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4 Wetlands of Boreal Canada

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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 sedimentaıy 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.

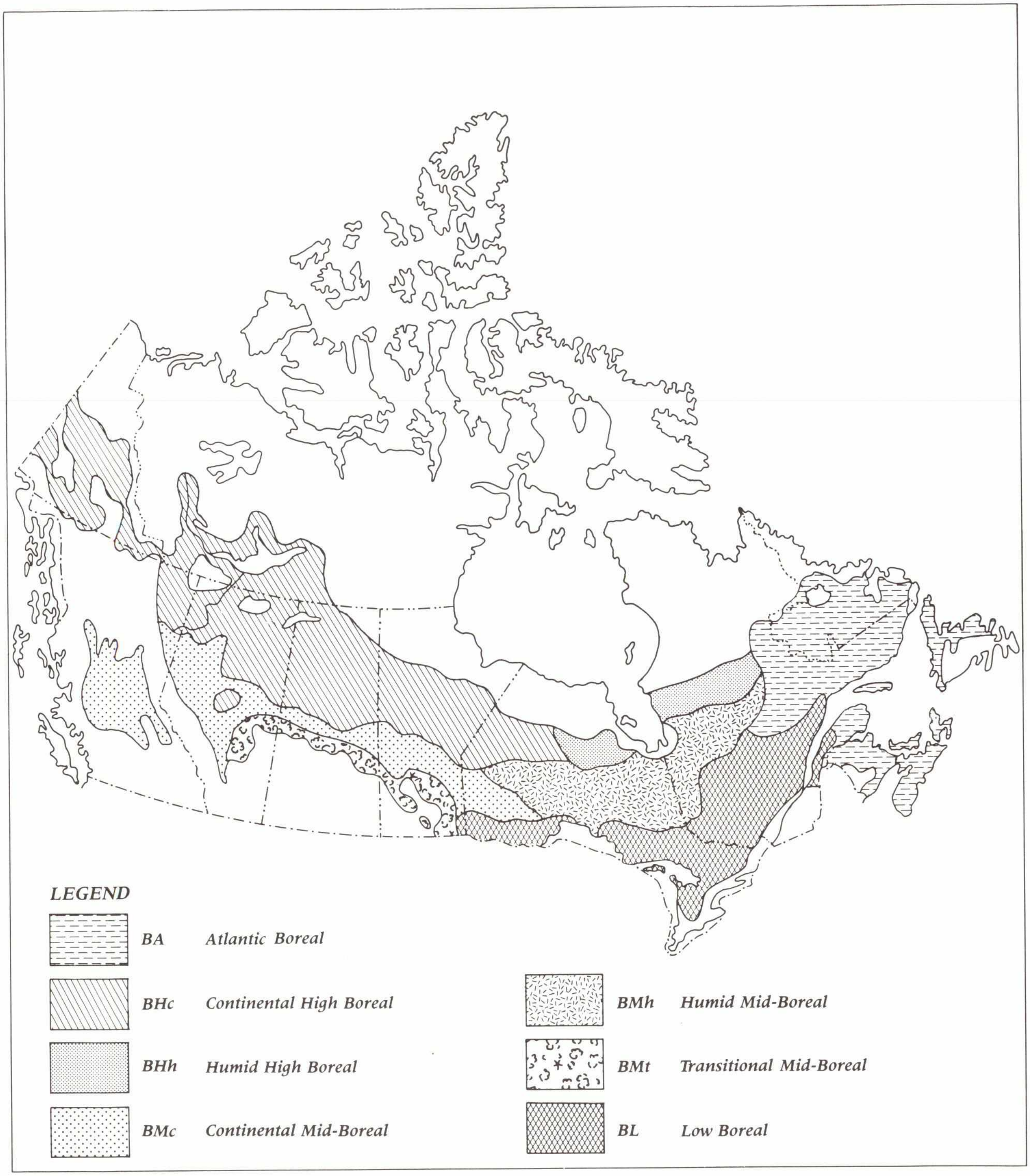
Boreal Wetland Regions and their Vegetation

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 sub-humid 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*.

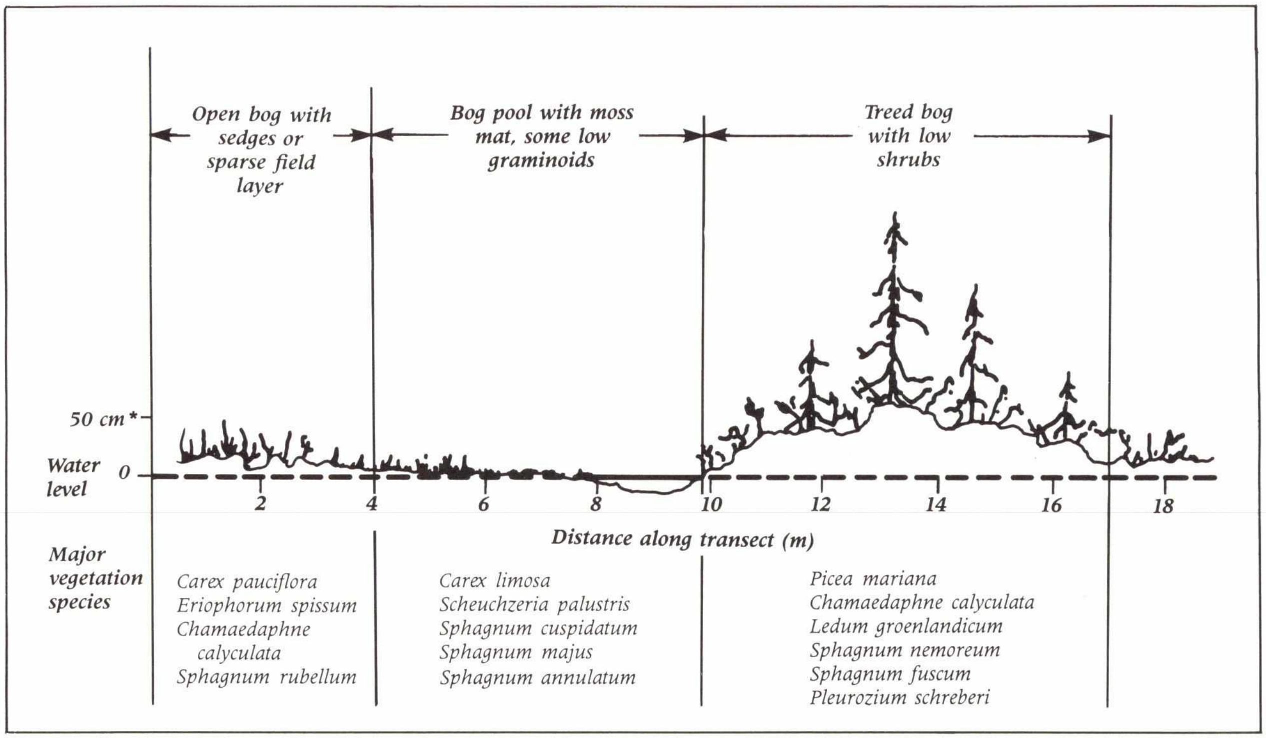
A cross-section of a treed ridge, a bog pool with moss cover, and a consolidated open domed bog at the Cochrane, Ontario, study site is presented to demonstrate that bog pools occur closest to the side of the ridges in the direction from which the water is moving (Figure 4–3), suggesting that the ridges 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.

