebrates. Being either estuarine-dependent or estuarine-associated, shellfish, finfish, and crustacean species use this habitat for spawning, feeding, cover, or nursery areas for their young. Freshwater wetlands also provide spawning, nursery, and cover habitat for a large number of non-marine fish. Most freshwater species spawn only in shallow water, and floodplain overflow areas of river systems are prime

Figure 10–2.
Wetlands provide essential habitat for numerous species of waterfowl as well as critical ecological functions vital to wildlife.

breeding places for a wide variety of warm-water species (Reppert *et al.* 1979).

The value of wetlands for invertebrates, reptiles, and amphibians is not well recognized. Snails, salamanders, and snakes have not captured the popular imagination in such a way as to inspire campaigns for wetland protection (Clark 1978). However, the invertebrates and cold-blooded vertebrates are also valuable and have considerable ecological significance, contributing to the support of the wetland faunal community as a whole through trophic and non-trophic roles (Clark 1978).

Wetlands are also critical habitats for many endangered species. As listed in Table 10–3, those species which have been classified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) include numerous ones using wetland and riverine habitats. These include 35 species of fish, birds, animals, or plants out of about 100 now designated by COSEWIC as endangered.

Hydrological and Biogeochemical Functions

Wetland hydrology—the quantity, quality, and movement of water—is a key factor on which all other wetland values depend. Wetlands also play an important role in the hydrology of their watersheds, often attenuating flood peaks and storm flows, modifying water quality, and buffering shorelines against erosion. Conservation of wetlands, for hydrological reasons alone, was identified as a key issue in the Inquiry on Federal Water Policy (Canada 1985).

Flood and storm waters by varying degrees are temporarily stored or "held back" by wetlands in a drainage basin. Hydrographic peaks may be modified by wetlands due to their topography, soil storage capacity, and restricted outlets. Although it is often suggested that wetlands release stored water during dry periods to maintain baseflows, stored water is usually lost from the wetland system during the growing season via vegetation (evapotranspiration) and open water surfaces (evaporation) at the expense of streamflow or groundwater recharge. More research on flood/storm peak modification effects by wetlands, and on the prediction of the hydrologic effects of wetland area losses, is required. The economic value of wetland effects in streamflow modification in studies in Michigan has been suggested to be over $100 000/ha (Richardson 1981). In the case of southern Ontario alone, this would translate into a fixed value exceeding $2.7 billion for protection of settled watersheds by remaining wetlands.

Table 10–3. Designated wetland and riverine species identified by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as of April 1985

COSEWIC Designation	Mammals	Birds	Fish	Plants
Endangered	(R)* Beluga Whale (W)* Wood Bison	(W) Piping Plover (W) Whooping Crane	(R) Gravel Chub	(W) Pink Coreopsis (W) Pink Milkwort (W) Southern Maidenhair Fern (W) Small White Lady's Slipper (W) Water-Pennywort
Threatened	—	(W) Henslow's Sparrow (W) White Pelican	(R) Shorthead Sculpin	(W) American Water-Willow (W) Plymouth Gentian
Rare	—	(W) Caspian Tern (W) King Rail (W) Prothonotary Warbler (W) Ross Gull (W) Trumpeter Swan	(R) Bigmouth Shiner (R) Blackstripe Top Minnow (R) Brindled Madtom (R) Central Stoneroller (R) Charlotte Unarmoured Stickleback (R) Giant Stickleback (R) Pugnose Minnow (R) Pugnose Shiner (R) River Redhorse (R) Shortnose Sturgeon (R) Silver Chub (R) Silver Shiner (R) Speckled Dace (R) Spotted Gar (R) Spotted Sucker	

**R—Riverine species, W—Wetland species.*

COSEWIC considers information from the most reliable sources and assigns status in one of the following categories:

ENDANGERED: *Any indigenous species of fauna or flora whose existence in Canada is threatened with immediate extinction throughout all or a significant portion of its range, owing to the actions of man.*
THREATENED: *Any indigenous species of fauna or flora that is likely to become endangered in Canada if the factors affecting its vulnerability do not become reversed.*
RARE: *Any indigenous species of fauna or flora that, because of its biological characteristics, or because it occurs at the fringe of its range, or for some other reasons, exists in low numbers or in very restricted areas in Canada but is not a threatened species.*
EXTIRPATED: *Any indigenous species of fauna or flora no longer existing in the wild in Canada but existing elsewhere.*
EXTINCT: *Any indigenous species of fauna or flora formerly indigenous to Canada no longer existing elsewhere.*

Source: Price (personal communication).

Large wetlands in urban or agricultural regions may have substantial value in their role as solar-powered water purification systems. Wetland soils and vegetation modify inflowing water by cycling elements, storing organic materials and other ions, and modifying water temperature. Freshwater wetlands "trap" nitrogen (N) and phosphorus (P), at least seasonally, and serve as settling areas for sediments. Whillans (1985) noted a potential value of wetlands of $50 000/ha for protection of Michigan watersheds by water purification and pollution sinks. At this value, and again using southern Ontario as an example, these wetlands would provide a fixed value exceeding $1.3 billion for Ontario. Growing evidence indicates significant potential for use of freshwater wetlands in some tertiary waste treatment functions (Wile and Miller 1981; Horwitz 1978; Kadlec 1978). Wetlands may also play a significant role in the modification of acid precipitation and sulphur (S) and heavy metals impacts on aquatic ecosystems in sensitive regions (Anderson 1986). They also can act to trap pesticide residues from farm runoff (herbicides and insecticides) in agricultural areas.

Wetland vegetation plays a major role in erosion control as it binds and stabilizes shoreline substrates, and dissipates the energy of waves, currents, and tides along freshwater and marine shores. Removal of wetland vegetation from shorelines and estuaries effectively eliminates the protective buffer for uplands, at times resulting in accelerated erosion and high costs to landowners and citizens. As in the case of river floodplains, estuarine wetlands provide a place for water to spread and be slowed by vegetation. Inherent limitations of wetland vegetation in providing such erosion control include undermining by wave and water, severe damage by ice and floating debris, and coverage by silt and debris during floods (Allen 1978).

Recreational, Scientific, and Educational Values

Outdoor recreation (including all those activities which help to restore and refresh people) is growing in national importance due to increased leisure time and a trend towards a higher standard of living. Wetlands provide recreation for naturalists, photographers, artists, canoeists, bird-watchers, hunters, fishermen, hikers, and others with outdoor interests. Some food-gathering activities, which may be considered recreational, occur within or adjacent to wetland areas; these include clamming on mudflats or picking berries. Noted recreational areas in Canada where wetlands form a major landscape include Point Pelee National Park (Figure 10–3) and the Big Creek Marsh in the Long Point National Wildlife Area (Ontario), Cap Tourmente National Wildlife Area (Quebec), Kouchibouguac National Park (New Brunswick), Delta Marsh (Manitoba), Last Mountain Lake (Saskatchewan), and the lower Fraser Delta (British Columbia). Many other wetlands across the country, often wildlife or conservation areas, provide recreational opportunities for regional or local residents. The value of the Point Pelee Marsh along Lake Erie as a significant recreational resource has been estimated by Kreutswiser (1981) (Table 10–4). It has been estimated that the recreational consumptive value of sport fishing, hunting, and trapping attributed to wetlands in Canada is approximately $1.5 billion per year (in 1981 dollars) (Coley 1985). Coley also has estimated that the annual value of non-consumptive recreation in wetlands exceeds $3 billion.

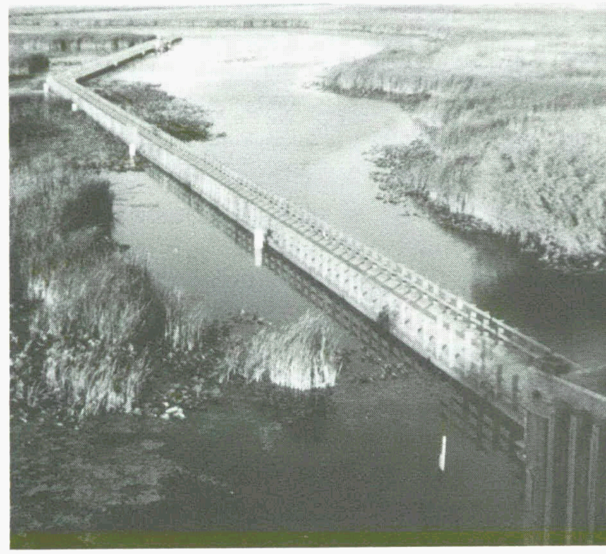


Figure 10–3.
Public boardwalk through shore marshes at Point Pelee National Park, southwestern Ontario.

Visual or aesthetic appreciation of the wetland environment is tied closely to many wetland activities. The visual diversity and contrast provided by the distinctive landscapes and unique biological and physical elements can positively affect the aesthetic sense. Wetlands in built-up areas are particularly

Table 10–4. Expenditures of recreational users of the Point Pelee Marsh

Mean user party expenditures	*Nature viewers*	*Canoeists*	*Primary users*	*Secondary users***
	n = 54	n = 9	n = 68	n = 100
Travel	$10.10	$ 3.78	$ 8.89	$ 9.03
Accommodation	6.83	0	5.44	6.67
Food and drink	9.48	3.64	8.06	10.10
Other	6.30	5.64	6.29	4.89
Total spending	32.71	13.06	28.68	30.69
Local spending	31.66	7.23	27.70	29.33
Estimated number of user parties			21 379	29 560
Estimated total spending ($1 066 748)			613 150*	453 598**
Estimated local spending ($1 025 695)			$592 198	$433 497**

Source: Modified from Kreutswiser (1981).
**Mean user party expenditure for all primary user respondents including four fishermen in party.*
***This assumes that one-half of the mean expenditure of secondary users can be attributed to the wetland recreational component of their visit.*

important for providing a visual, auditory, and olfactory "break" from the urban–industrial environment.

Wetlands also serve as outdoor education or natural history exhibits and as scientific laboratories (Figure 10–4, a and b). They provide an excellent resource base for research, teaching, or learning about ecosystem structure and functions. Ecological principles of natural systems, such as energy flow, diversity, recycling, and limited carrying capacity, can be effectively demonstrated. Environmental problems arising from failure to recognize the applicability of these concepts in our activities can be simulated and investigated with a view to a better understanding of man–environment interactions.

Renewable Resources Harvest

Canadians also directly reap economic and other benefits related to wetland productivity. For example, wild rice and cranberries are harvested from wetlands. At least eight wild rice processing plants exist in Canada, annually producing from 200 000 to 500 000 kg in the 1980–82 period with a value of up to $7 million annually (Winchell and Dahl 1984). These plants are concentrated in Saskatchewan, Manitoba, and Ontario but limited harvesting is also now underway in Nova Scotia. Marsh hay is cut in some areas for use as winter forage.

Fish and wildlife associated with wetland habitats are harvested for sport and profit, or for more traditional lifestyle uses. Several fur-bearing mammals, which are highly dependent on wetland habitats, are commercially hunted or trapped for their pelts or meat. The value to Canada in 1976 of mink, beaver, and muskrat alone exceeded $50 million (Statistics Canada 1985b). Other native and commercial trapping has been estimated to exceed $19 million in wetlands annually (Coley 1985). Many of the most commercially valuable fish and shellfish in the United States, and also likely in Canada, are wetland- or estuary-dependent (Horwitz 1978). Interpretation of data published for 1983 (Fisheries and Oceans Canada 1985; Statistics Canada 1985a) indicates that the national landed value of such species may have exceeded $78 million, a significant portion of the Canadian fishery in that year (Table 10–5). Fish farming of several species is a growing commercial business in western Canada with shallow water wetlands used as fish-holding areas. For example, a significant autumn rainbow trout harvest is conducted each year by this method.

(a)

(b)

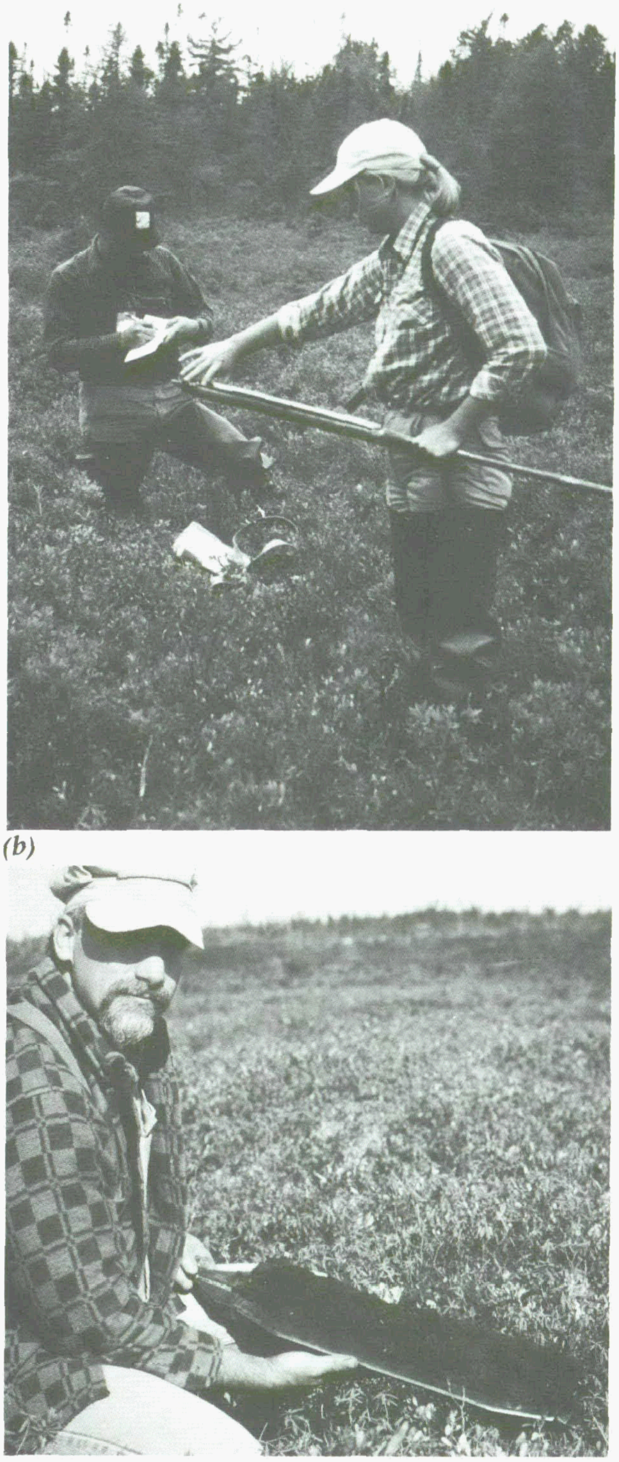


Figure 10–4.
The study of peatland ecology and developmental history is undertaken through integrated analysis of surface vegetation, waters, and physiography and subsurface coring of peat profiles. Researchers in (a) Kejimkujik National Park, Nova Scotia, and (b) Kouchibouguac National Park, New Brunswick.

*Table 10–5. Canadian wetland fisheries values (1983)**

Fishery sector	Saltwater 1983 landed value ($000s)	Freshwater 1983 landed value ($000s)
Freshwater fishery		
Sturgeon (× 30%)	—	108
Catfish	—	446
Yellow pickerel (× 30%)	—	3 907
Pike	—	1 873
Perch	—	11 972
Carp	—	160
Sunfish	—	130
Ocean groundfish fishery		
Flatfish (Flounder × 20%)	5 004	—
Tomcod	20	—
Ocean and freshwater pelagic/finfish fishery		
Alewife (× 30%)	212	70
Eel	961	392
Salmon (× 30%)	34 794	40
Smelt	491	3 686
Capelin	5 621	—
Shad (× 30%)	14	—
Ocean mollusc/crustacean fishery		
Clam (× 75%)	5 612	—
Oyster	2 927	—
Total freshwater fishery	—	22 787
Total ocean fishery	55 656	—
Total 1983 wetland fishery	78 443	

Source: Interpreted from Fisheries and Oceans Canada (1985) and Statistics Canada (1985a).

**Table includes fishery species deemed to be, in part or in whole, dependent on coastal and interior wetlands, shallow waters, and estuaries in Canada for feeding, reproduction, or other essential life functions (P.J. Rubec, personal communication; J.S. Beckett, personal communication).*

A potential domestic market of $2.3 million in Saskatchewan alone has been predicted (G.D. Adams, personal communication).

An Environment Canada study on the economics of Canadian waterfowl concluded that the present waterfowl resource enables Canadians to receive annual net benefits in the order of $118 million, indicating the considerable importance of wetland habitat conservation (Fogarty *et al.* 1982).

The Conversion Perspective

Across Canada, a wide range of pressures on the wetland resource base exists. These include drainage for agricultural and urban expansion, infilling for construction of port facilities, industrial parks, roads, and recreational lands, harvesting for horticultural and energy uses, and alterations of water regimes for hydroelectric development or forest harvesting. In each sector, these have led to significant economic benefits to Canadians which must be weighed against those conservation values identified in the preceding section of this chapter. The following discussion examines the major aspects of the use of wetland resources in Canada which in some way reclaim, alter, or destroy their physical structure, water regime, soils, or biota.

Agricultural Reclamation

Historically, agricultural reclamation has been the major force behind wetland decline in Canada, accounting for widespread and significant encroachment on the wetland resource base. The conversion of wetlands to agricultural uses began with the arrival of the first settlers and continues to this day. Significant issues include the following:

(1) Drainage, infilling, and cultivation of wetlands in the "prairie pothole region" of western Canada.
- Alberta, Manitoba, and Saskatchewan contain the largest single expanse of arable land in Canada. Located in the southern third of the provinces, this area is characterized by an abundance of shallow "sloughs" or "potholes", varying in size from fractions of a hectare to several hundred hectares (Figure 10–5). The high density of these wetlands also makes the region a vital component of North American migratory bird habitat. Migratory birds, especially waterfowl, are dependent on these wetlands for food, nesting and brood habitat, protective cover, and staging areas.
- The intense conflict over the use of prairie wetlands for wildlife habitat or for agriculture is the most extensively documented of the wetland issues in Canada. Losses of wetland habitat to agriculture over the past century have been progressive and severe, occurring in all parts of the prairie pothole region. In addition to the direct loss of wetland basins through artificial drainage, agricultural intensification often results in the deterioration of marsh-edge vegetation—the essential upland component of waterfowl habitat. This widespread reduction of habitat has been cited as a major factor in the diminishing annual production of waterfowl, particularly since 1960 (Mattson *et al.* 1978; Rakowski 1980).

Figure 10–5.
The prairie pothole area of southwestern Manitoba near Minnedosa, with a mosaic of small wetlands and intensive agricultural land uses.

(2) Extensive diking of large expanses of salt marshes protecting these areas from tidal inundation.
  - Some of the largest and most important areas of marshland in Atlantic Canada are also the focus of conflict between agriculture and wildlife use: the Tantramar Marsh (straddling the Nova Scotia–New Brunswick boundary at the head of the Bay of Fundy); the Annapolis Valley (west–central Nova Scotia); the Fraser River Estuary and Delta (southern British Columbia); Lake St. Pierre, the Kamouraska area, and the St. Lawrence River Estuary (Quebec). Although coastal dikes were often originally constructed for protection against flooding, a large proportion of the dikeland is currently under production for forage crops, fruits, and vegetables and is used as pasture for livestock.

(3) Agricultural reclamation of lake-shore and river-shore wetlands, and scattered pockets of inland bogs, marshes, and swamps.
  - The extensive organic wetlands of the Cariboo–Chilcotin District (British Columbia) are of major importance to ranching operations for hay production or direct fall and winter grazing, with increasing pressure for more active management and more extensive conversion.
  - Substantial drainage has occurred on four major river floodplains of Nova Scotia: the Cornwallis, Annapolis, Musquodoboit, and Shubenacadie rivers, which comprise the principal agricultural area of that province.
  - Drainage for agriculture is identified as the major factor in the decline of southern Ontario's wetland area (Snell 1986; Bardecki 1984). Because this area is important for staging waterfowl, fisheries and wildlife habitat, flood buffers, and shoreline protection along the Great Lakes, much concern has been expressed regarding continued small-scale drainage.
  - A number of peatland areas have been drained to provide highly productive agricultural areas. Sites in the lower St. Lawrence Valley in Quebec, the Holland Marsh in southern Ontario, peatlands in southeastern Manitoba, and the Fraser River Delta of British Columbia are examples. However, in some cases, such as the Alfred Bog in eastern Ontario, drainage of peatlands has resulted in loss of valuable wildlife habitat and relatively rare flora, and associated degradation of adjacent protected conservation lands.

Originally, wetlands were reclaimed for agriculture because they were viewed as potentially productive farmland. More recently, wetland drainage has often been the result of economic pressure to bring every available unit of arable land into production (Figure 10–6). Agricultural expansion onto marginal lands, including wetlands, has been encouraged by an increased demand for goods, ready markets, rising production costs and the attendant need to increase farm efficiency, as well as by government subsidies. In some cases, the development of prime agricultural land for other uses forces farming activity onto the less productive marginal lands, including wet areas. In other cases, the growing demand for agricultural land and subsequent price or tax increases result in the improvement of existing resources including the drainage of wetlands, rather than the acquisition of more land. However, several major concerns have been raised across the nation regarding the agricultural use of wetlands: their value for crop production, the economic and environmental costs of drainage, and their promotion and subsidization by governments.

The agricultural use of wetlands has proven successful in some areas. Market gardening production of national and regional significance, an industry worth over $100 million annually, has been based on peatlands, for example in the fertile farmland of the Fraser Delta, British Columbia. However, numerous reports detail drainage schemes which have resulted in only limited agricultural benefit. Reed and Smith (1972) noted that many hectares of diked land remain idle in the Maritimes because of the limited agricultural value of reclaimed tidal marsh often due to high residual soil salinity. In a study of drainage projects, Found *et al.* (1975) identified specific projects with poor cost–benefit ratios particularly in eastern and northern Ontario. Other case studies (Day *et al.* 1976; Diebolt 1981) reveal the failure of drainage to increase agricultural productivity as expected. Wetland clearing and drainage in the Prairies often result in increased soil salinization, which ultimately reduces crop success (Cowan 1982). In addition to the financial costs of wetland drainage, possible environmental costs include changes in groundwater levels, water quality, and magnitude and timing of streamflow, often resulting in downstream flooding, reduced baseflows, and the loss of vegetation and wildlife habitat.

Figure 10–6.
Drainage of wetlands for agriculture has been the major factor in Canada resulting in wetland land use conversions. The Ford Marsh on Lake St. Clair, Ontario, has been extensively altered by drainage installations.

Provincial and federal legislation has been criticized for accelerating the drainage of wetlands for agricultural use, particularly through programs which include subsidies and cost-sharing agreements (Bardecki 1981, 1984; Day *et al.* 1976; Found *et al.* 1975). An assessment of the Canada–Ontario Eastern Ontario Subsidiary Agreement on Drainage (Cecile *et al.* 1985) indicated that most of the drainage undertaken in this region has been non-economical (i.e. the costs will never be recouped in increased agricultural production) and in fact has led to considerable negative environmental effects.

