2 Wetlands of Arctic Canada

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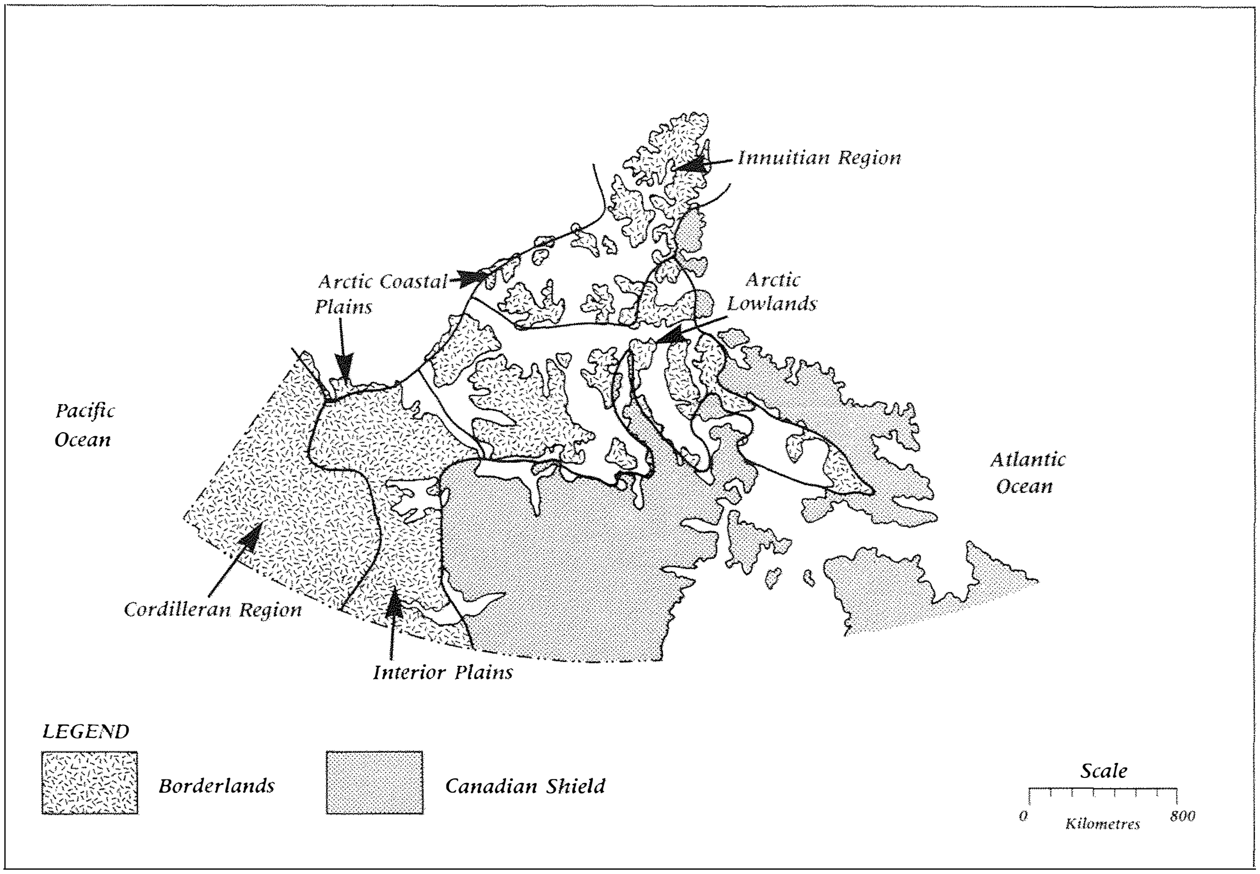
Wetlands of Arctic Canada

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

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



Source: Bostock (1970).

Figure 2–1.
Physiographic regions of arctic Canada.

Environmental Setting

Geography

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

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

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

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

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

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

Climate

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

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

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

Regional Ecology and Wetlands

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

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

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

High Arctic

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

Mid-Arctic

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

Low Arctic

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

Criteria for and Distribution of Arctic Wetlands

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

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

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

Arctic Wetland Regions

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

High Arctic Wetland Region (AH)

