BCS 311: Land and Environments of the Circumpolar World I

Module 6: Terrestrial Ecosystems

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Overview

Ice, snow, water and gravity acting on rocks, sediments and soils shape northern landscapes. Northern landscapes developed in association with severe climates provide the environment in which the flora, fauna and people of the Subarctic and Arctic regions survive and thrive. The physical environment and biota combine to generate distinctive Northern habitats and ecosystems ranging from polar deserts to boreal forests, streams and lakes to northern rivers. The region is relatively young in geological and evolutionary time scales as the last ice age ended only a few thousand years ago. The region's ecosystems continue to evolve and the climate has continually changed as other factors (e.g., the long range transport of pollutants) have become increasingly important. There is increasing recognition of the complex interactions within Northern ecosystems and concern over future sustainability. Scientists will need to use all their knowledge, and apply the principles of ecology to better understand changes in terrestrial ecosystems.

Learning Objectives

Upon completion of this module, you should be able to:

1. Compare and contrast variations in species composition among forest, forest-tundra and tundra biomes.

2. Discuss the influence of the five fundamental soil-forming factors (i.e., surficial geology (parent materials), topography, drainage, vegetation and time) on soil development in forest and tundra environments.

3. Discuss the influence of small-scale variations in topography on small-scale variations in terrestrial biota species composition.

4. Identify the major factors that regulate ecosystem dynamics.

Required Readings

Callaghan, T.V. *et. al*. 2005. Chapter 7. Arctic Tundra and Polar Desert Ecosystems. *In:* Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, U.K., pp. 243-249 and pp. 315-324.

Jonasson, S., T.V. Callaghan, G.R. Shaver and L.A. Nielsen. 2000. Arctic Terrestrial Ecosystems and Ecosystem Function. *In:* M. Nuttall and T.V. Callaghan (eds.) The Arctic: Environment, People and Policy. Harwood Academic Publishers, Australia, pp. 275-313.

For the Learning Activities:

Locate a hydrological atlas for the circumpolar region.

Locate a guide to the local flora and fauna for the region where you live.

Key Terms and Concepts

- Biome
- Boreal Forest
- Brunisol
- Cryosol
- Forest-Tundra
- Gleysol
- High Arctic
- Histosol
- Low Arctic
- Luvisol
- Podzol
- Polar Front
- Subarctic
- Tundra

Learning Material

Introduction

Subarctic and Arctic regions are distinguished by cold climates. The climate experienced by the flora and fauna is not what humans perceive and experience. Biota live near or in the ground so it is important to explore the microclimate on and in the vegetation and soil. Temperature and moisture regimes change dramatically at the leaf surface within the vegetation canopy and within the soil profile. The microclimatic regimes also change over short lateral distances due to small topographic ground surface variations.

Variations in net radiation over short lateral distances affect ground temperatures, the length of the growing season, the quantity of solar energy available to sustain photosynthesis and the supply of water to plants. Water in its various forms is an important, often limiting, element for life on land. The reduction in terrestrial primary production with increasing latitude is also related to seasonal variations in the input of solar energy, day length and temperatures. The limited quantity or low intensity of sunlight may limit plant growth at high latitudes for much of the year. Considering the physical environment that influences terrestrial life it is essential to identify the range of factors in which organisms live and how these factors interact.

6.1 Biomes

A biome or biogeographic region is a major ecological community that stretches over thousands of square kilometres and is related to the general climate and topography that determines biota habitats. Local conditions result in small-scale patches (i.e., square metres) of different types of vegetation. These patches repeat and provide the pattern characteristic of the landscape or biome. Species composition of biomes, defined mainly by their plant communities, varies between continents and is a matter of debate among ecologists, although there is general agreement in the main pattern (Figure 6.1).

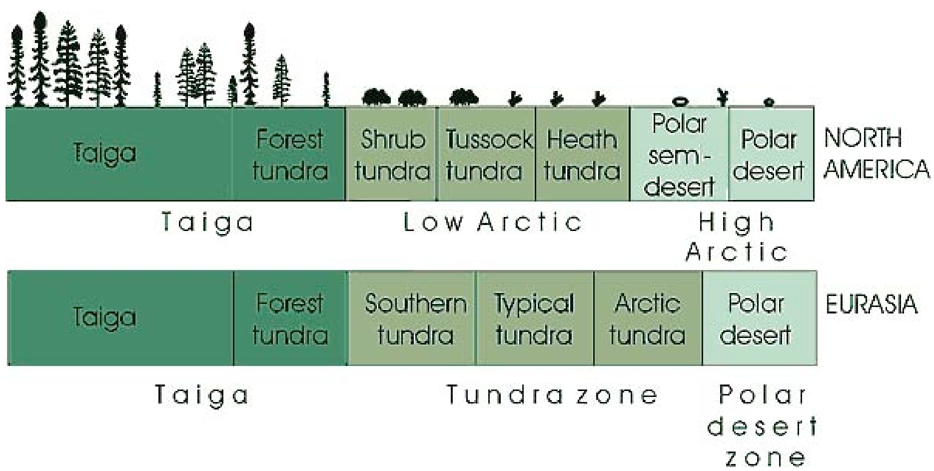

Figure 6.1. A comparative classification of North American and Eurasian boreal forest and tundra vegetation. Source: CAFF (2001).

Each plant community is associated with distinctive invertebrate and vertebrate faunas and communities of soil organisms. The interaction of flora, fauna and the associated physical environment generates the processes that constitute the terrestrial ecosystems of Subarctic and Arctic regions. For example, Bliss and Peterson (1992) describe the general vegetation patterns observed in the Low Arctic shrub tundra particularly well:

> In the Low Arctic, riparian zones along rivers and streams are occupied by herbaceous and tall shrub vegetation. Rolling uplands north of the tree line generally contain low shrubs of *Salix* and *Betula* along with dwarf shrubs of the various heath species that fit within a matrix of upland sedges, including cottongrass tussocks and

forbs. Beyond these landscapes are large areas dominated by sedges, dwarf shrub species (mainly heaths), and scattered low shrubs of *Salix* and *Betula*. Lowlands that are imperfectly drained and the more expansive coastal plain lowlands are dominated by wetland sedges, grasses, and mosses forming extensive mires. Elevated habitats generally contain low or dwarf shrubs, cushion plants, lichens and graminoids; species adapted to well drained or intermediately drained soil. These are the major vegetation types within the Low Arctic of Alaska, mainland Canada and much of mainland Siberia.

Spatial variations in the composition of vegetation cover are correlated with variations in physical properties of soils in which plants are growing. Various soil-forming factors, including climate, topography, drainage and parent materials (i.e., bedrock or sediments), are examined below to illustrate the interactions between the **atmosphere**, **lithosphere** (rock and soil) and **hydrosphere** (surface water and groundwater) that contribute to the spatial patterns exhibited in the biosphere. Soil taxonomy employed in this text is derived from the Canadian System of Soil Classification (1998).

Boreal Forest (Taiga)

Boreal forests are composed largely of coniferous, evergreen vegetation dominated by spruce (*Picea*), pine (*Pinus*), fir (*Abies*) and tamarack/larch (*Larix*) that occupy a broad circumpolar belt across the Northern hemisphere covering an estimated area of 15.8 million km^2 globally (Figure 6.2).

Regions occupied by boreal forest are dominated by cold, dry air masses (continental Arctic, continental Polar) for most of the year. Mean winter temperatures commonly vary from –20°C to –30°C. Temperatures rise rapidly in the spring and summer in response to increasing day length and insolation.

