1 Peatland habitats

This book deals with the diverse, beautiful, and fascinating world of peatlands. They represent very special kinds of transitional, amphibious ecosystems with habitats between uplands and water, where organic matter tends to accumulate because of the waterlogged, often poorly aerated conditions. Here we encounter *Sphagnum* peat mosses with an infinite variety of colours—greens, reds, browns; insect-eating plants and beautiful orchids; reeds, sedges, and cotton grasses; low, often evergreen shrubs; floating plants and emergents at the water's edge; quaking mats; vast wetlands with spectacular surface patterns; springs and soaks; thickets, sparsely treed woodlands, and tall forests. As a consequence of their diverse vegetation, peatlands also house a multitude of microorganisms, insects, birds, and other animals.

Peat accumulations are often several metres thick, sometimes even more than ten metres, and provide material that can be harvested and used as fuel and for horticulture. After drainage, large areas have been converted to arable land, meadows, or forests. The peats are also valuable archives of past vegetation and climate, where we may find the buried remains of ancient settlements, trackways, fields, and even preserved humans—the so-called 'bog people' of northern Europe (Coles and Coles 1989; Turner and Scaife 1995).

The aim of this chapter is to provide the reader with an understanding of the main terms and concepts used in peatland science, and a general appreciation of the main peatland habitats. It is essential at the outset to provide a basic language of peatlands which, even if not universally agreed upon, will define the usage for this book. The variation in terminology reflects the great diversity and complexity of habitats and ecosystems. Unfortunately several terms are not consistently used, even in the same country or language. This reflects traditional differences in understanding and comprehension among specialists, and differences between geographical areas. Table 1.1 lists a select set of peatland types in several languages. Many glossaries and definitions are available; particularly useful are IPS (1984) and Joosten and Clarke (2002).

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Table 1.1 Peatland terminology. It is difficult to find exact translations, and the terms are sometimes used inconsistently, even within the same language.

English	German	Russian	French	Finnish	Swedish
Wetland	Nassboden, vernässter Boden, Feuchtgebiete	Заболоченная местность, З. земля	Milieux humides	Kosteikko	Våtmark
Peat[a]	Torf	Торф	Tourbe	Turve	Torv
Peatland	Torfmoor	Торфяник, торфяное болото	Tourbière	Turvemaa	Torvmark
Mire	Moor	Болото	Tourbière, tourbière vivante	Suo	Myr
Bog	Regenmoor, Hochmoor	Болото атмосферного питания, верховое болото	Tourbière ombrotrophe, tourbière haute	Ombrotrofinen suo, rahkasuo	Mosse
Fen	Niedermoor	Низинное болото	Tourbière minérotrophe, tourbière basse, bas-marais	Sarasuo, minerotrofinen suo	Kärr
Marsh	Marschmoor	Марш[b]	Marais	Marskimaa	–[c]
Swamp forest	Bruchwald, Moorwald	Болото лесное	Marécage, forêt marécageuse	Korpi	Sumpskog

[a] An English word related to the word used for peat in other languages is 'turf' (often used in old literature, e.g. King 1685).
[b] Rarely used term, usually used for translation and in plural form ('марши').
[c] No commonly used term since marshes are usually classified as shore vegetation. 'Mad' or 'raning' are used locally for grazed or mown marshes.

1.1 Wetlands, peatlands, and mires

The three main terms used in the current literature to encompass the subject are wetlands, peatlands, and mires. These terms are defined somewhat differently, although there is considerable overlap (Fig. 1.1). The broadest concept is that of wetlands.

1.1.1 Wetlands

Wetlands are '. . . neither firm "lands" in the conventional sense, nor bodies of open water; hence they occupy a transitional position between land and water. The ecosystems that develop on such lands are dominated by the persistent presence of excess water' (National Wetlands Working Group 1988). Wetlands include shore, marsh, swamp, fen, and bog. Scientifically, we can characterize wetland by the following points:

- The water table is near the ground surface.
- As a consequence, the substrate is poorly aerated.

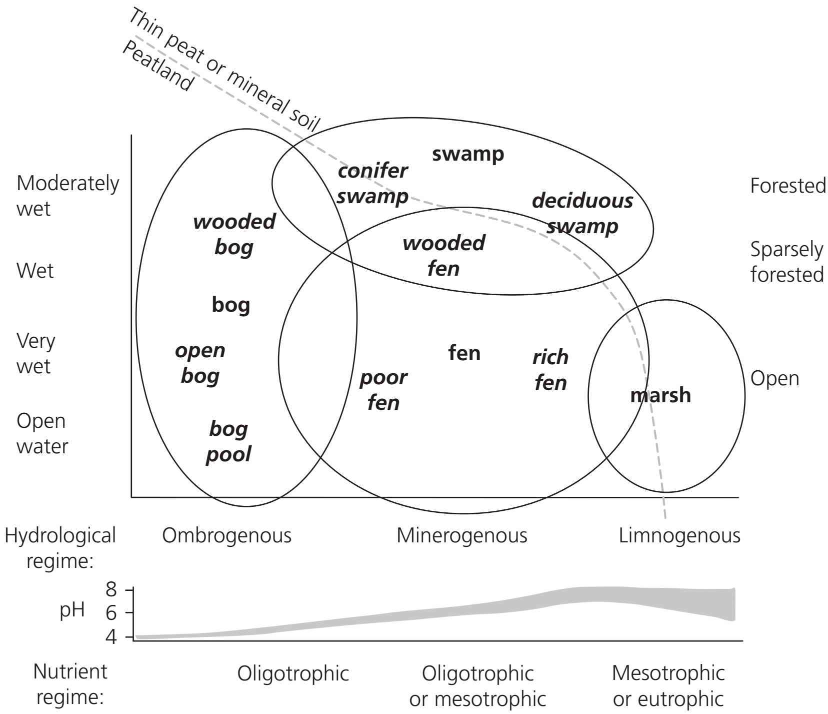


Fig. 1.1 A general scheme to define the position of broad wetland types in an ordination based on the two most important environmental gradients. Wetness, or distance between vegetation surface and water table, varies along the vertical axis, and the complex gradient with variation in pH, base saturation, and nutrient status is depicted along the horizontal axis. Wetland is an even broader category than shown here, since it includes various habitats of shore and shallow waters.