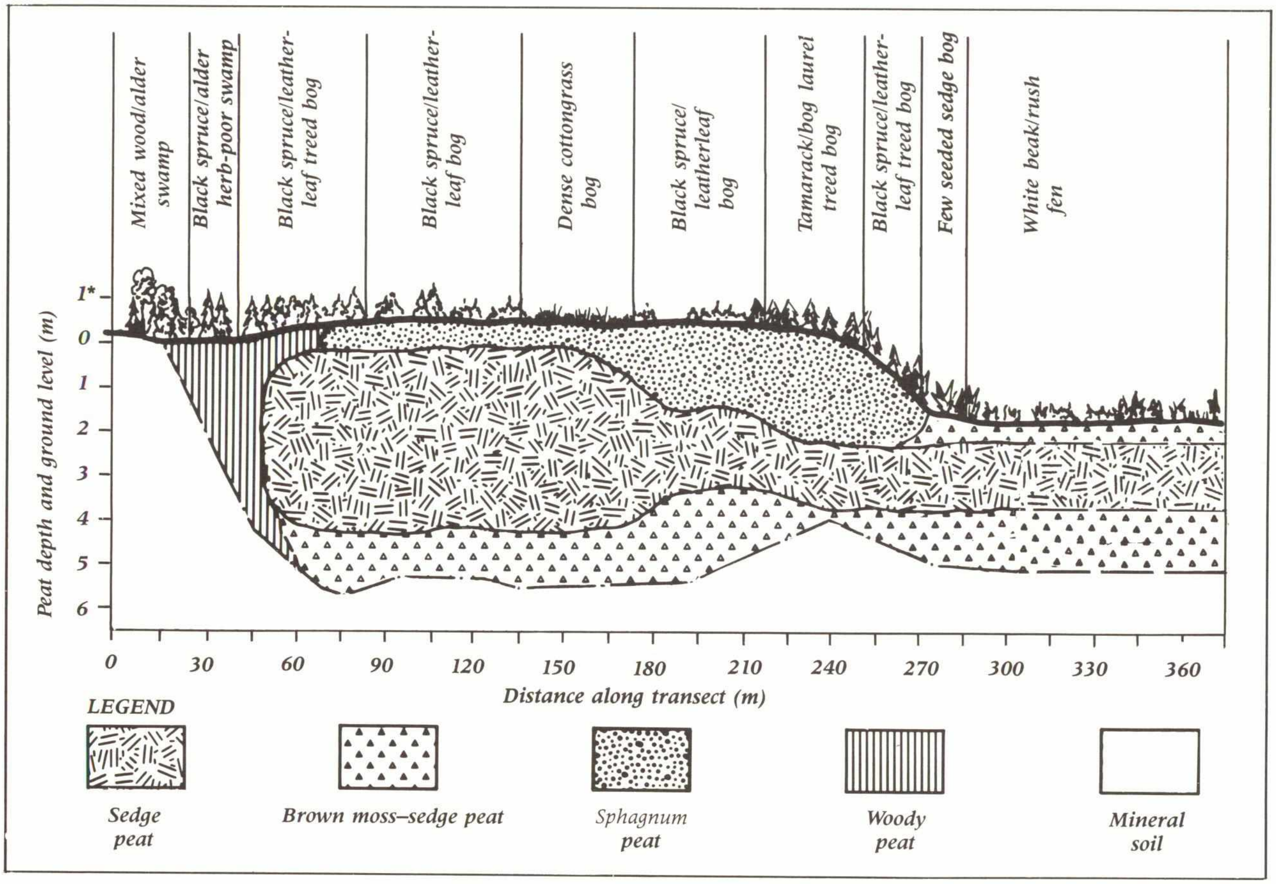
This domed bog is one of several large and varied wetland complexes within an area of about 1 000 km^2 around Timmins, Ontario. Together they retain large quantities of water that often falls within a short period of time and then they discharge it slowly into rivers. Although these wetlands are not 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

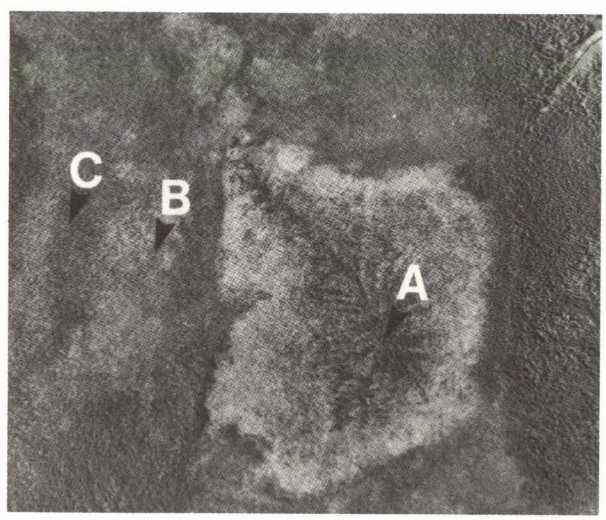


Figure 4–5.
Aerial photograph of a domed bog with dry centre near Cochrane, Ontario, with drainage lines radiating from the centre (A). The bog is surrounded by a treed fen (B), with an alder swamp at its outer fringe (C).

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-

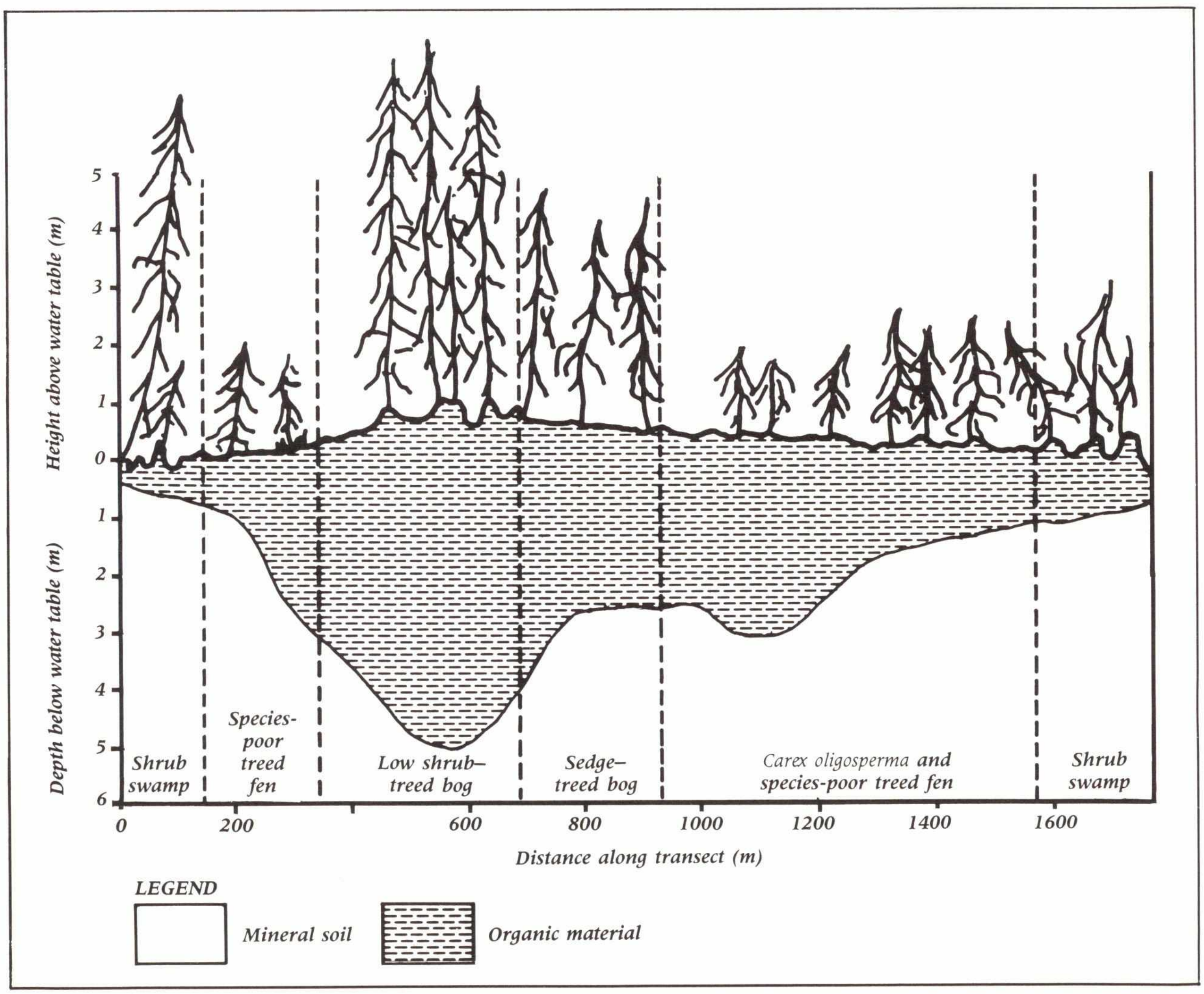


Figure 4–6.
Transect through a domed bog with linear crest and swamp margin near Cochrane, Ontario.