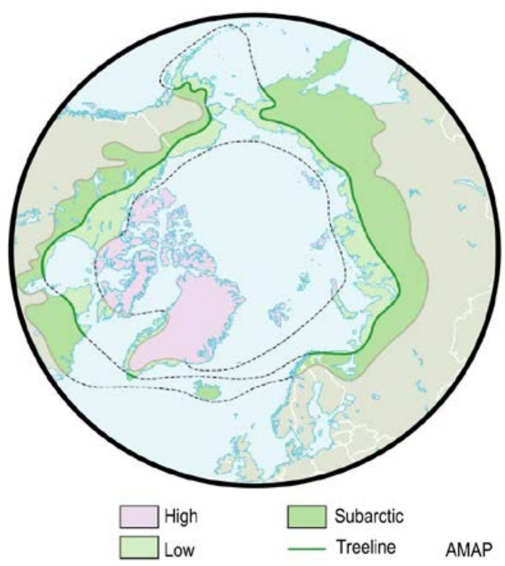

Figure 6.2. Distribution of terrestrial biomes in the circumpolar North. Sources:

Bliss, L.C., 1981. North American and Scandinavian tundras and polar deserts. *In*: L.C. Bliss, O.W. Heal and J.J. Moore (eds.) Tundra ecosystems: A comparative analysis, pp. 8-24. Cambridge University Press, Cambridge. Appears in AMAP Assessment Report: Arctic Pollution Issues published in 1998.

Mean summer temperatures range from 12^oC to 15^oC. The large annual temperature range is characteristic of boreal forests. The growing season is short. The frost-free season varies from 50 to 100 days and temperatures remain above 10^oC for at least 30 days in the northernmost regions and 120 days in the southernmost regions. Precipitation is largely cyclonic in nature and strongly associated with atmospheric processes operating along the polar front. So pronounced is the influence of the polar front that many researchers consider the southern boundary of the boreal forest to coincide with its mean January position. Mean annual precipitation is generally less than 600 mm. Most precipitation falls in summer, but more than 100 mm of snow can fall over the long winter season.

Soils associated with boreal forests are typical of mid-latitude and Subarctic regions. In areas where permafrost is absent or sporadic, **Podzols**, **Luvisols** and **Brunisols** develop on well to imperfectly drained upland surfaces. Podzols are coarse-grained mineral soils developed on parent materials derived from glacial tills and glaciofluvial sediments and are the dominant soil order present in the Subarctic region. Plant litter that accumulates on the surface of these soils decomposes slowly resulting in a thick layer of organic matter. Podzols exhibit strong acidity (pH 3.5-4.5) deriving from the intensive leaching of cations associated with humid climates. The translocation of organic matter, iron, aluminum oxides (e.g., limonite ($2Fe_2O_3.H_2O$) and gibbsite ($Al_2O_3.3H_2O$)), and their accumulation at depth characterize these soils (Figure 6.3). The low nutrient status of Podzols makes these soils relatively infertile.

Where parent materials are more alkaline in character due to the presence of carbonate minerals, Luvisols and Brunisols develop. Luvisols are fine-grained mineral soils derived from glacial tills, and glaciolacustrine and glaciomarine sediments. A thick organic layer develops on the surface of these soils. The **translocation** of clay minerals and their accumulation at depth characterizes Luvisolic soils. In comparison with Podzolic soils, the high nutrient status of Luvisols makes these soils relatively fertile.

Gleysols and **Histosols** (organic soils) develop in poorly drained lowlands, on river floodplains and along lake margins. Gleysols are mineral soils associated with environments that experience persistently high water tables, especially where the ground surface is underlain by permafrost. Weakly differentiated soil horizons are indicative of prolonged water saturation and strongly reducing conditions that impart dark soil colours (Figure 6.3). Histosols are composed largely of decomposing plant litter (peat) that is subjected to prolonged water saturation. These environments are characterized by the slow **anaerobic** decomposition of plant litter that allows a considerable thickness of organic matter to accumulate within lowland depressions.

The North American boreal forest is commonly subdivided into three forest regions: the open lichen woodland, the northern coniferous forest and the mixed forest. Open lichen woodlands consist of an open canopy forest with trees irregularly spaced as much as 25 metres apart while light-coloured lichens and mosses dominate the understory. White spruce (*Picea glauca*), black spruce (*Picea mariana*), dwarf birch (*Betula glandulosa*) and Labrador tea (*Ledum* spp.) dominate the typical spruce-lichen woodland on better drained sites associated with Podzolic and Brunisolic soils (Figure 6.3). Lichens (primarily *Cladina* spp.) and mosses (*Sphagnum* spp.) characterize the understory vegetation. In poorly drained Gleysolic soils the vegetation cover is characterized by the presence of widely scattered black spruce (*Picea mariana*) and tamarack (*Larix laricina*) associated with a variety of shrubs including Labrador tea (*Ledum* spp.), birches (*Betula* spp.), willows (*Salix* spp.) and heaths (*Vaccinium* spp.) (Figure 6.3). Mosses (e.g., *Sphagnum* spp., *Aulacomnium* spp.) dominate the ground cover. Coniferous tree species appear to be well adapted to cold, moist soils because they are able to tolerate nearly saturated soils with strongly acidic, low nutrient supply conditions.

Learning Activity 1

Obtain a hydrological atlas for the region in which you live. Determine the proportion of the land surface currently covered in wetlands. Think about the influence that wetlands have on the movement of surface water across these landscapes.

The composition of the northern coniferous forest varies regionally across the circumpolar North (see Figure 37, p. 112 in the 1998 AMAP report listed in the Supplemental Readings). In northern Canada these forests are characterized by a closed canopy consisting largely of white spruce, black spruce and balsam fir (*Abies balsamea*) with some trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*), jack pine (*Pinus banksiana*) and paper birch (*Betula papyrifera*). Soils consist primarily of well-drained Podzols in regions underlain by the Canadian Shield, and Luvisols and Brunisols in regions underlain by calcareous glacial, glaciolacustrine and glaciomarine sediments. Common understory species include shrubs such as alder (*Alnus* spp.), Labrador tea, bearberry (*Arctostaphylos uva-ursi*), blueberry (*Vaccinium angustifolium*), herbs, club-mosses and feather-mosses, and lichens.

In poorly drained lowlands the vegetation is dominated by mosses (*Sphagnum* spp.) in areas associated with acidic groundwater and sedges (*Carex* spp.) where groundwater is more alkaline in character. Prolonged saturation of soils in lowland settings gives rise to Gleysols and Histosols in which few tree species can survive except notably shallow-rooted black spruce and tamarack.

Learning Activity 2

Read Chapter 7 in the 2005 ACIA Report to discover how climate change is affecting terrestrial ecosystems. What changes in these wetlands do you anticipate will occur in response to climate change? Will these plant communities continue to serve as carbon sinks?

In contrast to wetland plant communities, river floodplain (**riparian**) communities are dominated by broadleaf deciduous tree species such as paper birch, trembling aspen, balsam poplar and willow (*Salix* spp.). The nutrient-rich groundwater and moist warm, well-aerated soil conditions that develop during the summer growing season favour deciduous over evergreen species.

The mixed forest occurs south of the Canadian Shield where soils are deeper and the climate is less severe. Podzols remain the dominant soil order in this region, but greater areas of Luvisolic and Brunisolic soils are also present. The milder climate and more nutrient-rich soils allow for broadleaf, deciduous species to outperform or co-exist with coniferous, evergreen species. White spruce, trembling aspen, paper birch and balsam poplar dominate these forests.

Figure 6.3 a – d. Representative soil profiles (following photographs).