- Inundation lasts for such a large part of the year that the dominant plants and other organisms are those that can exist in wet and reducing conditions.

The Ramsar Convention provides a very wide definition:

> For the purpose of this Convention wetlands are areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres (Ramsar 1987).

The Canadian Wetland Classification has a narrower definition, extending to water depths up to two metres, and which is more ecosystemic in character:

> A wetland is defined as: land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment (National Wetlands Working Group 1997).

There are a multitude of wetland definitions used for scientific, inventory and regulatory purposes. Considerable work has been done in the USA to define wetlands by length of time of surface flooding during wet periods, and to define upland limits to wetlands with the use of indicator plants (see Tiner 1998; 1999). Much of this work in the USA has emphasized the marsh and open water communities, in contrast with other wetland inventories that are broader and include bogs and fens (e.g. in Canada and Sweden).

1.1.2 Peat and peatland

In order to define peatland we must first define peat. Peat is the remains of plant and animal constituents accumulating under more or less water-saturated conditions owing to incomplete decomposition. It is the result of anoxic conditions, low decomposability of the plant material, and other complex causes. Peat is organic material that has formed in place, i.e. as sedentary material, in contrast to aquatic sedimentary deposits. Quite different plant materials may be involved in the process of peat formation, for instance, woody parts, leaves, rhizomes, roots, and bryophytes (notably *Sphagnum* peat mosses). Most of the material originates above ground as photosynthetic organic material, and is deposited as litter on the surface to be buried by new layers of litter. However, some of the photosynthate is translocated to roots or rhizomes beneath that eventually die and are added to the peat, and a certain fraction of the dead plant material is recycled by invertebrates, bacteria and fungi, before they too die and add to the peat material.

Peatland is a term used to encompass peat-covered terrain, and usually a minimum depth of peat is required for a site to be classified as peatland. In Canada the limit is 40 cm (National Wetlands Working Group 1997), but in many countries and in the peatland area statistics of the International Mire Conservation Group it is 30 cm (Joosten and Clarke 2002). For purposes of clarity and uniformity, we will use 30 cm to define peatland.

1.1.3 Mire

Mire is a term for wet terrain dominated by living peat-forming plants (e.g. Sjörs 1948). The concept of 'peat-forming plants' is, however, somewhat problematic. Even if some species more commonly give rise to peat than others, peat formation is a *process* that can befall most plant materials. Both peatland and mire are narrower concepts than wetland, because not all wetlands have peat as substrate.

In one sense mire is a slightly broader concept than peatland, because peat accumulation can occur on sites that have not accumulated the required depth of peat to qualify as peatland. In another sense peatland is broader—a drained site, for instance a site being used for peat harvesting, is still a peatland, but having lost its original peat-forming vegetation it is no longer a mire. A reason for the seemingly conflicting definitions is that the terms are used for different purposes. Mire is a term often used in botanical and ecological investigations of the vegetation types, and then often used collectively for fens and bogs (see sections 1.4.3 and 1.4.4). Peatland is often used in forestry and land management, which makes the peat depth limit crucial. There are also traditional differences among countries; in North America the term peatland has been more widely used, whereas in Scandinavia mire (*myr*) is more commonly used.

1.2 Peatland habitats along wetness and chemical gradients

Two complex environmental gradients are responsible for the differentiation of peatland habitat types. One is linked to wetness and aeration and the other is a combination of pH, calcium (Ca) content, and base saturation. The latter is to some degree linked to nutrient availability, but is not a universal predictor of productivity.

1.2.1 Variation in wetness and aeration

The overriding physical condition controlling peatlands is the high water table. The initial formation of peat is related to wet conditions near the surface. Oxygen moves very slowly in stagnant water, and is used up rapidly by microorganisms in saturated soil, creating anoxic conditions.

Among and within peatlands the position of the water table varies in time and space, so some surfaces of the peatland are below, some at, and some slightly raised above the water level permanently or temporarily. This creates a variable moisture–aeration regime, which depends not only on the position of the water table, but also on pore structure of the peat, the fraction of the total pore spaces filled with water versus air, and the oxygen content of the water. This regime can be segregated for analytic purposes into the moisture factor and the aeration factor, although they are related.

The lack of oxygen influences the rate of decomposition of organic matter that is laid down by the peatland plants. In virgin mires with actively growing surface vegetation there is a net gain of organic matter and hence active growth of the peat layer. Different organisms respond differently to the depth of, or depth to, the water table. Limitations for vascular plants relate primarily to lack of oxygen in the rooting environment (discussed further in Chapter 3).

1.2.2 Variation in pH, base richness, and nutrient availability

The accumulation of peat usually causes increasingly more acid and nutrient-poor conditions, as the influence of the cations derived from mineral soil decreases with time. The organic matter has a high cation exchange capacity (CEC), and tends to take up (adsorb) cations in exchange for hydrogen ions. Therefore, most chemicals, notably cations, are adsorbed on the peat particles, and only a minor—but important—fraction is actually free in solution.

The chemical regime can be segregated into two factor groups. One is the variation in pH, linked also to electrical conductivity, Ca content, and base richness. The other is availability of plant nutrients. As in most terrestrial ecosystems nitrogen (N) is a key nutrient, but the scarcer phosphorus (P) and potassium (K) are more often limiting in peatlands than in mineral soil. Each of these nutrients has its own chemistry and variation, and one cannot automatically assume strong correlations of their availability to pH, Ca, and base richness (Bridgham *et al.* 1996; more details given in Chapter 9).