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

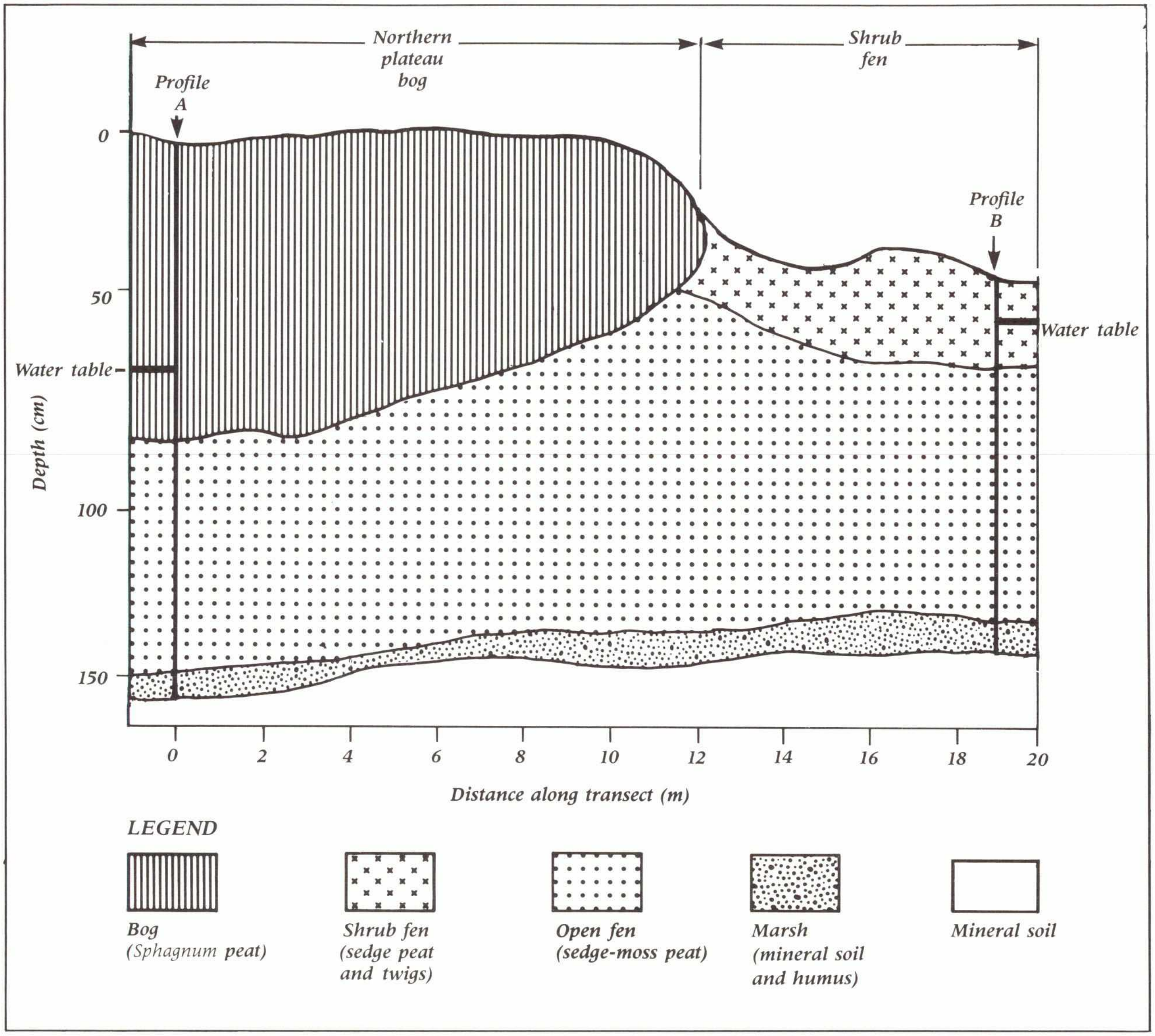


Figure 4–8.
Cross-section of a northern plateau bog near Riverton, Manitoba, indicating wetland environments during deposition.

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),

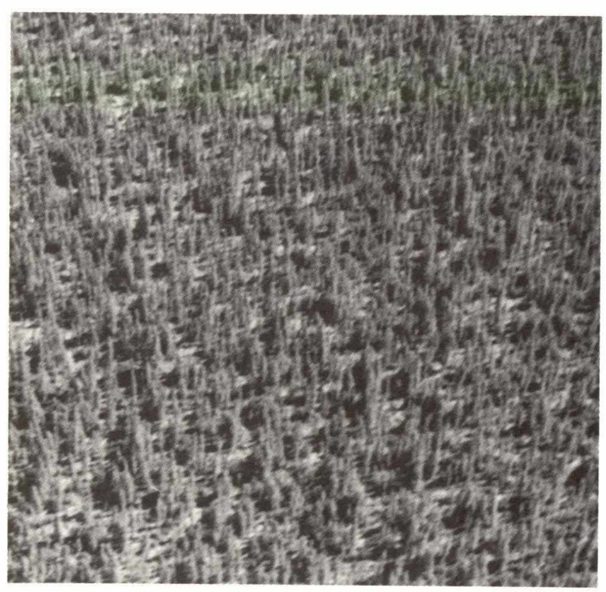


Figure 4–9.
Aerial view of a featureless flat bog with an open Picea mariana*-lichen cover near Kimiwan Lake, Alberta.*

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 feather-mosses, 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