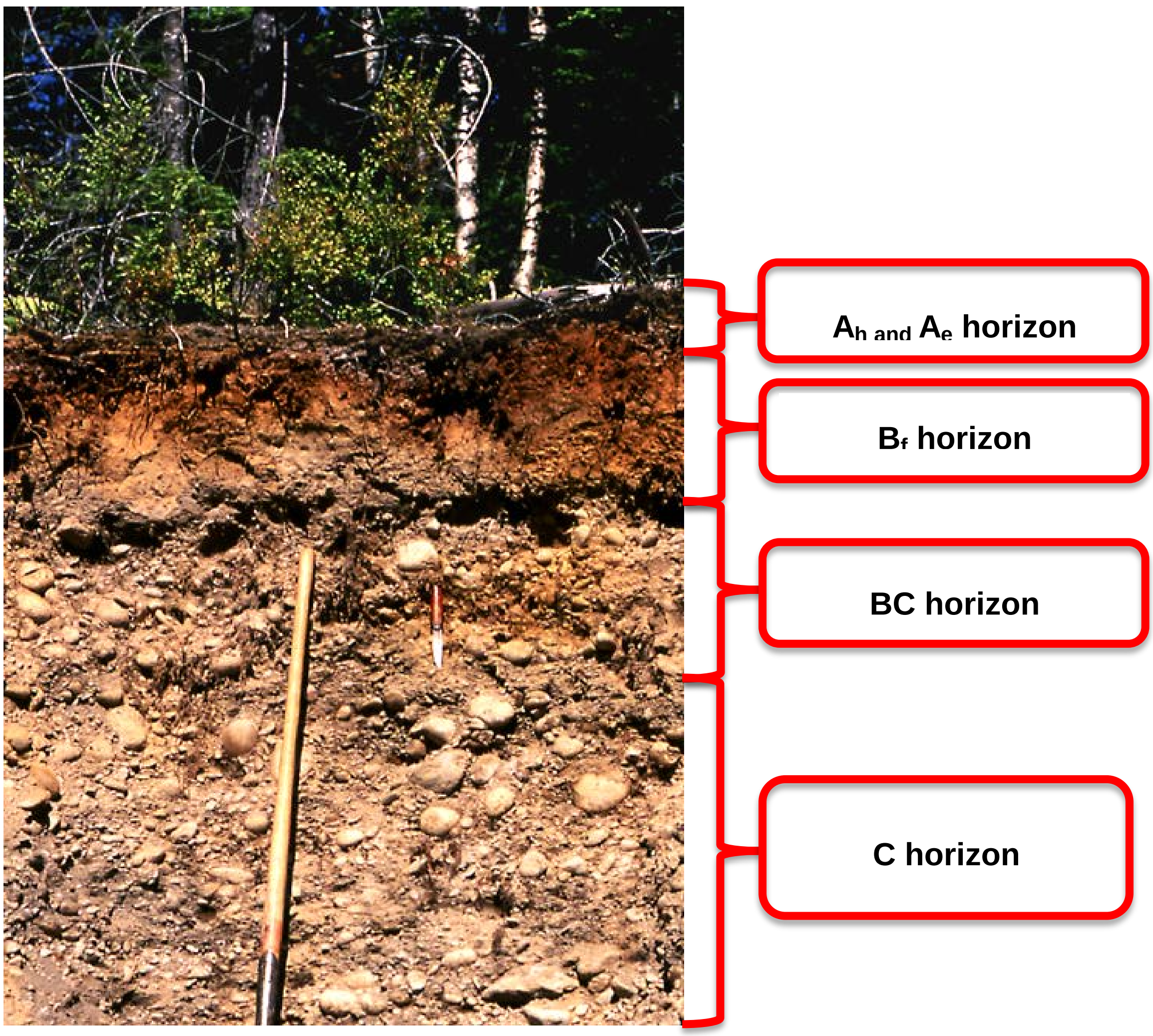

Figure 6.3a. Podzolic soil profile.

Podzolic soil profile: the diagnostic soil horizons are the pale grey eluviated A_e horizon and the underlying B_f horizon that is enriched in iron and aluminum oxides. The bright orange and yellow colours of the B_f horizon are indicative of the oxidation of iron and aluminum oxides in a well-drained soil. The soil is developed on a sand and gravel parent material exposed at the base of the pit.

Source: http://sis.agr.gc.ca/cansis/taxa/soil/podzolic/humo-ferric_podzol_bcs.jpg

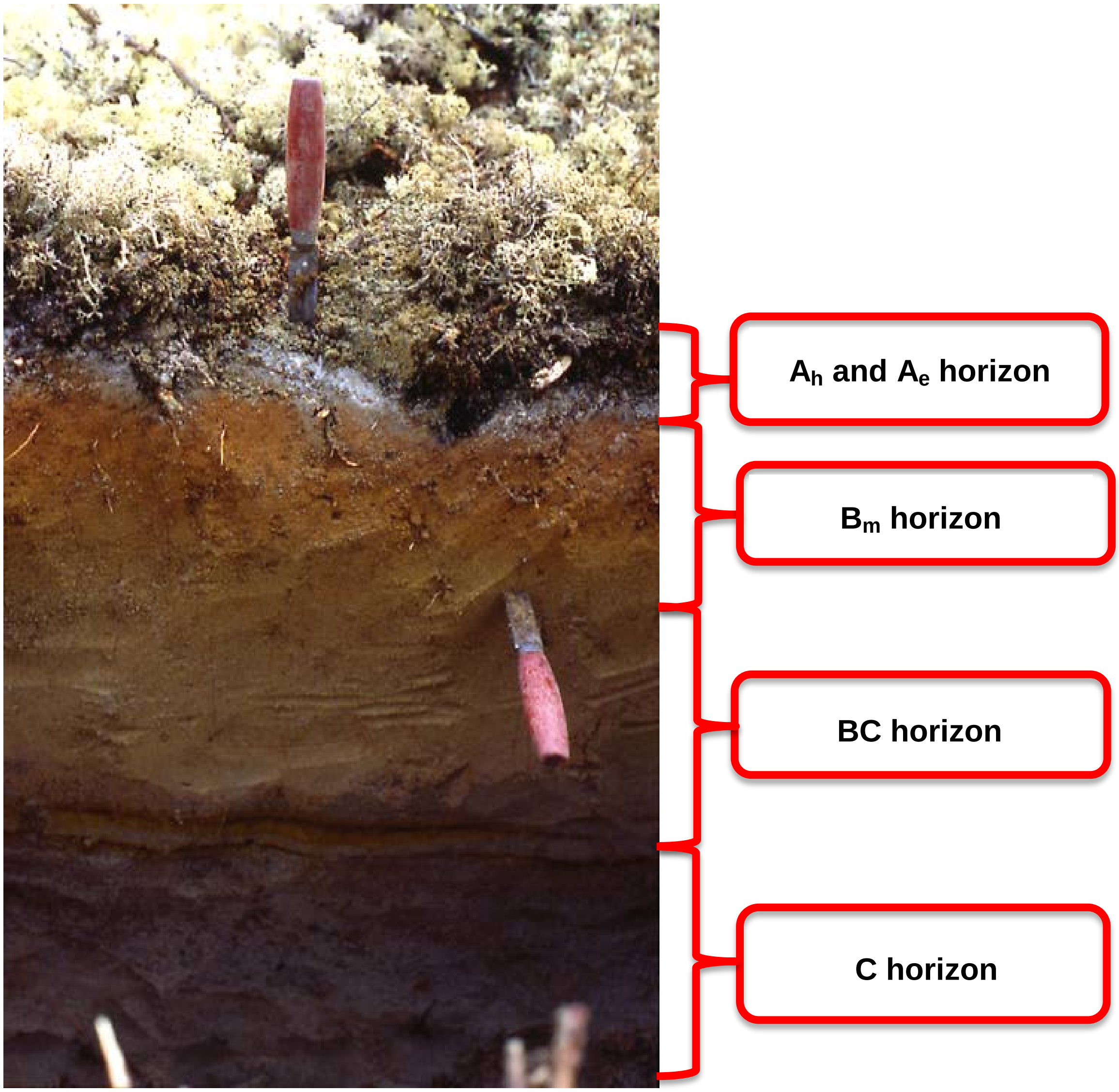

Figure 6.3b. Brunisolic soil profile.

Brunisolic soil profile: the diagnostic soil horizons are the weakly developed eluviated A_e horizon and the underlying darker coloured B_m horizon that is slightly enriched in iron and aluminum oxides, indicated by the brown colours. The soil is developed on a sandy parent material exposed at the base of the pit.