1.3 Origin of groundwater and trophic classes

From early scientific work the importance of the origin of the mire water as a major controlling factor has been recognized (e.g. Du Rietz 1954). Peat accumulation begins on wet mineral soils or as quaking mats encroaching on open water. At this stage the water in the peat surface is connected with, or has passed over or through, mineral parent materials. Such sites are termed *minerogenous* (or *geogenous*) to indicate that water is added to the peatland from the surrounding mineral soil. However, as the peat layer grows higher, the vegetation may become progressively more isolated from the mineral soil water. Peatlands with a surface isolated from mineral-soil-influenced groundwater will receive water only by precipitation. These peatlands are called *ombrogenous*. To emphasize the chemical effects on the site we refer to minerogenous peatlands as *minerotrophic*, nourished by mineral soil groundwater. Correspondingly we refer to ombrogenous peatlands as *ombrotrophic*, nourished by precipitation (and airborne dust). The terms minerogenous and ombrogenous define the hydrological regime, whereas the terms minerotrophic and ombrotrophic focus on the way nutrients are provided and affect plant growth and productivity.

Many mire ecologists follow the simple convention of using the term *fen* for minerotrophic mires and *bog* for the ombrotrophic ones. The idea of giving vernacular terms a strict meaning in ecological literature was probably first introduced in Sweden (*kärr* = minerotrophic, *mosse* = ombrotrophic, *myr* for both), Germany, and Finland. Later these terms were adopted into English as *fen, bog*, and *mire*. This is a useful convention, not least when it comes to communicating peatland science in popular form, and we follow it in this book.

Minerogenous peatland is further divided into three major hydrologic systems (von Post and Granlund 1926; Sjörs 1948):

- *Topogenous peatlands* have flat (or virtually flat) water tables, and are located in terrain basins with no outlet, a single outlet, or both inlets and outlets.
- *Soligenous peatlands* are sloping, with directional water flow through the peat or on the surface.
- *Limnogenous peatlands* are located along lakes, streams, or intermittent stream channels that are flooded periodically by waters carried in these channels.

Another set of terms is *oligotrophic, mesotrophic*, and *eutrophic*. These terms are commonly used in limnology in relation to plankton productivity, which is often explained in terms of levels of N or P. The terms have also been adopted for use in peatland work, and the sequence oligo-, meso-, eutrophic is explained as a gradient of increasing productivity and nutrient availability. The oligotrophic class is portrayed as somewhat broader than the ombrotrophic class (Fig. 1.1), and it includes weakly minerotrophic sites with low pH. However, there are also oligotrophic sites (with low productivity) in minerotrophic conditions that have very high pH and Ca content, because the P has become unavailable by binding with Ca.

1.4 The main ecosystems: marsh, swamp, fen, bog

In a long-term programme of wetland studies in Canada, four high-level ecosystem classes were identified—*marsh, swamp, fen*, and *bog* (National Wetlands Working Group 1988, 1997). These four terms, and the ecosystem classes that they represent, are among the most common used in the wetland literature.

As indicated above, moisture–aeration and pH–base richness are the principle determinants of biological variation, and in Fig. 1.1 the four main ecosystem classes are positioned along these two environmental gradients. The wetlands occupy the total area of the graph (and even go beyond the scheme), whereas the peatlands (requiring >30 cm peat) are more restricted. Ombrotrophic bogs occupy the left-hand side of the model, the nutrient-poorest and most acid, whereas the minerotrophic fens, swamp forests, and marshes are on the right-hand side of the model, which has higher pH and usually more nutrients. The minerotrophic peatlands encompass a much broader range of nutrient and pH variation, and hence also a good deal more abiotic and biotic variation than the bogs. The general relationship between oligo-, meso-, and eutrophic classes can also be seen, but this portrayal disguises the fact that some high-pH sites are rather oligotrophic. To the right we find the peatlands on shallower peats or adjacent to streams and lakes. The vertical axis shows increasing dryness, progressing from open water through open types, wooded or thicketed types, and forested types.

From this scheme it is clear that the peatland category includes the bog and most fen ecosystems, and covers a substantial part of the swamp forests.

However, most of the marshes are not peatlands, and we do not deal with them in any detail in this book.

A basic principle of classification is that it is purposive; that is, it is done for a specified purpose or use. It is difficult to find 'natural' classifications, because there are often no sharp boundaries between ecosystems. A physiognomic and dominance type approach is useful, because it is based on structure and form of vegetation, and on the main dominants that control the appearance of the vegetation. Such a classification can be used by people who are not specialists in flora, and also from the point of view of vegetation mapping and remote sensing. In order to clarify the divisions between the four main peatland ecosystems and some of their physiognomic groups, we present a key in Table 1.2, and the key features of marsh, swamp, fen, and bog in Table 1.3. Generally the physiognomic groups are not sharply distinguished in the field, and they are separated by rather arbitrary cut-off levels for the main vegetational features.

1.4.1 Marsh

Marshes (Fig. 1.2) are characterized by standing or slowly-moving water with submergent, floating-leaved, or emergent plant cover. They are permanently flooded, or seasonally flooded and intermittently exposed. Nutrient-rich water generally remains within the rooting zone for most of the growing season. Bottom surfaces may be mineral glacial drift, aquatic sedimentary deposits, or precipitates of inorganic compounds or organics. Initial root mats of peat may be developing over the mineral or sedimentary deposits. The transition between sedge-dominated marshes and limnogenous fens is gradual, but generally marshes have higher nutrient levels and higher productivity of vascular plants, but less bryophyte cover than fens (Bayley and Mewhort 2004).

Many marsh habitats are not peatlands since they have only little peat, which means that most vascular plants are rooted in the underlying mineral soil or sedimentary deposit from which they can take up nutrients. However, marshes often have some mineral-rich organic deposits, or shallow accumulations of true peat, developing over mineral or aquatic sedimentary deposits. The deep beds of *Phragmites* peat beneath Irish bogs are a case of peat development in marshes, but it is a matter of common usage whether one should call the *Phragmites* community a marsh or a fen (or 'reedswamp'). Under semi-arid or tropical conditions, marshes are often the predominant kind of wetlands (for example, *Papyrus* marshes in Africa).

The main physiognomic groups of marsh are *open water marsh, emergent marsh* (including reedswamp which is actually a marsh, or sometimes rather a fen), and *meadow marsh*. These types are often arranged as zones

Table 1.2 Key to the main peatland classes—bog, fen, marsh, and swamp—and physiognomic groups within the classes. Separation of the physiognomic groups is augmented by physiography, hydromorphology, and floristics (modified from Harris *et al*. 1996). The key was developed for northern Ontario and is valid for most boreal regions, but can be adapted even to tropical peatlands.