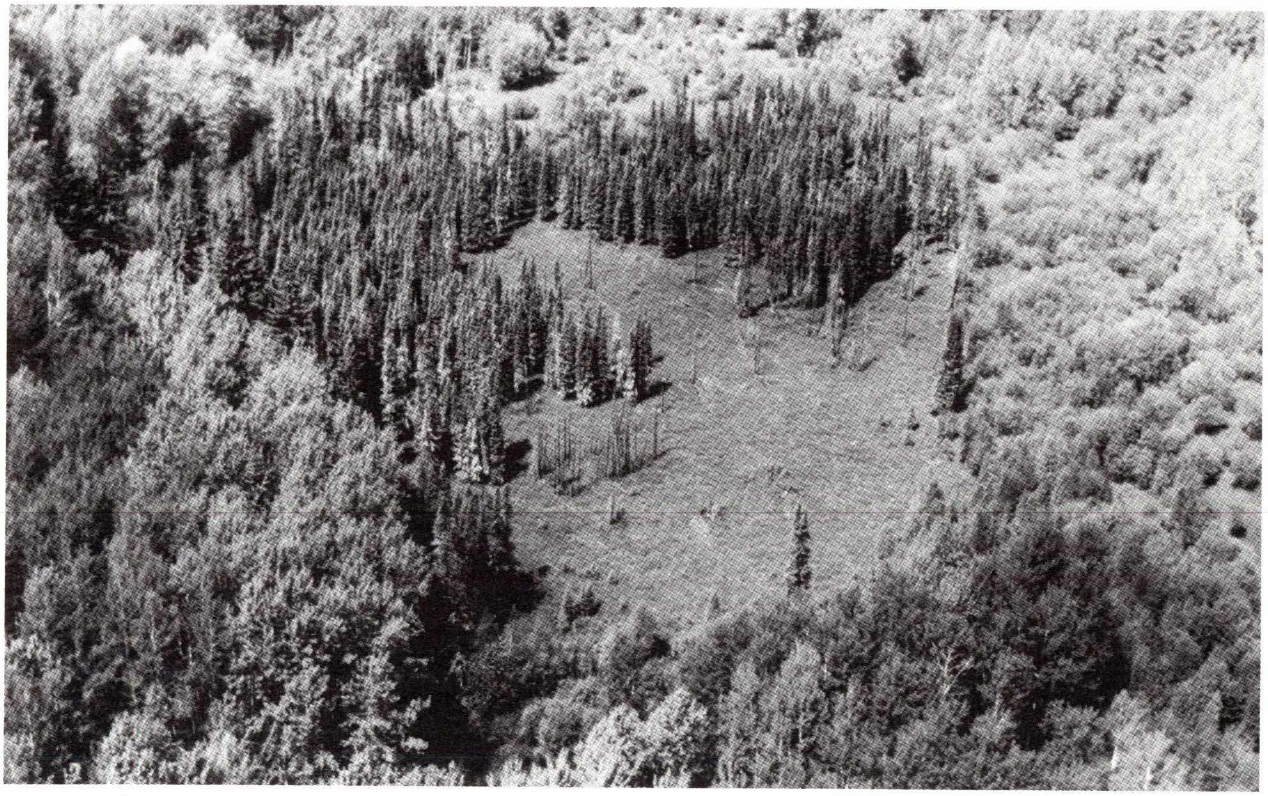


Figure 4–10.
A small basin bog near Lac la Biche, Alberta. The treeless portion failed to regenerate to spruce after a fire.

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*	*Decom-position (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

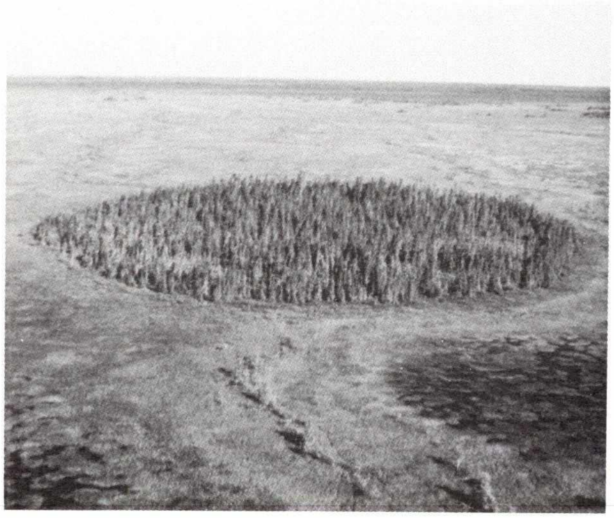


Figure 4–11.
A treed peat plateau bog in a large fen near Amisk Lake, Saskatchewan.

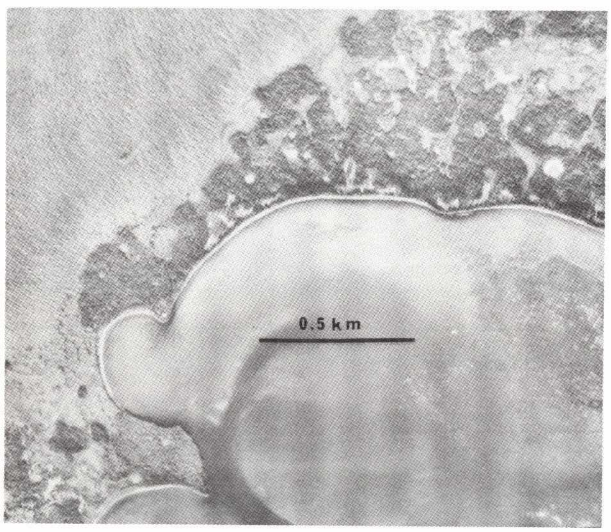


Figure 4–12.
Aerial photograph showing a peat plateau bog complex near Playgreen Lake, Manitoba, that developed between a lake and a ribbed fen. Circular collapse scar fens occur in the densely forested peat plateau bogs. The peat plateau bogs to the left of the small bay have completely collapsed, as 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

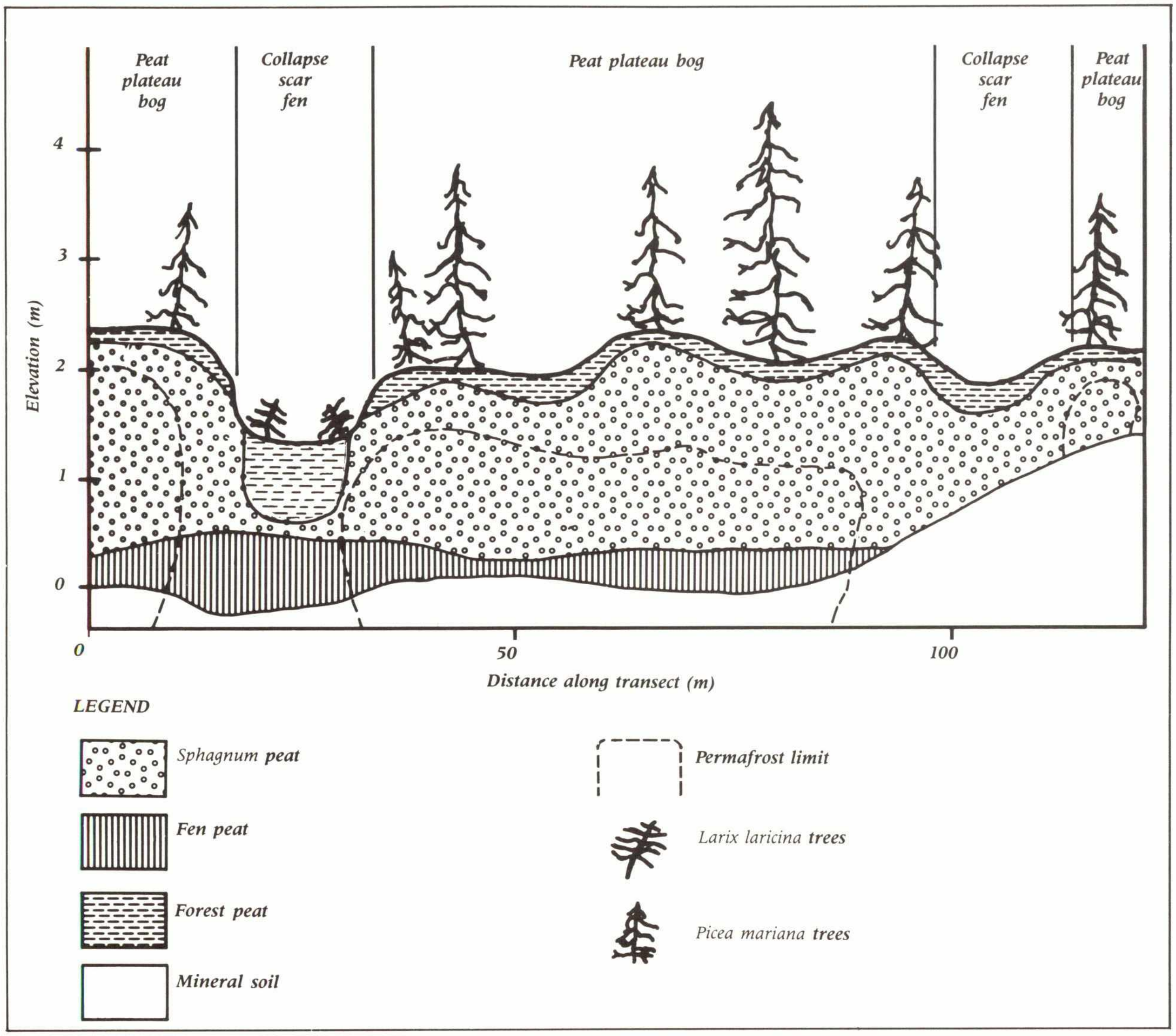


Figure 4–13.
Cross-section of a peat plateau bog complex with collapse scar fen near Knee Lake, Manitoba.