Property tax and quota allotment systems provide incentives for farmers to reclaim poorly drained lands. However, there is a general lack of mandatory, comprehensive assessment of the cost–benefit or environmental impacts associated with drainage projects. Present procedures for obtaining approval and assistance for drain construction do not adequately take into consideration the uses and values of wetlands, and the associated implications of drainage.

Urban and Industrial Use

Although not as extensive as agricultural reclamation, urban and industrial development results in a progressive conversion of wetlands which excludes other uses. Wetlands across Canada have been developed for harbour facilities, manufacturing plants, garbage dumps, warehouses, roads, airports, residential developments, utility rights-of-way, and shopping centres. Since 1950, increasing pressures for the dredging, draining, and filling of wetlands for these developments have resulted in severe reductions of the wetland base. Wetlands near urban centres are under particularly severe stress, yet it is these wetlands that are most valued by urban dwellers because of their relative ease of access (Figure 10–7). Rubec (1980) has estimated that less than 0.2% of all of Canada's wetlands lie within 40 km of the centre of the cities where over 55% of Canada's population reside—in our 23 largest metropolitan areas.

Figure 10–7.
Urban expansion such as this example near Hull, Quebec, has depleted most wetlands nearest Canadian cities. Remaining areas are rare and may be the nation's most valued wetlands.

The shorelines of the St. Lawrence River, lower Great Lakes, and Canada's east and west coasts are the focus of this urban expansion. Historically representing the meccas for urban growth, many major centres have been established adjacent to natural harbours, facilitating transportation of renewable resources and manufactured goods.

Lake Ontario has suffered rapid and severe losses of shoreline marsh wetlands due to urban and industrial expansion, primarily along the heavily populated western shore from the Niagara River to the Oshawa area. Industries and harbours occupy the greatest area of reclaimed marsh, followed by urban utilities and facilities for residential activities (Lemay 1980). In fact, no natural harbour along Lake Ontario remains unexploited for port facilities (Laidlaw 1978). New port facilities on the Lake Erie shoreline, with attendant urban expansion and industrial complexes, increase the potential for environmental impact and resource use conflicts in that area.

The northern shoreline of the St. Lawrence River is another area of urban and industrial development, particularly in major port centres such as Montreal, Quebec City, and Trois-Rivières. Residential construction, harbour dredging, public utilities, and industrial expansion comprise the primary land uses encroaching on wetlands (Le Groupe Dryade 1980). Of most concern in this area is the decline of important migratory bird habitat. Although the rate of land use change appears to be declining, current pressures are significant in the context of a reduced resource base (Environment Canada 1986a).

The Atlantic and Pacific coastal areas of Canada are also under pressure to accommodate urban and industrial development. There is concern about encroachment on coastal salt marshes and deltaic freshwater marshes, and the impact on fish and wildlife resources, particularly salmonids and waterfowl.

Along the Pacific coast, urban population and development are concentrated in the Strait of Georgia region, which includes the southern mainland and southeast coast of Vancouver Island. Wetland conversion and degradation in the region are mainly related to the expansion of shipping facilities (including extensive dredging to deepen the shipping channel), major diking schemes for flood control, landfills for industrial and residential development, and the impact of log handling, storage, and boom assembly on the estuarine ecosystem. Of particular concern is the estuary of the Fraser River which accommodates the largest salmon runs in the world, supports the largest population of wintering waterfowl in Canada, and represents the most important stopping points for migrating birds on the Pacific Flyway.

North of the Strait of Georgia, the effect of development has been relatively minimal. Increasing pressure is anticipated, however, due to requirements for more log storage and movement and to the construction of port facilities for the transportation of interior coal and gas. Prince Rupert, which is the major centre on the northern coast, is adjacent to the Skeena River Estuary; this estuary and the Kitimat River Estuary to the south are focal points for development in the north. Factors such as relative proximity to coal and gas fields, established port facilities, and abundant hydro power encourage further industrial development.

In the Prairies, large saline wetlands in several locations are being degraded by potash and salt extraction plants, through dumping of tailings and runoff from these tailings, which often contain elevated levels of toxic contaminants.

Although urban and industrial pressures on the wetlands of Canada's east coast have not been as severe as those on the Strait of Georgia, development has resulted in significant changes to wetlands. Reed and Smith (1972) noted the predominant influence of agricultural use on wetlands and, to a lesser extent, the effect of urban and industrial development on the declining salt marsh area.

Atlantic coastal areas appear to be on the verge of undergoing greater pressure from development projects. Current issues centre upon the possible impacts of urban and industrial expansion, especially roads and port facilities, on large and productive estuarine salt marshes which provide important habitat for a variety of aquatic and wildlife populations. The Halifax–Dartmouth and Saint John areas have come under considerable pressure in recent years.

Beyond these shorelines, wetlands proximal to other Canadian cities are also under substantial direct pressure for conflicting uses. The collective conversion of these wetlands is particularly significant since they represent a valuable conservation and recreational resource to the residents of urban centres.

Energy Development

Canada's wetlands are also endangered by the ever-growing demand for energy production and transmission. The impoundment of reservoirs for hydroelectric generation has flooded extensive wetland areas; the control of river regimes has altered delta marshes and mudflats; heavy oil extraction plants have contributed to wetland water pollution through wastewaters, drilling mud, and oil residues; and the construction and maintenance of an extensive network of transmission lines have interfered with a wide range of wetland areas. Furthermore, the recent search for energy alternatives has introduced new threats to our wetland resource including the harnessing of tidal power and the extraction of peat for the generation of electrical energy (see the following section on peat harvesting).

Unlike direct conversions related to agriculture and urban development, the production of hydroelectric energy can result in far-reaching and subtle changes in the nature and area of wetlands in a watershed. Predicted changes to wetlands resulting from such developments tend to be well documented in the environmental impact statements of development proposals. A case study of the W.A.C. Bennett Dam on the Peace River provides insight into the upstream and downstream implications of hydroelectric development.

A number of factors contributed to the highly controversial nature of this project, ensuring that much attention and study were focused on the site. For example, the Peace–Athabasca Delta of northeastern Alberta is ranked among the largest freshwater deltas and the most biologically productive wetlands in the world. It covers an area of 4 400 km^2, is situated primarily in Wood Buffalo National Park, and is the foremost delta in the national park system. It provides high-quality waterfowl habitat, which is especially important during drought years on the southern Prairies and because of continued drainage of the prairie potholes. It is a key link in all four North American flyways which cross it. The Delta also plays a major role in the well-being and lifestyle of the local people and their regional economy.

The construction of the Bennett Dam in 1968, 1 170 km upstream, effectively reduced spring flooding and average water levels on the Delta. By 1970, more than 50 000 ha of mudflats were exposed, which resulted in the replacement of the original marsh vegetation by grassland and willow scrub. Ice-jam floods have occasionally resulted in replenished vegetation since 1972, although it remains to be seen whether the ecology of the Delta will survive in the long term (Hughes and Cordes 1981). The Peace–Athabasca Delta Project Group predicted a long-term 50% decline in shorelines which are important to many wildlife species. The Group also expected waterfowl production to decline by approximately 20–30% due to the loss of suitable habitat. Damage to the fish and wildlife populations may affect a major source of income for the Chipewyan Indian Reserve, located on the Lake Athabasca portion of the Delta.

While the combination of these factors is not typical of all wetland areas affected by energy development, this case is useful for demonstrating the nature of physical and biological changes, and socio-economic implications, related to the damming of rivers for power generation. This issue also provides a good example of the complexity of the legal and jurisdictional framework for water management in Canada, since Lake Athabasca (which is adjacent to the Delta) traverses both Saskatchewan and Alberta, and the headwaters of the Peace River are in British Columbia.

There are problems on the Saskatchewan River Delta which are similar in nature to those of the Peace–Athabasca Delta, albeit on a smaller scale. Changes in the flows of the North and South Saskatchewan rivers, and hence the water regime of the Delta, are the result of several activities, including the construction of two dams for the generation of hydroelectric power. River flow also has been controlled to some extent by installations for irrigation and recreation. The Saskatchewan River Delta is an extremely productive wildlife habitat, and provides an integral part of the livelihood of many delta residents. It is clear that the fluctuating water levels of the Delta have adversely affected the fish, fur-bearing animals, and waterfowl on which the local economy depends, even though the extent of this impact has not been accurately defined (Committee on Saskatchewan River Delta Problems 1972). Over 1 500 km² of delta wetland habitat have been destroyed by the flooding of the lower Delta; this in turn is the result of the expansion of Cedar Lake in Manitoba, due to the Grand Rapids Dam (G.D. Adams, personal communication).

Similar effects are also likely to occur in the following large wetland habitats: the James Bay Development Territory in Quebec, the Churchill Falls Development in Labrador, the Nelson River in Manitoba, the Liard River in British Columbia, and the Slave River in Alberta. The proposed or projected construction of large-scale hydro dams on northern rivers is of considerable concern because of the crucial importance of their deltas in supporting a rich wildlife community.

The interest in tidal-power development in Canada has been focused on the Bay of Fundy, where the tides are among the highest in the world. Dams would be required to maintain a hydraulic head in smaller bays and valleys along the Fundy shoreline, the flow from which would be controlled to generate electricity. These dams would have an effect on tidal amplitude and therefore on tidal wetlands, particularly the salt marshes situated at the head of the Bay of Fundy (Pearce and Smith 1974).

Several sites have been the subject of feasibility studies over the past three decades: Passamaquoddy and Cobscook bays, located on either side of the international border between New Brunswick and Maine, and Shepody Bay, Cumberland Basin, and Cobequid Bay, all located at the head of the Bay of Fundy. Studies have concluded that, despite the technological feasibility of the schemes, prevailing economic conditions render them impractical.

Pearce and Smith (1974) examined the potential effect of altered tidal regimes on salt marshes and their use by waterfowl. They concluded that waterfowl use of Passamaquoddy Bay and Cobequid Bay would probably be influenced only minimally by the power structures, despite some reduction of wetland area. Because Shepody Bay and Cumberland Basin are bordered by extensive salt marshes and mudflats, enclosure of these bays would have much more substantial influence on wetland area and on waterfowl use. They indicated that further studies would be required to evaluate these changes adequately and to assess potential impacts on seabirds and shorebirds.

Construction of a demonstration tidal-power generating station has been completed in the lower reaches of the Annapolis River Basin in southwestern Nova Scotia. There is apparently little concern for further encroachment on the wetland resource, since the area has already been modified by the barrage. The Annapolis River Valley is generally not considered to be an important area for wildlife, primarily because of its lack of undisturbed habitat (Martec Limited 1980).

Peat Harvesting

Although peat has been commercially harvested in Canada for the past 50 years, interest in using the nation's abundant reserves of organic matter has heightened since the 1970s. Canada is second only to the Soviet Union in estimated peat reserves, having just over 30% of the total world reserve. In recent years, peat production in Canada has totalled approximately 500 000 tonnes annually, valued in 1983 at over $47 million, with Quebec and New Brunswick contributing almost half of this total (Table 10–6). The demand for peat, for agricultural and horticultural uses and as a fuel (Figure 10–8, a and b), steadily increases each year (Bedard 1982; Levesque 1982). However, to date no national peatland reclamation policy exists in Canada.

While peatlands are generally less productive than other wetland ecosystems, their large extent, remoteness, and interspersion throughout more productive environments provide habitat for a wide variety of wildlife species which may be threatened by large-scale utilization of peatlands (Osborne 1982; Clarke-Whistler and Rowsell 1982). Peat mining may also cause changes in the quality of receiv-

Table 10–6. Peat production in Canada by province (1983)

Province	Metric tonnes (000s)	$ (000s)
Newfoundland	3	20
Prince Edward Island	—	—
Nova Scotia	10	2 008
New Brunswick	151	9 792
Quebec	238	18 216
Ontario	4	546
Manitoba	54	7 266
Saskatchewan	8	1 053
Alberta	47	6 585
British Columbia	14	2 324
Yukon	—	—
Northwest Territories	—	—
Total	529	47 810

Source: Statistics Canada (1983).

ing waters, thus affecting fish and invertebrates downstream or reducing the potential of downstream usage. Drainage of a peatland causes a reduction in the water table beneath the bog, with a possible drawdown effect in the surrounding area. Other impacts related to peat mining include direct removal of habitat, and secondary disturbances associated with roads and vehicular traffic, noise, and human presence (Clarke-Whistler and Rowsell 1982).

The use of peatlands in Canada for energy has been minimal to date. Uncertainties about the extent and quality of peat resources, the economic feasibility of generating peat-fired electrical energy, and the long-term environmental impacts associated with peat mining have thus far hindered the development of large-scale utilization of the resource for fuel purposes. In the last decade, however, research has been aimed at addressing these issues (Chornet 1983). Inventories and evaluations of peat resources are being undertaken to encourage development in the context of long-term resource management (Keys *et al.* 1982; Tibbetts 1983; Monenco Ontario Limited 1981). Fuel peat demonstration projects such as those in Newfoundland and Saskatchewan are assessing the potential for a fuel peat industry (Winsor 1983a, 1983b; Rees 1983; Korpijaakko and Guilor 1983). Other technical studies are addressing problems associated with harvesting, processing and transportation, and reclamation of harvesting sites. In general, current research supports development of a limited scale of peat exploitation for energy, although the future of the resource is dependent on more detailed economic and technical evaluations (Monenco Ontario Limited 1981; Wells and Vardy 1980; Tarnocai 1984; Manuel 1984).

(a)

(b)

Figure 10–8.
(a) Drainage system at a peat harvesting site in eastern Manitoba. (b) Commercial raspberry production on a drained and managed peatland in eastern Manitoba.

Forest Harvesting

Forested wetlands are not usually considered when the issue of wetland damage or conversion is discussed. In many parts of Canada, however, a significant portion of the annual harvest of black spruce (*Picea mariana*) depends on these sites which are in fact sensitive, easily damaged, and difficult to manage. In the Eastern Temperate Wetland Region, in southern Ontario in particular, selected hardwood harvesting in some treed swamps is a significant activity. The overall economic value of peatland and hardwood swamp forestry may be as high as 2% of the national forest industry. This corresponds to a net annual value to Canada of over $525 million.

In Ontario, where over 7.9 million ha of productive forest are mainly made up of peat-dominated wetlands (i.e. peatlands) (Ketcheson and Jeglum 1972), the physical damage to site and inadequate regeneration are two of the most severe problems in peatland forestry (Jeglum *et al.* 1982). In most provinces, peatlands are usually distant from major population centres; hence few people are aware of either the economic or the ecological consequences resulting from damage to these sites. Although the problem in some areas is widespread and serious, few studies have been done which provide quantitative documentation.

Sensitivity

Although peatlands generally have low-strength soils, some peatlands are more sensitive to damage during harvesting operations than others. In general, depth of peat, degree of decomposition, and depth to water table determine site sensitivity. Sites that have a high water table, and deep, moderately to well decomposed (mesic–humic) organic material are more sensitive than sites with a deeper water table and poorly decomposed (fibric) organic material. In Ontario, where attempts to classify peatland sites have been ongoing for a number of years (Jeglum *et al.* 1974; Gemell 1979; Scott and Virgo 1977), the less sensitive sites are dominated by black spruce and *Ledum* shrubs, whereas the more sensitive sites are dominated by black spruce and *Alnus* shrubs. In the *Ledum* type, peats tend to be more shallow and have deeper fibric material. The *Alnus* type, which tends to have deeper and more highly decomposed peat, is further subdivided depending on whether or not the site is influenced by seepage water. The stronger seepage condition represents the type of peatland most sensitive to damage.

Harvesting Impacts

In order to harvest these peatland sites a number of approaches are being used. Prior to the mechanization of harvesting, logging of peatlands was carried out during the winter using horses to skid the logs to a landing. This method of harvesting caused little site damage, and residual trees or seedlings provided a basis for regenerating the new stand. Mechanization brought the narrow-wheeled skidder and the opportunity to harvest peatlands on a year-round basis. Since peatlands have a low bearing capacity, the narrow-wheeled skidder easily penetrates the surface root mat causing deep rutting on the site. Those sites with a high water table and well-decomposed peat are especially sensitive to this practice. On those sites where significant seepage occurs, the water table over the entire site can be substantially altered. Because of the low bearing characteristics of these sites, the skidders are unable to make frequent passes over the same ground. This results in uncontrolled roaming over the site during the skidding operation with widespread rutting and damage.

A recent study by McColm (1983) showed that in the Ontario Clay Belt over 40% of a cutover site was rendered untreatable and did not regenerate because of extensive site damage. Damage was attributable to the use of inappropriate logging equipment during the frost-free season. Better planning, strategic road location, and the scheduling of operations so that less sensitive sites were harvested during the frost-free period were suggested as methods for reducing damage. Similar results were obtained during a study of rutting on recently harvested peatlands (A. Groot, personal communication). How long these untreatable and unregenerated conditions last is uncertain; but there is no doubt that the successful regeneration of a site is significantly delayed and represents an economic cost for the future.

Winter harvesting of peatlands reduces substantially the extent and degree of damage associated with these sites. Unfortunately, in some areas of the country, such as the Clay Belt, most of the commercial cut for many of the companies is taken from peatlands. Under these circumstances, the scheduling of harvesting on peatlands only during the winter months is operationally difficult. In recent years, therefore, much effort has been directed towards the development of techniques which will enable the forest industry to operate on these sites throughout the year. These efforts have resulted in the development of wide, high-flotation tires mounted on a conventional wheeled skidder (Mellgren and Heidersdorf 1984). The tires exert a much lower ground pressure and are able to traverse the sites, even after repeated passes, with significantly less damage than that caused by the conventional narrow-wheeled skidder.

Drainage

While attempts to ameliorate site damage through improvements in mechanized harvesting techniques are being made, other approaches are also being tried in an effort to reduce damage and at the same time improve productivity. One such technique is drainage. Although widely used in Europe, particularly in the Scandinavian countries, as a method for improving the productivity of peatland sites, there has been little incentive in Canada, until recently, to adopt this silvicultural technique. Recent predictions of a decline in the availability of preferred tree species, particularly on sites close to existing mill locations, have prompted both government and industry to examine the possibility of using drainage in those areas where forested peatlands are an important component of the commercial forest base.

To evaluate both the economic benefits and the environmental impacts of forestland drainage, one of the first large-scale operational drainage trials in Canada has been recently carried out on a 400 ha site near Cochrane, Ontario. This trial, which is being co-sponsored by the Ontario Ministry of Natural Resources and the Canadian Forestry Service, has taken advantage of the experience gained in Finland using forest drainage.

Ongoing studies in Ontario have been established to evaluate the effects of the drainage on: (a) water quality and quantity in the streams both within and downstream from the site; (b) physical and chemical characteristics of the peat; (c) subsidence of the peat; (d) water levels in the various peatland types; (e) composition and growth of understory vegetation (mosses, herbs, shrubs); (f) growth rates of the major tree species (black spruce and tamarack (*Larix laricina*); and (g) foliar nutrient content in the major tree species. It is anticipated that projects such as this will demonstrate not only that improvements in forest productivity can be realized, but that forested peatland site accessibility and damage reduction can be achieved.

Recreational Use

Recreation on and adjacent to wetlands across Canada is both a reason for the preservation of wetlands and a factor in their decline. Activities such as game-bird hunting, fishing, bird-watching, hiking, and nature photography are considered "non-destructive", except in cases of overuse or disregard for the fragility of the ecosystem. Organizations which promote these recreational activities are often instrumental in the protection of wetlands through political lobbying, wetland acquisition, or wetland management.

There are, however, "destructive" recreational uses which have largely accompanied the trend towards acquisition of leisure homes on lakeshore sites. Coupled with the fact that many rural economies have benefited from tourist expenditures in vacation periods, wetlands have been widely perceived as nuisance areas. Marshes have been fragmented and eliminated in efforts to clean up the shoreline, dredged and deepened to provide bathing areas and boat access, infilled for the extension of cottage lots (Figure 10–9), and eradicated by the construction of docks and marinas. Ironically, the resulting loss of wetlands degrades the natural assets which originally attracted people to these areas. A decline in fish and wildlife populations, impaired water quality, and a noticeable loss of "natural aesthetics" are all possible effects of such wetland destruction.

Although wetlands continue to be eliminated from recreational waterfronts across Canada, the most detailed reports available pertain to the situation in Ontario. The Trent–Severn and Rideau River waterways have lost a majority of the original shoreline marshes to recreational development (Kawartha Region Conservation Authority 1981; Lewies and Dyke 1973; Laidlaw 1978). Substantial areas of the Lake Erie shoreline have also been converted to privately owned cottage lots. Further recreational conversion is expected on Lake Erie wetlands in association with industrial development, due to the lack of well-drained areas.

Trends in Wetland Conversion Across Canada

Wetland conversion from a natural state to other uses, in many cases considered a "loss" of wetland ecological characteristics, value, or function, has become a key environmental issue across Canada. In this section, brief reviews, with quantitative depiction of the rates of conversion mainly drawn from data of the Canada Land Use Monitoring Program of Environment Canada (Rubec and Rump 1984; Rump 1983; Environment Canada 1986b; Lynch-Stewart 1983), are presented for selected geographic segments of Canada. These are:
(1) the Pacific Coast;
(2) the Prairies;
(3) the Eastern Temperate Zone;
(4) the Boreal;
(5) the Atlantic Coast and Maritimes;
(6) the North; and
(7) the Mountains.

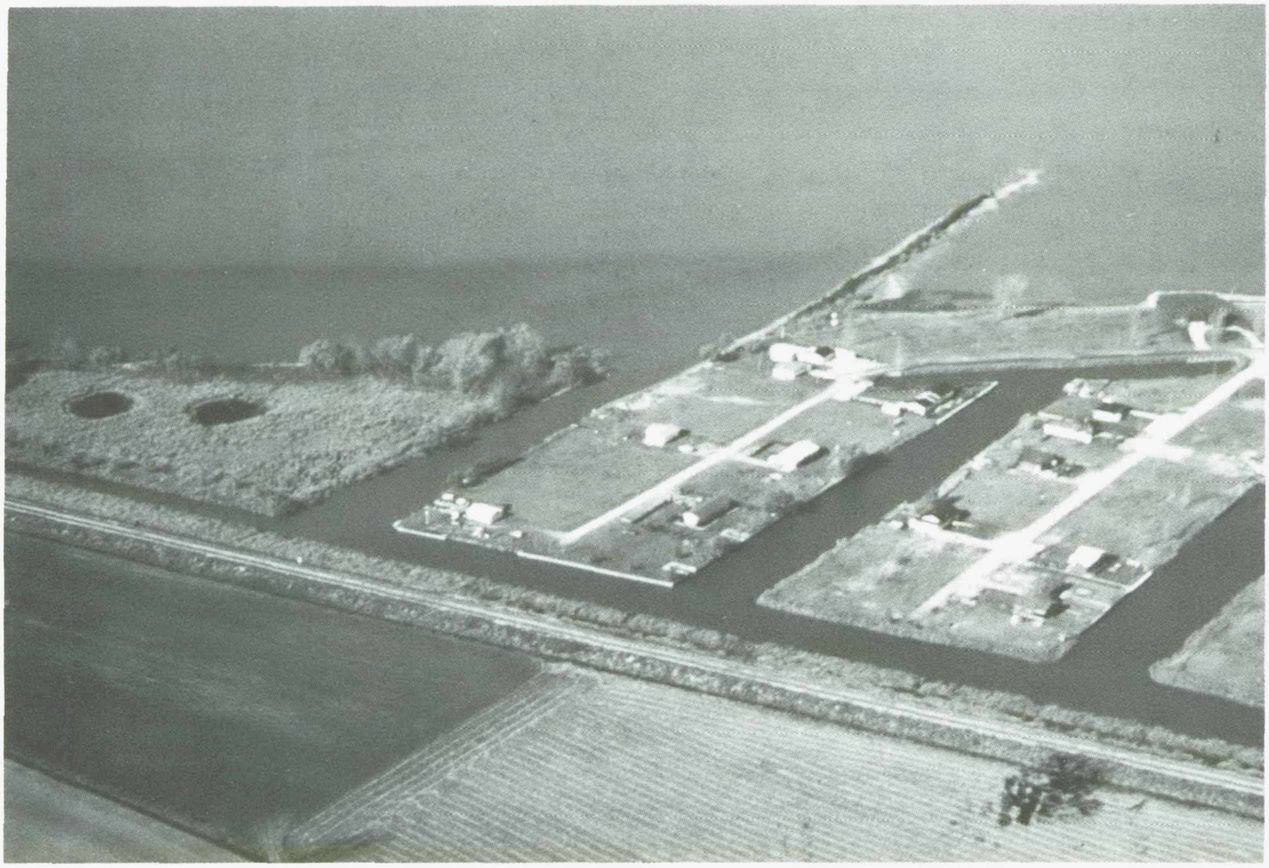


Figure 10–9.
Recreational cottage development of former marshes at the mouth of the Thames River on Lake St. Clair, Ontario.