1 Permanently or seasonally flooded by lake or stream water. Mostly mineral substrate, sometimes with peat. Open vegetation.	**Marsh**
2 Permanently flooded. Submergent or floating-leaved plants cover > 25%, emergent plants cover < 25%.	**Open water marsh**
2 Not permanently flooded. Emergent plants or graminoids cover > 25%.	
3 Flooded for most of the growing season. Relatively open cover of graminoids and herbs. Dominance of emergent species, interspersed with pools or channels with submerged and floating plants.	**Emergent marsh**
3 Flooded seasonally. Closed cover of graminoids. Often tusssocky.	**Meadow marsh**
1 Not flooded by lake or stream water.	
4 Woody vegetation (height > 2 m) with canopy cover > 25%.	
5 Conifer trees dominant.	
6 Indicators of minerotrophy present. Trees dense and large enough to be merchantable (height often > 10 m).	**Conifer swamp forest**
6 Indicators of minerotrophy absent. Trees generally stunted and sparse.	**Wooded bog (Bog forest)**
5 Broad-leaved species dominant.	
7 Hardwood trees dominant, height usually > 10 m and large enough to be merchantable.	**Hardwood swamp forest**
7 Tall shrubs (height > 2 m) dominant.	**Thicket swamp forest**
4 Woody vegetation (height > 2 m) absent or with canopy cover < 25%.	
8 Indicators of minerotrophy present.	
9 Woody vegetation (height > 2 m) with cover < 10%. Lawns and carpets dominate.	**Open fen**
9 Woody vegetation (height > 2 m) with cover 10–25%. Often with mounds which support low-growing trees or tall shrubs. The hummock and lawn-carpet levels are of similar magnitudes.	**Wooded fen**
8 Indicators of minerotrophy absent.	
10 Woody vegetation (height > 2 m) absent or with cover < 10%. Mixture of lawns and carpets (with *Sphagnum* and low sedges), and hummocks (with *Sphagnum*, dwarf shrubs and lichens).	**Open bog**
10 Woody vegetation (height > 2 m) with 10–25% cover of small conifers. Dominated by hummock level.	**Sparsely wooded bog**

beside open waters including lakes, ponds, pools, rivers, streams, and drainage ways. The main complex factors within marshes are water level (floodings, drawdowns) and in some places disturbance by wave or current energy.

Table 1.3 Key features of marsh, swamp, fen, and bog.

Peatland attribute	Marsh	Swamp	Fen	Bog
Vegetation	Submergents, floating-leaved, reeds, tall sedges	Forests, talls hrub thickets, herbs, graminoids, bryophytes	Open or sparse cover of low trees, low shrubs, graminoids, herbs, bryophytes (brown mosses and *Sphagnum*)	Open or with low trees, dwarf shrubs, low cyperaceous plants, bryophytes (especially *Sphagnum*)
Soils/peats	Mineral, organic-rich mineral, or shallow peat	Mineral, organic-rich mineral, shallow to deep peat; woody peat is common	Usually > 30 cm peat; sedge and sedge-*Sphagnum* are common peat types	Usually > 30 cm peat; *Sphagnum* peat is common
Moisture regime	Permanently or seasonally flooded by lake or stream water	Hummocks providing aerated support to trees; lower parts sometimes flooded	Groundwater fluctuates below to above surface in lawns, carpets and mud-bottoms; hummocks mostly above water table	Groundwater fluctuates below to above surface in lawns, carpets and mud-bottoms; hummocks well above water table
Microtopography	Level or tussocky	Irregular, with high hummocks and wet depressions	Level, or with scattered hummocks, or patterned with ridges alternating with depressions (flarks)	Level, or patterned with hummocks or ridges alternating with hollows
Nutrient regime	Minerotrophic; eu- to mesotrophic	Minerotrophic; eu- to oligotrophic	Minerotrophic; eu- to oligotrophic	Ombrotrophic; oligotrophic

1.4.2 Swamp or swamp forest

Swamp forests (Fig. 1.3) are forested or sometimes thicketed wetlands (in vernacular English a swamp could refer to almost any kind of wetland). They have minerogenous water that may come from watercourses or the underlying soil or lateral groundwater throughflow. They have standing or gently flowing water in pools or channels, or subsurface flow. Periodic flooding is common, but the water table is usually well below the surface, at least for the hummock or mound level, so that the surface layer is aerated and supports the roots of trees or other tall woody plants. Substrates are organic–mineral mixtures, or shallow to deep peat (in which wood can comprise a large component).

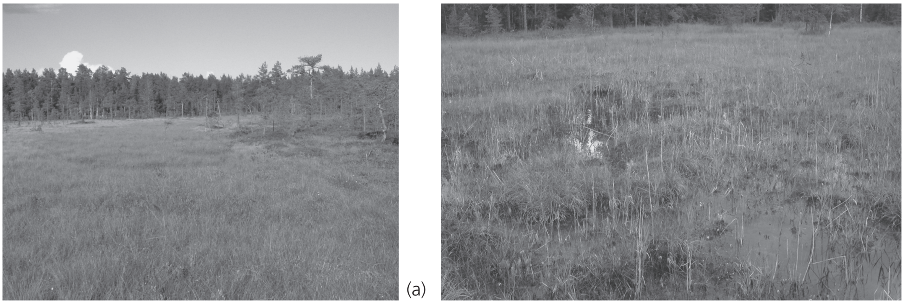
Fig. 1.2 Tussock meadow marsh with *Calamagrostis canadensis* and *Carex stricta* along a slow-flowing stream that overflows the marsh periodically. Ontario, Canada. (See also Plate 1.)

Fig. 1.3 Deciduous and coniferous swamp forests: (a) Herb-rich alder (*Alnus glutinosa*) swamp forest, eastern Sweden. (b) Black spruce (*Picea mariana*) swamp forest with *Sphagnum girgensohnii* hummocks, Ontario, Canada. (See also Plates 2 and 3.)