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

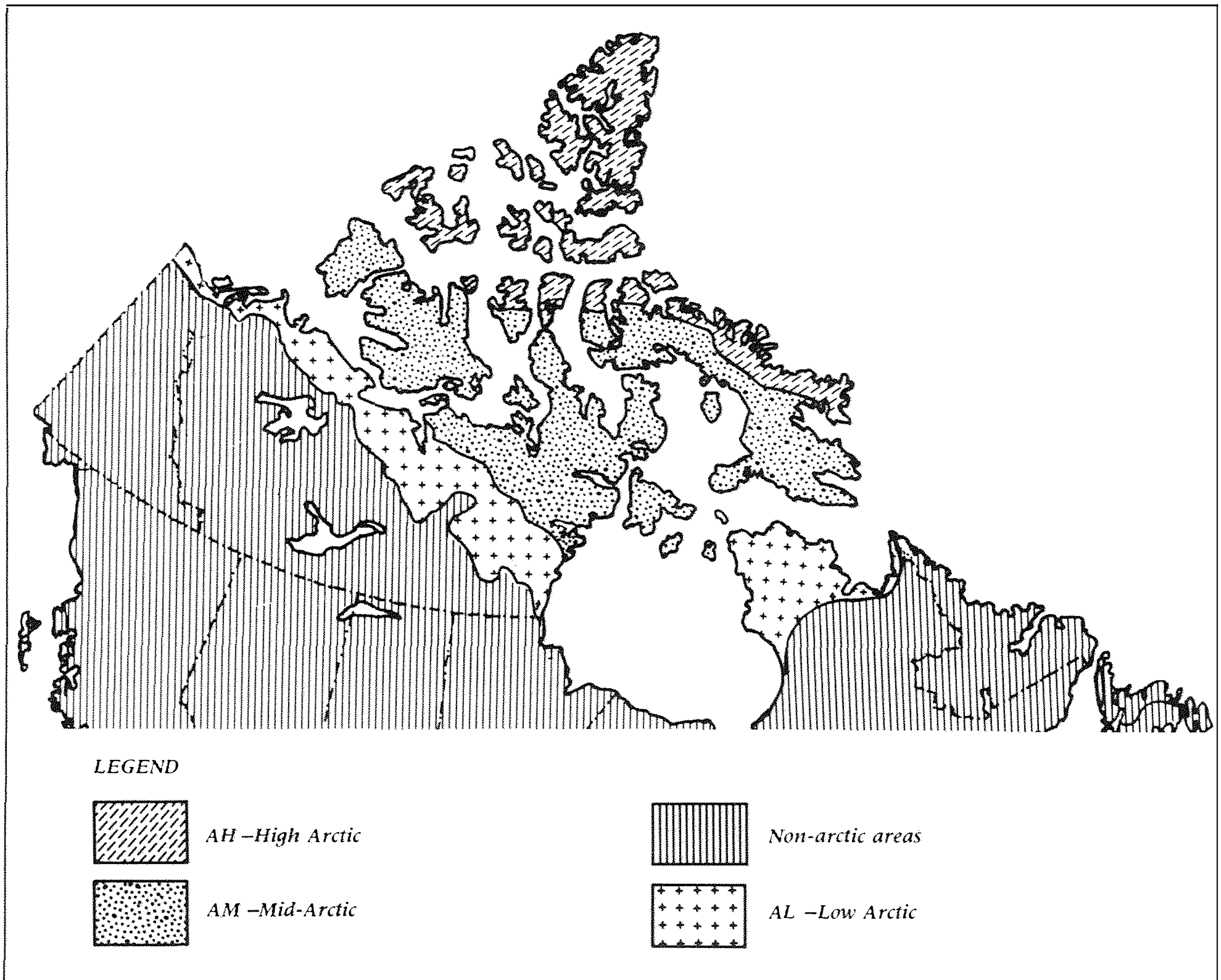


Figure 2–2.
Arctic wetland regions of Canada.

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

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

Mid-Arctic Wetland Region (AM)

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

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

Table 2–1. Climatic data for arctic wetland regions

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

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

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

Low Arctic Wetland Region (AL)

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

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

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

Arctic Wetland Forms

Lowland Polygon Bogs and Fens

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

Internal and External Morphology

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

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

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

(a)

(b)

(c)

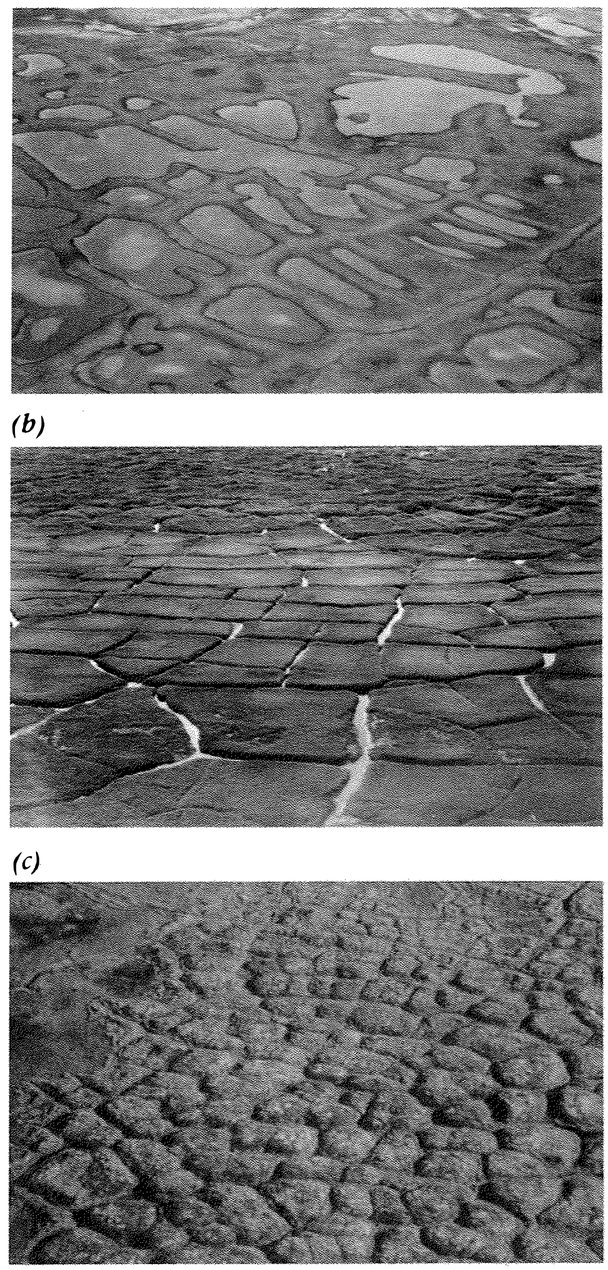


Figure 2–3.
Lowland polygons at various stages of development from low-centre (a) to high-centre (c). Locations: (a) Bathurst Island, (b and c) Mackenzie Delta area.