For the purposes of this discussion, these segments of Canada are arbitrarily chosen within the general breakdown of the wetland regions of Canada as listed in Table 10–7.

Pacific Coast Wetlands

The Pacific Oceanic (OP) and Pacific Temperate (TP) Wetland Regions cover Canada's western coastal margin. The major wetland issue in this area of Canada has been the conversion and disruption of many small but ecologically significant marshes at river mouths, estuaries, and in river valleys. However, documentation of trends of wetland losses in quantitative or temporal terms is very sparse.

A study by Pilon and Kerr (1984) examined land use change on wetlands within a portion of British Columbia's southwestern Fraser Lowland. Wetlands were identified on the basis of soil and habitat characteristics. A map of these wetland areas was superimposed on land use maps for 1967 and 1982 to obtain change data. The analysis focused on the dynamics of wetland land use change relating to built-up, agricultural, recreational, and extractive land uses, as well as "natural" wetlands. Natural wetlands were defined as wet soil areas with unaltered natural vegetation cover and no known land use. The study reveals that 27% of natural wetlands in the study area were converted between 1967 and 1982 but only 11% were permanently "lost". Much of the remainder was actually

Table 10–7. Regional trends in wetland land use conversion across Canada: wetland regions and subregions*

Geographic area	*Wetland regions and subregions*
1. Pacific coast	OPn, OPs; TP
2. Prairies	PCa, PCg; PI; BMt
3. Eastern temperate	TE; BAg (minor); BL (minor)
4. Boreal	BAg (minor), BAi, BAn; BHc, BHh; BL; BMc; BMh
5. Atlantic coast and Maritimes	BAa, BAc, BAe, BAm, BAo; SAc, SAo; OA
6. Northern Canada	AH; AL; AM; SH; SL; ME
7. Mountains	MCc, MCn, MCs; MIc, MIn, MIs; MRc, MRn, MRs

**Wetland regions and subregions as defined by the National Wetlands Working Group (1986).*

changed to recreational and conservation uses which would preserve the natural wetland state. Built-up uses on wetlands almost doubled during this same period, resulting in permanent losses.

An additional study by Kessel-Taylor (1984a) concentrated on the urban centred regions (UCRs) of Vancouver and Victoria, examining wetland conversion from settlement to current times (Table 10–8). Urban centred regions are specifically defined settled areas in and around major cities in Canada as indicated in the Canada Land Use Monitoring Program conducted by Environment Canada (Rump 1983). About 79% of the wetlands originally present in Vancouver and 76% of those present in Victoria had been lost up to 1981 according to this analysis of Canada Land Inventory land capability and land use data.

Prairie Wetlands

The Continental Prairie (PC) and Intermountain Prairie (PI) Wetland Regions cover much of the south–central portions of British Columbia, southern Alberta, Saskatchewan, and Manitoba. These areas include the Aspen Parkland (PCa) and the Grassland (PCg) Prairie Wetland Subregions as well as portions of the Transitional Mid-Boreal (BMt) Wetland Subregion.

The intense conflict over the use of prairie wetlands for wildlife and waterfowl habitat versus their use for agricultural purposes is the most extensively documented wetland issue in Canada. Ten selected studies in the three western provinces provide data on past and current general trends (Table 10–9). A more extensive reference listing of

Table 10–8. Pacific coast major urban centred regions: wetland conversion summary

Urban centred region (UCR)	Area of UCR (km^2)	Estimated area of wetlands at settlement (km^2)	Area of wetlands 1981 (km^2)	Loss from settlement to 1981 (%)
Vancouver	1 800.8	462.0	98.4	79
Victoria	742.1	48.4	11.7	76

Source: Kessel-Taylor (1984a).

Table 10–9. Selected quantitative wetland land use conversion studies in western Canada

Region and authors	Study area size	Era	Net wetland change results
1. Aspen Parkland (Alta.) (Schick 1972)	699 km^2	(a) PP*–1950 (b) PP–1970	49% loss (area) 61% loss (area)
2. Battle River, 8 sub-basins (Alta.) (Ritter 1979, 1980)	12 950 km^2	PP–1978	3–13% loss (area)
3. South Saskatchewan River Basin (Alta.) (Schmitt 1980)	45 km^2	PP–1979	21% loss (area)
4. Southern Saskatchewan (Millar 1981)	82 km^2	1950–1980	27% permanent impact (no. of sites)
5. Black Soil Zone (Alta., Sask., Man.) (Goodman and Pryor 1972)	130 km^2	PP–1970	13% loss (area)
6. Newdale Plain (Man.) (Adams and Gentle 1978)	248 km^2	1964–1974	17% affected 7% eradicated (no. of sites)
7. Valley River Watershed (Man.) (Pokrant and Gaboury 1983)	1 786 km^2	1948–1981	68% loss (area of water and wetlands)
8. Minnedosa Pothole Region (Man.) (Kiel *et al.* 1972)	131 km^2	1928–1964	27% loss (area)
9. Minnedosa Pothole Region (Man.) (Rakowski *et al.* 1974)	131 km^2	(a) 1964–1974 (b) 1928–1974	41% loss (area) 57% loss (area)
10. Minnedosa Pothole Region (Man.) (Rakowski and Chabot 1983)	131 km^2	(a) 1974–1982 (b) 1928–1982	33% loss (area) 71% loss (area)

Sources: Lynch-Stewart (1983); Rubec and Rump (1984); Millar (1986).
*PP—Presettlement Period.

western Canada wetland losses has been prepared by Millar (1986). Losses have been progressive and severe and continue today.

A series of studies has focused on the Minnedosa pothole region of southwestern Manitoba. For the 1928–1964 period, Kiel *et al.* (1972) showed a conversion of wetlands in the Minnedosa region due to: (a) clearing and cultivation of surrounding basins; (b) infilling and road construction; and (c) complete or partial drainage. Over 50% of the available potholes were noted to have been adversely affected by these practices but only 27% were deemed to be permanently "lost". Rakowski *et al.* (1974) reported a further 40% decline in the Minnedosa wetland area from 1964 to 1974. Subsequently, Rakowski and Chabot (1983) reported the loss of a further 33% of the wetlands during the period from 1974 to 1982. In 1928, wetlands covered 13% of the Minnedosa Plain, whereas by 1982 they were reduced to 4% of the Plain. Adams and Gentle (1978) also have recorded that, from 1964 to 1974, 17% of selected sections of the Minnedosa wetlands were altered by clearing of wooded perimeters or by partial drainage, and 7% of the available ponds in these sections were eradicated permanently in that period. The loss of wetlands in the Minnedosa area appears to be continuing.

Several broader regional studies have focused on wetlands in western Canada. Goodman and Pryor (1972) examined wetlands in 600 randomly selected quarter sections across the Black soil zone of Alberta, Saskatchewan, and Manitoba for the 1940–1970 period and reported a total 13% loss of wetland area (with an additional 6% adversely affected). Millar (1981) reported detailed surveys of transects in southern Saskatchewan from 1950 to 1980. Over 27% of the wetlands in selected quarter sections showed permanent changes while 73% suffered short-term, transitory impacts.

Transitory impacts such as clearing, partial drainage, grazing, mowing, and edge burning, while they vary from year to year, have profound effects on wildlife, possibly more significant than impacts due specifically to drainage. Little data are available but net impacts on wetland vegetation, water regimes, and water quality are substantial (G.D. Adams, personal communication).

Selected watershed basins have been studied in western Canada as well. Ritter (1979, 1980) examined portions of the Battle River Basin in Alberta showing a severe loss of waterfowl habitat due to ditching and drainage (9% of water bodies and 18% of available river shorelines) from initial settlement to 1978. Studies by Schmitt (1980) on the South Saskatchewan River revealed similar wetland conversion results (21% of water bodies and 15% of shoreline wetlands lost) from settlement to 1979.

Other studies include that of Schick (1972), who reported an analysis of a small area of the Alberta Parkland documenting a loss of 61% of the wetlands from about 1900 to 1970. A study of the Valley River Watershed in Manitoba by Pokrant and Gaboury (1983) indicates a loss of 68% of the water and wetlands in this basin between 1948 and 1981.

Studies of wetland losses near western Canadian UCRs are also reported in Kessel-Taylor (1984a); studies for Edmonton, Calgary, Saskatoon, Regina, and Winnipeg are summarized in Table 10–10. Losses since settlement times in western UCRs range from 76 to 98%, with remaining wetlands being extremely few in several cases, notably in the Regina and Saskatoon UCRs.

In Edmonton, the Wagner Bog is a notable example of wetland conservation and has been pro-

Table 10–10. Western Canada major urban centred regions: wetland conversion summary

Urban centred region (UCR)	*Area of UCR (km²)*	*Estimated area of wetlands at settlement (km²)*	*Area of wetlands 1981 (km²)*	*Loss from settlement to 1981 (%)*
Edmonton	6 250.1	325.2	78.0*	76*
Calgary	2 818.8	41.4	9.2	78
Saskatoon	708.2	9.9	0.6	94
Regina	1 009.0	15.5	0.3	98
Winnipeg	1 819.9	1 340.1	39.6	97

Source: Kessel-Taylor (1984a).
**Data for 1976.*

posed as one of Alberta's Natural Areas (Clayton 1982; Griffin 1982). The Priddis Slough and Radio Tower Slough in Calgary have also been recommended for conservation.

Eastern Temperate Wetlands

The wetlands of the temperate areas of eastern Canada span southern Ontario, Quebec, and parts of New Brunswick. The Eastern Temperate (TE) and small portions of the Low Boreal (BL) Wetland Regions and the Gulf Atlantic (BAg) Wetland Subregion are included here. Wetland conversion pressures in all of this area have been severe with significant losses since settlement due to agricultural drainage. In the post-war period, urban and industrial expansion, including housing development, road and seaway construction, infilling, harbour and marina construction, and agricultural drainage, has led to continuing losses of wetlands in the temperate areas of eastern Canada.

Documentation of wetland conversion and wetland inventory programs in these areas is extensive. Quantitative studies for the temperate portion of Ontario and Quebec are summarized in Table 10–11, with 15 studies listed.

Studies by Le Groupe Dryade (1980) indicate that between 1945 and 1975 about 42% of the wetlands in shore areas of the St. Lawrence River were lost. This loss occurred mainly prior to 1960 and was mostly due to agricultural drainage, infilling, residential construction, dredging for seaway construction, and highway and industrial construction (Environment Canada 1986a). Reed and Moisan (1971) have also noted losses of 32% of *Spartina* marshes in the St. Lawrence Estuary since settlement, mainly due to agricultural diking.

Of the 15 studies reported in Table 10–11, 8 have examined historical trends in wetland conversions ranging from 1800 to 1950/1978 with 42–90% loss of original area. Three studies have covered the periods of 1915/1931 to 1976/1978 with losses ranging from 39 to 56%. Four contemporary studies have examined wetlands in Ontario from 1960/1966 to 1969/1978 with losses of 1–25% recorded.

Two studies have provided examination of wetland losses along the shorelines of Lake Ontario. Whillans (1982) noted an average net loss of 43% over 62 selected marshes along Lake Ontario since settlement times and severe losses of 75–100% of wetlands in the heavily settled areas near Hamilton and Toronto. Lemay and Mulamoottil (1984) also reported losses, due to land reclamation programs, of 56% of the marsh area in the Toronto Islands from 1931 to 1976.

As summarized in Table 10–12, Kessel-Taylor (1984a) has documented the general losses of wetland areas near 10 Ontario and 3 Quebec UCRs. Losses since settlement range from 58 to 97% in most of these cases, with the exception of two cities in northern Ontario (Sudbury and Thunder Bay) where losses of 51% and 30% from 1800 to 1976/1981 are recorded through analysis of Canada Land Inventory data bases. Losses around Kitchener also appear to be relatively low, being 37% since settlement. In 9 of the 13 UCRs examined in Ontario and Quebec, it was estimated that less than 8 500 ha of wetlands remained within each UCR by 1976 or 1981, with Ottawa–Hull, Quebec, Montreal, and St. Catharines each having 12 000–30 000 ha of wetlands within its immediate vicinity. The most severe losses have been in the Windsor, Toronto, and Montreal areas.

In Ontario, conservation programs have protected numerous wetland areas. In Hamilton, areas such as the Red Hill Creek Marsh, Cootes Paradise, Woodburn Floodplain, and the Beverly Swamp are components of the 1 800 ha of remaining wetland in this UCR. The Second Marsh at Oshawa has been conserved as a focal point surrounding proposals for expanded local port and nuclear power station facilities. In Ottawa, the Stoney Swamp and Mer Bleue Bog are significant conservation lands, as is the Byron Bog near London. Similarly, environmentally sensitive lands in the St. Catharines–Niagara region include the Wainfleet Marsh, Humberstone Marsh, Willoughby Swamp, Point Albino Marsh, Nickel Beach, and Shisler Point Woodlot and Wavercrest Bush, both treed swamps. In Toronto, about 1% of the UCR now has wetlands, including the Highland Creek Swamp, Toronto Island Marshes, and lower Rouge River Valley. The Federation of Ontario Naturalists (1985) has published a map and report on 53 priority wetlands in Ontario. This is based on extensive surveys of provincially significant wetlands conducted by the Ontario Ministry of Natural Resources, and on data from Environment Canada as well as from naturalists' clubs in Ontario.

Table 10–11. Quantitative wetland land use conversion studies in Ontario and Quebec

Region and authors	Study area size	Era	Net wetland change results
Ontario			
1. Southern Ontario (Cox 1972)	36 counties	PP*–1950	55% loss (area)
2. Southern Ontario (Snell 1981, 1986)	38 counties (73 800 km²)	PP–1970	70% loss (area)
3. Southern Ontario (Bardecki 1981)	8 selected NTS** sheets	1966–1978	1% drained (area)
4. Lake Ontario Marshes Toronto to Oshawa (Lemay 1980)	(a) 3.7 km² (b) 8 selected marshes	1931–1976 1860–1976	44% loss (marsh area) 56% loss (area)
5. Kawartha Lakes Marshes (Lewies and Dyke 1973)	46 km²	1960–1969	20% loss (marsh area)
6. Point Pelee Marsh (Rutherford 1979)	39 km²	1880–1975	71% loss (marsh area)
7. Lake St. Clair Wetlands (McCullough 1981)	35 km²	1965–1978	25% loss (area)
8. Lake St. Clair Marshes (Rutherford 1979)	(a) 173 km² (b) 173 km²	1915–1978 PP–1978	39% loss (marsh area) 90% loss (wetland area)
9. Lake Ontario Shorelines: Niagara River to Prince Edward County (McCullough 1981)	90 km²	PP–1978	42% loss (area)
10. Lake Ontario Shoreline Marshes (Whillans 1982)	62 selected shore marshes	1789–1979	43% average loss (area)
11. Toronto Waterfront Marshes (Lemay and Mulamoottil 1984)	8 selected marshes	1931–1976	56% reclaimed (area)
12. Walpole Island Indian Reserve, Ontario (McCullough 1981)	113.7 km²	1963–1978	5% loss (area) plus extensive diking
Quebec			
13. St. Lawrence River Shoreline: Cornwall to Matane (Le Groupe Dryade 1980; Environment Canada 1986a)	70 km²	1945–1975	42% converted (area)
14. Montreal Urban Region (Champagne and Melançon 1986)	4 023 km²	1966–1981	7% loss (area)
15. St. Lawrence Estuary Tidal Marshes (Reed and Moisan 1971)	31.6 km² (shore marshes)	PP–1970	32% diked (area)

Source: after Lynch-Stewart (1983).
**PP—Presettlement Period.*
***NTS—1:50 000 national topographic map series.*

In Quebec, three UCRs were studied by Kessel-Taylor (1984a). Total wetlands remaining as of 1981 ranged from 5 to 17% of the total area. Losses are continuing, with Champagne and Melançon (1986) recording a 7% decline of total wetland area in Montreal from 1966 to 1981.

Boreal Wetlands

The boreal area of Canada encompasses much of the High Boreal (BH) and most of the Mid-Boreal (BM) and Low Boreal (BL) Wetland Regions. It includes the Continental (BHc, BMc) and Humid (BHh, BMh) Wetland Subregions of these wetland regions. Some subregions of the Atlantic Boreal (BA) Wetland Region are included here as well, but excluded are the settled Maritime subregions considered in the following section on Atlantic and Maritime Wetlands. The Northern (BAn) and Interior (BAi) Wetland Subregions and some of the Gulf Atlantic (BAg) Wetland Subregion are included in this discussion. The major wetland conversion issues in this area have related to the

Table 10–12. Summary of major urban centred regions wetland conversion trends from settlement to current period for the eastern temperate area of Canada

Urban centred region (UCR)	Area of UCR (km^2)	Estimated wetland area at settlement (km^2)	Wetland area 1981 (km^2)	Loss of wetlands from settlement to 1981 (%)
Quebec				
Chicoutimi–Jonquière	398.5	114.5	21.7	81
Montreal	3 148.0	1 944.6	228.0	88
Quebec City	1 000.0	405.3	168.5	58
Ontario				
Hamilton	863.2	101.7	18.5	82
Kitchener	1 481.8	101.3	63.0	37
London	971.8	26.8	7.7	70
Oshawa	191.5	18.0	4.9	73
Ottawa–Hull	2 864.0	868.2	297.3	66
St. Catharines–Niagara	1 282.2	522.5	119.5*	77*
Sudbury	1 173.8	147.6	80.4	45
Thunder Bay	529.5	104.5	73.5	30
Toronto	2 732.1	172.5	22.6	87
Windsor	403.5	421.8	11.4	97

Source: Kessel-Taylor (1984a).
**1976 data.*

development of hydroelectric reservoirs and corridors, peat for agriculture, peat for energy development, and forestry harvesting practices.

Wetland monitoring and inventory programs exist in some areas, including the Peace–Athabasca Delta, the Nelson River, and the James Bay hydro development. However, data on regional trends in wetland loss or conversion do not appear to exist.

Atlantic and Maritime Wetlands

Wetlands in Atlantic Canada encompass the Atlantic Boreal (BA), Atlantic Subarctic (SA), and Atlantic Oceanic (OA) Wetland Regions and include the Acadian, Coastal, Eastern, Maritime, and Oceanic Wetland Subregions (BAa, BAc, BAe, BAm, and BAo, respectively). They include the Coastal Low Subarctic Wetland Subregion (SLc) and the Coastal and Oceanic Atlantic Subarctic Wetland Subregions (SAc and SAo, respectively). The major wetland issues in this area have been conversion for agriculture, urban development of coastal salt marshes, and peatland harvesting for horticulture and potential energy development.

Major wetland or peatland inventory programs have provided an excellent data base in most of New Brunswick, Prince Edward Island, Nova Scotia, and insular Newfoundland. Most areas in Labrador remain non-inventoried. Sensitive coastal environments of Newfoundland have also been inventoried in terms of potential hydrocarbon development impacts. However, few studies provide any temporal or quantitative assessment of regional trends in wetland loss or conversion.

Hirvonen (personal communication) estimates that 11 600 ha of salt marsh remained in Nova Scotia as of 1982, a loss of 65% of the original salt marshes since settlement, mainly due to agricultural dikes and subsequent reclamation. Gartley (1982) provided information on 14 000 ha of dikeland in New Brunswick. Kessel-Taylor (1984b) applied a rural wetland conversion methodology to two test areas in Nova Scotia (Table 10–13) for comparison with wetland results obtained from the ongoing Canadian Wildlife Service Wetland Protection and Mapping Program. This study suggests that wetland losses from settlement to current times have been about 42% in the Annapolis Valley and about 12% in the Musquodoboit Watershed.

Analyses of wetland conversions since settlement times in the vicinity of UCRs in Atlantic Canada also have been reported by Kessel-Taylor (1984a) for St. John's, Halifax, and Saint John. These are summarized in Table 10–14. The rates of wetland loss in these three UCRs have been low in comparison with other areas of Canada. Here, the

Table 10–13. Total wetland conversions in selected areas of Nova Scotia

Test area location	Estimated wetland area at settlement (km^2)	Contemporary wetland area 1966*/1978** (km^2)	Loss from settlement to 1966/1978*** (%)
Bridgetown, NS (Annapolis Valley)	81.7	47.6	41.7
Musquodoboit, NS (east coast watershed)	67.9	59.7	12.1

Source: Kessel-Taylor (1984b).
*CLI land use/land capability analysis.
**Canadian Wildlife Service, Wetland Protection Mapping and Designation Program.
***Summed for common test area.

losses have ranged from 16 to 18% since settlement; however, in most cases the remaining wetlands are very limited and highly valued. For example, the Chezzetcook Inlet, a site of highly valued salt marshes near Halifax, continues to be debated in terms of conservation versus interests for expanded road construction. The total 1976 areas of wetlands in the Halifax, St. John's, and Saint John UCRs were about 38%, 13%, and 9%, respectively.

Northern Wetlands

Wetlands in northern Canada encompass the areas of the High Arctic (AH), Mid-Arctic (AM), Low Arctic (AL), High Subarctic (SH), Low Subarctic (SL), and Eastern Mountain (ME) Wetland Regions. Pressures on these wetlands, often key wildlife habitats, are mainly related to ongoing and potential hydrocarbon development and facilities siting. However, to date, these have had few direct impacts as development in most areas, except the Beaufort Sea, has been minor.

In many areas of northern Canada, wetland distribution is often unknown as data bases featuring these sensitive areas do not exist. One study by Lynch-Stewart *et al.* (1984) provides a map and fact sheet data base for wetlands of the Beaufort Sea and Northwest Passage areas. Additional studies using satellite and other remote sensing data provide inventories of wetlands in portions of the District of Keewatin (Edlund 1982), King William Island (Hélie 1984), southwestern Baffin Island (Wittmann 1985), and Coats Island, NWT (Rubec *et al.* 1983).