The main physiognomic groups of swamp forest are *conifer swamp forest*, *hardwood swamp forest* (deciduous or evergreen), and *thicket swamp*. These types are located either along open waters, in drainage ways, near springs, or as a part of larger peatlands where they sometimes form a zone between the peatland and the upland forest. The thickets are often somewhat wetter than the swamp forests. The main complex factors within the swamp forests are nutrient regime, pH–base richness, moisture–aeration, and light.

1.4.3 Fen

These are minerotrophic peatlands with water table slightly below, at, or just above the surface (Fig. 1.4). Usually there is slow internal drainage by seepage, but sometimes with oversurface flow. Peat depth is usually greater than 30 cm, but sometimes less (for instance adjacent to the peatland-mineral soil margin). Two broad types are *topogenous* (basin) fen and *soligenous* (sloping) fen.



(a) (b)

Fig. 1.4 Fens: (a) Topogenous poor fen dominated by *S. papillosum*. In the foreground *Carex rostrata*, towards the background with increasing cover of *Eriophorum vaginatum*. The shelf to the right is the transition to the bog. Sweden, midboreal zone. (b) Extremely rich calcareous fen with marl deposition. The vegetation is dominated by brown mosses (*Scorpidium scorpioides* and *Campylium stellatum*). The picture also shows *Menyanthes trifoliata, Drosera anglica*, and scattered *Phragmites australis*. Sweden, midboreal zone. Photo (b) by Sebastian Sundberg. (See also Plates 4 and 5.)

The main physiognomic groups of fen are open fen and wooded fen (with tree cover, or a sparse tall shrub cover, sometimes called *shrub carr*). The latter indicates that the distinction between fen and peaty swamp forest is diffuse. In Table 1.2 we set the limit at 25% tree cover, but there is no universal agreement on this. The dominant fen vegetation could be bryophytes, graminoids, or low shrubs. Ground surfaces may be relatively firm, loose and spongy, or floating mats (quaking mats) occurring in basins or invading out over open water. The main complex factors are nutrient regime, pH–base richness, and moisture–aeration (and to some extent light in wooded fens and under dense sedges).

1.4.4 Bog

Bogs (Fig. 1.5) are ombrotrophic peatlands with the surface above the surrounding terrain or otherwise isolated from laterally moving mineral-rich soil waters. Some bogs are convex in shape (raised bogs), but bogs can also be quite flat or sloping, with slight rises at the margin that isolate them from incoming minerogenous water. The peat is almost always more than 30 cm deep.

The main physiognomic groups are *open bog* and *wooded bog* (bog forest). In bogs with a pattern of hummocks and hollows, there is large variation in wetness. Ground surfaces may be relatively firm or loose and spongy, but quaking mats occur along internal water bodies (bog pools) or in hollows in wet centres of raised bogs. The main complex factors influencing biotic variation are moisture–aeration and light. Since bogs are nourished only through precipitation there is less local chemical variation than among the fens. Bogs are extremely nutrient-poor and strongly acidic; surface water pH is usually around 4 or even lower, but in some coastal areas the pH and the content of some minerals may be higher as a result of sea spray influence.

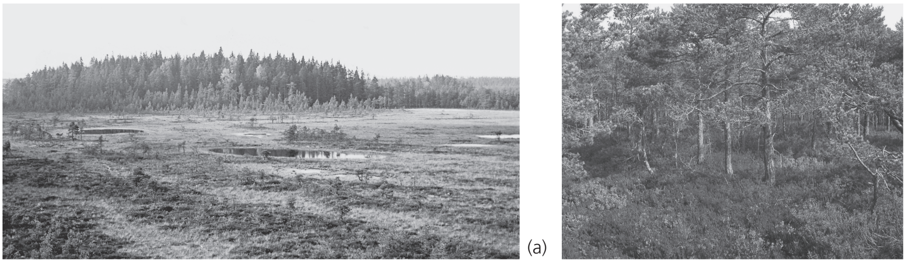


Fig. 1.5 Bogs: (a) Open bog with dwarf-shrub-dominated hummocks (dark areas) and lawns with *Eriophorum vaginatum* and *Scirpus cespitosus* (light-coloured). Sweden, southern boreal zone. (b) Wooded bog with *Pinus sylvestris* and a dense shrub understorey dominated by *Vaccinium uliginosum* and *Rhododendron tomentosum* (= *Ledum palustre*). Eastern Sweden, boreo-nemoral zone. (See also Plates 6 and 7.)

1.4.5 A word of caution

Bog and fen are old, vernacular words which were only given a strict scientific meaning during the last century. Even if the term bog is used in a scientific paper to describe a site, it may not be a bog according to the definition above. For instance, in North American literature until the 1960s the term 'bog' was used rather loosely for a *Sphagnum*-dominated peatland. After the influential publications of Sjörs (1959; 1963) and Heinselman (1963; 1970) the term bog became reserved for ombrotrophic peatlands, following the Scandinavian usage. However, the non-specific words continue to live on in names on maps, for instance, and botanical usage is still variable. In botanical literature, mire (*myr* in Scandinavia) is sometimes used as a collective term for fen and bog. In one sense this is logical since not all marshes and swamp forests are peat producing, but with the definition we use it is clear that those marshes and swamp forests that produce peat should also be considered as mires.

1.5 Environmental gradients as a basis for a finer classification

A framework to describe the habitat variation in peatlands was developed in Sweden by Du Rietz and elaborated by Sjörs (1948). It has been adopted in Norway (e.g. Økland 1990a, Moen 2002), and has also had a large impact in other countries. In this system there are three main lines of vegetational variation, related to primary environmental regimes, but distinguished in the field on the basis of vegetation composition. The environmental factors causing vegetational variation within site are the same as those governing the separation into the main ecosystems:

- the *bog–poor fen–rich fen* series, related to pH and base richness;
- the *hummock–mud-bottom* series, related to moisture–aeration regime;

- the *mire margin–mire expanse* series, related to the distance from the upland mineral soil.

Variation in these directions forms the basis for peatland classification, for example the one used by the Swedish Wetland Inventory (Chapter 10).