Source: http://sis.agr.gc.ca/cansis/taxa/soil/brunisolic/dystric_yt.jpg

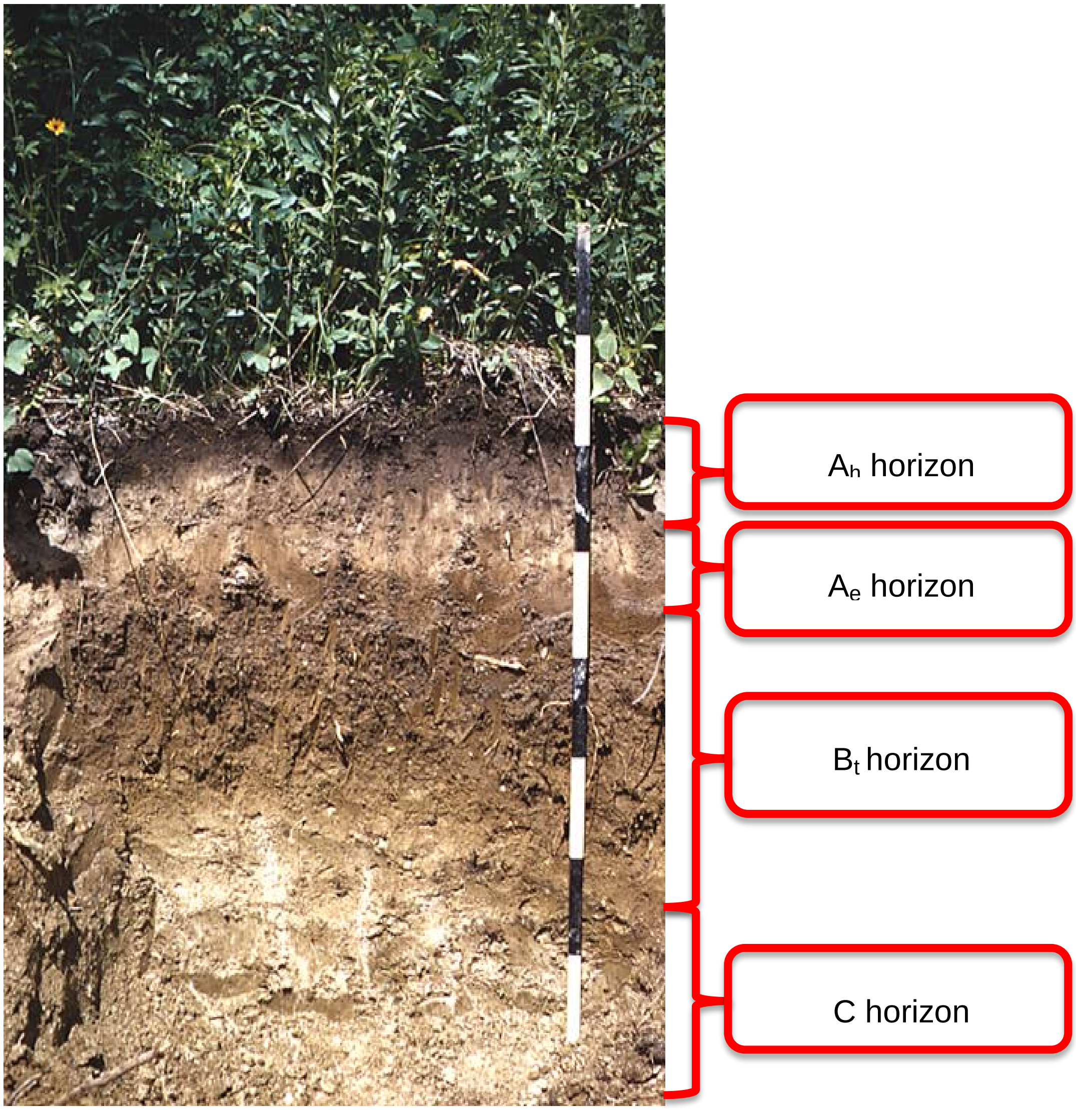

Figure 6.3c. Grey Luvisolic soil profile.

Luvisolic soil profile: the diagnostic soil horizons are the thick, dark-coloured A_h horizon developed beneath the vegetation cover and the underlying grey brown B_t horizon that is enriched in clay. These soils develop on clay-rich parent materials.

Source: http://sis.agr.gc.ca/cansis/taxa/soil/luvisolic/gray_pr.jpg

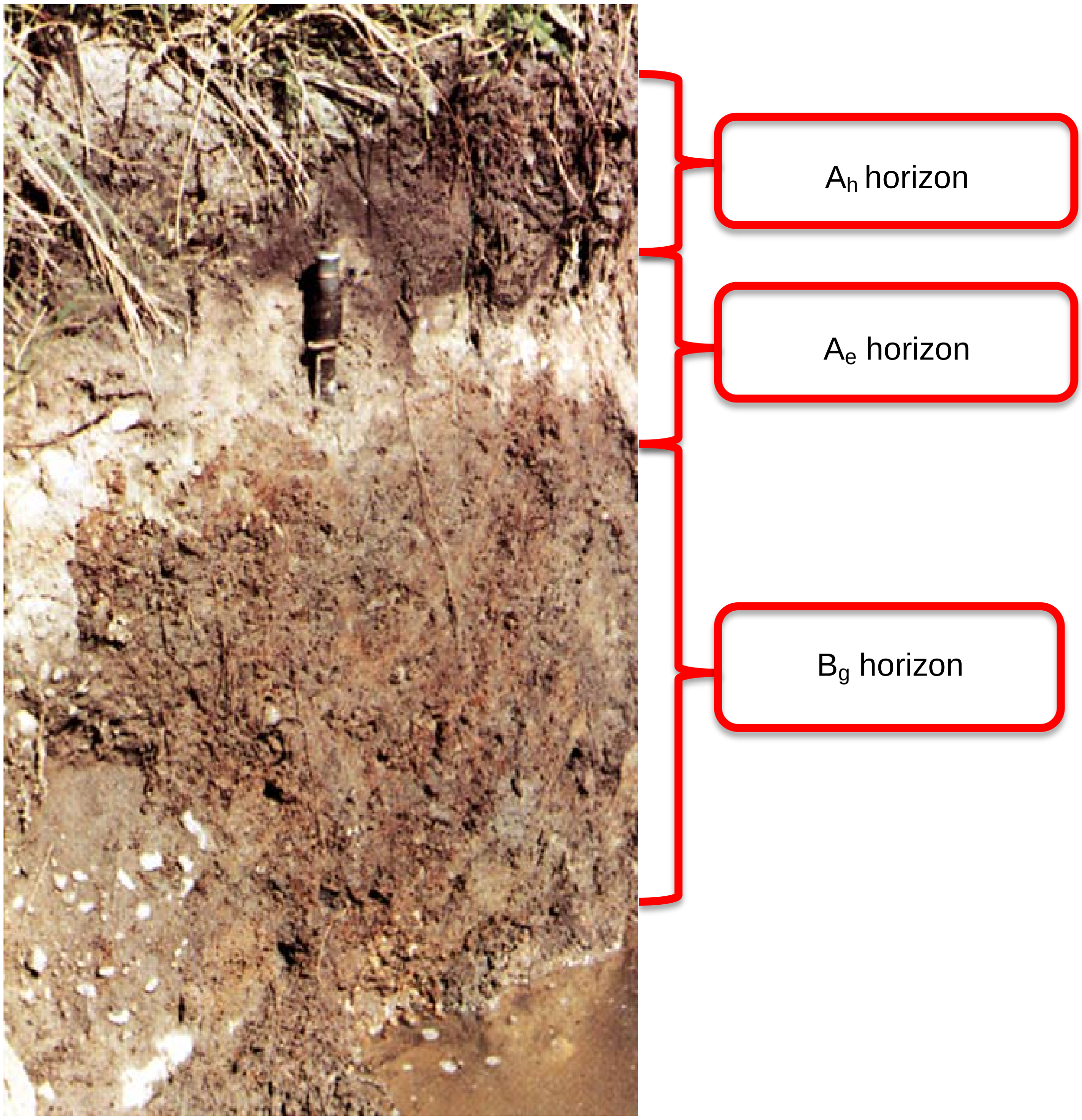

Figure 6.3d. Gleysolic soil profile.

Gleysolic soil profile: the diagnostic characteristics of these soils are the weak development of distinct horizons and the dark grey and black colours indicative of the reduction of iron and aluminum oxides under anaerobic conditions in poorly-drained soils (i.e. gleyed B_g and C_g horizons).