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.

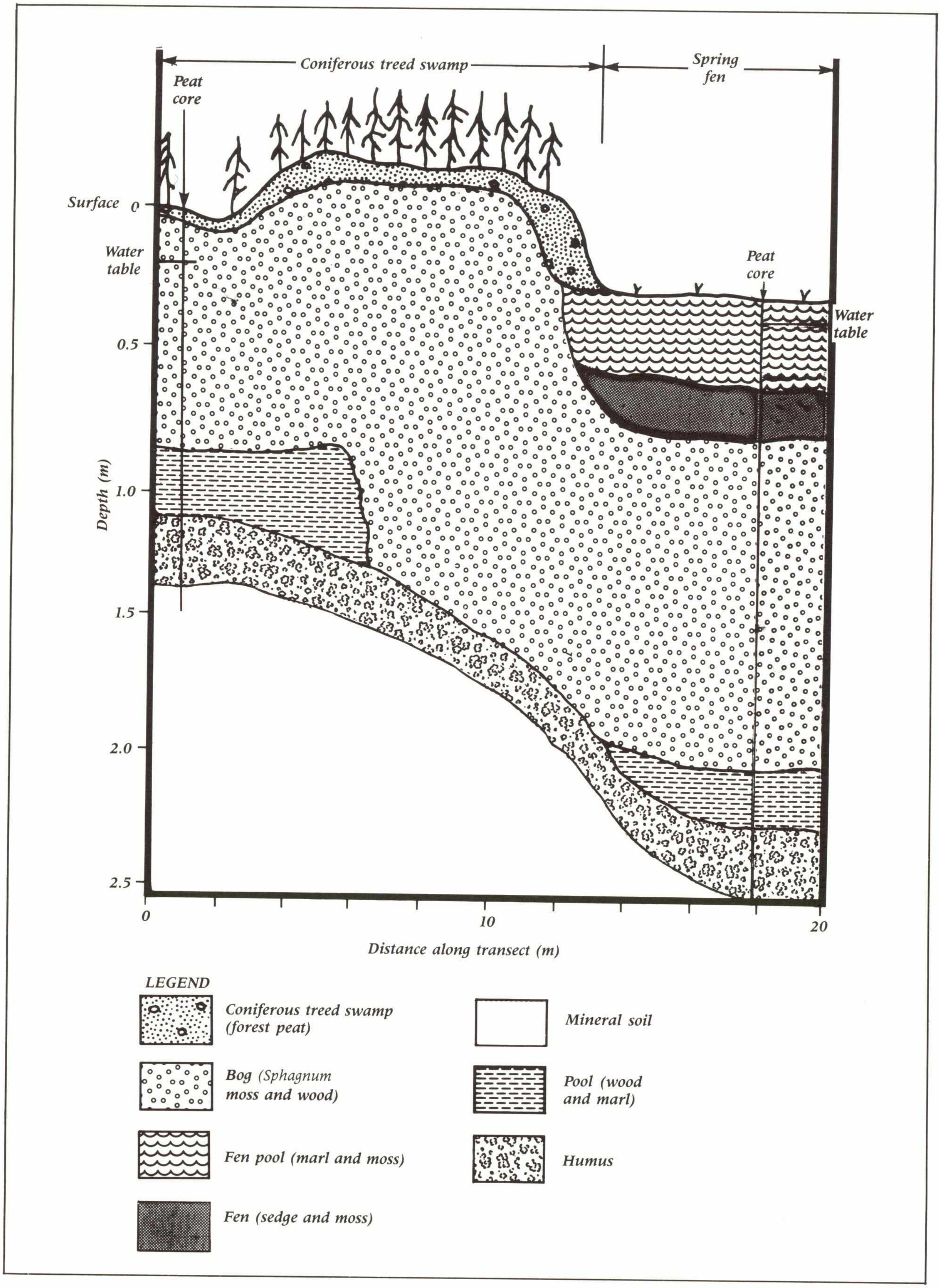


Figure 4–17.

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

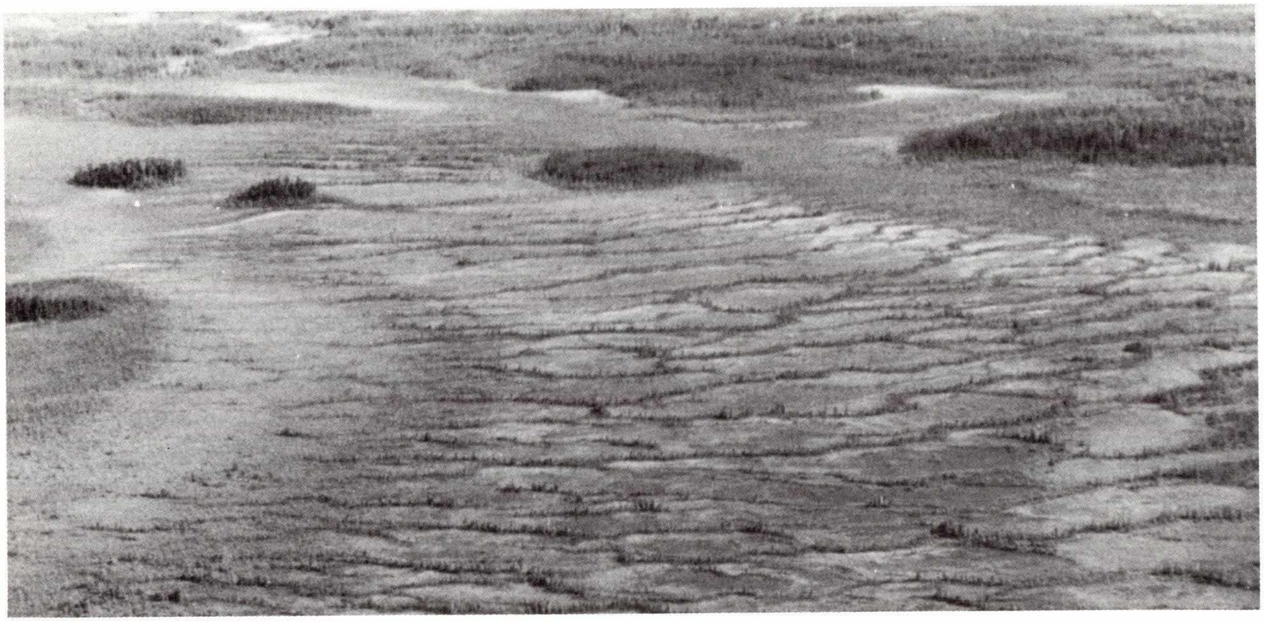


Figure 4–18.
A northern ribbed fen near Besnard Lake, Saskatchewan, with drainage towards the viewer.