1.5.1 The bog–poor fen–rich fen series

Ombrotophic equates with bog, and minerotrophic with fen. The minerotrophic sites are further divided into poor fen and rich fen (and sometimes with a finer grouping into extremely poor, intermediate, rich, and extremely rich). In this system, 'rich' implies that the type is rich in a floristic sense, which is associated with higher pH and base richness (as reflected for instance by electrical conductivity of the mire water). In this text, whenever we use rich and poor we will use them in the floristic sense, and whenever we wish to refer to the degree of richness of nutrients we will specify 'nutrient-rich'. It is a common but unfortunate mistake to equate 'rich' as used here with 'nutrient-rich' or eutrophic. Bogs are always oligotrophic, but rich fens can be either quite productive or oligotrophic (since P becomes unavailable at high Ca concentration).

There is considerable overlap, but the approximate pH ranges of the mire types are:

- bog, 3.5–4.2 (higher in oceanic areas)
- poor fen, 4–5.5
- intermediate and moderately rich fen, 5–7
- extremely rich fen, 6.8–8.

Northern temperate and boreal bogs are extremely acid because of the acidifying effect of the dominant *Sphagnum* mosses (Chapter 4) and the low buffering capacity of the incoming rainwater. In fens pH depends on the properties of the soil and bedrock that the water has passed through or over, with rich fens occurring in areas with calcareous soil. In practice, plant indicators are used to recognize the levels of richness. In a first subdivision, bogs are recognized by the *absence of sensitive indicators of minerotrophy*, which are plants that cannot exist under the paucity of some mineral cations in the bogs. Then the principle of sensitive indicators of successively richer sites is used to separate poor and rich fens. The various indicators extend only so far down into poorer conditions; for example, poor fens are defined by the absence of rich fen indicators. They have to be defined for a region, since they differ between, for example, oceanic and continental areas.

Most of Sjörs's work has been in the open and sparsely wooded mires, bogs, and fens. A similar sequence can be recognized for the treed sequence: bog forest–poor swamp–intermediate swamp–rich swamp (see Fig. 1.1). This requires a different set of indicator species from the open mires (Jeglum 1991; Økland *et al*. 2001b).

1.5.2 The hummock–mud-bottom series

Many workers have noted that the simple measure of depth to the water table from the ground surface has one of the strongest relationships with vegetational gradients in peatlands, and mire ecologists have followed the practice of Sjörs (1948) in dividing mires into microtopographic or microstructural levels along the water table gradient: hummock–lawn–carpet–mud-bottom–pool (Fig. 1.6).

- *Hummocks* are raised 20–50 cm above the lowest surface level and are often characterized by dwarf shrubs. The lower limit of the hummock can be rather well defined in regions where there is a good correlation between the lowest level occupied by a certain species and the duration of flooding. An example is the lower limit of *Calluna vulgaris* used by Malmer (1962a,b).
- *Lawns* are most of the time 5–20 cm above water table; graminoids (cyperaceous plants, grasses, etc.) are dominant. Because of their strong rooting systems, lawns are so firm that footprints rapidly disappear. The bryophyte cover is very diversified, and lawns seem to have the greatest species richness.
- *Carpets* are often from 5 cm below to 5 cm above the water table. They often have a sparse cover of cyperaceous plants, and their bryophyte dominance makes them so soft that a footprint remains visible for a long time.
- *Mud-bottoms* are often inundated and may almost totally lack vascular plants. They are often covered incompletely by creeping mosses or liverworts,

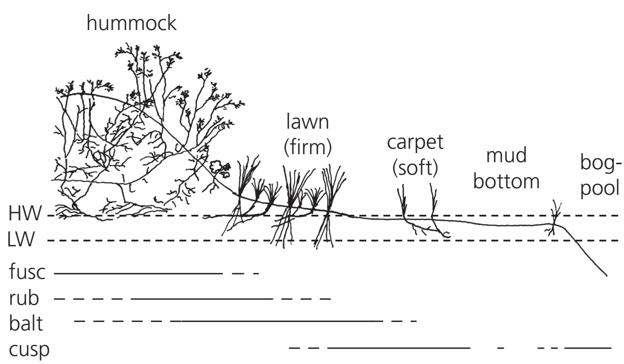


Fig. 1.6 Schematic presentation of the microtopographic gradient in a bog. The hummocks have aerated peat, which allows for the growth of dwarf shrubs. Lawns often have a dense cover of graminoids (e.g. *Scirpus cespitosus, Eriophorum vaginatum*) with dense rhizomes and roots making them firm. Carpets have a sparse cover of cyperaceous plants, whereas mud-bottoms are often inundated and lack plants almost totally. Pools may have some floating *Sphagnum* at the margin. Approximate levels for high water (HW) and low water (LW) are indicated. The distribution is indicated for the peat mosses *Sphagnum fuscum, S. rubellum, S. balticum*, and *S. cuspidatum*.

but otherwise have exposed bare peat, often with a thin covering of algae. They are often so soft that one may sink deeply over the boot tops.

- *Pools* are permanently water-filled basins, often with some vegetation at their edges.

This variation was described mostly from the perspective of fens and bogs, but one can apply these levels to swamps and marshes to obtain comparable characterizations of ground surfaces relative to water tables.

These terms were originally coined by Sjörs in his English summary (Sjörs 1948). They are not literal translations of his original Swedish terms, and this has caused some confusion, especially in British literature. In the original, Sjörs (1948) stressed that lawns are firm structures (*fastmatta*), whereas carpets are softer (*mjukmatta*). Mud-bottoms have a loose consistency (*lösbotten*) and they are usually covered by bare peat, in contrast with the common English-language use of 'mud', which usually indicates a wet substrate with high mineral content.

These levels give many peatlands a characteristic patterning. In bogs we speak about a hummock–hollow microtopography and then use 'hollow' as a rather general term for the depressions between the hummocks (encompassing lawns to mud-bottoms). Sometimes the hummock level dominates, with hollows as narrow, wet pits without any segregation of distinct lawn–carpet–mud-bottom–pool phases. This is common in drier, continental, often wooded bogs. In British literature, 'hollow' is sometimes restricted to the carpet and mud-bottom levels (Lindsay *et al*. 1985). In patterned fens the wet, mud-bottom-dominated structures are termed *flarks* (*rimpi* in Finnish), as described in Chapter 10.