Wetlands in northern environments are particularly sensitive. Transient and long-term development projects lead to permanent alteration of these fragile ecosystems which are dominated by perennially frozen peatlands in many cases. Northern wetlands, as overviewed by Rubec and Lynch-Stewart (1986), are often the coincident sites of vital wildlife production areas and hence are the basis for much of the northern wildlife harvest and tourism industries.

Mountain Wetlands

The majority of wetlands within mountainous areas of Canada are found in British Columbia, Alberta, and Yukon and include the Coastal Mountain (MC), Interior Mountain (MI), and Rocky Mountain (MR) Wetland Regions. This includes their Central (MCc, MIc, MRc), Northern (MCn, MIn, MRn), and Southern (MCs, MIs, MRs) Wetland Subregions. The Eastern Mountain

Table 10–14. Summary of wetland conversion trends in Atlantic Canada major urban centred regions

Urban centred region (UCR)	Area of UCR (km^2)	Estimated wetland area at settlement (km^2)	Area of wetlands 1981 (km^2)	Loss of wetlands from settlement to 1981 (%)
Halifax (NS)	2 941.5	91.6	75.4	18
St. John's (Nfld.)	1 039.7	153.0	127.3	17
Saint John (NB)	1 811.9	189.5	159.6	16

Source: Kessel-Taylor (1984a).

(ME) Wetland Region in Labrador is included in the discussion of Northern Wetlands. Within these mountain areas, numerous types of wetlands are present. Some of these are affected by hydro corridors and roads but only a minor portion can be said to be under pressure. Little data exist even as to their general distribution.

Wetlands in intermountain areas, however, are under pressure in many areas, particularly in southern British Columbia. The Cariboo–Chilcotin region, for instance, is subject to expanding agricultural use. Bogs, sedge-rich "meadows", and lake shoreline wetlands are being lost, but little data exist as to the rate of loss or trends in this area. Much of this area has wetlands characteristic of the Intermountain Prairie (PI) Wetland Region (discussed in the section on Prairie Wetlands).

A research project assessing the accuracy of LANDSAT Thematic Mapper satellite digital data for wetland monitoring in central British Columbia and in the Fraser Delta was undertaken by B.C. Research in Vancouver, on behalf of two Environment Canada agencies—the Canadian Wildlife Service and the Lands Directorate (Tomlins 1986).

National Overview

Wetlands were once abundant in southern Canada, but they are now a scarce land resource in many areas. The continued incremental conversion of wetlands over time has seriously depleted wetland areas at the expense of wildlife and waterfowl habitat. The remaining areas are also highly valued by Canadians due to their proximity to population centres and because of their economic, recreational, and aesthetic values.

Regionally specific studies have been completed that provide limited data on wetland rates of conversion. In particular the Canada Land Use Monitoring Program of Environment Canada has established or completed case studies in all regions of southern Canada. Since settlement, approximately 65% of Atlantic tidal and salt marshes, 70% of the lower Great-Lakes–St. Lawrence River shoreline marshes and swamps, up to 71% of prairie potholes and sloughs, and 80% of Pacific coast estuarine wetlands, such as those in the Fraser River Delta, are estimated to have been converted to other uses. Primarily this is due to agricultural drainage and diking, to urban and industrial expansion, to construction of port, road, and hydroelectric facilities, and to increased demands for recreational properties (Environment Canada 1986b).

Conclusions

The wetlands of Canada form a vital natural resource of significant economic importance. As outlined in this chapter, these wetlands bring economic benefits to Canadians through a variety of sectors including:

- recreational hunting of waterfowl;
- recreational sport fishing and hunting;
- commercial and native harvesting of mink, muskrat, beaver, and other wetland-dependent game;
- non-consumptive recreation (photography, bird-watching, and education);
- commercial fisheries of wetland- and estuary-dependent species of fish and shellfish;
- peatland softwood and wetland hardwood forestry;
- wild rice and hay harvesting;
- aquaculture of fish;
- market gardening on managed peatlands;
- peat production for horticulture and energy;
- water purification and sinks for pollutants;
- flood peak modification in watersheds; and
- shoreline protection.

The overall national economic values attributable to wetlands in each of these sectors, as summarized in Table 10–15, amount to \$5–10 billion in total annually. This is a significant component of the nation's total economy which has not generally been appreciated.

There are still important gaps in our knowledge of wetland values, uses, and conversions. Existing research does not adequately assess and represent the many types and functions of wetlands. Quantitative reports are primarily local or regional in focus, and preclude an accurate, comprehensive view of the national situation due to information gaps, overlaps, and inconsistencies. Significant research needs also exist in the analysis of social, economic, and legislative factors involved in the conversion of wetlands to other uses.

Agricultural reclamation has been the major force behind wetland decline in southern Canada. Related activities, particularly drainage, continue to threaten a dwindling wetland area. The dredg-

Table 10–15. Wetland economic values for Canada

	Sector and source	Estimated value ($000s)
1.	Recreational, consumptive sport fishing (Coley 1985). (Includes commercial and private $1.12 billion × 80%)	1 200 000
2.	Recreational, consumptive hunting (Coley 1985). (Includes waterfowl $118 million annually—Fogarty *et al.* 1982)	234 000
3.	Non-consumptive recreational photography, bird-watching, guiding, travel, education (Coley 1985)	3 000 000
4.	Consumptive commercial mink, beaver, muskrat trapping (Statistics Canada 1985b; Whillans 1985)	51 300
4a.	Other trapping (Coley 1985)	19 000
5.	Peat for energy, horticulture (Tarnocai 1984; Statistics Canada 1983)	47 810
6.	Wild rice harvesting (Winchell and Dahl 1984)	7 000
7.	Aquaculture—fish, etc. (Saskatchewan only) (G.D. Adams, personal communication)	2 300
8.	Perch, pickerel, alewife, capelin, salmon, oysters, flounder, clams, etc. in estuaries, commercial fishery (not included in No. 1 above) (Fisheries and Oceans Canada 1985; Statistics Canada 1985a)	78 400
9.	Peatland forestry (value of national forest industry of $29.3 billion × 2% estimated). (Includes spruce in bogs, fens; hardwoods in swamps) (Canadian Forestry Service 1985)	525 000
10.	Hay harvesting (estimated)	500
11.	Peatland market garden crops (estimated)	100 000
12.	Water purification, pollution sink (Whillans 1985) ($50 000/ha × 540 000 ha in southern Ontario × 50% estimated)	1 350 000*
13.	Flood peak modification (Richardson 1981) ($100 000/ha × 540 000 ha in southern Ontario × 50% estimated)	2 700 000*
14.	Shoreline protection	no data**
Total sectors 1–14		$9.32 billion
Total sectors 1–8 (only)		$4.74 billion

**Fixed, non-annual values.*
***Likely to be in the $100s of millions.*

ing, draining, and filling of wetlands for urban and industrial development have been exerting increasing pressure on a severely reduced wetland base over the past few decades, especially those wetlands nearest urban centres. The wetland resource also suffers under the increasing demand for energy production and transmission. Furthermore, recreational land uses represent a subtle, localized, and important form of wetland conversion.

The awareness and concern expressed by a wide range of resource agencies regarding wetland use and misuse, and their current and proposed research efforts, are reasons for optimism for the future of Canada's remaining wetlands. The recent creation of the Wildlife Habitat Canada Foundation, the signing of the Canada–United States North American Waterfowl Management Plan, and wetland conservation policy developments in several provinces are also all reasons for optimism. However, conservation of this resource base can be fully realized only through the direction and support of extensive policy and strategy initiatives for wetland management with full participation by all levels of government, as well as incentives for preservation by the general public.

Acknowledgements

Review comments and suggestions by the following individuals have contributed to the completion of this text: G. Adams, J. Millar, J. Beckett, W. Cowan, H. Hirvonen, S. Anderson, D. Keys, W. Simpson-Lewis, P. Rump, J. Arbour, M. Melançon, A. Kerr, and J. Seguin. Data on trends in wetland conversion are drawn from the Canada Land Use Monitoring Program of the Lands Directorate of Environment Canada. Figures 10–2, 10–6, and 10–9 are courtesy of the Canadian Wildlife Service. Figure 10–3 was provided by E. Manning.

References

ADAMS, G.D. (personal communication). November 1985. Canadian Wildlife Service, Environment Canada. Saskatoon, Saskatchewan.

ADAMS, G.D., AND G.C. GENTLE. 1978. Spatial changes in waterfowl habitat, 1964–1974, on two land types in the Manitoba Newdale Plain. Canadian Wildlife Service, Environment Canada. Occasional Paper No. 38. Saskatoon, Saskatchewan. 29 p.

ALLEN, H.H. 1978. Role of wetland plants in erosion control of riparian shorelines. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. November 7–10, 1978. Lake Buena Vista, Florida.

ANDERSON, J. 1986. Effects of acid precipitation on wetlands. Lands Directorate, Environment Canada. Working Paper No. 50. Ottawa, Ontario. 67 p.

BARDECKI, M.J. 1984. Wetland conservation policies in southern Ontario: a delphi approach. Department of Geography, York University. Geographical Monograph No. 16. Downsview, Ontario. 275 p.

BARDECKI, M.J. 1981. The role of agriculture in declining wetlands. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 64–73.

BECKETT, J.S. (personal communication). December 1986 and February 1987. Fisheries Research Branch, Fisheries and Oceans Canada. Ottawa, Ontario.

BEDARD, E. 1982. Survey of the horticultural peat industry in Canada. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 26–35.

CANADA. 1985. Currents of change. Inquiry on Federal Water Policy. Final Report. Ottawa, Ontario. 222 p.

CANADIAN FORESTRY SERVICE. 1985. Canada's forests 1985. Agriculture Canada. Brochure. Ottawa, Ontario. 10 p.

CECILE, C.P., M.J. BARDECKI, AND E.A. SNELL. 1985. The Eastern Ontario Subsidiary Agreement Drainage Program, impacts on the land resource: an initial evaluation. Lands Directorate, Environment Canada. Working Paper No. 40. Ottawa, Ontario. 58 p.

CHAMPAGNE, J., AND M. MELANÇON. 1986. Wetlands of the Montreal region. 1966–1981. Lands Directorate, Environment Canada. Working Paper No. 39, Ste-Foy, Quebec. 21 p. and map.

CHORNET, E. 1983. Peat options for the future. *In* Symposium 83, Energy from Peat. September 18–22, 1983. St. John's, Newfoundland. pp. 15–50.

CLARK, J.E. 1978. Fresh water wetlands: habitats for aquatic invertebrates, amphibians, reptiles and fish. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. November 7–10, 1978. Lake Buena Vista, Florida. pp. 330–343.

CLARKE-WHISTLER, K., AND J.A. ROWSELL. 1982. Peatlands: a fish and wildlife habitat. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 170–191.

CLAYTON, P. 1982. Update on the Wagner Bog. Edmonton Naturalist 10(2):49–51.

COLEY, R. 1985. Submission to the Inquiry on Federal Water Policy. Ottawa, Ontario. Unpublished. 12 p.

COMMITTEE ON SASKATCHEWAN RIVER DELTA PROBLEMS. 1972. Resources development and problems of the Saskatchewan River Delta. Report prepared for the Saskatchewan Water Resources Committee. Regina, Saskatchewan. 181 p.

COWAN, W. 1982. Breeding habitat competition on every hand agriculture. Ducks Unlimited (Canada) Ltd. Winnipeg, Manitoba. 18 p.

COX, E.T. 1972. Estimates of cleared wetlands in southern Ontario. Wildlife Branch, Ontario Ministry of Natural Resources. Toronto, Ontario. Unpublished. 3 p.

DAY, J.C., R.F. BRADY, AND M.J. STAITE. 1976. The environmental impacts of land drainage: a case study in the Dundalk Plateau, Ontario. Proceedings, Conference on Environmental Aspects of Irrigation and Drainage. Waterloo, Ontario. 12 p.

DIEBOLT, P.A. 1981. Environmental impact assessment of outlet drain reconstruction: a case study of the Wood Disse Drain, Ontario. M.A. thesis, Department of Geography, University of Waterloo, Waterloo, Ontario. 190 p.

EDLUND, S.A. 1982. Plant communities on the surficial materials of north–central district of Keewatin, Northwest Territories. Geological Survey of Canada. Paper 80-33. Ottawa, Ontario. 20 p.

ENVIRONMENT CANADA. 1986a. Wetlands of the St. Lawrence River region. Lands Directorate, Environment Canada. Working Paper No. 45. Ottawa, Ontario. 29 p.

ENVIRONMENT CANADA. 1986b. Wetlands in Canada—a valuable resource. Lands Directorate, Environment Canada. Fact Sheet 86-4. Ottawa, Ontario. 8 p.

ENVIRONMENT CANADA AND THE UNITED STATES DEPARTMENT OF THE INTERIOR. 1986. North American Waterfowl Management Plan. A strategy for cooperation. Canadian Wildlife Service and United States Fish and Wildlife Service. Ottawa, Ontario, and Washington, DC. 19 p.

FEDERATION OF ONTARIO NATURALISTS. 1985. Priority wetlands of southern Ontario. Map and extended text. Don Mills, Ontario.

FISHERIES AND OCEANS CANADA. 1985. Canadian fisheries, annual statistical review, 1983. Volume 16: Tables 31 and 39. Economic and Commercial Analysis Directorate, Fisheries and Oceans Canada. Ottawa, Ontario. 183 p.

FOGARTY, J.P., J.E. MARSHALL, AND A.J. JACQUEMOT. 1982. *In* Economics of Canadian Waterfowl. Policy and Program Development Directorate, Environmental Conservation Service, Environment Canada. Ottawa, Ontario. pp. 28–35.

FOUND, W.C., A.R. HILL, AND E.S. SPENCE. 1975. Economic and environmental impacts of land drainage in Ontario. Department of Geography, York University. Geographical Monograph No. 6. Downsview, Ontario. 175 p.

GARTLEY, C. 1982. Reclamation of dykeland for agricultural production in New Brunswick. Proceedings, 7th Annual Meeting, Canadian Land Reclamation Association. September 1982. Sydney, Nova Scotia. 13 p.

GEMELL, J.R. 1979. The identification of forest sites in the Clay Belt. *In* Proceedings, 2nd Ontario Conference on Forest Regeneration. Ontario Ministry of Natural Resources. March 6–8, 1979. Kapuskasing, Ontario. pp. 42–54.

GOODMAN, A.S., AND S.P. PRYOR. 1972. A preliminary study of the methods and rates of alteration of waterfowl habitat in the Black soil zone of western Canada. Canadian Wildlife Service, Environment Canada. Edmonton, Alberta. Unpublished. 77 p.

GRIFFIN, D.F. 1982. History of the Wagner Bog. Edmonton Naturalist 10(2):3–8.

GROOT, A. (personal communication). April 1985. Canadian Forestry Service. Sault Ste Marie, Ontario.

HÉLIE, R.G. 1984. Surficial geology of King William Island, NWT. Geological Survey of Canada. Map No. 4. Ottawa, Ontario.

HIRVONEN, H.E. (personal communication). Environment Canada. October 1984. Dartmouth, Nova Scotia.

HORWITZ, E.L. 1978. Our nation's wetlands. Council of Environmental Quality. Report of Interagency Task Force. Washington, DC.

HUGHES, F.M., AND L.D. CORDES. 1981. Peace–Athabasca Delta—wetland in transition. Geography Magazine 53(14):890–896.

JAWORSKI, E. 1981. The economics of wetland protection. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 58–62.

JAWORSKI, E., AND C.N. RAPHAEL. 1978. Fish, wildlife and recreational values of Michigan's coastal wetlands. Land Resource Programs Division, Department of Natural Resources. Lansing, Michigan.

JEGLUM, J.K., A.N. BOISSONNEAU, AND V.F. HAAVISTO. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report O-X-215. Sault Ste Marie, Ontario. 54 p.

JEGLUM, J.K., V.F. HAAVISTO, AND A. GROOT. 1982. Peatland forestry in Ontario: an overview. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 127–167.

KADLEC, R.H. 1978. Wetlands for tertiary treatment. *In* Wetland functions and values: the state of our understanding. Proceedings, National Symposium on Wetlands. November 7–10, 1978. Lake Buena Vista, Florida. pp. 490–504.

KAWARTHA REGION CONSERVATION AUTHORITY. 1981. An inventory and analysis of the wetland areas within the Kawartha region. Fenelon Falls, Ontario. 136 p.

KESSEL-TAYLOR, I. 1984a. The application of the Canada Land Data System for quantitative analysis of land use dynamics on wetlands for twenty-three urban centred regions in Canada. Lands Directorate, Environment Canada. Canada Land Data Systems Report No. R003200. Ottawa, Ontario. 143 p.

KESSEL-TAYLOR, I. 1984b. An evaluation of a methodology (Snell 1981) for determining presettlement and existing wetlands in Canada. Lands Directorate, Environment Canada. Miscellaneous Report. Ottawa, Ontario. 50 p.

KETCHESON, D.E., AND J.K. JEGLUM. 1972. Estimates of black spruce and peatland areas in Ontario. Canadian Forestry Service, Environment Canada. Information Report O-X-172. Sault Ste Marie, Ontario. 29 p.

KEYS, D., D.E. GEMMELL, AND R.E. HENDERSON. 1982. New Brunswick peat: resources, management and development potential. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 222–236.

KIEL, W.H., JR., A.S. HAWKINS, AND N.G. PERRET. 1972. Waterfowl habitat trends in the aspen parkland of Manitoba. Canadian Wildlife Service, Environment Canada. Report Series No. 18. Ottawa, Ontario. 61 p.

KORPIJAAKKO, E., AND P. GUILOR. 1983. Fuel peat demonstration project at Buffalo Narrows. *In* Symposium 83, Energy from Peat. September 18–22, 1983. St. John's, Newfoundland. pp. 15–50.

KREUTSWISER, R. 1981. The economic significance of the Long Point Marsh, Lake Erie as a recreational resource. Journal of Great Lakes Research 7(2):105–110.

LAIDLAW, S.A. 1978. A report concerned with the loss of wetlands in southern Ontario. Environmental Protection Service, Environment Canada. Toronto, Ontario. 118 p.

LE GROUPE DRYADE. 1980. Habitats propices aux oiseaux migrateurs le long des rives de la Rivière Outaouais, de la Rivière Richelieu, du Fleuve Saint-Laurent, de l'Estuaire du Saint-Laurent, de la Côte Nord du Golfe du Saint-Laurent, de la Péninsule gaspésienne, des Îles-de-la-Madeleine. Canadian Wildlife Service, Environment Canada. Ste-Foy, Quebec. Unpublished. 65 p.

LEMAY, M.H. 1980. Assessment of the effects of urbanization as a basis for the management of the waterfront marshes between Toronto and Oshawa, Ontario. M.A. thesis, University of Waterloo, Waterloo, Ontario. Unpublished. 280 p.

LEMAY, M., AND G. MULAMOOTTIL. 1984. A study of changing land uses in and around Toronto waterfront marshes. Urban Ecology 8:313–328.

LEVESQUE, M. 1982. Overview of the agricultural peatlands in Canada. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 48–77.

LEWIES, R.W., AND R.D. DYKE. 1973. Wetland gains and losses, Lindsay District. Ontario Ministry of Natural Resources. Lindsay, Ontario. Unpublished. 8 p.

LYNCH-STEWART, P. 1983. Land use change on wetlands in southern Canada: review and bibliography. Lands Directorate, Environment Canada. Working Paper No. 26. Ottawa, Ontario. 115 p.

LYNCH-STEWART, P., R.G. HÉLIE, AND D. OUIMET. 1984. Northern wetlands research project: procedures, results and guidelines. Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 53 p.

MANUEL, P. 1984. Peat policies and activities in Canada. I: Highlights. II: Details. J. Phillip Nicholson Policy and Management Consultants Ltd., for the Peat Energy Program, National Research Council of Canada. 2 volumes. National Research Council Report No. 24353–24354. Ottawa, Ontario.

MARTEC LTD. 1980. Annapolis Tidal Power Project—Environmental Assessment. Report for the Tidal Power Corporation, Kentville, Nova Scotia. 200 p.

MATTSON, M., G. HOCHBAUM, AND D. SOPROVICH. 1978. The establishment of a waterfowl and habitat monitoring program on selected physiographic regions in southern Manitoba: area selection and evaluation of techniques. Canadian Wildlife Service, Environment Canada. Winnipeg, Manitoba. 80 p.

MCCOLM, R.G. 1983. Post cut classification of recent cutover 1978–82. Abitibi-Price Inc. Smooth Rock Falls Licence. Summary of Results. Ontario Ministry of Natural Resources, Cochrane District. Cochrane, Ontario. 11 p.

MCCULLOUGH, G.B. 1981. Wetland losses in Lake St. Clair and Lake Ontario. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 81–89.

MELLGREN, P.G., AND E. HEIDERSDORF. 1984. The use of high flotation tires for skidding in wet and/or steep terrain. Forest Engineering Research Institute of Canada. Technical Report No. TR-57. Pointe Claire, Quebec. 48 p.

MILLAR, J.B. 1981. Habitat changes in Saskatchewan waterfowl strata 30 to 33 between Fall 1978 and Fall 1980—Prairie Waterfowl Habitat Evaluation Program. Canadian Wildlife Service, Environment Canada. Saskatoon, Saskatchewan. Unpublished. 60 p.

MILLAR, J.B. 1986. Observations on the condition of Canadian prairie wetlands. Presented at Symposium on Freshwater Wetlands and Wildlife. March 24–27, 1986. Charleston, South Carolina. Unpublished.

MONENCO ONTARIO LTD. 1981. Evaluation of the potential of peat in Ontario. Ontario Ministry of Natural Resources. Occasional Paper No. 7. Toronto, Ontario. 193 p.

NATIONAL WETLANDS WORKING GROUP. 1986. Wetland regions of Canada. *In* Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

OSBORNE, J.M. 1982. Potential environmental impact of peatland development. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 198–220.

PEARCE, P.A., AND A.D. SMITH. 1974. The potential influence on waterfowl of port and tidal power development in the Bay of Fundy. Waterfowl Studies. H. Boyd, editor. Canadian Wildlife Service, Environment Canada. Report Series No. 29. Ottawa, Ontario. pp. 91–100.

PILON, P., AND M.A. KERR. 1984. Land use monitoring on wetlands in the southwestern Fraser Lowland, British Columbia. Lands Directorate, Environment Canada. Working Paper No. 34. Vancouver, British Columbia. 31 p. and map.

POKRANT, H., AND M. GABOURY. 1983. Remote sensing to assess land use/land cover changes affecting the Dauphin Lake fishery. Manitoba Surveys and Mapping Branch, Remote Sensing Centre. Winnipeg, Manitoba. 35 p.

PRICE, S. (personal communication). November 1985. World Wildlife Fund (Canada). Toronto, Ontario.

RAKOWSKI, P.W. 1980. A habitat priority evaluation of the Minnedosa district of Manitoba. Canadian Wildlife Service, Environment Canada. Winnipeg, Manitoba. 38 p.