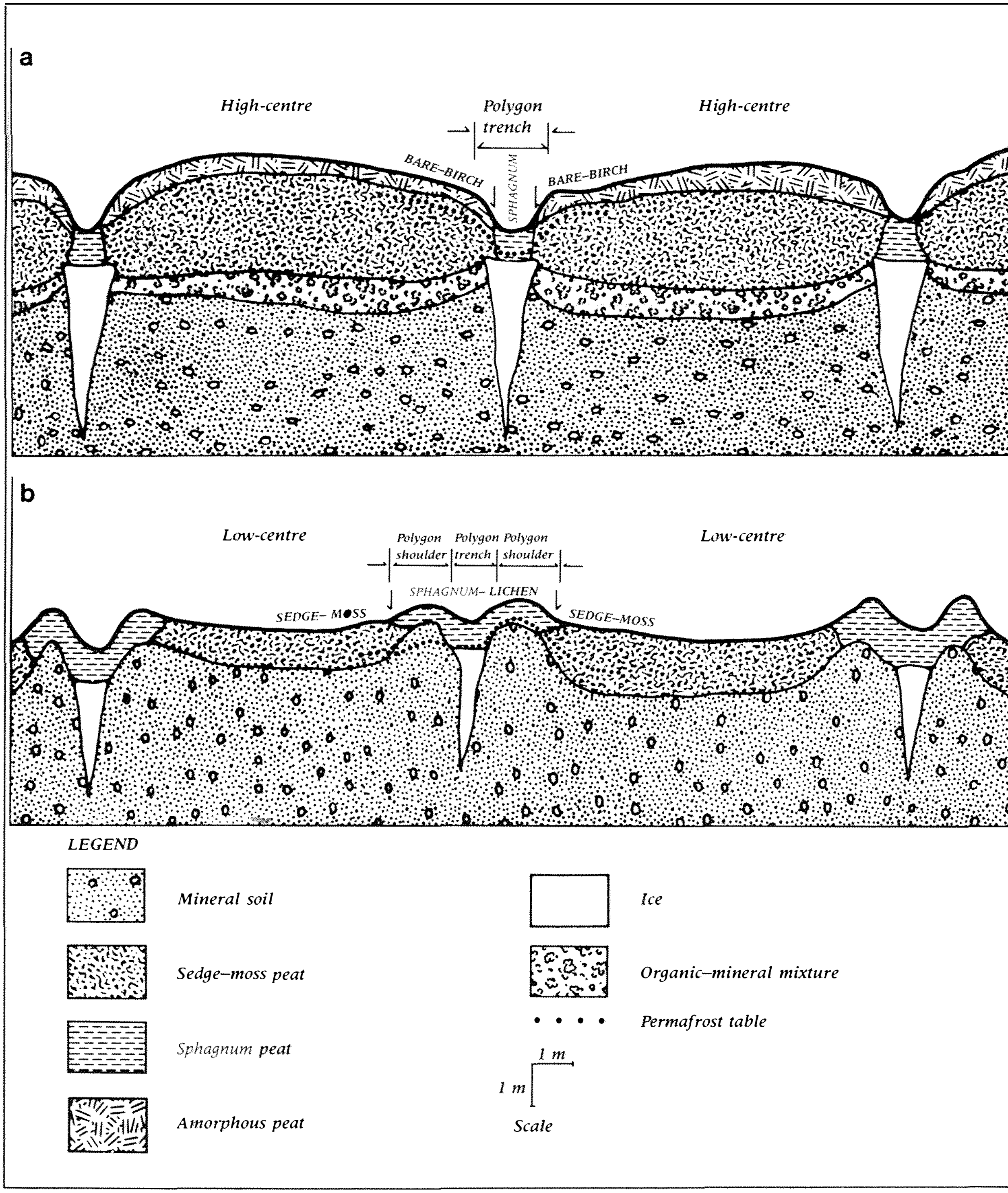


Figure 2–4.
Cross-section of a high-centre lowland polygon (a) and low-centre lowland polygon (b). Locations: (a) Lat. 68°58′ N, Long. 133°48′ W and (b) Lat. 69°56′ N, Long. 131°18′ W.