1.5.3 The mire margin–mire expanse series

This is the gradient one sees when walking from upland forests down into forested peatlands (e.g. swamp forests), then into sparsely wooded peatlands (e.g. wooded fens or bog forests), then into open mires. This gradient is related to the water table, deeper at the margin and shallower towards the open mires. It is a common gradient in boreal regions where wooded and forested peatlands are abundant, covering as much as half of the total peatland area. This gradient was recognized in Sweden in the work of Sjörs (1948), and more recently discussed for instance by Økland (1990a). It is also implicit in the Finnish system (see section 1.6.1). Most of the species of the mire margins also grow on dry ground. The differentiation of the mire margin communities is probably caused by simultaneous variations in several abiotic factors. The peat is normally thin, and deeply-rooted vascular plants can reach the mineral soil beneath. The relatively dense tree and shrub layers create shade and shed litter that contains nutrients for the ground flora. The mire margins are in most cases swamps or wooded fens, although some ecologists include pine bogs among them.

1.6 Peatland classifications

1.6.1 Peatlands in Finland

The system used in Finland is one of the most detailed and complex of peatland classifications. Its origin is based on early work of Cajander (1913), who recognized sites mainly on the basis of understorey vegetation and tree cover (since the system was developed largely for the purpose of drainage for forestry). The basis is water level and nutrient status, with the addition of information relating to supplementary nutrient influence, such as seepage and spring water (Eurola and Holappa 1985). The schematic presentation in Fig. 1.7 is from Ruuhijärvi (1983). As in Fig. 1.1, the trophic types are indicated on the horizontal axis together with the corresponding ombrotrophic–minerotrophic gradient. Wetness is depicted on the vertical axis with the main division based on degree of forest cover: treeless, sparsely covered by trees, and forested types. The types are grouped into four main types of peatland—*letto* (rich open peatlands), *neva* (other open wet peatlands), *korpi* (spruce and birch-dominated peatlands), and *räme* (pine-dominated or hummocky peatlands). These types are represented by the letters L, N, K, and R, which can be combined to indicate intergrading of two main types, and further subdivided into subtypes based on dominant understorey vegetation. Ruuhijärvi and Reinikainen (1981) list the Finnish abbreviations and give English translations for all types.

1.6.2 Wetlands in Ontario

In pioneering work by Sjörs (1959; 1963) in the Hudson Bay Lowland in Ontario, Canada, the Swedish approach was used to characterize the peatlands. This has had a large impact on the peatland work in Ontario and elsewhere in Canada and the USA. Subsequently, since the early 1970s wetland classification in Canada has been greatly advanced by the efforts of an informal committee. This classification is hierarchical with four levels: class, form, type, and specialized needs (National Wetlands Working Group 1997). There are five classes: shallow open water, marsh, swamp, fen, and bog. These are divided into peatland forms, based upon the morphology of the peat body and its physiographic location (see Chapter 10). The lowest level of classification, specialized needs, represents special purposes such as floristic associations, soil types, nutrient levels, and so on. A detailed classification of vegetation types was proposed in the wetland classification system for north-western Ontario (Harris *et al.* 1996), and this is one of the more comprehensive treatments to date in Canada of the total range of variation of wetland vegetation for a particular region. In this classification, 36 wetland vegetation types were recognized for the whole range of wetlands, including marsh, fen, bog, and swamp. For simplicity, these 36 types were combined by Racey *et al.* (1996) into 17 ecosites, on the basis of similarities in moisture regime, nutrient regime, soil, or substrate. These ecosites can be ordered in the same way as the Finnish and Swedish systems (Fig. 1.8).