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

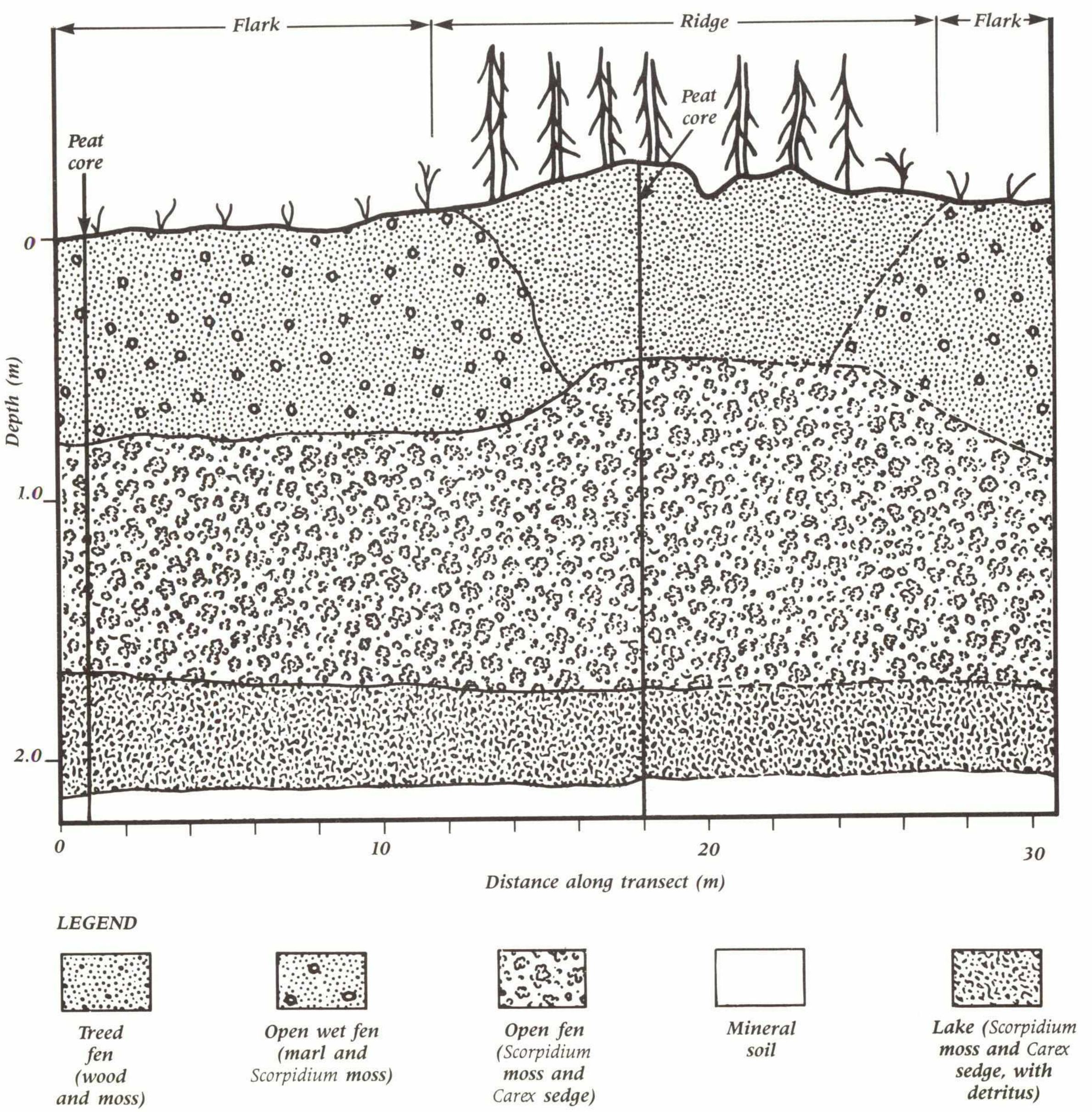


Figure 4–19.
Cross-section of a northern ribbed fen, indicating wetland environments during deposition, near Smith, Alberta.

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*.

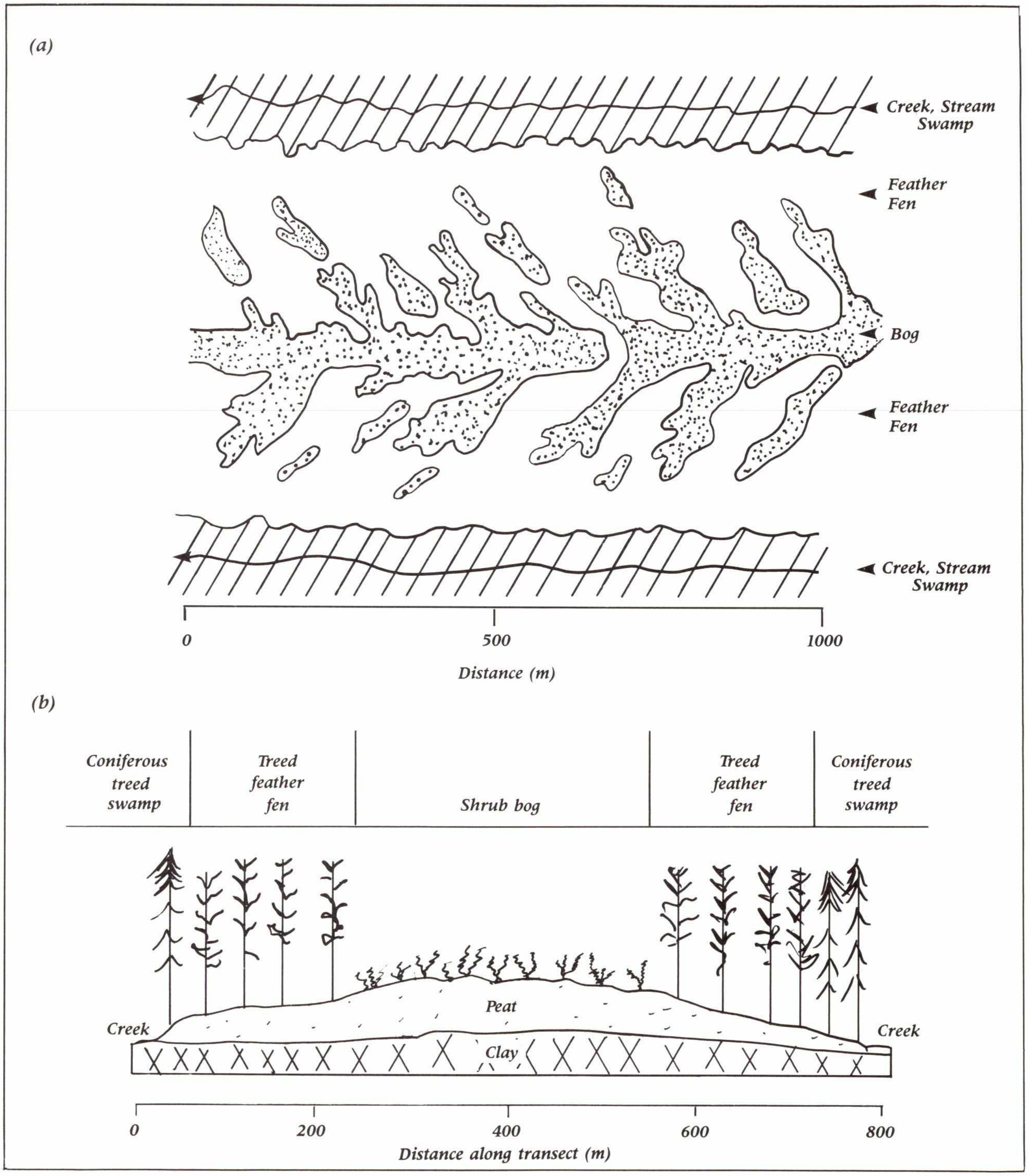
These fens occur in the southern James Bay area of Quebec (Grondin and Ouzilleau 1980). Here, the mineral-soil landscape consists of marine clays that slope gently towards the Bay. The clays are shallowly dissected by small, parallel streams, forming a base for the development of these striking feather 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.