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

(a) (b)

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

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

Ice Wedges and Ice Content

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

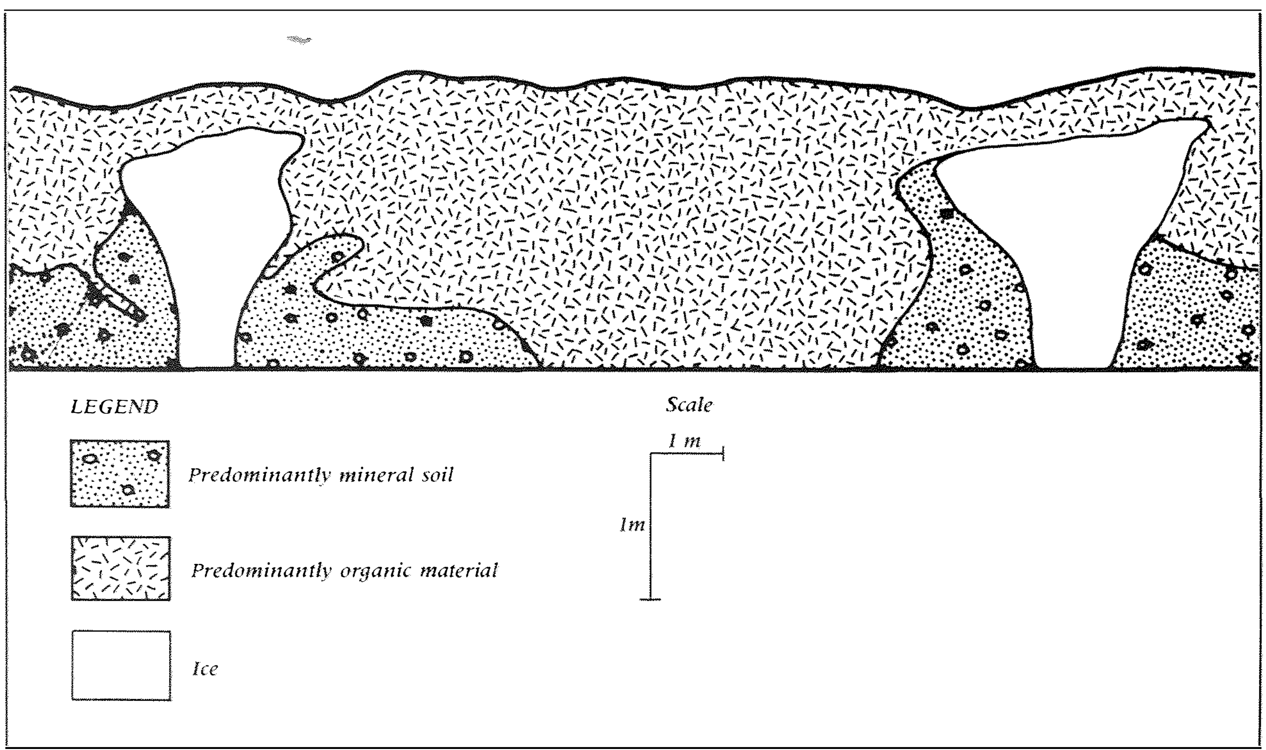


Figure 2–6.
Cross-section of wave-eroded polygons showing contorted mineral soil near the ice wedges. Location: Lat. 69°23′ N, Long. 133°2[illegible]′ W.

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

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

The Polygonal Pattern

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

Associated Peat Materials

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

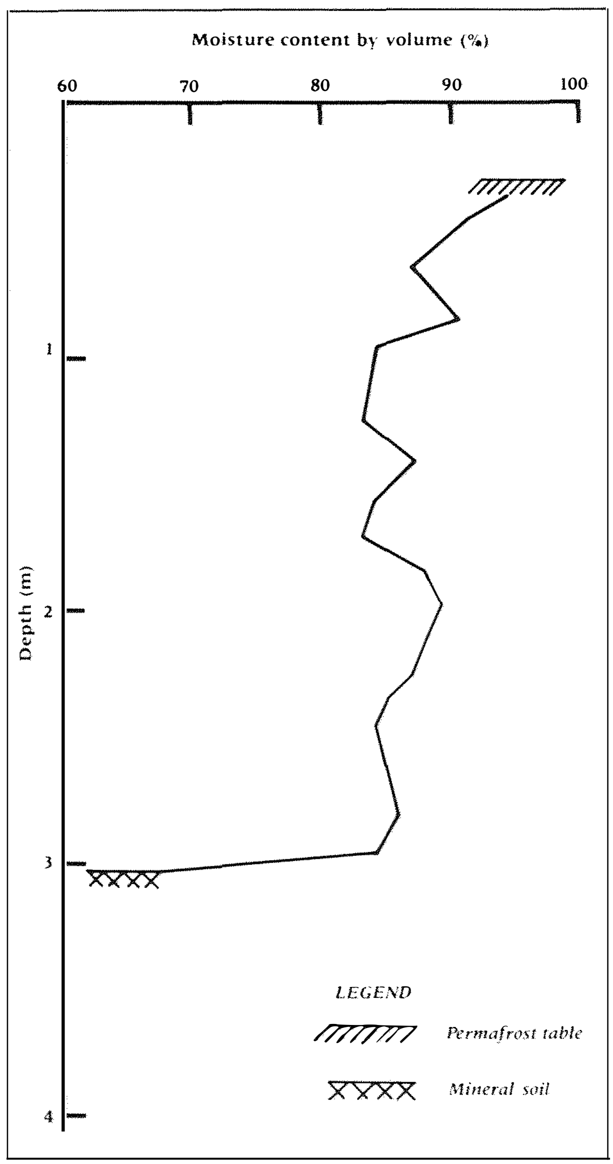


Figure 2–7.
Volumetric moisture content of a high-centre lowland polygon.