Source: http://sis.agr.gc.ca/cansis/taxa/soil/gleysolic/gleysol_pr.jpg

Forest-Tundra

Forest-tundra describes an environment situated between the arctic tree line to the north and the northernmost limit of continuous forest including open lichen woodland to the south (Figure 6.4). The arctic tree line marks the boundary between tundra (where tree species do not exhibit true growth form) and areas where trees take true growth form (mature trees exceed 5 metres in height). In North America, the arctic tree line is approximately equivalent to the position of the 10°C mean July isotherm and coincides approximately with the mean July position of the polar front and the southern limit of continuous permafrost. Climatic conditions experienced in the boreal forest extend northward into the forest-tundra region. Podzols and Brunisols develop on well to imperfectly drained sites where permafrost is absent, while Gleysols and Histosols (organic soils) develop in poorly drained sites underlain by permafrost. Cryoturbation affects these latter soils so that Gleysolic Turbic **Cryosols** and Organic Cryosols are common soil groups encountered in the forest-tundra region.

A variety of habitats and plant communities are encountered within forest-tundra (Figure 6.4). Lichen-heath-dwarf shrub communities characterize well-drained upland surfaces. Lichen-moss-dwarf shrub communities with scattered trees (*Picea* spp.) and open *Picea* spp. forests occupy lower slopes and sheltered basins. Wetlands dominated by an open cover of black spruce and tamarack along with Labrador tea, Sphagnum moss and lichens occupy poorly drained lowlands.

Figure 6.4. Forest tundra (Finnish Lapland).

Note the juxtaposition of open canopy forest on well to imperfectly drained uplands and the largely treeless, poorly drained wetlands inhabited by shrubs, heaths and mosses at the centre of this image.

Source: CAFF (2001) Ecology, in Arctic Flora and Fauna: Status and Conservation (Helsinki: Edita). http://www.caff.is/sidur/uploads/OSA_02.PDF

Periglacial landforms known as **palsas** and **peat plateaux** develop in poorly drained landscapes within the forest-tundra biome in association with discontinuous permafrost. Palsas are peaty mounds that possess a core of alternating layers of segregated ice and peat or mineral soil (Figure 6.5). These landforms are 1.0 to 7.0 metres in height and less than 100 metres in diameter. Peat plateaux are broad, flat-topped expanses of frozen peat containing segregated ice (Figure 6.5). These landforms may cover several km^2.

These features develop within wetlands where peat moss begins to accumulate on a waterlogged sedge meadow. Over time peat accumulates to a sufficient depth that portions of the peat fail to thaw in summer. Freezing of groundwater within peat contributes to the formation of segregated ice lenses. The growth of these ice lenses is sustained by the continuous movement of groundwater towards the freezing plane within the peat until the moisture supply is depleted. The growth of segregated ice lenses displaces the peat surface upwards, a process referred to as frost heaving, causing a raised mound of peat to appear. As peat mounds emerge from the wetlands a positive feedback mechanism is initiated that operates to insure further growth of the palsa. The newly formed palsa is swept free of winter snow allowing frost to penetrate deeply into the underlying peat. Frozen peat conducts heat in winter more easily than wet peat in summer so more heat is lost from the palsa in winter than is gained in summer. As a result the core of the palsa continues cooling facilitating further growth of segregated ice lenses and frost heaving of the ground surface.

Figure 6.5a. A group of well developed palsas within a tundra wetland environment.

Source: http://en.wikipedia.org/wiki/File:Palsaaerialview.jpg

Figure 6.5b. The leaning trees in this Alaskan forest are named drunken forests. Credit: Tingjun Zhang.

Source: http://nsidc.org/cryosphere/frozenground/how_fg_affects_land.html

Local variations in topographic relief associated with development of palsas and peat plateaux favour development of distinctive vegetation communities. Waterlogged meadows that surround peat landforms are dominated by mosses (*Sphagnum* spp.) where surface waters are acidic and poor in mineral nutrients or sedges (*Carex* spp.) where surface waters are more alkaline and nutrient-rich. Improved drainage associated with raised surfaces of palsas and peat plateaux allow the establishment of typical wetland vegetation such as black spruce (*Picea mariana*), tamarack (*Larix laricina*), Labrador tea (*Ledum* spp.), dwarf birch, heaths such as bog rosemary (*Andromeda polifolia*) and a variety of lichens. Trees growing at the margins of these peat landforms tilt outwards as the ground heaves beneath creating “drunken forests” (Figure 6.5).

Tundra

At high latitudes growth of woody vegetation is restricted by a lack of summer warmth and available plant nutrients, especially nitrate-nitrogen. Dwarf shrubs, grasses, sedges, mosses and lichens dominate the vegetation capable of enduring the harsh growing conditions. The treeless circumpolar tundra spans an estimated area of 25 million km^2 globally (Figure 6.2).

Riparian zones along rivers and streams in the Low Arctic are occupied by herbaceous and tall shrub vegetation. Rolling uplands north of the tree line generally contain low shrubs of willow (*Salix* sp.) and birch (*Betula* sp.) with dwarf shrubs of various heath species that fit within a matrix of upland sedges, including cotton grass (*Eriophorum* sp.) tussocks and forbs. Beyond these landscapes are large areas dominated by sedges, dwarf shrub species (mainly heaths) and scattered low shrubs of willow and birch. Sedges, grasses and mosses that form extensive wetlands dominate imperfectly drained lowlands and expansive coastal plain lowlands. Elevated habitats generally contain low or dwarf shrubs, cushion plants, lichens and grasses; species adapted to well drained or imperfectly drained soil. These are the major vegetation types within the Low Arctic of Alaska, mainland Canada and much of mainland Siberia.

In the High Arctic of the Canadian Archipelago, the northern portion of the Taimyr Peninsula and the Russian Archipelagos the vegetation is shorter and sparser. There are few wetland areas, but much of the landscape is covered with cushion plants, lichens and mosses or with scattered vascular plants in a substrate of mosses and lichens. These are the polar steppes. Other vast areas known as polar deserts have almost no plant cover. Cushion plants such as purple saxifrage (*Saxifraga oppositifolia*), draba (*Draba* spp.) and Arctic poppy (*Papaver radicatum*) occur with small amounts of mosses and lichens.

Regions occupied by tundra are dominated by cold, dry air masses (cA, cP) for most of the year. Mean winter temperatures commonly vary from –20°C to –30°C except in coastal areas where a maritime influence, especially adjacent to polynyas, makes temperatures less severe than further inland. Temperatures rise rapidly in the spring and summer in response to increasing daylength and insolation. Mean summer temperatures never exceed 10°C. The growing season is short. In the High Arctic temperatures exceed 0°C only in July and August while in the Low Arctic temperatures exceed 0°C for up to four months. Annual precipitation varies from less than 200 mm in the High Arctic to between 200 and 400 mm in the Low Arctic. Cyclonic storms account for most of the precipitation much of which falls as snow, particularly in the fall.

A variety of soils are present in tundra regions ranging from deep peat in poorly drained wetlands to coarse, rocky materials on upland surfaces. On upland surfaces frost action produces accumulations of angular rock clasts known as a block field or **felsenmeer** (Figure 6.6). Frost action involves the expansion of water within pores and fractures in rock upon freezing generating pore pressures capable of shattering rocks.

Figure 6.6. Felsenmeer developed on igneous rocks near timberline, Canadian Arctic. Source: Northern Portal, University of Saskatchewan.

Decomposition of organic materials and primary minerals occurs slowly in high latitude environments and over most of the tundra region the typical soil profile consists of an organic surface layer of variable thickness overlying a strongly gleyed mineral soil. These tundra soils are called **Cryosols** (Figure 6.7) if permafrost lies within two metres of the ground surface and the effects of cryoturbation are evident (e.g., presence of patterned ground, Turbic Cryosol) or if permafrost lies within one metre of the ground surface with no evident cryoturbation (Static Cryosol). Organic Cryosols consist largely of peat. Brunisols can also be found in the tundra region, particularly in the Low Arctic near the forest-tundra transition zone. These mineral soils develop on well-drained sites where permafrost is absent or at such depths that the effects of cryoturbation do not influence the soil profile.

Figure 6.7. Cryosolic soil profile. Note how organic-rich materials (indicated by dark colours) have been moved downwards from the soil surface to depth and the corresponding upward displacement of soil parent materials (indicated by paler colours) in response to cryoturbation within the active layer.

Credit: Darwin Anderson, Department of Soil Science, College of Agriculture and Bioresources, University of Saskatchewan.