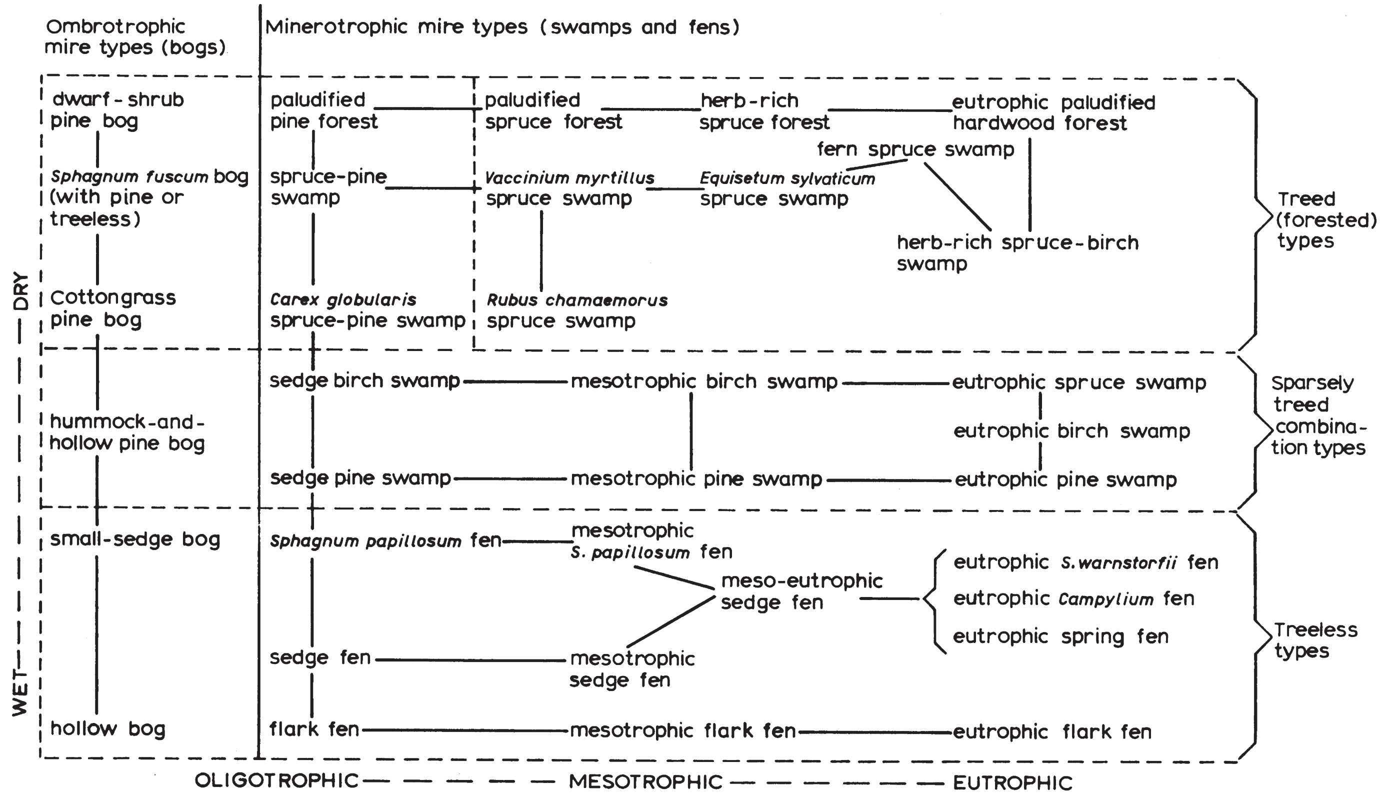


Fig. 1.7 A scheme of the Finnish peatland types (Ruuhijärvi 1983). Because the conifer species differ, this is not valid in North America. Reproduced with permission from Rauno Ruuhijärvi.

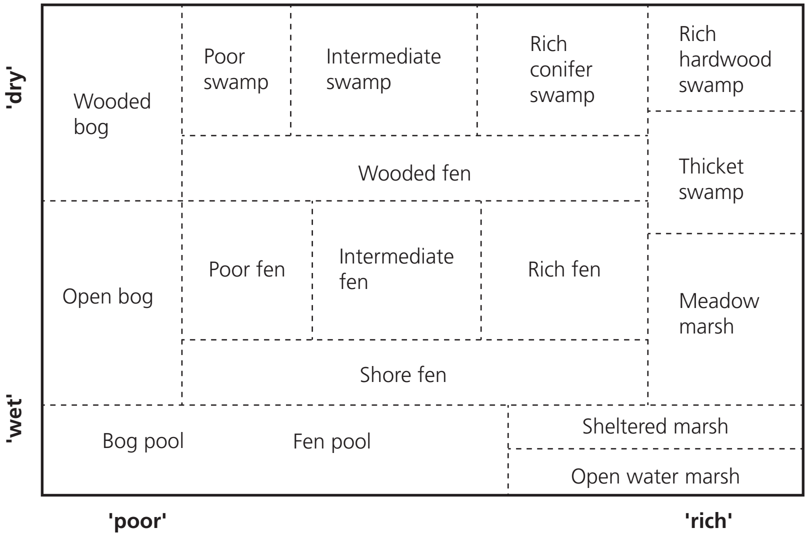


Fig. 1.8 A scheme showing the position of wetland ecosites, recognized on the basis of similarities in moisture regime, nutrient regime, soil or substrate (Racey *et al*. 1996). The scheme was developed for north-western Ontario, and the ecosites are further subdivided into 36 vegetation types. Largely valid also in boreal Europe.

1.6.3 Phytosociological classification

In large parts of Europe (except the Nordic countries and the British Isles) the Braun–Blanquet system for classification of vegetation, including peatlands, is widely used. We refer to Dierssen's work for an introduction (1996) and in-depth treatment (1982). This classification is based on floristic composition. These phytosociological units can be arranged to show relationships to the classifications that we use in this book based on gradients of wetness and chemistry (Fig. 1.9).

1.6.4 The British National Vegetation Classification

Another phytosociological approach is the National Vegetation Classification (NVC), which was developed in the 1980s as a standard tool for conservation work, covering all vegetation types in Britain (Rodwell 1991). Computerized matching can be used to classify a site based on frequency and abundance of species (Hill 1993; Smart 2000), but identification can also be made from quick observations using simply written keys (Elkington *et al*. 2001). Particularly important are *constant* species, i.e. the ones occurring in more than 60% of the samples from a site. Rather than focusing on a hierarchical classification, the described communities are named in an intuitively understandable manner, e.g., 'M8 *Carex rostrata*—

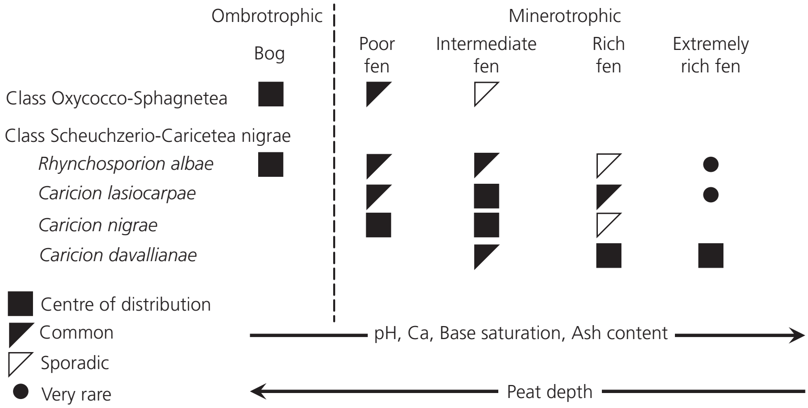


Fig. 1.9 Examples of European mire vegetation types according to the Braun–Blanquet system. The classification is based on plant species composition, and the graph illustrates how some of the vegetation types relate to the rich–poor gradient. *Class* is the highest level (named after characteristic species with suffix '-etea'), followed by *Order* (suffix '-etalia'; not shown in the graph) and *Alliance* (-ion). Note that hummocks with dwarf shrubs belong to the same class regardless if they are on a bog or in a fen, and lawns to another class. In contrast to, for instance, Scandinavian classification a main distinction is not made between bog and fen. Modified from Dierssen (1982).

Sphagnum warnstorfii mire', 'M19 *Calluna vulgaris—Eriophorum vaginatum* blanket mire'. These communities can then be related to environmental conditions, and the system can be used for mapping and monitoring purposes.