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

The peat associated with high-centre lowland polygons is generally moderately or well decomposed, with a rubbed fibre content between 6 and 76% and a von Post value of 4 to 7. The peat is generally acid, ranging in pH from 3.4 to 6.9. The chemical and physical composition of peat materials from high-centre polygons in three locations is presented in Table 2–2. The analysis of these peat samples indicates that the carbon (C) content ranges between 25 and 52% while the nitrogen (N) content ranges between 0.3 and 2.8%. The ash content of these arctic peat materials, which ranges between 7.6 and 39.7%, is generally higher than that of peat materials in southern Canada. The bulk density is 0.13 g/cm³ for woody peat and ranges from 0.05 to 0.15 g/cm³ for other peat materials. Calorific values were determined for a peat profile sampled at latitude 69°09′ N, longitude 134°17′ W (Table 2–2), and ranged between 2 868 and 4 644 cal/g.

Vegetation

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

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

The vegetation on the high-centre polygons is dominated by low and high shrubs. The most common species are shrub birch, willows, *Rubus chamaemorus*, *Arctostaphylos rubra*, and *Empetrum nigrum*. Some grasses (*Poa* spp.) and lichens (*Cetraria cucullata*, *Cetraria nivalis*, and *Alectoria* spp.) are also

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

Soil horizon	Depth (cm)	Material	pH ($CaCl_2$)	Total C (%)	Total N (%)	CEC (me/100 g)	Exchangeable cations (me/100 g) Ca	Mg	Na	K	Fibre content Unrubbed (%)	Rubbed (%)	Ash (%)	Bulk density (g/cm³)	Calorific value (cal/g)
Location: Lat. 69°26′ N, Long. 133°01′ W															
Oh	0–30	w–s	3.4	36.9	1.4	133.6	13.7	3.2	9.8	0.4	60	6	23.6	0.12	—
Ohz	30–40	w–s	3.5	47.3	1.5	176.8	35.0	7.9	13.5	0.4	52	8	7.6	0.15	—
Omz1	40–150	bm–s	3.9	37.8	1.7	134.2	26.9	9.2	2.7	0.3	78	40	11.3	0.07	—
Omz2	150–215	bm–s	4.0	45.1	1.8	134.2	36.7	11.0	1.3	0.2	76	40	9.7	0.05	—
Wz	215–268	pure ice	—	—	—	—	—	—	—	—	—	—	—	—	—
Cz	268–288	—	7.0	—	—	—	—	—	—	—	—	—	—	—	—
Location: Lat. 69°09′ N, Long. 134°17′ W															
Om	0–7	w	6.3	24.9	1.4	—	79.2	20.9	1.1	1.9	—	20	39.7	—	2 868
Ah	7–20	—	6.2	14.8	0.9	—	63.9	13.0	1.2	0.5	60	20	72.2	—	1 290
Ckgj	20–58	—	7.5	4.5	0.4	—	—	—	—	—	—	—	—	—	—
Ahz	58–65	—	7.4	15.3	1.1	—	—	—	—	—	68	20	72.2	—	1 569
Ckgjz	65–75	—	7.3	3.7	0.3	—	—	—	—	—	—	—	—	—	—
Omz1	75–80	bm	5.2	36.4	2.4	—	98.8	19.6	0.9	0.2	—	16	18.7	—	4 521
Ofz1	80–310	bm	6.7	25.6	1.5	—	83.5	16.4	0.5	0.2	100	76	38.9	—	3 161
Omz2	310–710	bm	5.6	36.2	2.4	—	91.5	16.5	0.3	0.3	60	30	14.8	—	4 644
Ofz2	710–735	s–bm	3.6	27.7	2.8	—	80.4	6.7	—	0.2	80	76	33.6	—	3 598
Ckgz	735+	sand	7.1	7.6	0.7	—	—	—	—	—	—	—	—	—	—
Location: Lat. 75°40′ N, Long. 97°40′ W															
Of	0–25	m	5.7	49.4	0.4	105.0	62.0	14.0	1.1	0.4	80	60	15.0	0.05	—
Ofz	25–78	m	5.9	52.5	0.3	105.0	63.0	19.0	0.9	0.3	72	60	12.0	0.05	—
Omz	78–130	s	6.9	37.8	0.3	75.0	59.0	18.0	0.8	0.4	52	42	28.0	0.08	—
Cz	130–150	sand	—	—	—	—	—	—	—	—	—	—	—	—	—

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

present. Unvegetated surfaces commonly occur on high-centre polygons, resulting from continuous erosion, mainly by wind.