Source: http://www.soilsofcanada.ca/gallery/image.php?id=152

Shrub Tundra

Woody shrubs such as dwarf willow, dwarf birch, alder and Labrador tea dominate shrub tundra vegetation communities (Figure 6.8). On well-drained slopes characterized by Brunisolic Turbic Cryosols and Static Cryosols these shrubs are associated with heath plants, grasses, mosses and lichens. Common heath plants include Arctic white heather (*Cassiope tetragona*), crowberry (*Empetrum nigrum*), bearberry (*Arctostaphylos uva-ursi*), rock cranberry (*Vaccinium vitis-idaea*) and bilberry (*Vaccinium uliginosum*). The understory vegetation cover is dominated by grasses such as alpine meadow grass (*Poa* spp.) and polar grass (*Arctagrostis latifolia*), mosses and brightly coloured lichens.

Figure 6.8. Shrub tundra. Source: CAFF (2001).

On poorly drained mineral soils characterized by Turbic Gleysolic Cryosols dwarf shrubs, grasses, mosses and sedges increase, while lichen cover decreases. The dwarf shrubs such as willow, birch, Labrador tea, bilberry, and Arctic white heather occur along with Arctic avens (*Dryas integrifolia*), common grasses such as polar grass (*Arctagrostis* sp.) and sedges (*Carex* spp., *Eriophorum vaginatum*).

Wet Tundra (Sedge Meadows and Tussock Tundra)

Wet tundra vegetation communities are dominated by sedges (*Carex* spp., *Eriophorum* spp.), Arctic willow (*Salix arctica*), polar grass (*Arctagrostis latifolia*), alpine bistort (*Polygonum viviparum*) and mosses and occur on poorly drained mineral soils characterized by Turbic Gleysolic Cryosols (Figure 6.9). Poorly drained organic terrain within the continuous permafrost zone is characterized by the presence of ice-wedge polygons. Soils in these areas are Turbic Organic Cryosols. Mosses dominate the elevated, better-drained peat areas along with dwarf birch, Labrador tea, heath and bog rosemary (*Andromeda polifolia*). The surrounding wetland is completely dominated by sedges and mosses.

Figure 6.9. Tussock tundra (northeast Greenland). Source: CAFF (2001, 27), Ecology, in Arctic Flora and Fauna: Status and Conservation (Helsinki: Edita), http://www.caff.is/sidur/uploads/OSA_02.PDF

Mesic Tundra

Mesic tundra vegetation communities develop in proximity to late lying snow banks (Figure 6.10). Soils in these microhabitats are well drained Static Cryosols. Grasses such as bluegrass (*Poa* spp.) and fescue (*Festuca* spp.), Arctic white heather (*Cassiope tetragona*) and Arctic willow (*Salix arctica*) dominate the ground cover. Other common plants include saxifrages (*Saxifraga* spp.), Arctic poppy (*Papaver radicatum*), Arctic avens (*Dryas integrifoila*), mountain sorrel (*Oxyria digyna*), cinquefoil (*Potentilla* spp.) and buttercups (*Ranunculus* spp.) along with a variety of mosses and lichens. Brightly coloured lichens such as *Rhizocarpon geographicum* and *Alectoria* spp. are common on exposed rock surfaces.

Figure 6.10. Mesic tundra established along the margin of a late-lying snow bank, Canadian Arctic Archipelago. The tundra surface is characterized by hummocks composed largely of Arctic white heather and Arctic avens. Source: Northern Portal, University of Saskatchewan.

Polar Steppe Communities

Polar steppe plant communities develop on well to imperfectly drained, fine-grained soils (Static Cryosols) in the High Arctic often in association with the tops of high-centred ice wedge polygons (Figure 6.11). Ground cover is dominated by woodrushes (*Luzula* spp.), foxtail grass (*Alopercus* sp.), goose grass (*Puccinellia* spp.), snow grass *(Phippsia* sp.), cushion plants such as chickweed (*Cerastium* spp.), draba (*Draba* spp.), saxifrage (*Saxifraga* spp.), moss campion (*Silene acaulis*), sedges (*Carex* spp.) and a variety of mosses and lichens.

Figure 6.11. Semi-desert Polar steppe (Northeast Greenland): cushion plants occur sparsely across the gravel surface. Source: CAFF (2001, 27), Ecology, in Arctic Flora and Fauna: Status and Conservation (Helsinki: Edita), http://www.caff.is/sidur/uploads/OSA_02.PDF

Polar Desert Communities

The term polar desert is applied to barren areas (i.e., plants cover less than 5 percent of the surface area) associated with rock outcrops, felsenmeer and sterile gravel (Figure 6.12). A variety of lichens (e.g., *Rhizocarpon geographicum, Umbilicaria spp., Cladonia rangifera*) dominate polar desert plant communities. Cushion plants such as saxifrages (Saxifraga spp.), chickweed (*Cerastium spp*.), Arctic avens (*Dryas integrifolia*) and Arctic poppies (*Papaver radi*catum) are common members of polar desert communities.

Figure 6.12. Polar desert (Cornwallis Island, Canada).

Source: CAFF (2001, 27), Ecology, in Arctic Flora and Fauna: Status and Conservation (Helsinki: Edita), http://www.caff.is/sidur/uploads/OSA_02.PDF

Fjell Fields

Upland surfaces mantled by felsenmeer present extremely dry habitats characterized by a thin, discontinuous vegetation cover (i.e., less than 20 percent of the ground surface) consisting of Arctic avens (*Dryas integrifolia*), heaths (*Cassiope sp., Empetrum* sp.) including alpine azalea (*Loisleuria procumbens*), Arctic poppy (*Papaver radicatum*) and lichens (Figure 6.13).

Figure 6.13a and b. Fjell field dominated by Arctic poppy (*Papaver radicatum*), Arctic avens (*Dryas integrifolia*) and lichens established on felsenmeer, Ellesmere Island, Canadian Arctic Archipelago. Source: Northern Portal, University of Saskatchewan.

Learning Activity 3

For this exercise use a guide for local flora and fauna where you live. If your place of residence lies outside the Subarctic or Arctic regions, try to locate information on the natural history of northern environments to assist you with this exercise. Compile a list of common plants (e.g., trees, shrubs, herbs, mosses, lichens) and animals (e.g., insects, birds, mammals) for an upland environment with well-drained soils. Repeat this exercise for a wetland environment with poorly drained soils. Do your observations corroborate the information presented in this module? If not, what differences in community composition did you observe?

6. 3 Ecological Effects of Microclimatic Variation on the Land

It is within these broad habitats that small-scale variation in environmental conditions has direct effects on species and system ecology. In particular, the interlinked factors of snow and ice cover, soil type, moisture content and permafrost conditions can significantly modify the microclimate in which flora and fauna live. An example of this is the Stordalen wetland adjacent to Lake Tornetrask near Abisko in northern Sweden where the peat surface shows distinct hummocks and depressions underlain by permafrost typical of many tundra sites. The hummocks with a vegetation of *Empetrum hermaphroditum* and *Vaccinium microcarpon* heaths association containing chokeberry (*Rubus chameamorus*), willow (*Betula nana*) and crustose lichens have low moisture content compared to depressions with a *Carex rotundata* (sedge) and *Drepanocladus schulzei* (moss) association including *Eriophorum vaginatum* and *Sphagnum balticum*. The snow is thin (5 – 15 cm) on more exposed hummocks compared with sheltered depressions (25 – 50 cm). Observed over four years, snowmelt was completed and soil thaw began on the hummocks 4 – 10 days before depressions with later snow blanket. When it began the thaw was 2 – 3 times faster and continued longer in wet, peat-filled depressions and extended to twice the depth (80 – 120 cm) of the hummocks (Figure 6.14). At the end of summer the surface of the mire refroze. By early January the frost front moved down until the soil was completely frozen under the hummocks. However, in three of the four years under the depressions freezing of the peat was incomplete and a layer of unfrozen peat remained throughout the winter.