RAKOWSKI, P.W., AND B.P. CHABOT. 1983. Changes in land use in the Minnedosa district of southwestern Manitoba: an update on the Kiel–Hawkins transect. Canadian Wildlife Service, Environment Canada. Winnipeg, Manitoba. Unpublished. 15 p.

RAKOWSKI, P.W., R.W. NERO, AND R.C. HUTCHINSON. 1974. Present status of waterfowl habitat in the prime duck production area of Manitoba. Canadian Wildlife Service, Environment Canada. Winnipeg, Manitoba. Unpublished. 10 p.

REED, A., AND G. MOISAN. 1971. The *Spartina* tidal marshes of the St. Lawrence Estuary and their importance to aquatic birds. Naturaliste canadien 98:905–922.

REED, A., AND A.D. SMITH. 1972. Man and waterfowl in tidal shorelines of eastern Canada. *In* Proceedings, Coastal Zone Seminar. March 21–23, 1972. Bedford Institute. Dartmouth, Nova Scotia.

REES, D. 1983. The Bishop's Falls fuel peat demonstration project. *In* Symposium 83, Energy from Peat. September 18–22, 1983. St. John's, Newfoundland.

REPPERT, R.T., W. SIGLES, E. STRAKHIV, L. MESSMAN, AND C. MEYERS. 1979. Wetland values: concepts and methods for wetlands evaluation. United States Army Corps of Engineers. Institute for Water Resources. Fort Belvoir, Virginia.

RICHARDSON, B. 1981. Selected Proceedings of the Midwest Conference on Wetland Values and Management. St. Paul, Minnesota.

RITTER, A. 1979. Wetland reconnaissance within the Battle River Basin: 1978 summary. Ducks Unlimited (Canada) Ltd. Calgary, Alberta. Unpublished. 36 p.

RITTER, A. 1980. Wetland reconnaissance within the Battle River Basin: 1979 summary. Ducks Unlimited (Canada) Ltd. Calgary, Alberta. Unpublished. 25 p.

RUBEC, C.D.A. 1980. Wetlands near urban centres in Canada. Lands Directorate, Environment Canada. Canada Committee on Ecological Land Classification. Newsletter No. 9. Ottawa, Ontario. pp. 2–3.

RUBEC, C.D.A., AND P. LYNCH-STEWART. 1986. Wetland conservation in Canadian arctic and subarctic ecosystems. Paper presented at Symposium on Freshwater Wetlands and Wildlife. March 24–27, 1986. Charleston, South Carolina. Unpublished. 12 p.

RUBEC, C.D.A., AND P.C. RUMP. 1984. Prime wetland land use monitoring activities and needs in southern Canada. *In* Proceedings, 3rd Annual Western Provincial Conference on Rationalization of Water and Soil Research and Management. November 20–22, 1984. Winnipeg, Manitoba. pp. 405–429.

RUBEC, C.D.A., R.G. HÉLIE, AND D. OUIMET. 1983. Terrestrial ecosystems of Coats Island, NWT. Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 1:125 000 map with extended legend.

RUBEC, P.J. (personal communication). June 1986. Fisheries and Oceans Canada. Moncton, New Brunswick.

RUMP, P.C. 1983. Land use monitoring in Canada. *In* Proceedings, International Conference on Renewable Resources Inventories for Monitoring Changes and Trends. Corvallis, Oregon. 4 p.

RUTHERFORD, L.A. 1979. The decline of wetlands in southern Ontario. B.E.S. thesis, University of Waterloo, Waterloo, Ontario. Unpublished. 68 p.

SCHICK, C.D. 1972. A documentation and analysis of wetland drainage in the Alberta parkland. Canadian Wildlife Service, Environment Canada. Edmonton, Alberta. Unpublished. 15 p.

SCHMITT, K. 1980. Wetland reconnaissance within the South Saskatchewan River Basin. Ducks Unlimited (Canada) Ltd. Calgary, Alberta. Unpublished. 29 p.

SCOTT, R.D., AND K.D. VIRGO. 1977. A site classification system for clearcut areas in the Clay Belt. Ontario Ministry of Natural Resources, Kapuskasing District. Kapuskasing, Ontario. Unpublished. 36 p., appendices, and figures.

SHAY, J. 1981. Wetland protection in the 80's. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 19–25.

SNELL, E.A. 1981. An approach to mapping the wetlands of southern Ontario. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Research Session. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario.

SNELL, E.A. 1986. Wetland distribution and conversion in southern Ontario. Lands Directorate, Environment Canada. Working Paper No. 48. Ottawa, Ontario. In preparation.

STATISTICS CANADA. 1983. General review of the mineral industries. Catalogue 26-201. Annual. Ottawa, Ontario. 23 p.

STATISTICS CANADA. 1985a. Fisheries statistics of Canada. Canada Summary 1976. Ottawa, Ontario. 28 p.

STATISTICS CANADA. 1985b. Fur production, Season 1983–84. Catalogue 23-207. Ottawa, Ontario.

TARNOCAI, C. 1984. Peat resources of Canada. National Research Council of Canada. Publication No. 24140. Ottawa, Ontario. 17 p.

THIBODEAU, F.R., AND B.D. OSTRO. 1981. An economic analysis of wetland protection. Journal of Environmental Management 12:19–30.

TIBBETTS, T.E. 1983. Summary of the National Peat Program activities 1982–83. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 26–35.

TILTON, D.L. 1978. The ecology and values of Michigan's coastal wetlands, phase II. United States Fish and Wildlife Service. St. Paul–Minneapolis, Minnesota.

TOMLINS, G.F. 1986. Assessment of LANDSAT-5 thematic mapper data for mapping and monitoring wetlands and neighbouring land cover/land use. Physical Technology Division, B.C. Research, Vancouver, British Columbia. Final Report to Canadian Wildlife Service and Lands Directorate, Environment Canada. 250 p. and appendices.

WELLS, E.D., AND R.B. VARDY. 1980. Peat resources of Newfoundland with emphasis on its use for fuel. *In* Proceedings, Symposium on Peat as an Energy Alternative. Institute of Gasification Technology. December 1–3, 1980. Arlington, Virginia. pp. 679–698.

WHILLANS, T.H. 1982. Changes in marsh area along the Canadian shore of Lake Ontario. Journal of Great Lakes Research 8(3):570–577.

WHILLANS, T.H. 1985. Wetland issues in Canada—a discussion paper. Contract Report. Environmental Conservation Service, Environment Canada. Ottawa, Ontario. Unpublished. 70 p.

WILE, J., AND G. MILLER. 1981. The use of wetlands for waste water renovation. *In* Proceedings, Ontario Wetland Conference. A. Champagne, editor. Federation of Ontario Naturalists. September 18–19, 1981. Toronto, Ontario. pp. 163–170.

WINCHELL, E.H., AND R.P. DAHL. 1984. Wild rice production, prices and marketing. Agricultural Experiment Station, University of Minnesota. Miscellaneous Publication No. 29. 35 p.

WINSOR, S. 1983a. St. Shotts sod peat project. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 203–206.

WINSOR, S. 1983b. The Bishop's Falls peat project. *In* Symposium 82, Peat and Peatlands. J.D. Sheppard, J. Musial, and T.E. Tibbetts, editors. September 12–15, 1982. Shippagan, New Brunswick. pp. 211–214.

WITTMANN, S. 1985. Vegetation mapping of the Great Plain of the Koukdjuak, Baffin Island using LANDSAT MSS data. Nova Scotia Land Survey Institute, Lawrencetown, Nova Scotia. Preliminary Report to Lands Directorate, Environment Canada. Ottawa, Ontario. Unpublished. 17 p.

Appendix I

The Canadian Wetland Classification System

C. Tarnocai (Chairman)
G.D. Adams
V. Glooschenko
W.A. Glooschenko
P. Grondin
H.E. Hirvonen
P. Lynch-Stewart
G.F. Mills
E.T. Oswald
F.C. Pollett
C.D.A. Rubec
E.D. Wells
S.C. Zoltai

The Canadian Wetland Classification System

The development of a nationally applicable wetland classification system in Canada was first envisaged in 1973 with the completion of an organic terrain classification system by the National Committee on Forest Lands. Subsequently, Zoltai et al. *(1975) proposed a four-level, hierarchical, ecologically based wetland classification system. This was refined for Canadian wetland classification by Tarnocai (1980). Jeglum* et al. *(1974) and Millar (1976) refined regional wetland classifications for Ontario and the Prairies. Other regional Canadian systems also exist, including that developed for Quebec by Couillard and Grondin (1986) and for British Columbia by Runka and Lewis (1981). The Canadian Wetland Classification System represents a synthesis of existing systems at the national level.*

In its current form, this national classification system has been developed through the National Wetlands Working Group (NWWG) of the Canada Committee on Ecological Land Classification on the basis of the collective expertise and research of many wetland scientists across Canada. The NWWG, created in 1976, promotes holistic, ecologically based management, use, and conservation of Canadian wetlands. It acts through the informal support and contributions of federal, provincial, territorial, and non-government agencies.

The Canadian Wetland Classification System has not been fully applied and tested throughout Canada in all local and regional settings. As such, it remains "provisional" and subject to revision in future editions. Recently, it was used to form the basis of a national perspective on Canada's wetlands (National Wetlands Working Group 1986).

This classification system continues to evolve as new research is undertaken. Classification keys for the wetland forms will be developed based on their field application. In addition, the NWWG is developing a generalized key for wetland classes. Specific experience with the wording of wetland form and type descriptions will also govern future versions of this classification. Breakdown into more specific types for categories such as mosses and forbs may also occur.

A national field description and registry form for wetland ecosystems was developed by the NWWG (Tarnocai 1980).

Subsequently, this field form was modified for computerized data entry. Entitled "Canadian Wetland Registry Input Document for Field Data", the form and a companion manual are available from the Land Resource Research Centre, Agriculture Canada, Ottawa. They permit the collection of standardized field data and the organization of descriptive information on the location, soils, hydrology, peat development, and physical and chemical properties of soil and water in Canadian wetlands.

What is a Wetland?

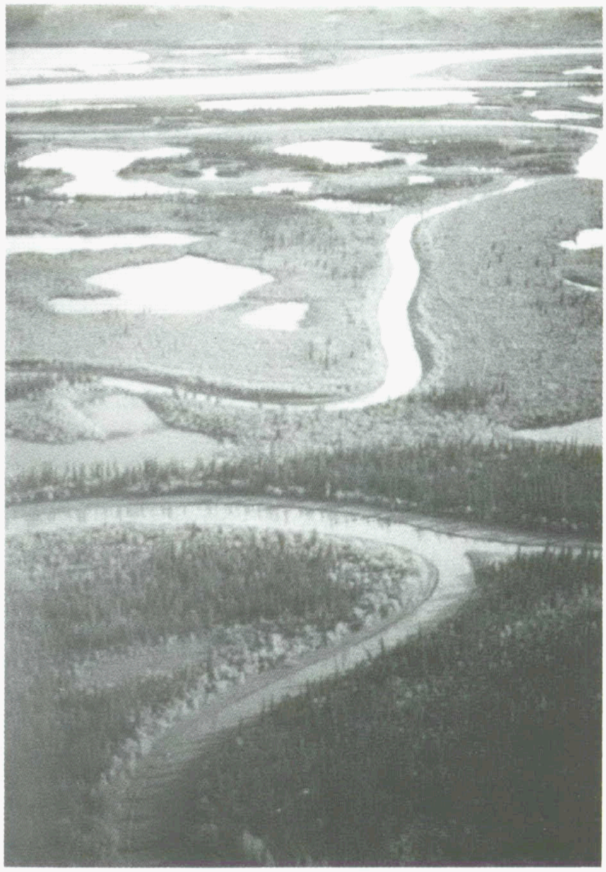
A *wetland* is defined as land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity which are adapted to a wet environment. Wetlands include:

Organic wetlands

- Peatlands which are characterized by more than 40 cm of peat accumulation on which Organic soils (excluding Folisols) develop.

Mineral wetlands

- Mineral soil areas which are influenced by excess water but which, for climatic, edaphic (factors related to soil), or biotic reasons, produce little or no peat. Gleysolic soils or peaty phases of Gleysolic soils are characteristic of these wetlands.
- Mineral soil areas of shallow open water which is generally less than 2 m deep. In certain of these wetlands, vegetation is lacking and soils are poorly developed as a result of frequent and drastic fluctuations of surface water levels or of wave action, water flow, turbidity, or a high concentration of salts or other toxic substances in the water or in the soil.
- Mineral soil areas which are modified by water-control structures (e.g. dams) or which are tilled and planted but which, if allowed to revert to their original state, become saturated for long periods and are then associated with wet soils (e.g. Gleysols) and hydrophytic vegetation.



Channel and shore marshes and associated wetlands in the Mackenzie Delta, Northwest Territories.

Wetland Classification

The Canadian Wetland Classification System contains three hierarchical levels: (1) class; (2) form; and (3) type. Five *wetland classes* are recognized on the basis of the overall genetic origin of wetland ecosystems. Seventy *wetland forms* are differentiated on the basis of surface morphology, surface pattern, water type, and morphology of underlying mineral soil. *Wetland types* are classified according to vegetation physiognomy.

This text is organized according to the five wetland classes: bog, fen, marsh, swamp, and shallow water. A class definition and description for the specific wetland forms of each class are presented. Wetland types, which are applicable to all wetland classes, appear at the end. Soil classification terms used in this text are taken from Canada Soil Survey Committee (1978).

Bog Wetland Class

A *bog* is a peatland, generally with the water table at or near the surface. The bog surface, which may be raised or level with the surrounding terrain, is virtually unaffected by the nutrient-rich groundwaters from the surrounding mineral soils and is thus generally acid and low in nutrients. The dominant materials are weakly to moderately decomposed *Sphagnum* and woody peat, underlain at times by sedge peat. The soils are mainly Fibrisols, Mesisols, and Organic Cryosols (permafrost soils). Bogs may be treed or treeless, and they are usually covered with *Sphagnum* spp. and ericaceous shrubs.

Bog Wetland Forms

All bog wetland forms are bogs as defined by the wetland classes, differing from one another in surface form, relief, or proximity to water bodies.

Atlantic Plateau Bog—A bog with a flat to undulating surface raised above the surrounding terrain, with the bog edges often steeply sloping down towards the mineral soil terrain. Pools that are often large are scattered on the bog, reaching a depth of 2–4 m.

Basin Bog—A bog situated in a basin that has an essentially closed drainage, receiving water from precipitation and from runoff from the immediate surroundings. The surface of the bog is flat, but the peat is generally deepest at the centre.

Blanket Bog—A bog consisting of extensive peat deposits that occur more or less uniformly over gently sloping hills and valleys. The peat thickness seldom exceeds 2 m.

Collapse Scar Bog—A circular or oval-shaped wet depression in a perennially frozen peatland. The collapse scar bog was once part of the perennially frozen peatland, but the permafrost thawed, causing the surface to subside. The depression is poor in nutrients, as it is not connected to the minerotrophic fens in which the palsa or peat plateau occurs.

Domed Bog—A large (usually more than 500 m in diameter) bog with a convex surface, rising several metres above the surrounding terrain. The centre is usually draining in all directions. Small crescentic pools often form around the highest point. If the highest point is in the centre, the pools form a concentric pattern, or eccentric if the pattern is off-centre. Peat development is usually in excess of 3 m.

Flat Bog—A bog having a flat, featureless surface. It occurs in broad, poorly defined depressions. The depth of peat is generally uniform.

Basin bog, with treeless, fire-scarred centre, near Lac La Biche, Alberta.

Floating Bog—A bog which occurs as a floating mat on or adjacent to ponds, and which is underlain by water or by fluid, loose peat. The surface of the floating bog is sufficiently elevated for the rooting zone to be free from contact with mineral-enriched lake water.

Lowland Polygon Bog—A bog with flat-topped or convex peat surfaces (often referred to as "high-centre polygons") separated by trenches over ice wedges that form a polygonal pattern when viewed from above. The peat was deposited in a permafrost environment, as shown by internal structures.

Mound Bog—A bog with small (up to 3 m in diameter and 0.5–1 m in height), isolated mounds occurring in fens. Mound bogs are sometimes referred to as "fen hummocks". The rooting environment is above the fen surface and is not affected by the mineral-rich waters of the fen. Several mounds may coalesce into larger bog "islands" in fens.

Northern Plateau Bog—A raised bog elevated 0.5–1 m above the surrounding fen. The surface is generally even, characterized only by small wet depressions. The plateau bog is usually teardrop-shaped, with the pointed end oriented in the downslope direction.

Palsa Bog—A bog composed of individual or coalesced palsas, occurring in an unfrozen peatland. Palsas are mounds of perennially frozen peat and mineral soil, up to 5 m high, with a maximum diameter of 100 m. The surface is highly uneven, often containing collapse scar bogs.

Peat Mound Bog—A bog with small (less than 3 m in diameter) mounds of frozen peat, rising less than 1 m above the surrounding perennially frozen fen. These bogs are found in arctic areas.

Peat Plateau Bog—A bog composed of perennially frozen peat, rising abruptly about 1 m from the surrounding unfrozen fen. The surface is relatively flat and even, and often covers very large areas. The peat was originally deposited in a non-permafrost environment and is often associated with collapse scar bogs or fens.

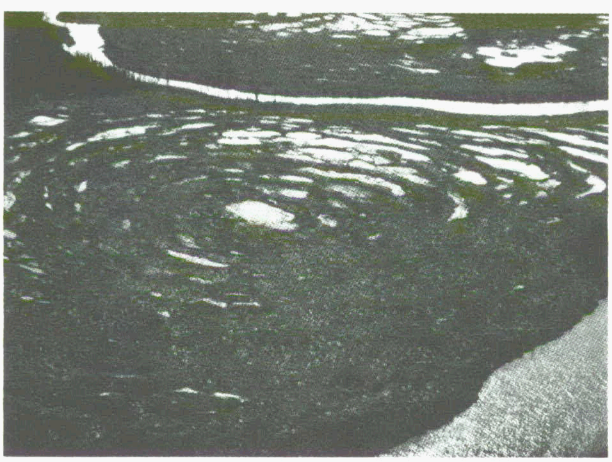
Polygonal Peat Plateau Bog—A perennially frozen bog, rising about 1 m above the surrounding fen. The surface is relatively flat, scored by a polygonal pattern of trenches that developed over ice wedges. The permafrost and ice wedges developed in peat originally deposited in a non-permafrost environment.

Shore Bog—A non-floating bog forming at the shore of a pond or lake. The bog surface is elevated at least 0.5 m above the level of the lake and its rooting zone is not affected by lake water. The bog often encroaches over the lake as shown by underlying lacustrine peat sediments.

Slope Bog—A bog occurring in areas of high rainfall on appreciably sloping land surfaces, fed by rainwater and by water draining from other nutrient-poor peatlands. The peat may exceed 1 m in thickness.

String Bog—A pattern of narrow (2–3 m wide), low (less than 1 m deep) ridges oriented at right angles to the direction of drainage. Wet depressions or pools occur between the ridges. The water and peat are very low in nutrients, as the water has been derived from other ombrotrophic wetlands. Peat thickness exceeds 1 m.

Veneer Bog—A bog occurring on gently sloping terrain underlain by generally discontinuous permafrost. Although drainage is predominantly below the surface, overland flow occurs in poorly defined drainage-ways during peak runoff. Peat thickness is usually less than 1.5 m.



Domed bog with concentric pattern of flarks and ridges near Cartwright, Labrador.

Flat bog in Experimental Lakes Area near Kenora, Ontario.

Fen Wetland Class

A *fen* is a peatland with the water table usually at or just above the surface. The waters are mainly nutrient-rich and minerotrophic from mineral soils. The dominant materials are moderately to well decomposed sedge and/or brown moss peat of variable thickness. The soils are mainly Mesisols, Humisols, and Organic Cryosols. The vegetation consists predominantly of sedges, grasses, reeds, and brown mosses with some shrubs and, at times, a sparse tree layer.

Fen Wetland Forms

All fen wetland forms are fens as defined in the wetland classes, differing from one another in surface form, relief, proximity to water bodies, or basin topography.

Atlantic Ribbed Fen—A fen with parallel peat ridges and pools that are oriented perpendicular to the direction of slope and drainage. The peaty strings are often narrow (less than 1 m wide) and generally low (less than 1 m deep). Pools may sometimes comprise about 75% of the area. The thickness of peat is 0.5–1.5 m.

Basin Fen—A fen occupying a topographically defined basin. However, the basins do not receive drainage from upstream and the fens are thus influenced mainly by local hydrological conditions. The depth of peat increases towards the centre.

Channel Fen—A fen occurring in a topographically well-defined channel which at present does not contain a continuously flowing stream. The depth of peat is usually uniform.

Collapse Scar Fen—A fen with circular or oval depressions, up to 100 m in diameter, occurring in larger fens, marking the subsidence of thawed permafrost peatlands. Dead trees, remnants of the subsided vegetation of permafrost peatlands, are often evident.

Feather Fen—A fen situated on a long, narrow ridge of mineral soil. The centre of the ridge is occupied by a bog, but many narrow, subparallel drainage-ways originate from the ridge and are occupied by a feather fen. Water from the fen drainage-ways is usually collected by a stream running parallel to the ridge. The average depth of peat is 1.5 m.

Floating Fen—A fen occurring adjacent to ponds or lakes, forming a floating mat, underlain by water or fluid, loose peat. The fen surface is less than 0.5 m above the level of the lake and the rooting zone is affected by lake water.

Lowland polygon fens located near Shingle Point on the Yukon coastal plain.

Horizontal Fen—A fen with a very gently sloping, featureless surface. This fen occupies broad, often ill-defined depressions, and may be interconnected with other fens. Peat accumulation is generally uniform.

Ladder Fen—A fen composed of parallel, low peat ridges and shallow pools oriented at right angles to the direction of drainage. It occurs as a narrow fen strip along the edges of domed bogs. The peat is usually 1–2 m deep.

Lowland Polygon Fen—A fen developed on perennially frozen lowlands where the intense winter cold causes the formation of polygonal cracks and ice wedges. The polygons consist of somewhat better-drained ridges which enclose very wet, low centres (hence the frequently used name "low-centre polygon"). Peat deposits are generally less than 1 m thick.

Net Fen—A fen with a broad net pattern of low, interconnected peat ridges ("strings"), enclosing wet hollows or shallow pools. The wetland surface is almost completely level; greater slopes result in the formation of northern ribbed fens.

Northern Ribbed Fen—A fen with parallel, low peat ridges ("strings") alternating with wet hollows or shallow pools, oriented across the major slope at right angles to water movement. The depth of peat exceeds 1 m.

Palsa Fen—A fen with mounds of perennially frozen peat (sedge and brown moss peat) and mineral soil, up to 5 m high and 100 m in diameter although they can be much smaller. Palsa fens generally occur in unfrozen peatlands and are frequently associated with collapse scar fens.