Age

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

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

Peat Mound Bogs

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

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

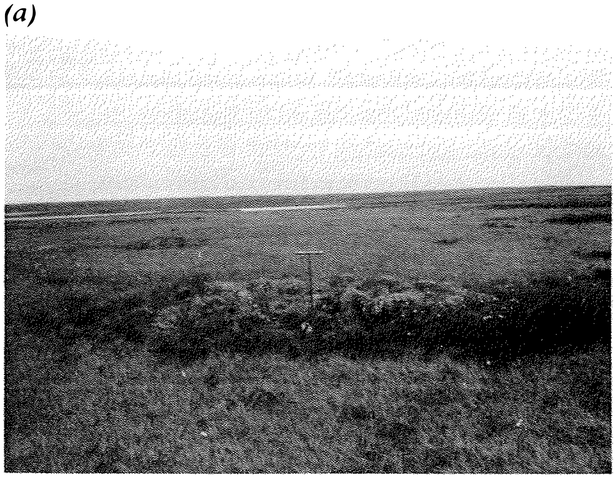
Table 2–3. Radiocarbon age (years before the present—BP) and rate of accumulation of peat deposits from high-centre lowland polygon bogs

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

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

**Top of peat deposit.*

(a)



(b)

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

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

A peat mound bog in the Kazan River area (67°32′ N, 94°03′ W) was cored (Figures 2–8 and 2–9) and the analytical data obtained from the peat samples are presented in Table 2–4. The uppermost sample shows that at a depth of 35 cm the humic

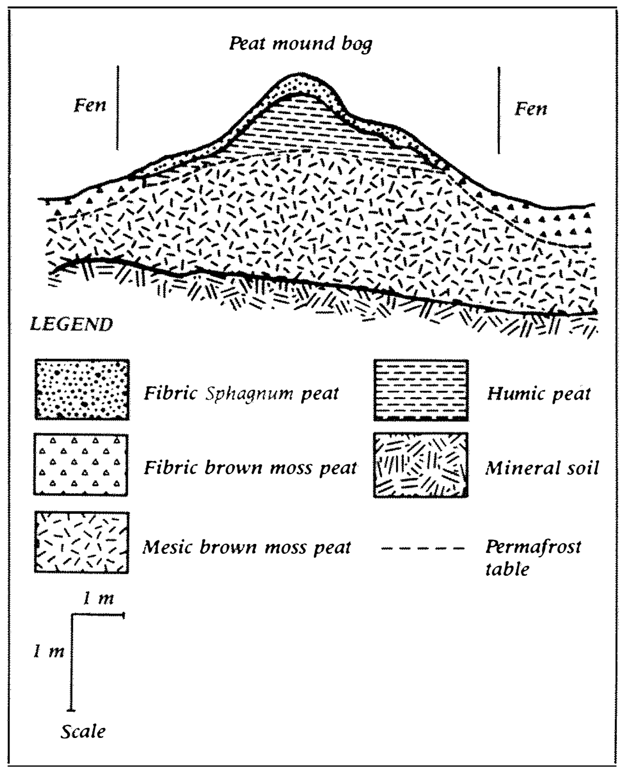


Figure 2–9.
Cross-section of a peat mound bog in a fen near Kazan River, NWT. The position of the permafrost table on July 18, 1976, is showed by a dashed line.

Sphagnum peat has a high level of nutrients. Samples from the lower depths also show relatively high levels of nutrients. Although this peat mound is located on the Canadian Shield, it is within the zone of post-glacial marine submergence, and nutrients such as calcium (Ca) and magnesium (Mg) are abundant in the soil. This is reflected in the mineral composition of the peat.

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

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

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

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

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

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

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

Snowpatch Fens

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

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

(a)

(b)

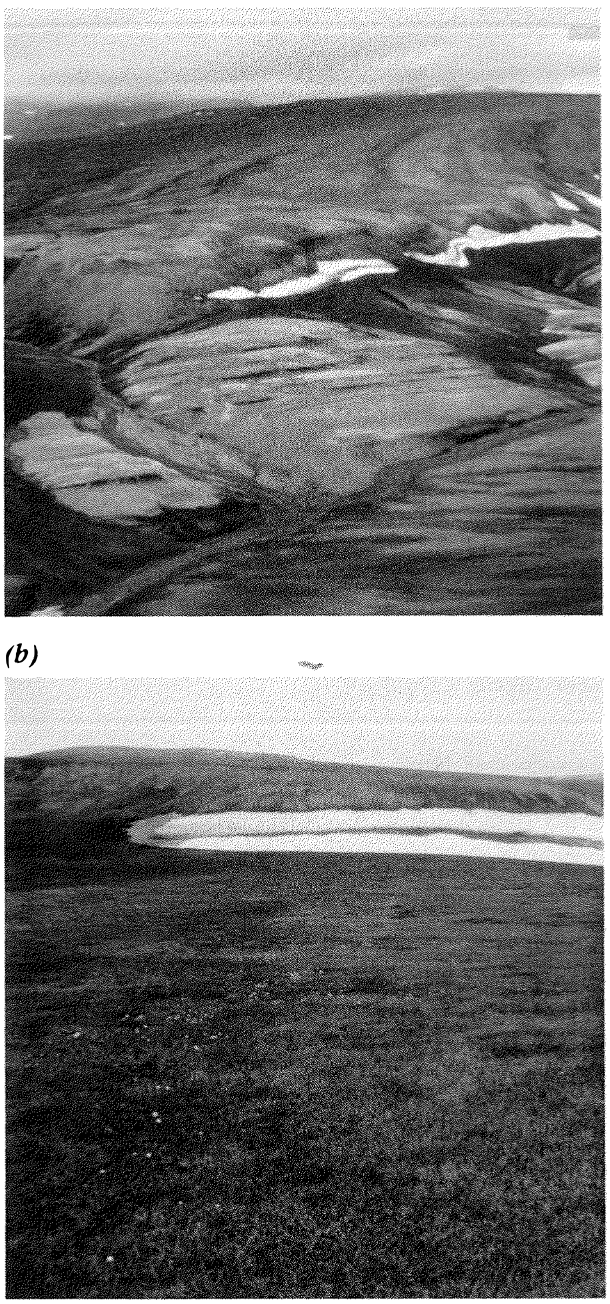


Figure 2–10.
Vegetated areas are snowpatch fens with seepage water fed by the snowbanks (a). A close-up of such a snowpatch fen with the snowbank above it is shown in (b). Both photographs were taken on Axel Heiberg Island, NWT.