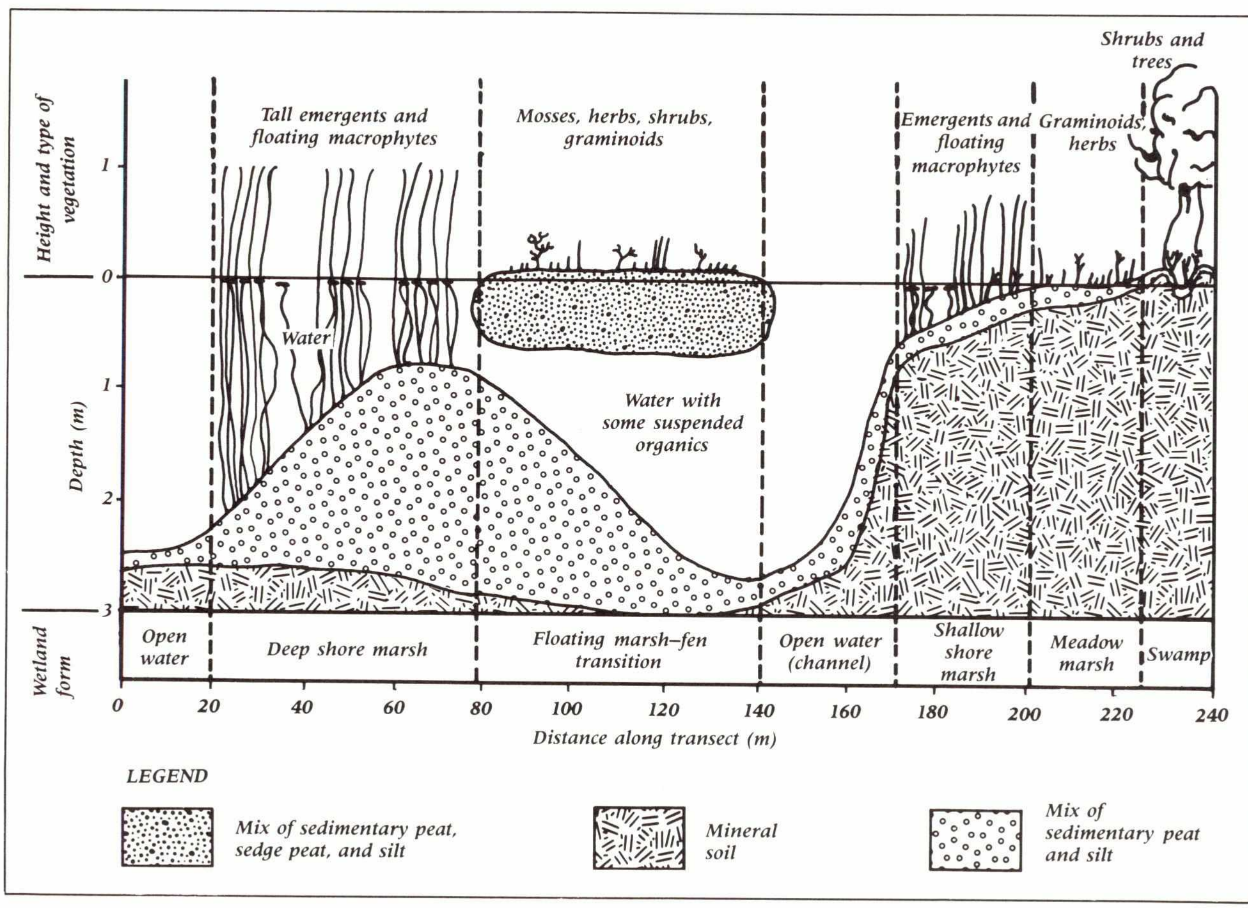


Figure 4–22.
A transect through a marsh complex showing different vegetation communities and peat stratigraphy.

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.

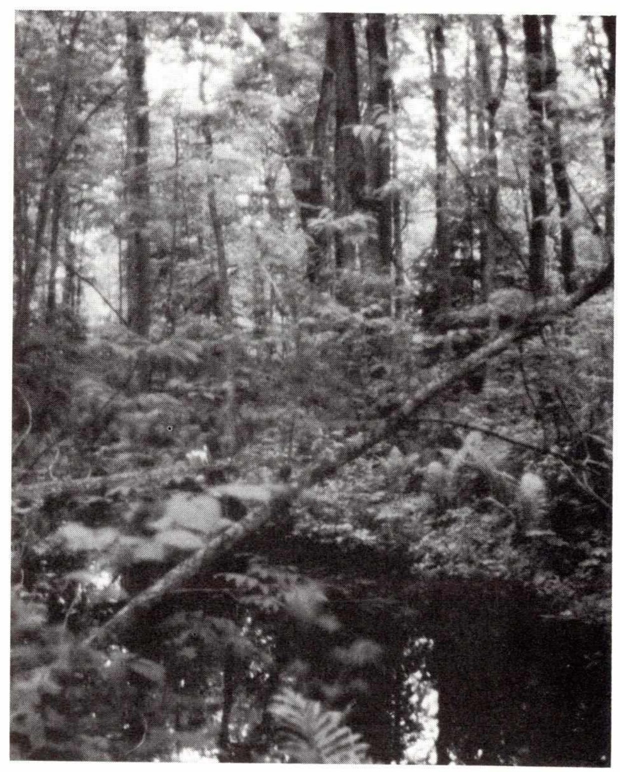


Figure 4–23.
Interior of a treed stream swamp with black ash and luxuriant ground vegetation.

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)						Conductivity (mS/cm)
					Ca	Mg	K	Fe	S	P	
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

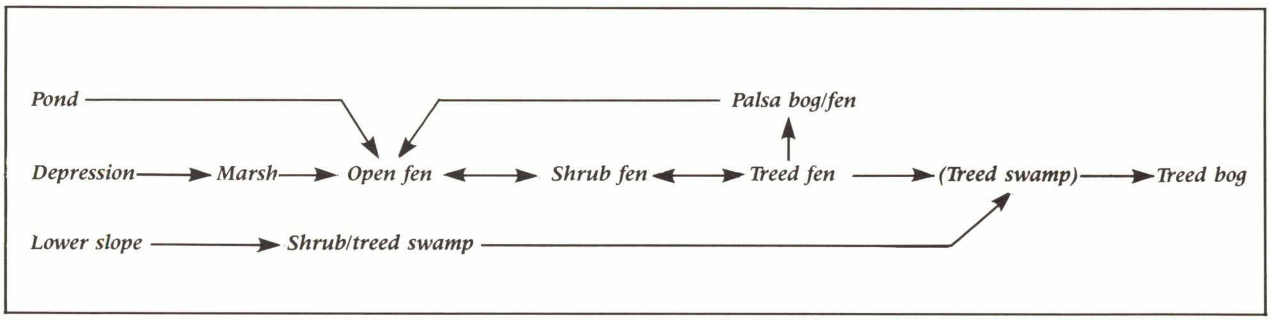
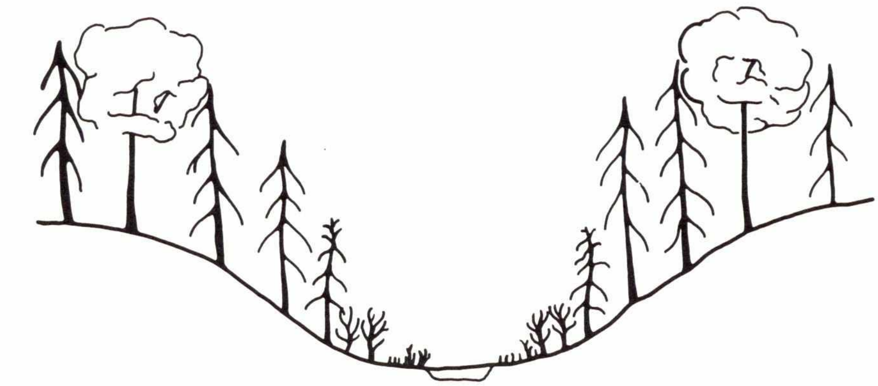


Figure 4–24.
Diagram of wetland developmental trends in boreal wetland regions.