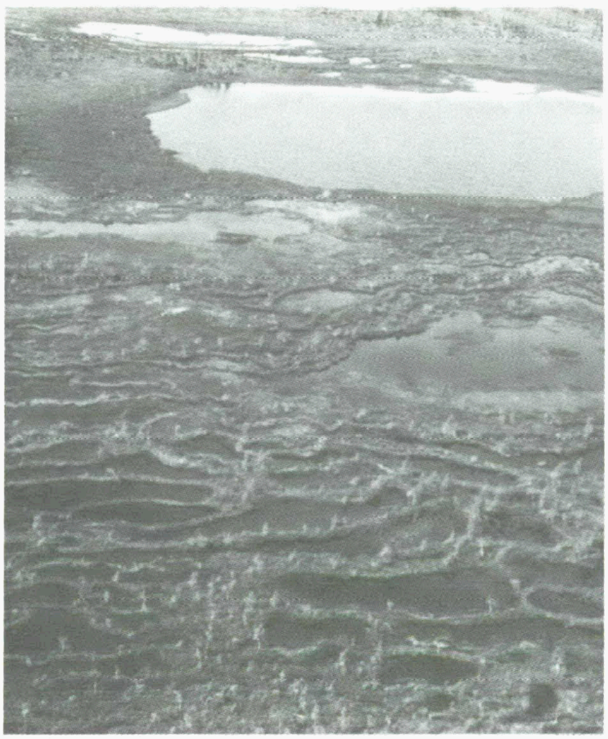
Shore Fen—A fen with an anchored surface mat that forms the shore of a pond or lake. The rooting zone is affected by the water of the lake at both normal and flood levels.

Slope Fen—A fen occurring mainly on slowly draining, nutrient-enriched seepage slopes. Pools are usually absent, but wet seepage tracks may occur. Peat thickness seldom exceeds 2 m.

Snowpatch Fen—A fen occurring on uniform slopes underlain by permafrost. These fens are fed by the gradual melting of persistent snowpatches on the slopes above the fens. The thickness of peat is usually less than 0.5 m.

Spring Fen—A fen nourished by a continuous discharge of groundwater. The surface is marked by pools, drainage tracks, and, occasionally, somewhat elevated "islands". The nutrient level of water is highly variable between locations.

Stream Fen—A fen located in the main channel or along the banks of permanent or semi-permanent streams. This fen is affected by the water of the stream at normal and flood stages.



Atlantic ribbed fen near Lac Joseph, eastern Quebec.

Horizontal fen near Prince Rupert, British Columbia.

Marsh Wetland Class

A *marsh* is a mineral wetland or a peatland that is periodically inundated by standing or slowly moving water. Surface water levels may fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation or mudflats. The waters are rich in nutrients, varying from fresh to highly saline. The substratum usually consists of mineral material, although occasionally it consists of well-decomposed peat. The soils are predominantly Gleysols, with some Humisols and Mesisols. Marshes characteristically show zonal or mosaic surface patterns composed of pools or channels interspersed with clumps of emergent sedges, grasses, rushes, and reeds, bordering grassy meadows and peripheral bands of shrubs or trees. Submerged and floating aquatics flourish where open water areas occur.

Marsh Wetland Forms

All marsh wetland forms are marshes as defined in the wetland classes, differing from one another in source of water or basin topography.

Active Delta Marsh—A marsh occupying lowlands on deltas, usually with drainage connections to active river channels. The marsh is subject to inundation at least once during a season, followed by a slow drawdown of the water levels. A high rate of sedimentation may occur in many parts of the marsh.

Channel Marsh—A marsh occurring in well-defined, abandoned channels where stream flow is discontinuous or blocked. Spring freshets or groundwater inflows may flood large portions of the channel, inducing marsh development.

Coastal High Marsh—A marsh influenced by brackish or saline waters of tidal marine origin. It is located above mean high-water levels and is inundated only by flood tides. It occurs on marine terraces, flats, embayments, or lagoons.

Coastal Low Marsh—A marsh influenced by brackish or saline waters of tidal marine origin. It is located below mean high-water levels and is inundated daily. It occurs on marine terraces, flats, embayments, or lagoons.

Estuarine High Marsh—A marsh influenced by waters of varying salinity and of tidal marine origin. It is located above mean high-water levels and is inundated only at highest tides and/or storm surges. It occurs in river estuaries or in connecting bays.

Estuarine low marsh, Chezzetcook Inlet, Nova Scotia.

Estuarine Low Marsh—A marsh influenced by waters of varying salinity and of tidal marine origin. It is located below mean high-water levels and is frequently inundated. It occurs in river estuaries or in connecting bays.

Floodplain Marsh—A marsh occurring on fluvial floodplains adjacent to river channels. The marsh is subject to annual flooding and sedimentation for various lengths of time, with possibly some water impounded on the marsh following flooding.

Inactive Delta Marsh—A marsh occupying higher portions of a delta, usually some distance from active river channels. The marsh is inundated only during very high flood stages or by wind-driven waves. Shallow water may be impounded for long periods of time.

Kettle Marsh—A marsh usually occupying well-defined elliptical catch basins located in moraines and glacio-fluvial or glacio-lacustrine landscapes. The kettles are moderately deep bowls with moderately to steeply sloping sides. The water sources are chiefly surface runoff from a local catchment area and some interbasin flow or groundwater inflow.

Seepage Track Marsh—A marsh occupying spring or water discharge sites on or at the base of slopes. This marsh features saturated, quaking ground, flowages or drainage tracks, and occasional open pools where drainage is impeded.

Shallow Basin Marsh—A marsh occurring in a uniformly shallow depression or swale, having a gradual gradient from the edge to the deepest portion. The marsh edge may be poorly defined due to rapidly receding water levels.

Shore Marsh—A marsh occupying the contact zone between high and low water marks bordering semi-permanent or permanent lakes. The marsh is usually found along protected shorelines, in lagoons behind barrier beaches, on islands, or in embayments. The marsh is subject to flooding by rises in lake levels, wind waves, or surface runoff.

Stream Marsh—A marsh occupying shorelines, bars, streambeds, or islands in continuously flowing water courses. The marsh is subject to prolonged annual flooding and is often covered by thick layers of sediments.

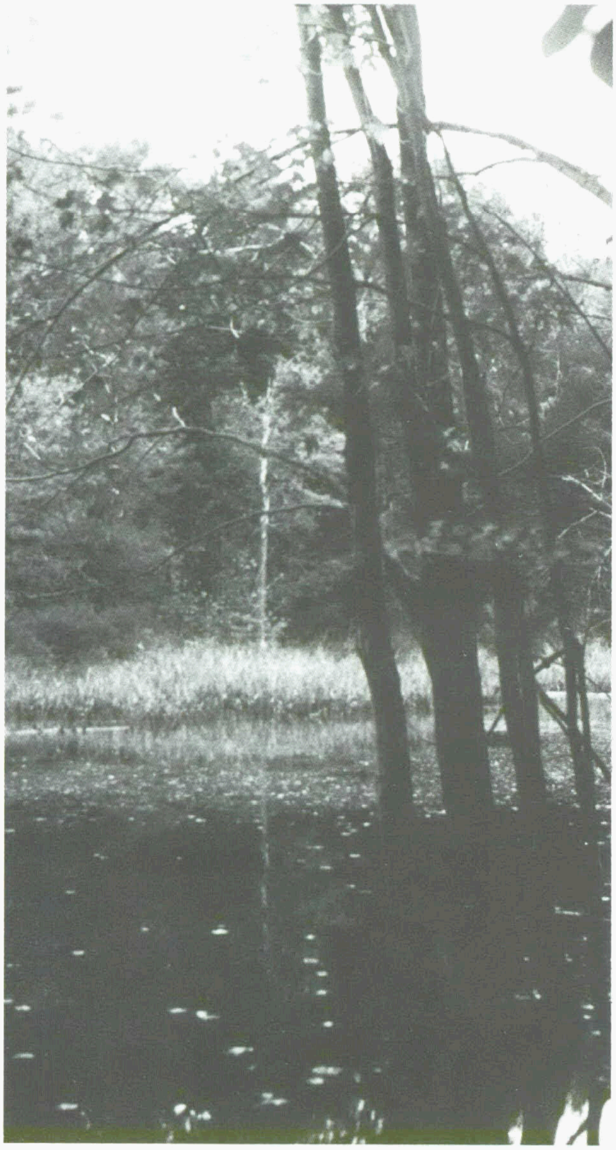
Terminal Basin Marsh—A marsh occurring in a topographically low catch basin situated at the terminal end of internal drainage systems receiving a variable water supply from surface runoff, channel wetlands, streams, or groundwater. The marsh has no overflow or drainage outlets and most water loss is due to evaporation.

Tidal Freshwater Marsh—A marsh located upstream from estuarine and coastal marshes. The marsh is characterized by almost freshwater conditions, plant and animal communities dominated by freshwater species, and daily, lunar tidal fluctuations.

Stream marsh near McConnell, Manitoba, with patches of open water and scattered emergent vegetation.

Swamp Wetland Class

A *swamp* is a mineral wetland or a peatland with standing water or water gently flowing through pools or channels. The water table is usually at or near the surface. There is pronounced internal water movement from the margin or other mineral sources; hence the waters are rich in nutrients. If peat is present, it is mainly well-decomposed wood, underlain at times by sedge peat. The associated soils are Mesisols, Humisols, and Gleysols. The vegetation is characterized by a dense cover of deciduous or coniferous trees or shrubs, herbs, and some mosses.



Basin swamp at Backus Woods, near Tillsonburg, Ontario.

Swamp Wetland Forms

All swamp wetland forms are swamps as defined in the wetland classes, differing from one another in surface form, basin topography, or proximity to water bodies.

Basin Swamp—A swamp developed in a topographically defined basin where the water is derived locally but may be augmented by drainage from other parts of the watershed. Accumulation of well-decomposed peat is shallow (less than 0.5 m) at the edge, and may reach 2 m at the centre.

Flat Swamp—A swamp occurring in broad areas of poorly drained lowlands. The outer edges of the swamp usually merge gradually into the upland, without sharp boundaries. Peat build-up is generally thin (less than 0.5 m), but may exceed 2 m.

Floodplain Swamp—A swamp occurring in a valley which may be inundated by a seasonally flooding river. Slow drawdown after flooding preserves a high water table for most of the growing season. Shallow peat development may be encountered.

Peat Margin Swamp—A swamp occurring in a relatively narrow (up to 25 m wide) zone between the mineral uplands and the peatland. The high water table is maintained by the peatland, but drainage from the upland adds nutrient-enriched water to the swamp. Peat deposition (less than 1 m) is common.

Shore Swamp—A swamp occurring along the shores of permanent ponds or lakes. The high water table is maintained by the water level in the lakes, but seasonal flooding may take place. Peat development is possible.

Spring Swamp—A swamp nourished by the discharge of groundwater. The surface is characterized by low hummocks, small pools, and drainage tracks. The amounts of dissolved solids in the spring water vary regionally.

Stream Swamp—A swamp occurring along the banks of permanent or semi-permanent streams. The high water table is maintained by the level of water in the stream. The swamp is seasonally inundated, with subsequent sediment deposition.

Shallow Water Wetland Class

Shallow water is characteristic of intermittently or permanently flooded or seasonally stable water regimes, featuring open expanses of standing or flowing water which are variously called ponds, pools, shallow lakes, oxbows, reaches, channels, or impoundments. Shallow water is distinguished from deep water by mid-summer water depths of less than 2 m, and from other wetlands by summer open water zones occupying 75% or more of the wetland surface area.

Large open water areas (greater than 8 ha), located within wetland complexes, should be classified separately as shallow water units, despite the area or extent of bordering vegetation zones. Periodic flooding may increase water depths, but during droughts, low flows, drainage, or intertidal periods, drawdown flats may be exposed.

Shallow water is distinguished from uplands and bordering wetland complexes by water-eroded shorelines, or by the landward margins of mudflats, floating mats, emergents, or shrubs. In the open water zone, living vegetation, if present, is confined to submerged and floating aquatic plant forms.

Shallow basin potholes and sloughs near Minnedosa, Manitoba.

Shallow Water Wetland Forms

All shallow water wetland forms are shallow water wetlands as defined in the wetland classes, differing from one another in basin topography or proximity to various kinds of open water.

Channel Water—Shallow, intermittently flowing water in abandoned, eroded glacio-fluvial spillways. Periods of flowing water occur mainly in the spring following snowmelt, and after exceptionally high precipitation.

Delta Water—Shallow ponds occurring on deltas that have been impounded by the shifting of river channels and the deposition of sediments. Periodic flooding in the delta usually inundates the delta water body.

Estuarine Water—Estuarine channels or bays periodically inundated by water of varying salinity. The water is less than 2 m deep.

Kettle Water—Predominantly shallow ponds with deep central portions, occupying basins with moderately sloping sides. The water sources are surface runoff from the local catchment area and seepage inflow. Drainage is limited to subsurface seepage, or overflow during flooding.

Non-tidal Water—Brackish water bodies mainly in pools and ponds located above the mean high-tide zone. The water is less than 2 m deep.

Oxbow Water—Shallow ponds or lakes in old, abandoned channels of rivers impounded behind natural levees on river floodplains. Periodic flooding by the river usually inundates the oxbow water body.

Shallow Basin Water—Shallow ponds located in gently sloping depressions, receiving water from the catchment area. The basin edges are usually poorly defined. Surplus water is drained by open outlets or by seepage.

Shore Water—Shallow water confined to the upper littoral or near-shore zone of permanent open water bodies. Shore water may occupy large portions of shallow bays or shoals, merging with deep water zones.

Stream Water—Inland, shallow, fresh to saline flowing water which flows continuously and is confined to a main water course. Seasonal periods of flood stages may occur.

Terminal Basin Water—Shallow ponds in topographically defined basins where incoming water is supplied by drainage of the upper catchment area, as well as from the immediate surroundings. Outlet channels are lacking.

Thermokarst Water—Shallow water body in a basin formed by the thawing and subsidence of ice-rich permafrost. The banks may be unstable due to continuing thermal erosion.

Tidal Water—Coastal lagoons or bays influenced by tidal action and salt water of marine origin. The normal mean tide-water level is less than 2 m deep.

Tundra Pool Water—Uniformly shallow water body formed in lowlands covered by thin peat. The shores are formed by steep, but low (less than 0.3 m) banks of perennially frozen peat. Permafrost usually occurs under the water bodies.

Tidal water mudflats on the edge of the Minas Basin at Wolfville, Nova Scotia.

Wetland Types

The terms used to describe wetland types are based on the general physiognomy of the vegetation cover, rather than on species descriptions. The physiognomic terms, when used in conjunction with wetland forms, constitute the wetland types.

Treed

This wetland type is dominated by tree species. Specific types are:

Coniferous Treed

This wetland type is dominated by needleleaf species in the tree layer (more than 5 m tall). The most common species are *Picea mariana* and *Larix laricina* which grow on organic soils and represent a characteristic type in the boreal forest regions. *Thuja occidentalis* is the most common species found in the nutrient-rich southern wetlands in eastern Canada, and *Pinus contorta, Thuja plicata,* and *Chamaecyparis nootkatensis* occur on the Pacific coast wetlands.

Hardwood Treed

This wetland type is dominated by broadleaf species in the tree layer (more than 5 m tall). The most common species are *Acer* spp., *Fraxinus nigra, Ulmus americana, Betula* spp., and *Populus balsamifera*. Wetlands of this type generally occur on mineral soils or on highly decomposed organic soils.

Shrub

This wetland type is dominated by shrub species. Specific types are:

Tall Shrub

This wetland type includes both tall shrubs (more than 1.5 m) and medium shrubs (0.5–1.5 m). The species include true shrubs and stunted trees.

Low Shrub

This wetland type includes both low shrubs (0.1–0.5 m) and ground shrubs (less than 0.1 m).

Mixed Shrub

This wetland type includes tall shrubs (more than 1.5 m), medium shrubs (0.5–1.5 m), and low shrubs (0.1–0.5 m).

Forb

This wetland type is dominated by forb species (non-grassy herbs).

Graminoid

This wetland type is dominated by undifferentiated grass-like plants. Specific types are:

Grass

This wetland type is dominated by low, tall, or mixed grass species.

Reed

This wetland type is dominated by reed species (*Phragmites*).

Tall Rush

This wetland type is dominated by *Scirpus* spp. and *Typha* spp.

Low Rush

This wetland type is dominated by *Juncus* spp. and *Triglochin* spp.

Sedge

This wetland type is dominated by sedge (*Carex* spp. and *Eriophorum* spp.) vegetation.

Moss

This wetland type is dominated by moss species. The most common mosses are *Sphagnum*, feathermosses (*Pleurozium* spp., *Hylocomium* spp., and *Ptilium* spp.) and brown mosses (*Drepanocladus* spp., *Scorpidium* spp., and *Tomenthypnum* spp.).

Lichen

This wetland type is dominated by lichen (mostly *Cladina* spp.).

Aquatic

This wetland type is dominated by aquatic species. Specific types are:

Floating Aquatic

This wetland type is dominated by plants with leaves floating on the surface of the water.

Submerged Aquatic

This wetland type is dominated by plants with leaves found mainly below the surface of the water.

Non-vegetated

This wetland type has a vegetation cover that occupies less than 5% of the surface.

References

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication 1646. Ottawa, Ontario. 164 p.

COUILLARD, L., AND P. GRONDIN. 1986. La végétation des milieux humides du Québec. Les publications du Québec. Quebec Ministry of Environment. Quebec, Quebec. 376 p.

JEGLUM, J.K., A.N. BOISSONNEAU, AND V.F. HAAVISTO. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report O-X-215. Sault Ste Marie, Ontario. 54 p.

MILLAR, J.B. 1976. Wetland classification in western Canada: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Canadian Wildlife Service, Environment Canada. Report Series No. 37. Ottawa, Ontario. 38 p.

NATIONAL WETLANDS WORKING GROUP. 1986. Canada's wetlands. Map folio. Energy, Mines and Resources Canada and Environment Canada. Ottawa, Ontario.

RUNKA, G.G., AND T. LEWIS. 1981. Preliminary wetlands managers manual, Cariboo Resource Management Region. Assessment and Planning Division, British Columbia Ministry of Environment. Technical Paper No. 5. 1st edition. Victoria, British Columbia. 113 p.

TARNOCAI, C. 1980. Canadian wetland registry. *In* Proceedings, Workshop on Canadian Wetlands. C.D.A. Rubec and F.C. Pollett, editors. Lands Directorate, Environment Canada. Ecological Land Classification Series No. 12. Ottawa, Ontario. pp. 9–39.

ZOLTAI, S.C., F.C. POLLETT, J.K. JEGLUM, AND G.D. ADAMS. 1975. Developing a wetland classification for Canada. *In* Proceedings, 4th North American Forest Soils Conference. B. Bernier and C.H. Winget, editors. Laval University Press. Quebec, Quebec. pp. 497–511.

Appendix II

Authors' Affiliations

Authors' Affiliations

Foreword: *F.C. Pollett*, Petawawa National Forestry Centre, Canadian Forestry Service, Chalk River, Ontario

C. Tarnocai, Land Resource Research Centre, Agriculture Canada, Ottawa, Ontario

Chapter 1: *S.C. Zoltai*, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta

Chapter 2: *C. Tarnocai*, Land Resource Research Centre, Agriculture Canada, Ottawa, Ontario

S.C. Zoltai, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta

Chapter 3: *S.C. Zoltai*, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta

C. Tarnocai, Land Resource Research Centre, Agriculture Canada, Ottawa, Ontario

G.F. Mills, Manitoba Soil Survey, Winnipeg, Manitoba

H. Veldhuis, Canada Soil Survey, Winnipeg, Manitoba

Chapter 4: *S.C. Zoltai*, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta

S. Taylor, Great Lakes Forestry Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario

J.K. Jeglum, Great Lakes Forestry Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario

G.F. Mills, Manitoba Soil Survey, Winnipeg, Manitoba

J.D. Johnson, Northern Forestry Centre, Canadian Forestry Service, Edmonton, Alberta

Chapter 5: *G.D. Adams*, Canadian Wildlife Service, Environment Canada, Saskatoon, Saskatchewan

Chapter 6: *V. Glooschenko*, Wildlife Branch, Ontario Ministry of Natural Resources, Toronto, Ontario

P. Grondin, Le Groupe Dryade Limited, Ste-Foy, Quebec

Chapter 7: *E.D. Wells*, Newfoundland Forestry Centre, Canadian Forestry Service, St. John's, Newfoundland

H.E. Hirvonen, Lands Branch, Environment Canada, Hull, Quebec

D.B. Scott, Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia

K.D. MacKinnon, Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia

F.S. Medioli, Centre for Marine Geology, Dalhousie University, Halifax, Nova Scotia

R.I. Goudie, Canadian Wildlife Service, Environment Canada, St. John's, Newfoundland

E. Hudgins, Canadian Wildlife Service, Environment Canada, Sackville, New Brunswick

A.D. Smith, Canadian Wildlife Service, Environment Canada, Sackville, New Brunswick

D.G. Keys, Three-D Geoconsultants Limited, Fredericton, New Brunswick
A.R. Anderson, Nova Scotia Department of Mines and Energy, Halifax, Nova Scotia

Chapter 8: *A. Banner*, Research Section, British Columbia Forest Service, Smithers, British Columbia
R.J. Hebda, Archaeology Division, British Columbia Museum, Victoria, British Columbia
E.T. Oswald, Pacific Forestry Centre, Canadian Forestry Service, Victoria, British Columbia
J. Pojar, Research Section, British Columbia Forest Service, Smithers, British Columbia
R. Trowbridge, Research Section, British Columbia Forest Service, Smithers, British Columbia

Chapter 9: *W.A. Glooschenko*, National Water Research Institute, Environment Canada, Burlington, Ontario
I.P. Martini, Department of Land Resource Science, University of Guelph, Guelph, Ontario
K. Clarke-Whistler, Beak Associates Consulting Limited, Mississauga, Ontario

Chapter 10: *C.D.A. Rubec*, Lands Branch, Environment Canada, Hull, Quebec
P. Lynch-Stewart, Lands Branch, Environment Canada, Hull, Quebec
G.M. Wickware, Wickware and Associates Incorporated, Burlington, Ontario
I. Kessel-Taylor, Lands Branch, Environment Canada, Hull, Quebec

Glossary

While definitions for terminology are presented throughout this book, they are often difficult to pinpoint. This Glossary provides definitions which are consistent with their usage in the text, and, in most cases, a published reference for the definition is provided. The terminology of the Canadian Wetland Classification System is presented in Appendix I.

In this book various national reference sources have also been used in association with regional reports and papers to provide consistent terminology and spelling as much as possible. These include the following:

Soils: Clayton *et al.* (1977); Canada Soil Survey Committee (1978)
Mosses: Ireland (1982)
Trees: Hosie (1979)
Flora: Scoggan (1978)
Birds: Godfrey (1986)
Mammals: Banfield (1974)
Fish: Scott and Crossman (1973)
Place names: Energy, Mines, and Resources Canada (1980)

Wherever necessary, new terminology has been substituted to conform to revised national standards that have been developed since the release of the references noted above.

Active layer: The top layer of ground in areas underlain by permafrost which is subject to annual thawing and freezing (Brown and Kupsch 1974).

Anaerobic: Having no molecular oxygen in the environment (Agriculture Canada 1976).

Aquatic peat: Peat formed beneath a body of standing water. It is primarily derived from various aquatic mosses, plants, and algae. The material is slightly sticky, dark brown to black in colour, and is usually well decomposed (humic) (Zoltai and Tarnocai 1975). Synonyms: sedimentary peat; allochthonous peat; detrital peat; gyttja.