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

Basin Fens

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

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

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

Tundra Pool Shallow Waters

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

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

(a)

(b)

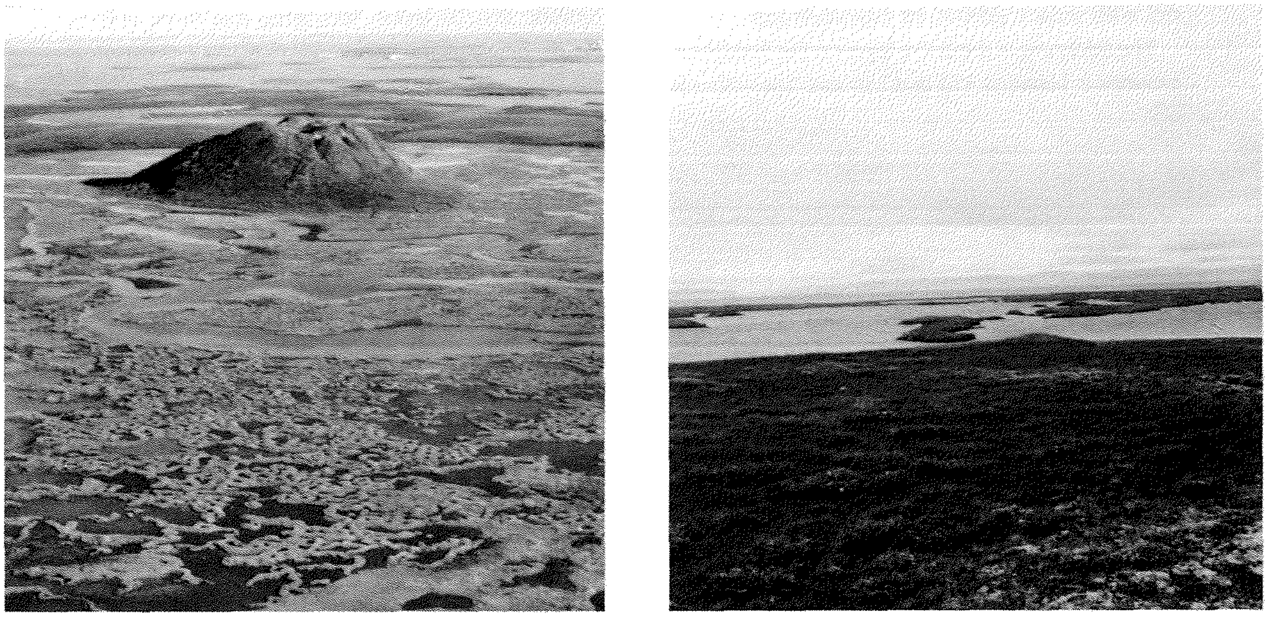


Figure 2–11.
Various sizes of shallow water bodies in a wetland complex in (a) the Tuktoyaktuk area and (b) a tundra pool with vegetated shoreline on Bylot Island, NWT.

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

Floodplain Marshes

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

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

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

Floodplain Swamps

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

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

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

(a)

(b)