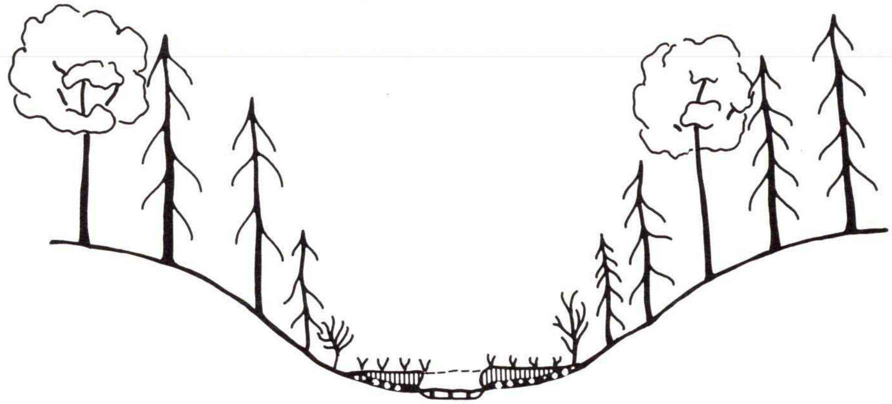
may be arrested at a more advanced stage by any one of several environmental conditions. Thus, a wetland may develop to a fen, but bogs often cannot develop on them because of environmental conditions such as the high nutrient content of groundwater, the abundance of groundwater, or low amounts of precipitation. 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

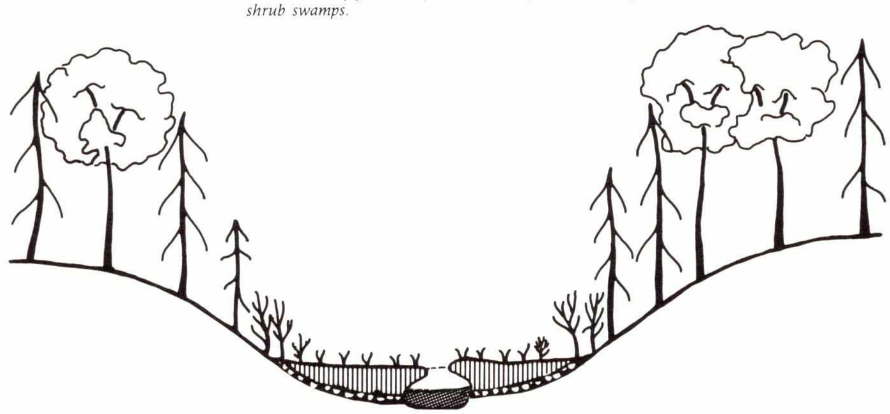
In the boreal areas of Canada, wetlands are initiated in depressional sites which receive water from external sources and which have poor internal and external drainage. Such depressions initially contain a wet meadow–marsh phase, ringed by a shrub–treed swamp (Figure 4–25a). As peat accumulates, open 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-



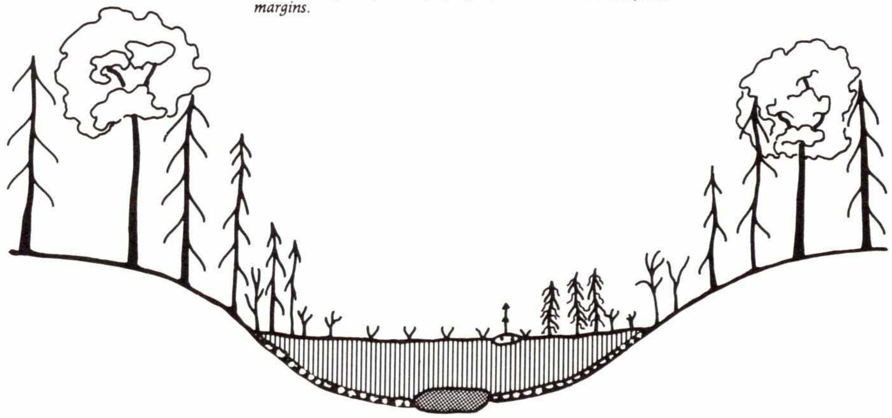
A. *Initial stage: small pool, marsh, and marginal shrub swamps.*



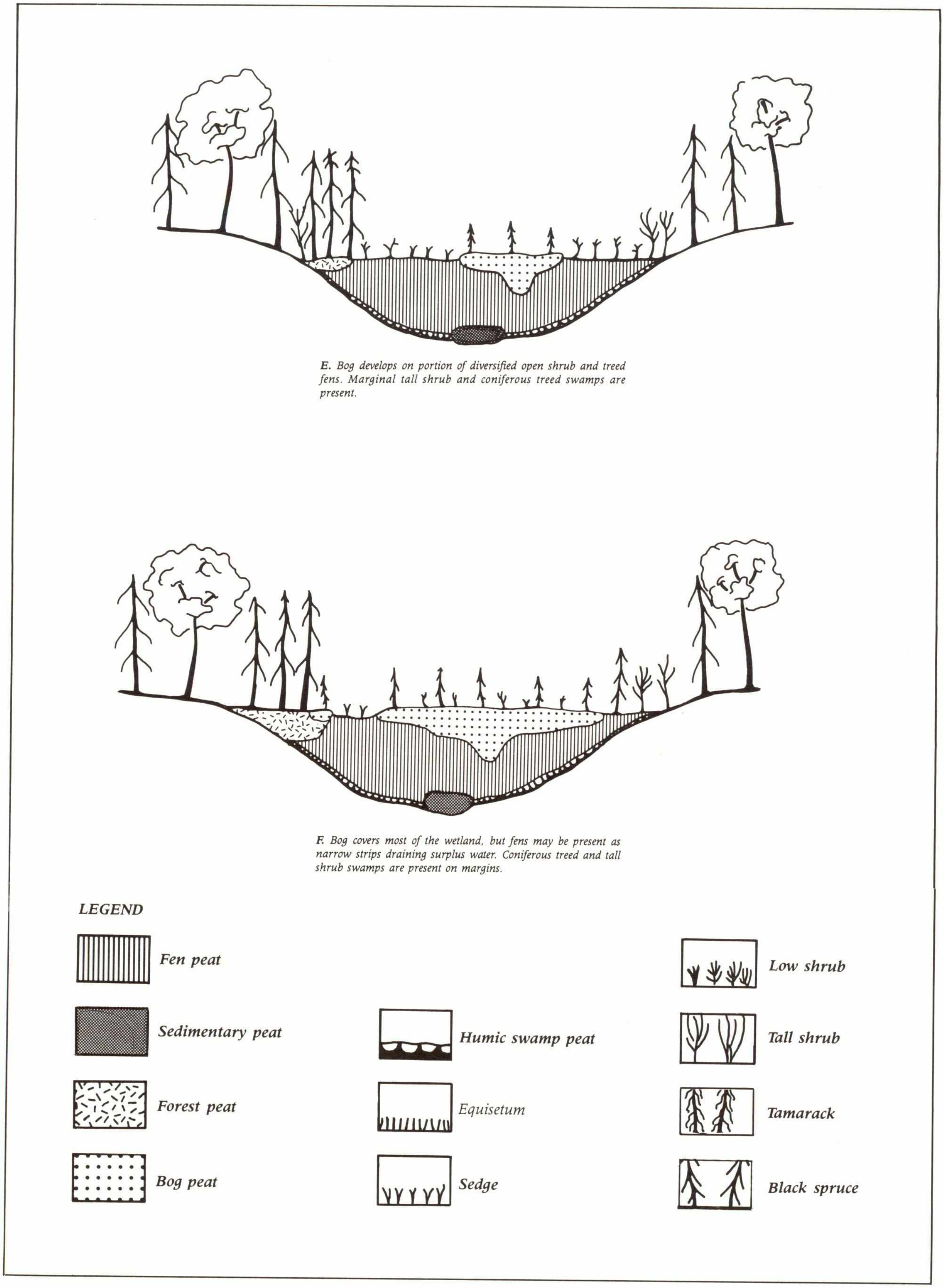
B. *Initiation of fen development around pool, with marginal shrub swamps.*



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		Diving ducks	
			Hours of use	Number of species	Hours of use	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.

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