Arctic: The area of Canada extending north from the most northward extension of trees, with lichen–moss–heath or barren landscapes and permafrost conditions.

Atlantic: The area of Canada entirely encompassing the provinces of Nova Scotia, New Brunswick, Prince Edward Island, and Newfoundland–Labrador, in addition to portions of the Gulf of St. Lawrence in Quebec.

Autotrophic: Capable of deriving energy for life processes from the oxidation of inorganic materials (Agriculture Canada 1976).

Basal peat: Peat occurring at the base of a peat deposit immediately above the mineral-soil substrate, usually in contact with mineral soil.

Basin: The total physical depression capable of catching and holding surface water, or the greatest potential depth that a wetland can attain given an unlimited water supply (Millar 1976).

Boreal: An area where the dominant vegetation consists of closed-canopied coniferous forest or various proportions of coniferous and broad-leaved forests (La Roi *et al.* 1967).

Brown moss peat: In Europe, peat composed of brown moss species, mainly *Amblystegium*, *Paludella*, and *Hypnum* (Cajander 1913; Stanek 1977); in Canada, peat composed of various proportions of mosses of Amblystegiaceae (*Scorpidium*, *Drepanocladus*, *Calliergon*, *Campylium*), *Hypnum*, and *Tomenthypnum*.

Cation exchange capacity: The total amount of exchangeable cations (the extent to which soil is occupied by a particular cation) that a soil can absorb, expressed in milliequivalents per 100 grams of soil (me/100 g).

Collapse scar: Vegetation pattern produced by thawing and collapsing permafrost in a peat plateau or palsa. It is usually waterlogged, treeless, and may contain dead, partially submerged trees. It is a common feature where the distribution of permafrost is discontinuous (Zoltai 1971). It may occur as a fen or bog form.

Conservation: That aspect of renewable resources management which ensures that utilization is sustainable and which safeguards ecological processes and genetic diversity for the maintenance of the resources concerned. Conservation ensures that the fullest sustainable advantage is derived from the living resource base and that facilities are so located and conducted that the resource base is maintained (Environment Canada 1986).

Coprogenous earth: See *Sedimentary peat.*

Cryoturbation: A process of moving or disturbing a body of soil or unconsolidated earth material by frost action (Brown and Kupsch 1974). Synonym: frost churning.

Decomposition: The separation of organic material into simpler compounds (Gilpin 1976).

Degree-day: A measure of the departure of temperature for a day from some reference temperature, expressed in degrees of temperature. These departures are computed for the day and totalled and averaged for weeks, months, seasons, or years (Atmospheric Environment Service 1982).

Diatomaceous earth: The remains of diatoms in a fine, grayish, siliceous form either as a powder or porous, rigid material (Agriculture Canada 1976).

Discharge: Seepage inflow to a basin or spring from an elevated water table or zone of saturation. Discharge ponds receive water from groundwater inflow (Sloan 1970).

Drawdown: A decrease in the water level of reservoirs or impoundments caused by intensive use or withdrawal for management practices (Veatch and Humphrys 1966).

Dystrophic lake: A lake associated with acid peat bogs and largely filled with sediments consisting of unhumified or peaty organic matter. Typically the water is yellowish or brownish, low in calcium, often acid, and low in fish productivity (Veatch and Humphrys 1966).

Estuary: An inlet of the sea reaching a river valley as far as the upper limit of tidal rise (Fairbridge 1980).

Eutrophic: Designation applied to wetlands where plants grow in hard waters which are rich in nutrients (Barry 1954; Stanek 1977).

Evapotranspiration: The combined loss of water from a given area during a specific time period by evaporation from the soil (or water) surface and by transpiration from plants (Soil Conservation Society of America 1982).

Fen peat: Peat deposited in a fen environment, generally composed of various proportions of brown moss, sedge, or other fen plant remains. It is usually moderately to well decomposed (Zoltai and Tarnocai 1975).

Fibric: The least decomposed of all organic materials. There is a large amount of well-preserved fibre that is readily identifiable as to botanical origin. Fibres retain their character upon rubbing (Canada Soil Survey Committee 1978).

Flark: Usually an elongated, wet, and muddy depression in patterned peatlands. Flarks may be several hundreds of metres in length. On slopes they are only a few metres wide, but on nearly level peatlands they may be a hundred or more metres wide. The long axis of flarks is always perpendicular to the direction of contours (Sjörs 1961a; Pollett 1968; Stanek 1977).

Folic material: Organic matter associated with the accumulation of layers of leaves, twigs, branches, and mosses resulting in deep surface soil layers over mineral or lithic contacts (Canada Soil Survey Committee 1978). Synonym: Folisolic soil.

Forest peat: Moderately to well decomposed peat formed in forested peatlands. It has a dark brown to dark reddish-brown matrix, an amorphous to very fine-fibred structure, and may have a somewhat layered macrostructure. The main plant constituents are the wood of trees and shrubs, feathermosses, and, in some cases, lichens (Zoltai and Tarnocai 1975). Synonym: sylvic peat.

Fuel peat: Peat materials, meeting organic content/type criteria, suitable for harvesting for use in energy-producing combustion or chemical systems as an alternative energy source to gas, oil, nuclear power, and hydroelectricity.

Ground moraine: A moraine deposited beneath a glacier, or glacial drift deposited and overridden by glaciers to form level to gently sloping topography.

Groundwater: Water that is passing through or standing in the soil and underlying strata. It is free to move by gravity (Agriculture Canada 1976).

Growing degree-day: A measure of the departure of temperature for a day from a base temperature of 5°C, believed to be significant for plant growth. Growing degree-days can be accumulated for any period of time, such as seasons, or averaged for a number of years (Atmospheric Environment Service 1982).

Gyttja: See *Aquatic peat.*

Halophyte: Vegetation that grows naturally in soils having a high content of various salts (Agriculture Canada 1976).

Heterotrophic: Capable of deriving energy for life processes from the decomposition of organic compounds (Agriculture Canada 1976).

Horticultural peat: Peat that is mined specifically for sale and use in horticultural applications.

Humic: Highly decomposed organic material. Small amounts of fibre are present that can be identified as to their botanical origin. Fibres can be easily destroyed by rubbing (Canada Soil Survey Committee 1978).

Humid: With reference to climate, areas where the Thornthwaite Moisture Index is between 20 and 100, indicating a moist climate where moisture surpluses are more important than moisture deficiencies (Sanderson 1948).

Hummock: A small elevation or mound with an ice core in arctic environments, or with a gravel core and dense vegetation cover in southern areas (American Geological Institute 1976), with irregular to conical shape.

Hummocky moraine: Glacial deposits with rounded conical hills and depressions formed under stagnating ice sheets.

Hydrophyte: Vegetation that grows naturally in water or in saturated soil conditions. Synonym: hydrophilic vegetation.

Hydrosere: A collective term which includes all the stages in a succession beginning in water or wet habitats (Hanson 1962). It refers to serial progression of plant communities and soils resulting from gradual basin infilling or drying to a terrestrial community.

Hyperoceanic: With extreme climatic conditions associated with proximity to the ocean, including very high levels of rainfall, fog, airborne sea salt, and elevated temperatures.

Ice wedge: A vertical wedge-shaped vein of ground ice.

Infilling: See *Paludification.*

Inflow basin: A depression receiving surface water inflow or inflow of groundwater. The depression is usually situated in a topographic intermediate or low position with water levels located below surrounding water tables (Sloan 1970).

Inundation: Flooding or covering by water, usually on a seasonal or periodic basis.

Kame: An irregular ridge or hill of stratified glacial drift deposited by glacial meltwater (Agriculture Canada 1976).

Kettle: Circular or elliptical depressions formed in morainal or glaciofluvial materials by the melting of buried ice blocks. The materials slump inward and partially fill the depressions, forming bowl-shaped basins with gently sloping sides.

Lagg: The depressed margin of a domed bog (Agriculture Canada 1976).

Limnic peat: Peat at least 5 cm thick composed of marl, diatomaceous earth, or coprogenous earth (sedimentary peat) (Agriculture Canada 1976).

Maritimes: The area of Canada entirely encompassing the provinces of Nova Scotia, New Brunswick, and Prince Edward Island.

Mesic: Organic material in an intermediate stage of decomposition. Intermediate amounts of fibre are present that can be identified as to their botanical origin (Canada Soil Survey Committee 1978).

Minerotrophic: Nourished by mineral water. It refers to wetlands which receive nutrients from mineral groundwater in addition to precipitation by flowing or percolating water, indicating that nutrients are brought to the peat by water that has previously extracted them from a mineral soil (Stanek 1977; Du Rietz 1954; Sjörs 1961a).

Mire: A general English term embracing all kinds of peatlands and all kinds of peatland vegetation (Pollett 1968; Godwin and Conway 1939).

Moder: A zoogenous forest humus form of plant remains, not matted (Agriculture Canada 1976).

Moor: A Germanic term applied to any area of deep peat whether acid or alkaline. In England the word is applied to high-lying country covered with heather and other ericaceous dwarf shrubs, mainly *Vaccinium* spp. It is often used to refer to land with any of the acid-loving plant communities (Tansley 1953; Stanek 1977).

Mor: A non-zoogenous forest raw humus form with over 52% organic carbon (Agriculture Canada 1976).

Mull: A zoogenous forest humus form consisting of a mixture of organic matter and mineral soil, with a crumb or granular structure. Organic matter is 5–20% (Agriculture Canada 1976).

Muskeg: A North American term frequently employed for peatland. The word is of Algonquin Indian origin and is applied in ordinary speech to natural and undisturbed areas covered more or less with *Sphagnum* mosses, tussocky sedges, and an open growth of scrubby trees (Stanek 1977).

Nitrification: The biochemical oxidation of ammonium to nitrate (Agriculture Canada 1976).

Oligotrophic: Designation for peatlands formed of plants growing in soft waters that are poor to extremely poor in nutrients (Stanek 1977).

Ombrophilous: Fed entirely by precipitation, typically with sulphate and hydrogen as the predominant ions.

Ombrotrophic: A term meaning "nourished by rain". It refers to areas which are entirely dependent on nutrients from precipitation (Du Rietz 1949; Sjörs 1961b; Pollett 1968).

Open wetland: A wetland generally with a surface free of trees.

Organic matter: The non-mineral fraction of soil, composed of plant and animal residues at various stages of decomposition. Organic soils are saturated most of the year unless artificially drained and contain 17% organic carbon (Agriculture Canada 1976).

Outflow basin: A depression which normally receives water from direct precipitation or local runoff, but loses water through overflow or outflow through surface channels (Millar 1976) or by downward seepage to a water table which slopes away from the basin (Sloan 1970).

Pacific: That area of Canada comprising the coastal zone and islands along the western oceanic coast of British Columbia.

Paleoclimate: Climate in an historical context, such as during glacial times, as indirectly interpreted by other means such as palynological investigations.

Palsa· A peaty permafrost mound, usually possessing a core of alternating layers of segregated ice and peat/mineral soil (Brown and Kupsch 1974). It may occur as a fen or bog form.

Paludification: Term used to describe the process of bog expansion caused by a gradual rising of the water table as peat accumulation impedes drainage (Auer 1930; Pollett 1968).

Palynology: The study of pollens and spores in an historical context, through observations of peat and sedimentary deposits, to interpret past environments (Gilpin 1976).

Peat: Layer consisting largely of organic residues originating under more or less water-saturated conditions through the incomplete decomposition of plant and animal constituents. It is the result of anaerobic conditions, low temperatures, and other complex causes (Pollett 1968; Heinselman 1963).

Peatland: A generic term including all types of peat-covered terrain. Many peatlands are a complex of swamps, bogs, and fens, sometimes called a "mire complex" (Pollett 1968; Heinselman 1963).

Peat plateau: A low, generally flat-topped expanse of peat, elevated above the general surface of a peatland and containing segregated ice which generally extends downwards into the underlying mineral soil (Brown and Kupsch 1974; Tarnocai 1970).

Peat ridge: In patterned wetlands, the elevated, better-drained portion with mosses, sedges, shrubs, or trees. It is narrow, with its long axis across the slope. Peat ridges may interconnect into a net pattern (Drury 1956; Hamelin 1957; Stanek 1977). Synonyms: string, rib, strang.

Peat stratigraphy: A vertical sequence of layers of different materials within a peat deposit. Differences may be due to floristic composition, state of decomposition, or incidence of extraneous materials.

Perhumid: With reference to climate, areas where the Thornthwaite Moisture Index is above 100, indicating large moisture surpluses (Sanderson 1948).

Permafrost: Ground (soil and/or rock) that remains at or below 0°C for at least two years (Brown and Kupsch 1974).

Permafrost aggradation: Expansion of permafrost into previously non-permafrost ground.

Permafrost degradation: The thawing of a permafrost body, resulting in a net loss of perennially frozen ground.

Permafrost table: The upper boundary of permafrost (Brown and Kupsch 1974).

Phreatophyte: A plant deriving its water from subsurface sources, thereby transpiring large amounts of water (Soil Conservation Society of America 1982).

Polygon: A type of patterned ground consisting of a closed, roughly equidimensional figure bounded by more or less straight sides. Some or all of the sides may be irregularly curved (Brown and Kupsch 1974).

Polygon shoulder: A low ridge on either side and parallel to a polygon trench, believed to be composed of material displaced by a growing ice-wedge (Zoltai and Tarnocai 1975).

Polygon trench: A narrow, linear depression 20–100 cm deep, overlying ice-wedges. The trenches form a polygonal pattern when viewed from above (Zoltai and Tarnocai 1975).

Polygonal peat plateau: A peat plateau with ice-wedge polygons (Zoltai and Tarnocai 1975).

Pond: A general term for an open water body of a seasonal to permanent nature, held in an impoundment or natural basin. A pond usually implies a transitional form between a lake and a wetland (Veatch and Humphrys 1966).

Postglacial rebound: A gradually rising land surface that results from the removal of the weight of glacial ice.

Prairie: In a strict sense, Prairie is a treeless tract of level to hilly land with a dominance of grasses and forbs and a scarcity of shrubs (Soil Conservation Society of America 1982). In a broad sense, Prairie implies both grassland and parkland where trees, if present, occur in clumps or groves within a grassland matrix. Strong and Leggat (1981) distinguish prairie grassland from parkland by the criterion of a tree cover of 15% or less. The Prairie which has developed in dry subhumid to subarid climates is usually characterized by summer moisture deficits and Chernozemic soils (Coupland 1961).

Preservation: Keeping in existence in an unchanged state those natural resources, structures, or situations which have been inherited from the past (Gilpin 1976).

Primary peat productivity: The rate at which organic matter is stored by photosynthesis and the chemosynthetic activity of producer organisms or autotrophic plants, usually measured in grams per day (Soil Conservation Society of America 1982).

Radiocarbon dating: The determination of the age of material by measuring the proportion of the isotope C^{14} in the carbon it contains.

Recharge: The process by which water is added to the zone of saturation as in an aquifer (Soil Conservation Society of America 1982). In the case of ponds, recharge refers to outflow basins where surface water seeps downwards or outwards to a water table (Sloan 1970).

Rheophilous peatland: Peatland that is under the influence of groundwaters derived from outside its immediate catchment (Moore and Bellamy 1974), typically with bicarbonate as the predominant anion and calcium the predominant cation.

Runnel: A poorly defined drainage line on permafrost terrain, characterized by a slight depression on the surface and a deeper active layer than in interrunnel areas. It is often marked by taller and denser vegetation (Zoltai and Pettapiece 1973).

Salinity: The amount of soluble salts in the soil or in solution, expressed in parts per thousand (‰).

Salt marsh: Marsh forms affected by the daily or seasonal influence of brackish to saline waters, generally in coastal and dry prairie conditions.

Seasonal frost: A temperature condition where the ground surface layer is below 0°C during the cold season, but rises above freezing during the warm season.

Sedge peat: Peat material composed largely of above- and below-ground parts of *Carex*, or sometimes *Eriophorum*, plants growing under minerotrophic conditions (Zoltai and Tarnocai 1975).

Sedimentary peat: Peat composed of aquatic plant debris modified by aquatic animals. Synonym: coprogenous earth.

Sedimentation: The removal from solution of solids or detrital matter through settling by gravity to the bottom of water bodies. Geologically it is the formation or accumulation of materials in layers including separation, transportation, and redeposition, and consolidation into other rocks (Gilpin 1976; American Geological Institute 1980).

Solifluction: Slow downslope flow of saturated unfrozen earth materials (Brown and Kupsch 1974).

Specific conductivity: A measure of the rate of flow of ions in solution or dissolved solids (American Geological Institute 1976), expressed in millisiemens or microsiemens per centimetre (mS/cm or μS/cm).

Sphagnum ***cushion***: Tight cushions (hummocks) of living and dead *Sphagnum* (especially *Sphagnum fuscum*) material that rise above the water table in the neighbouring hollows (Moore and Bellamy 1974). Ombrotrophic conditions may be maintained on the cushions even in a minerotrophic environment.

***Sphagnum* peat**: Moss peat which is often poorly decomposed, raw, and consisting mainly of *Sphagnum* spp. remains, but which may be admixed with fragments of ericaceous shrubs such as *Carex* spp., *Eriophorum* spp., and wood (Stanek and Worley 1983; Puustjärvi 1979; Pollett 1968).

Standing crop: The total amount of biomass of the organisms of one or more species within an area. Standing crop usually measures annual biomass produced by plants during the peak of the growing season (Hanson 1962).

String: See *Peat ridge*.

Subarctic: An area where open-canopied coniferous woodlands are the dominant vegetation form with or without outliers of treeless tundra (La Roi *et al.* 1967).

Succession: The replacement of one community or population by another as a result of changes in the environment (Gilpin 1976).

Swale: An area of land lower than its surroundings, often lower than the water table, thus retaining water (United States Army Corps of Engineers 1986).

Sylvic peat: See *Forest peat*.

Temperate: Climates characterized by moderate to high annual levels of precipitation, mild winters, and warm summers.

Thermokarst: The development of characteristic landforms resulting from the thawing of ice-rich permafrost (French 1976; Washburn 1979).

Thermokarst lake: A lake occupying a closed depression formed by settlement of the ground following thawing of ground ice (Harris *et al.* 1985).

Thicket swamp: A swamp with more than 25% cover of tall (over 135 cm) shrubs, with a conspicuous herb layer. Fen mosses and *Sphagnum* mounds may be present (Jeglum *et al.* 1974). Synonym: tall shrub or shrub/treed swamp, depending on height and size of shrubs such as *Alnus* spp.

Tundra: A level to undulating, treeless plain characteristic of arctic regions (Agriculture Canada 1976).

Tussock: A thick tuft of sedge or other vegetation forming a small hummock of solid ground in a wetland (Niering 1985).

Upland: An area generally with adequate drainage to prevent waterlogging of soil, dominated by downward water flow with only minor lateral or upward flow; it contrasts with usually lower-lying wet areas.

Water table: The upper surface of the groundwater or that level below which the soil is saturated with water. It forms the locus of points in soil-water at which hydraulic pressure is equal to atmospheric pressure (Soil Conservation Society of America 1982).

Wetland conversion: The change in a wetland from a natural, undisturbed condition to another managed, altered, or totally different condition as a result of man's influence.

Wetland density: A measure of the occurrence of wetlands in a given area of land expressed generally as number of sites per square kilometre or hectares per square kilometre.

Wetland monitoring: Evaluation of the causal agents, rates, and trends in ecological or land use changes associated with wetland units in the landscape, expressed in terms of time period, geographic areas, or cumulative or synergistic effect.

Wet meadow: A moist, usually level area of continuous herbaceous vegetation developed on intrazonal acid soils with a thick, humus-rich soil horizon (Lewis 1977). It is a vegetation zone flooded for only a few weeks, which under natural conditions supports grassland, forbs, and tall shrubs (Millar 1976).

Wildlife habitat: The sum total of environmental conditions of a specific place that is occupied by an organism, population, or community (Hanson 1962). Habitat refers to a species distributional response to environmental factors at different points in the landscape (Whittaker *et al.* 1975). It is a recognizable living space including interacting physical and biological factors which furnish the minimal conditions for an individual or species population to survive and reproduce (Stelfox 1982).

References

AGRICULTURE CANADA. 1976. Glossary of terms in soil science. Agriculture Canada Publication No. 1459. Ottawa, Ontario. 44 p.

AMERICAN GEOLOGICAL INSTITUTE. 1976. Dictionary of geological terms. Anchor Books. Garden City, New York. 472 p.

AMERICAN GEOLOGICAL INSTITUTE. 1980. Glossary of geology. 2nd edition. R.L. Bates and J.J. Jackson, editors. Falls Church, Virginia. 751 p.

ATMOSPHERIC ENVIRONMENT SERVICE. 1982. Canadian climate normals, 1951–1980. Volume 4: Degree-days. Environment Canada. Downsview, Ontario. 280 p.

AUER, V. 1930. Peat bogs in southeastern Canada. Canada Department of Mines. Geological Survey of Canada. Memoir 162. Ottawa, Ontario. 32 p.

BANFIELD, A.W.F. 1974. The mammals of Canada. National Museums of Canada and University of Toronto Press. Toronto, Ontario. 438 p.

BARRY, T.A. 1954. Some considerations affecting the classification of the bogs of Ireland. Irish Forestry 11(2):48–64.

BROWN, R.J.E., AND W.O. KUPSCH. 1974. Permafrost terminology. Associate Committee on Geotechnical Research, National Research Council of Canada. Technical Memorandum No. 111. 62 p.

CAJANDER, A.K. 1913. Studien über die Moore Finlands. Acta Forestalia Fennica. Volume 2.

CANADA SOIL SURVEY COMMITTEE. 1978. The Canadian system of soil classification. Research Branch, Canada Department of Agriculture. Publication No. 1646. Ottawa, Ontario. 164 p.

CLAYTON, J.S., W.A. EHRLICH, D.B. CANN, J.H. DAY, AND I.B. MARSHALL. 1977. Soils of Canada. Agriculture Canada. Ottawa, Ontario. 2 volumes and map.

COUPLAND, R.T. 1961. A reconsideration of grassland classification in the northern great plains of North America. Journal of Ecology 49:135–167.

DRURY, W.H., JR. 1956. Bog flats and physiographic processes in the upper Kuskokwin River region, Alaska. Harvard University, Contributions of the Herbarium No. 178. Boston, Massachusetts.

DU RIETZ, G.E. 1949. Main units and main limits of Swedish mire vegetation (in Swedish with English summary). Svensk. Bot. Tidskr. 43:274–309.

DU RIETZ, G.E. 1954. Die Mineralbodenwasserzeigergrenze als Grundlage einer natürlichen Zweigliederung der nord- und mitteleuropäischen Moore. Vegetatio 5-6:571–585.

ENERGY, MINES, AND RESOURCES CANADA. 1980. Canada gazetteer atlas. Macmillan of Canada Ltd. Toronto, Ontario. 165 p.

ENVIRONMENT CANADA. 1986. World conservation strategy—Canada, a report on achievements in conservation. Report to Conference on Conservation and Development. D.P.W. Pollard and M.R. McKenzie, compilers. Environment Canada. Ottawa, Ontario. 61 p.