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

Active Delta Marshes

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

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

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

Other Shallow Waters

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

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

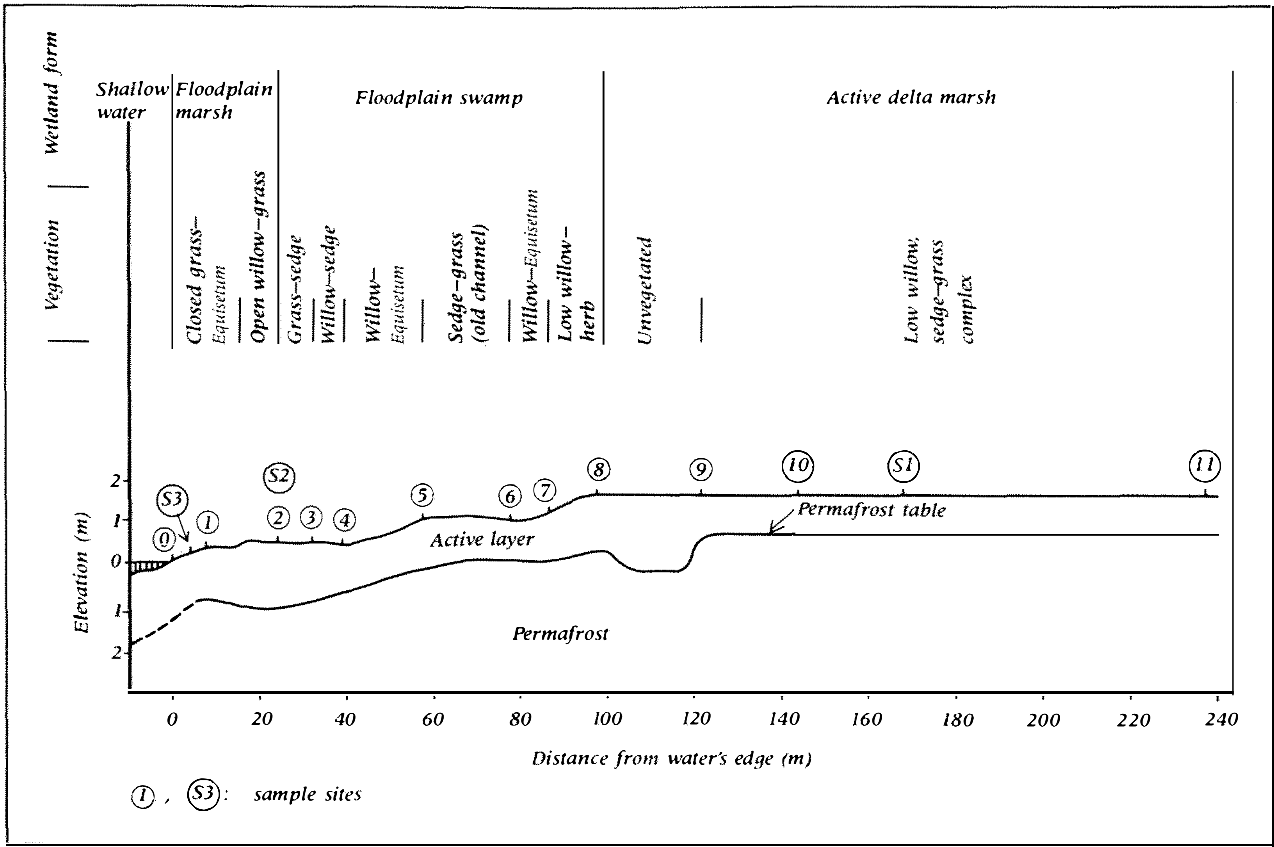


Figure 2–13.
A transect located at Lat. 69°22' N. Long. 134°02' W in the Kittigazuit Bay area, Mackenzie Delta, showing various wetlands.

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

Dynamics of Arctic Wetlands

Formation of Arctic Wetlands

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

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

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

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

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

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

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

Peat Accumulation

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

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

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

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

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

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

These rates of peat accumulation were calculated using depths measured primarily in perennially frozen peat. The moisture (ice) content of the frozen peat was similar to that of the unfrozen

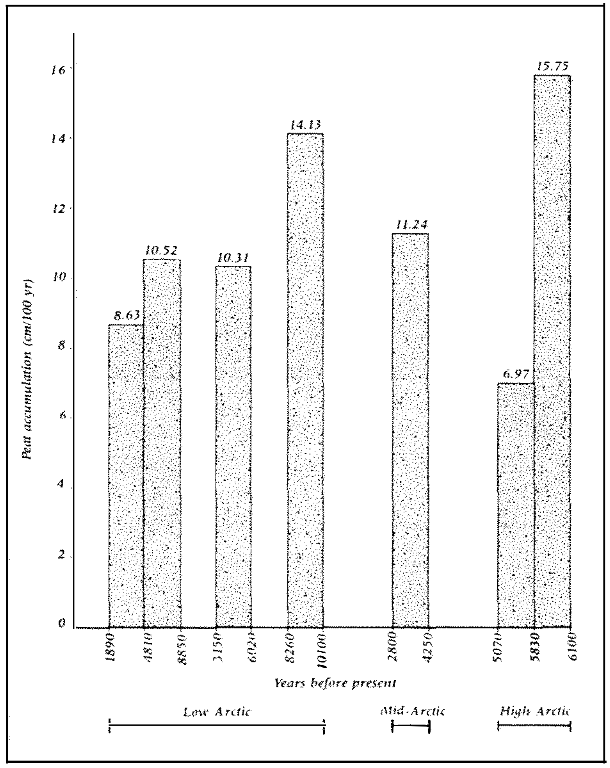


Figure 2–14.
The rate of peat accumulation at various periods in the Low, Mid-, and High Arctic Wetland Regions.

wet peat, and thus it was assumed that there was little volume change due to ice build-up in the perennially frozen peat layer.

Age of Arctic Peatlands

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

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

Stability of Arctic Wetlands

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

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

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

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

Arctic Wetland Values and Conservation

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

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

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

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

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

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

They estimate that 22% of the 278 000 km^2 of wetlands in the Northwest Territories and Yukon are now in some way legally protected within national or territorial wildlife areas, migratory bird sanctuaries, reserves, parks, or game sanctuaries. Protected wetland areas in the three arctic wetland regions include those within the Northern Ellesmere, Northern Yukon, and Auyuittuq national park reserves; Polar Bear Pass National Wildlife Area; Kendall Island, Bylot Island, Queen Maud Gulf, Banks Island, Harry Gibbons, East Bay, Anderson Delta, Dewey Soper, and McConnell River national migratory bird sanctuaries; and the Bowman Bay and Thelon territorial game sanctuaries.

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