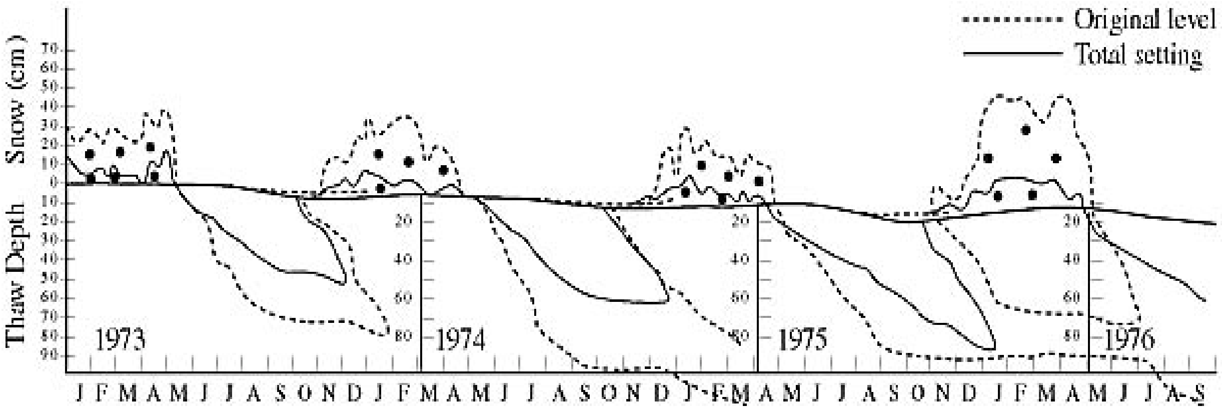

Figure 6.14. Duration and depth of thaw and refreezing in a well-drained hummock (solid line) and wet depression (dotted line) on a peat wetland in northern Sweden. Source: Ryden and Kostov (1980).

The example in Figure 6.15 from northern Sweden shows how small differences in topography affect snow cover, insolation and wind exposure. These factors combined with soil moisture content and soil thermal conductivity determine soil temperature and the length of the growing season. This directly effects plant root growth and activity and selects different plant species. Soil conditions influence soil microflora and fauna, rates of decomposition and nutrient mineralization. Figure 6.15 provides a general illustration of conditions in dry, moist and wet tundra systems. The relatively deep active layer and thin organic layer often occur in dry soils, while wet soils in which organic matter tends to accumulate because cold anaerobic conditions retard the rate of decomposition have a shallow active layer. Organic matter and moisture content are important determinants of soil temperature, thaw depth, cation exchange capacity, aeration, redox potential and other properties that affect biological processes in tundra soils. These small-scale variations in spatial and temporal patterns in the landscape (Figure 6.16) provide opportunities for animals and plants to extend their short summer season or assist their winter survival.

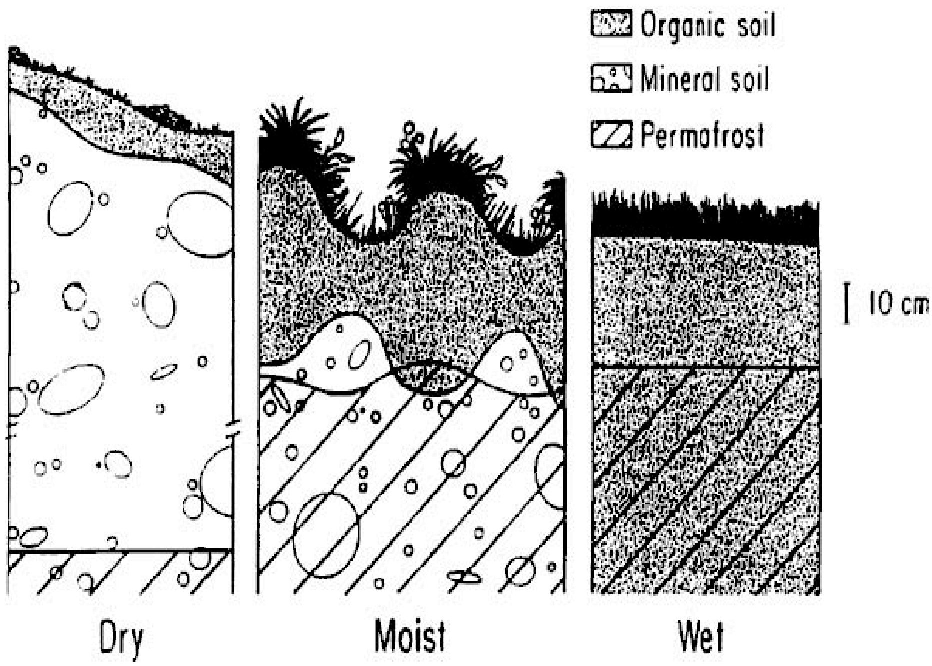

Figure 6.15. Variations in soil moisture conditions, organic matter accumulation and depth to the permafrost table associated with small-scale variations in topography in a tundra wetland. Source: Nadelhoffer et al. (1992).

Figure 6.16a. Low-centered polygons associated with wet tundra on Bylot Island, Canada. Source: CAFF (2001).

Figure 6.16b. Tundra peatland mosaic consisting of a stream, ponds, wetlands, and palsas in eastern European Russia. Source: CAFF (2001).

The Stordalen wetland with its hummocks and depressions is one example of how small changes in the microclimate can provide herbivores such as lemmings or reindeer with access to different plant species at different times as a result of changes in snow cover or timing of growth. Similarly, differential thawing rates of the surface soil allows lemming nests to be established before the spring thaw is widespread, but with the risk of flooding by adjacent later snowmelt. Small areas of early thaw provide migratory insectivorous birds with the opportunity to feed on soil invertebrates. General effects of variations in snow cover are shown in Table 6.1.

Conclusion

Low temperatures are important to northern biology. However, many other factors potentially and actually limit life on land. Factors including soil moisture, input of solar radiation, wind stress, organic matter decomposition rates and the quantity of plant nutrients in soils, acting in isolation and in combination, result in changes in the composition of organisms and rates of ecosystem processes. A variety of distinct biomes have developed within Subarctic and Arctic regions including boreal forest, open lichen woodland, forest-tundra and tundra.

Boreal forest is composed largely of coniferous, evergreen vegetation dominated by spruce (*Picea*), pine (*Pinus*), fir (*Abies*) and tamarack/larch (*Larix*). Open lichen woodlands consist of an open canopy forest with trees irregularly spaced as much as 25 metres apart while the understory is dominated by light-coloured lichens and mosses. White spruce (*Picea glauca*), black spruce (*Picea mariana*), dwarf birch (*Betula* spp.) and Labrador tea (*Ledum* spp.) dominate typical spruce-lichen woodland. Forest-tundra describes an environment situated between the arctic tree line to the north and the northernmost limit of continuous forest including open lichen woodland to the south. A variety of habitats and plant communities are encountered within forest-tundra. Open forests composed of spruce (*Picea* spp.) and tamarack (*Larix* spp.) are intermixed with dwarf shrubs, heaths, mosses and lichens. Further north growth of woody vegetation is restricted by lack of summer warmth and available plant nutrients during the growing season. Vegetation capable of enduring these harsh growing conditions is dominated by dwarf shrubs, grasses, sedges, mosses and lichens.

Table 6.1 Effects of variations in snow cover on a subarctic landscape (CAFF 2001).