FAIRBRIDGE, R.W. 1980. The estuary: its definition and geodynamic cycle. *In* Chemistry and biogeochemistry of estuaries. E. Olavsson and I. Cato, editors. J. Wiley and Sons. New York, New York. pp. 1–35.

FRENCH, H.M. 1976. The periglacial environment. Longman Group Ltd. London, UK, and Longman Inc., New York, New York. 309 p.

GILPIN, A. 1976. Dictionary of environmental terms. University of Queensland Press. St. Lucia, Australia. 191 p.

GODFREY, W.E. 1986. The birds of Canada. National Museums of Canada. Revised edition. Ottawa, Ontario. 595 p.

GODWIN, H., AND V. CONWAY. 1939. The ecology of a raised bog near Tregaron, Cardiganshire. Journal of Ecology 27:313–363.

HAMELIN, L.E. 1957. Les tourbières réticulées du Québec—Labrador subarctique: interprétation morpho-climatique. Cahiers de géographie de Québec 2:87–106.

HANSON, H.C. 1962. Dictionary of ecology. Philosophical Library. New York, New York. 382 p.

HARRIS, S.A., H.M. FRENCH, J.A. HEGINBOTTOM, G.H. JOHNSTON, B. LADANYI, D.C. SEGO, AND R.O. VAN EVERDINGEN. 1985. Glossary of permafrost and related ground ice terms. Associate Committee on Geotechnical Research. Permafrost Subcommittee, National Research Council of Canada. Preliminary Report. Ottawa, Ontario. 140 p.

HEINSELMAN, M.L. 1963. Forest sites, bog processes, and peatland types in the Glacial Lake Agassiz region, Minnesota. Ecological Monographs 33:327–372.

HOSIE, R.C. 1979. Native trees of Canada. 8th edition. Fitzhenry and Whiteside Ltd. Don Mills, Ontario. 380 p.

IRELAND, R.R. 1982. Moss flora of the maritime provinces. National Museums of Canada. Publication No. 13. Ottawa, Ontario. 738 p.

JEGLUM, J.K., A.N. BOISSONNEAU, AND V.F. HAAVISTO. 1974. Toward a wetland classification for Ontario. Canadian Forestry Service, Environment Canada. Information Report No. 0-X-215. Sault Ste. Marie, Ontario. 54 p.

LA ROI, G.H., C.G. HAMPSON, W.A. FULLER, AND E. NYLAND. 1967. The boreal forest. *In* Alberta, a natural history. W.G. Hardy, M.C. Johnson, and C.G. Hampson, editors. M.G. Hurtig Ltd. Edmonton, Alberta. pp. 151–191.

LEWIS, W.M. 1977. Ecology field glossary. Greenwood Press. Westport, Connecticut. 152 p.

MILLAR, J.B. 1976. Wetland classification in western Canada: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Canadian Wildlife Service, Environment Canada. Report Series No. 37. Saskatoon, Saskatchewan. 38 p.

MOORE, P.D., AND D.J. BELLAMY. 1974. Peatlands: a guide to marshes and shallow open water wetlands in the grasslands and parklands of the prairie provinces. Springer-Verlag New York Inc. New York, New York. 221 p.

NIERING, W.A. 1985. Wetlands. The Audubon Society Nature Guide Series. Alfred A. Knopf, Inc. New York, New York. 640 p.

POLLETT, F.C. 1968. Glossary of peatland terminology. Canada Department of Forestry and Rural Development. Internal Report No. N-5. St. John's, Newfoundland. 30 p.

PUUSTJÄRVI, V. 1979. Classification of virgin peat with regard to the requirements of horticultural peat use. *In* Classification of peat and peatlands. E. Kivinen, L. Heikurainen, and P. Pakarinen, editors. International Peat Society. Helsinki, Finland. pp. 239–259.

SANDERSON, M. 1948. The climates of Canada according to the new Thornthwaite classification. Scientific Agriculture 28:501–517.

SCOGGAN, H.J. 1978. The flora of Canada. National Museum of Natural Sciences. Publications in Botany No. 7. Ottawa, Ontario. 1 711 p.

SCOTT, W.B., AND E.J. CROSSMAN. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Fisheries and Oceans Canada. Bulletin No. 184. Ottawa, Ontario. 966 p.

SJÖRS, H. 1961a. Surface patterns in boreal peatlands. Endeavour 20:217–224.

SJÖRS, H. 1961b. Forest and peatland at Hawley Lake, northern Ontario. National Museums of Canada. Bulletin No. 171. Ottawa, Ontario. pp. 1–31.

SLOAN, C.E. 1970. Prairie potholes and the water table. United States Geological Survey. Professional Paper 700-B. Washington, DC. pp. B227–B231.

SOIL CONSERVATION SOCIETY OF AMERICA. 1982. Resource conservation glossary. 3rd edition. H.W. Pritchard, chairman. Madison, Wisconsin. 126 p.

STANEK, W. 1977. A list of terms and definitions. *In* Muskeg and the northern environment in Canada. N.W. Radforth and C.O. Brawner, editors. University of Toronto Press. Toronto, Ontario. pp. 367–387.

STANEK, W., AND I.A. WORLEY. 1983. A terminology of virgin peat and peatlands. *In* Proceedings, International Symposium on Peat Utilization. C.H. Fucshman and S.A. Spigarelli, editors. Bemidji State University, Bemidji, Minnesota. pp. 75–102.

STELFOX, H.A. 1982. Conceptual considerations for wildlife habitat inventory and the role of ecological land classification. Discussion paper, Second Wildlife Integration Workshop. March 21–24,1982. Banff, Alberta. Fish and Wildlife Division, Alberta Department of Energy and Natural Resources. Edmonton, Alberta. Unpublished. 3 p.

STRONG, W.L., AND K.R. LEGGAT. 1981. Ecoregions of Alberta. Research Evaluation and Planning Division, Alberta Department of Energy and Natural Resources. Technical Report No. T/4. Edmonton, Alberta. 64 p.

TANSLEY, A.G. 1953. The British Isles and their vegetation. 2 volumes. Cambridge University Press. Cambridge, UK. 930 p.

TARNOCAI, C. 1970. Classification of peat landforms in Manitoba. Agriculture Canada. Winnipeg, Manitoba. Unpublished. 60 p.

UNITED STATES ARMY CORPS OF ENGINEERS. 1986. Wetland plants of the Pacific Northwest. Seattle District Office. Seattle, Washington. 85 p.

VEATCH, J.O., AND C.R. HUMPHRYS. 1966. Water and water use terminology. Thomas Printing and Publishing Co. Kaukauna, Wisconsin. 375 p.

WASHBURN, A.L. 1979. Geocryology. Edward Arnold Ltd. London, UK. 320 p.

WHITTAKER, R.M., S.A. LEVIN, AND R.B. ROOT. 1975. On the reasons for distinguishing "niche, habitat, and ecotope". Letters to the editors. American Naturalist 109:479–482.

ZOLTAI, S.C. 1971. Southern limit of permafrost features in peat landforms, Manitoba and Saskatchewan. Geological Association of Canada. Special Paper No. 9. Winnipeg, Manitoba. pp. 305–310.

ZOLTAI, S.C., AND W.W. PETTAPIECE. 1973. Terrain, vegetation, and permafrost relationships in the northern part of the Mackenzie Valley and northern Yukon. Environmental–Social Committee, Northern Pipelines. Task Force on Northern Oil Development. Report No. 73-4. Ottawa, Ontario. 105 p.

ZOLTAI, S.C., AND C. TARNOCAI. 1975. Perennially frozen peatlands in the western Arctic and Subarctic of Canada. Canadian Journal of Earth Sciences 12:28–43.

General Index

Agricultural reclamation 291–294, 389–392

Amphibians and reptiles 231, 385

Arctic wetland forms 36–47

Arctic wetland regions
- — High Arctic (AH) 33–34
- — Low Arctic (AL) 35–36
- — Mid-Arctic (AM) 34–35

Atlantic freshwater marshes 282, 284

Atlantic peatlands 254–255

Atlantic wetland regions 253–254

Biogeochemical functions 385–387

Bog forms
- — Atlantic plateau bog 259, 417
- — Basin bog 113–116, 206–207, 259, 312–313, 417
- — Blanket bog 259, 417
- — Collapse scar bog 120, 417
- — Domed bog 104–108, 207–208, 259, 327–330, 417
- — Flat bog 111–113, 206–207, 326–327, 417
- — Floating bog 313, 316–318, 418
- — Lowland polygon bog 36–41, 418
- — Mound bog 418
- — Northern plateau bog 108–111, 418
- — Palsa bog 68–70, 116–121, 418
- — Peat mound bog 41–43, 418
- — Peat plateau bog 61–64, 116–121, 418
- — Polygonal peat plateau bog 64–68, 418
- — Shore bog 208, 313, 316–318, 418
- — Slope bog 259, 318–326, 418
- — String bog 259, 418
- — Veneer bog 78–82, 418

Boreal wetland forms 103–139

Boreal wetland regions
- — Atlantic Boreal (BA) 254
- — High Boreal (BH) 103
- — Low Boreal (BL) 103
- — Mid-Boreal (BM) 103

Canadian regional wetland classification systems 12–13

Canadian Wetland Classification System 13–17, 413–427

Chemical analyses of peat and water 21
Classification of wetlands 9–17, 166, 266–267, 351, 413–427
Climate 31–32, 56, 59–60, 101, 159–160, 205, 253, 309–311
Conservation 50–51, 192–193, 289–291, 382–389
Conservation programs 150, 193, 239–240, 293, 383, 402
Definition of wetland 3, 162–163, 350–351
Density of occurrence of wetlands 163
Distribution of wetlands 4, 33, 169–170, 284–286, 352–353
Drainage 187, 291, 342, 389–392, 397–398
Dynamics of wetland ecosystems 17–19, 47–48, 86–88, 140–144, 180–183, 224–227, 257, 337–342
Eastern temperate wetland complexes 233–237
Eastern temperate wetland forms 205–224
Economic valuations 231–232, 381–398, 407
Educational values 289, 344, 388
Energy development and impacts 254, 295–297, 394–395
Estuarine values 384–385
Estuary 351
Evaluation programs 240–242, 383, 404
Evolution of wetlands since deglaciation 7–9, 58–59, 160–161, 224–227, 341
Factors influencing wetland development 4, 257–265, 311
Fen forms
— Atlantic ribbed fen 259, 419
— Basin fen 44, 123–124, 179–180, 419
— Channel fen 77–78, 210–212, 419
— Collapse scar fen 78–82, 116–121, 419
— Feather fen 133–134, 419
— Floating fen 419
— Horizontal fen 121–123, 420
— Ladder fen 259, 420
— Lowland polygon fen 36–41, 420
— Net fen 420
— Northern ribbed fen 70–77, 126–133, 420
— Palsa fen 420
— Shore fen 209–210, 334–336, 420
— Slope fen 259, 336, 420
— Snowpatch fen 43–44, 420
— Spring fen 124–126, 420
— Stream fen 209–210, 334–336, 420

Fisheries values 230–231, 368, 388–389
Geographic setting 30–31, 58–59, 100–101, 158–159, 203–205, 252–253, 309, 352
Groundwater 164–165
Habitat diversity 384–385

Hydrology 164–166, 187–188, 232–233, 288, 337–338, 385–387

Ice wedge 38–39, 66

Industrial impacts 342, 392–394

Land use impacts 149–150, 186–187, 190, 192, 291–297, 342, 344, 369–370, 389–398

Loss of wetlands (conversions) 237–238, 369–370, 398–406

Marsh forms
— Active delta marsh 46, 133, 135, 421
— Channel marsh 172–175, 421
— Coastal high marsh 421
— Coastal low marsh 421
— Estuarine high marsh 267–270, 421
— Estuarine low marsh 267–270, 422
— Floodplain marsh 45, 82–83, 171–172, 422
— Inactive delta marsh 133, 135, 422
— Kettle marsh 175–177, 422
— Seepage track marsh 422
— Shallow basin marsh 177, 422
— Shore marsh 136–138, 221–222, 422
— Stream marsh 422
— Terminal basin marsh 178, 422
— Tidal freshwater marsh 222–223, 422

Mountain wetland regions 19
— Coastal Mountain (MC) 308, 405
— Eastern Mountain (ME) 254, 406
— Interior Mountain (MI) 405
— Rocky Mountain (MR) 405

North American Waterfowl Management Plan 193, 383, 407

Northern wetlands conservation 50–51, 405

Nutrient status and recycling 85–86, 139–140, 182–183

Oceanic wetland regions 18
— Atlantic Oceanic (OA) 254
— Pacific Oceanic (OP) 308–309

Organic soil classification 11–12

Pacific coast wetland forms 312–337

Peat
— Accumulation rates 48–49, 89–90, 144–145, 226, 258–260, 289
— Aging 41, 49–50, 90–92, 145–148, 225–226, 341
— Harvesting 294–297, 342, 395–396
— Physical properties 20–21

Peatland development processes 4–7, 257

Peatland forestry 294, 396–398

Prairie wetland forms 170–180

Prairie wetland regions
— Continental Prairie (PC) 161–162, 400
— Intermountain Prairie (PI) 162, 400

Productivity 145, 188–189, 270, 273, 277–278, 384–385

RAMSAR Convention 192, 233–235, 383

Rare and endangered species 386

Recreational values of wetlands 289, 342, 387–388, 398

Renewable resource harvest 388–389

Salinity and wetland development 183–186, 265, 351

Salinity classes 183, 351

Saline lakes 186

Salt marsh
— Definition 350–351
— Development 265–266, 278–282, 351–353
— Loss 369–370, 395, 399–400, 404–405
— Research priorities 370–371
— Values 367–369

Salt marsh occurrence
— Arctic 362–363
— Atlantic coast 267, 358–362
— Bay of Fundy 267–268, 360–361
— Gulf of St. Lawrence 268–269, 275, 359–360
— James/Hudson bays 363–367
— Newfoundland/Labrador 269–270, 361–362
— Pacific coast 353–358

Sampling methods for peat and water 19–20

Shallow water forms
— Channel water 424
— Delta water 424
— Estuarine water 424
— Kettle water 178–179, 424
— Non-tidal water 424
— Oxbow water 424
— Shallow basin 424
— Shore water 223–224, 424
— Stream water 424
— Terminal basin water 178, 424
— Thermokarst water 83–85, 424
— Tidal water 424
— Tundra pool water 44–45, 424

Subarctic wetland forms 60–85

Subarctic wetland regions
— Atlantic Subarctic (SA) 254
— High Subarctic (SH) 59
— Low Subarctic (SL) 60

Succession 88, 140–141, 226–227, 276, 285, 338–341

Swamp forms
— Basin swamp 214, 331, 423
— Flat swamp 423
— Floodplain swamp 45–46, 82–83, 138–139, 331–332, 423
— Peat margin swamp 106, 114–116, 213–214, 423
— Shore swamp 215–217, 423

— Spring swamp 217–219, 332–334, 423
— Stream swamp 214–215, 331, 423

Temperate wetland regions
— Eastern Temperate (TE) 201–205
— Pacific Temperate (TP) 308

Tidal power 395

Urban wetland loss 392–394, 399–405

Values of wetlands 50–51, 92–93, 148–150, 187–192, 288–297, 342, 344, 367–369

Vegetation analyses 22

Waste assimilation 188

Water loss 165–166

Wetland classes 13–15
— Bog 14
— Fen 14
— Marsh 15
— Shallow water 15
— Swamp 15

Wetland forms (*see listings for Bog, Fen, Marsh, Shallow water, and Swamp forms*)

Wetland phases
— Deep 322–325
— Forest 319–320
— Shallow 136, 325–326
— Wet 330
— Woodland 320, 322

Wetland regionalization 17–19

Wetland regions (*see listings for Arctic, Boreal, Mountain, Oceanic, Prairie, Subarctic, and Temperate wetland regions*)

Wetland stability 50, 88–89, 144

Wetland subforms
— Deep marsh 136, 168
— Floating marsh/fen transition 136–137
— Intermittent open water 168
— Intermittent saline lake 169
— Permanent open water 169
— Shallow marsh 137, 167–168
— Wet meadow marsh 137, 167

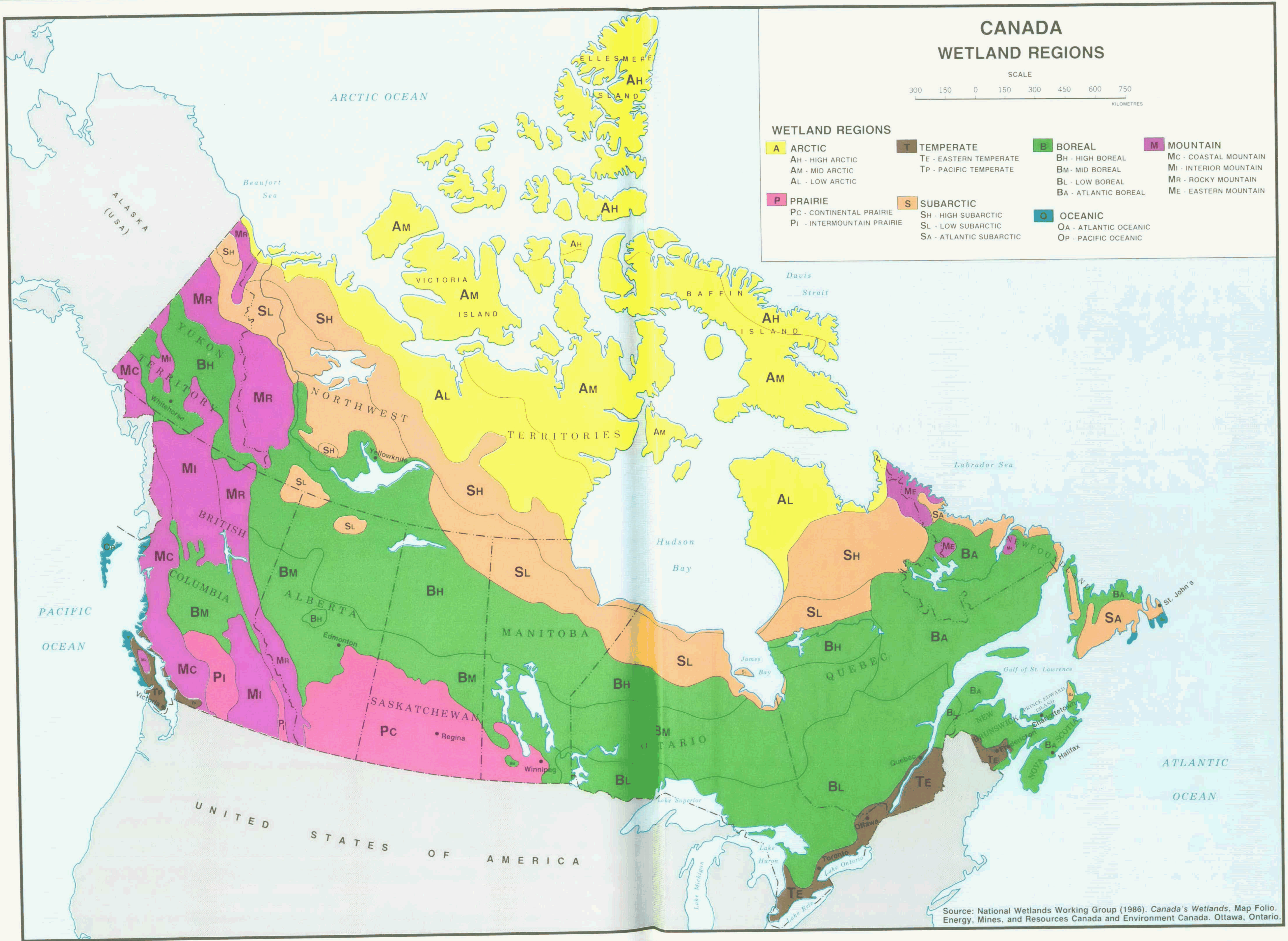
Wetland types 16
— Aquatic, submerged 178
— Aquatic, submerged/floating 178–179
— Graminoid 209, 211
— Moss 313
— Moss/Forb 316, 318
— Rush 171–177
— Sedge 177, 334–336
— Sedge/Grass 172, 179–180
— Shrub, low 329

— Shrub, tall 322–325
— Shrub/Treed (Thicket) 211–212
— Treed, coniferous 218–219, 312–313, 319–322
— Treed, hardwood 217–218

Wildlife Habitat Canada Foundation 193, 293, 383, 407

Wildlife values of wetlands 50–51, 92–93, 148–149, 189–191, 227–231, 286–287, 289, 311, 342, 368–369, 384, 388–389

Printed in Canada
by Les Editions Marquis
Montmagny, Québec


CANADA
WETLAND REGIONS
SCALE
300 150 0 150 300 450 600 750
KILOMETRES
WETLAND REGIONS
A ARCTIC
AH - HIGH ARCTIC
AM - MID ARCTIC
AL - LOW ARCTIC
P PRAIRIE
PC - CONTINENTAL PRAIRIE
PI - INTERMOUNTAIN PRAIRIE
T TEMPERATE
TE - EASTERN TEMPERATE
TP - PACIFIC TEMPERATE
S SUBARCTIC
SH - HIGH SUBARCTIC
SL - LOW SUBARCTIC
SA - ATLANTIC SUBARCTIC
B BOREAL
BH - HIGH BOREAL
BM - MID BOREAL
BL - LOW BOREAL
BA - ATLANTIC BOREAL
O OCEANIC
OA - ATLANTIC OCEANIC
OP - PACIFIC OCEANIC
M MOUNTAIN
MC - COASTAL MOUNTAIN
MI - INTERIOR MOUNTAIN
MR - ROCKY MOUNTAIN
ME - EASTERN MOUNTAIN
ARCTIC OCEAN
Beaufort Sea
ALASKA (U.S.A.)
ELLESMERE ISLAND
VICTORIA ISLAND
BAFFIN ISLAND
Davis Strait
Labrador Sea
Hudson Bay
James Bay
YUKON TERRITORY
Whitehorse
NORTHWEST TERRITORIES
Yellowknife
BRITISH COLUMBIA
ALBERTA
Edmonton
SASKATCHEWAN
Regina
MANITOBA
Winnipeg
ONTARIO
Ottawa
Toronto
QUEBEC
Quebec
NEWFOUNDLAND
St. John's
NEW BRUNSWICK
Fredericton
PRINCE EDWARD ISLAND
Charlottetown
NOVA SCOTIA
Halifax
Gulf of St. Lawrence
Victoria
PACIFIC OCEAN
ATLANTIC OCEAN
UNITED STATES OF AMERICA
Lake Superior
Lake Michigan
Lake Huron
Lake Ontario
Lake Erie
Source: National Wetlands Working Group (1986). Canada's Wetlands, Map Folio. Energy, Mines, and Resources Canada and Environment Canada. Ottawa, Ontario.

Wetlands of Canada provides the first comprehensive overview of the ecology, variety, and status of Canadian wetlands. The reader will acquire a sound appreciation of the origins and functions of wetlands and will understand why the conservation of wetlands is critical to Canada's environmental mosaic.

Unlike many other ecosystems, wetlands are found in all parts of the nation. They offer unparalleled and highly diverse values for biological, hydrological, ecological, and socioeconomic purposes. They are often critical to the livelihood of many Canadians and strategically important in sustaining biological life.