Typical Ecological Factors		Wind-Exposed Ridge	Sheltered Slope	Depression
Snow Cover	Depth (cm)	0–20	20–80	80+
	Length of snow-free period (typical values in months)	4–5	3–4	<3
Soil	Moisture	Dry	Dry-Mesic	Mesic-Moist
	Freeze-thaw processes	Intense	Low-Moderate	Low-Moderate
	Depth of soil active layer	Deep	Moderate	Moderate–Thin
	Nutrient status	Low	Moderate	Low–Moderate
Temperature	Variability	High	Moderate	Moderate
	Winter minima near soil surface	Very low	Moderate	Moderate–Near zero
Desiccative Stress in Spring		High	Moderate	Low
Herbivore Activity in Winter	Reindeer	Moderate–High	Moderate	Low
	Microtines (e.g., lemmings, voles)	Low	Moderate–High	Moderate–High
	Rock ptarmigan, mountain hare	High	Low	Low
Typical Plant Forms		Wind-Exposed Ridge	Sheltered Slope	Depression
Plant Group	Vascular plants	Trailing dwarf shrubs, cushion plants	Dwarf shrubs	Low herbs, dwarf willows
	Mosses *Bryophytes*	Small, compact, drought-tolerant species	Mesophytic mosses	Mesohygrophytic bryophytes
	Lichens	Wind-hardy fruticose species	Fruticose reindeer lichens	
Typical Species		Wind-Exposed Ridge	Sheltered Slope	Depression
Plant Group	Vascular plants	Alpine bearberry, *Arctocstaphylus alpine;* Alpine azalea, *Loiseleuria procumbens*	Dwarf birch, *Betula nana*; Bog blueberry, *Vaccinium uliginosum*	Polar willow, *Salix* spp.
	Mosses *Bryophytes*	Wooly fringe-moss, *Racomitrium lanuginosum*	Stairstep moss, *Hylocomium splendens*	*Kiaeria starkei*
	Lichens	*Alectoria nigricans*	*Cladina mitis*	

Discussion Questions

1. Discuss the influence of net radiation and the nature and quantity of precipitation in the spring and summer seasons on the species composition of terrestrial vegetation communities in northern landscapes (Figure 6.1).
2. Describe the combination of processes that contribute to the formation of palsas and peat plateaux.

Study Questions and Answers

1. Compare and contrast the composition of vegetation communities on well-drained soils in Subarctic and Arctic environments.

   In Subarctic regions well-drained soils are represented by Brunisols, Podzols and Luvisols. Permafrost generally occurs at depths greater than 1 metre. Mixed forests occur commonly on Brunisols and Luvisols. Forests dominated by evergreen needleleaf vegetation occur commonly on Podzols.

   Woody vegetation is more important in Subarctic vegetation communities. Warmer summer air and soil temperatures combined with adequate rainfall during the short summer growing season allow trees and shrubs to grow and dominate Subarctic vegetation communities. Mixed forests composed of broad-leaved deciduous trees (e.g., poplar, aspen) and evergreen needleleaf trees (e.g., pine, spruce, fir) occur in southern Subarctic regions. Further north climates become progressively cooler and drier and permafrost occurs closer to the ground surface. Forest composition changes in response to these environmental changes include deciduous trees gradually disappear from the flora except in riparian habitats; evergreen trees become progressively smaller in height; and the forest canopy opens allowing shrubs, herbs and lichens to become important components of the vegetation community.

   In Arctic regions well-drained soils consist of Brunisols and Static Cryosols. Permafrost lies close to the ground surface. Seasonal saturation of the active layer may occur.

   Shrubs and heaths dominate vegetation communities in southern Arctic regions. Further north climates become progressively cooler and drier. Precipitation in the form of snow affects the supply of soil moisture during the brief summer growing season. Permafrost lies close to the ground surface and active layer development occurs slowly. Soil temperatures in the rooting zones of vegetation remain cool throughout a short summer growing season. Vegetation composition changes in response to these environmental changes. Woody vegetation gradually disappears. The proportion of ground covered by plants decreases and herbs, cushion plants, mosses and lichens become important components of the vegetation communities.

2. Compare and contrast the composition of vegetation communities on poorly-drained soils in Subarctic and Arctic environments.

   Poorly-drained soils in the Subarctic region consist of Gleysols and Histosols. Plants must tolerate rooting in cool, acidic, water-logged soils. Open canopy forests composed of black spruce and tamarack share the landscape with shrubs (e.g., alder, willow), heaths (e.g., Labrador tea), mosses and sedges. Changes in microtopography associated with ice wedge polygon and palsa development affect small-scale changes in vegetation composition.

Poorly drained soils in the Arctic region consist of Turbic Cryosols and Turbic Histosols. Shallow active layers and water-logged soils contribute to vegetation communities dominated by cotton grass, herbs, mosses and sedges.

3. Discuss how mineral weathering, organic matter decomposition, translocation and accumulation influence the development of discrete soil horizons in northern soils.

   Subarctic: relatively warm spring and summer temperatures; spring snowmelt and summer rainfall supply moisture to soils; permafrost lies at depths greater than 1 metre. The combination of these environmental factors facilitates a greater degree of chemical weathering and more rapid organic matter decomposition. These processes generate clay minerals, iron and aluminum oxides and finely divided organic matter (humus) as well dissolved nutrients within the soil. Water percolating through the soil moves these materials downwards where they accumulate at depth to create discrete soil horizons enriched in humus (designated as “h”), soil horizons enriched in iron and aluminum oxides (designated as “f”), and soil horizons enriched in clay (designated as “t”).

   Arctic: colder and drier climates. Snow cover persists well into summer season; limited supply of water from snowmelt. Precipitation as rainfall does not occur until late summer. Permafrost lies close to the ground surface. The combination of these environmental factors suppresses chemical weathering and organic matter decomposition. This limits the supply of weathering products. Humus tends to accumulate at or near the ground surface. The shallow active layer permits soils to become saturated with water. Translocation of materials is limited by the depth of the active layer. Materials within the active layer can be disturbed by ice heave and cryoturbation. Under these circumstances it is difficult to generate clearly differentiated soil horizons.

4. Discuss the influence of small-scale variations in topography and drainage associated with high-centred ice wedge polygons or palsas on small-scale variations in the species composition of terrestrial biota.

   Uplift of the ground surface associated with lateral expansion of ice wedges or heaving of the ground surface associated with the growth of segregated ice lenses in soil or peat allows water to drain from areas of higher topographic relief. Over time improved drainage allows for the establishment of trees, shrubs, heaths, grasses and lichens while adjacent low-lying areas tend to be characterized by saturated soils and plants that tolerate cool, wet, acidic soils such as certain heaths, mosses and sedges.

Glossary of Terms

Anaerobic Respiration: The process of generating energy by the oxidation of nutrients using an external electron acceptor other than oxygen.

Atmosphere: The gaseous envelope surrounding Earth.

Broadleaf Vegetation: Plants having relatively broad rather than needlelike or scalelike leaves

Bryophyte: A plant of the Bryophyta, a division of photosynthetic, chiefly terrestrial, nonvascular plants, including the mosses, liverworts and hornworts.

Coniferous (or needleleaf) Vegetation: Any of the various mostly needle-leaved or scale-leaved, chiefly evergreen, cone-bearing trees or shrubs (e.g., pines, spruces, firs and tamaracks).

Cushion Plants: A type of low-growing plant having many closely spaced short upright shoots, typical of alpine and arctic habitats.

Deciduous Vegetation: Plants that shed their foliage (leaves or needles) at the end of the growing season.

Evergreen Vegetation: Plants that retain their leaves or needles in all seasons.

Felsenmeer: The term felsenmeer comes from the German meaning 'sea of rock'. In a felsenmeer (also known as a block field), frost action has broken up the top layer of the rock covering the underlying rock formation with jagged, angular boulders.

Forb: Any herbaceous plant that is not a grass.

Fruticose Lichens: A term relating to the branching nature of some lichens.

Herb: Plants or plant parts that are fleshy as opposed to woody; a herbaceous plant.

Hydrosphere: A term that relates to the water present at the Earth's surface, including rivers, lakes, groundwater and water vapour in the atmosphere.

Lithosphere: The lithosphere includes the crust and the uppermost mantle, which constitute the hard and rigid outer layer of the Earth.

Mesophytic (Mesohygrophytic): A land plant growing in an environment having an average supply of water.

Palsa: (plural: palsas or palsen) A term from the Finnish language meaning "a hummock rising out of a bog with a core of ice." Bugor and bulginniakhs are general terms in the Russian language (the latter of Yakutian origin) for palsas and pingos. Palsas are low, often oval, mounds of frost heaved peat or soil which contains permanently frozen ice lenses. They often occur in groups and are characteristically found in areas with discontinuous permafrost.

Peat Plateau: Peat plateaux are structures of coalesced palsas that form a continuous elevated flatland area usually in a peat bog.

Riparian Environment: Plant habitats and communities along river margins and banks characterized by plants that tolerate water saturated soils.

Translocation: A term that refers to the downward movement of solid (e.g., clay minerals, oxides) and dissolved materials (e.g., plant nutrients such as potassium (K^+), phosphorus (PO_4^{3-}), nitrogen (NO_2^-, NO_3^-)) within soils.

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