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4.2 Nutrients

The availability of nutrients (those chemicals essential for plant growth) has a strong influence on which plants are dominant in wetland vegetation. Overall fertility of a wetland is often referred to as the nutrient status.

The influence of water source on nutrient (or trophic) status has given rise to three terms that need to be mentioned because they have an international usage: ombrotrophic (rain-fed; low nutrient status), rheotrophic (flow-fed, with groundwater; more nutrients), and minerotrophic (fed by water that has been in contact with substrate minerals; high nutrient status).

Another three terms are more widely used as descriptors of nutrient level of wetland substrates or their waters: oligotrophic (nutrient-poor or infertile), mesotrophic (moderately fertile), and eutrophic (nutrient-rich or fertile). These are useful terms, despite the loosely defined boundaries between the three categories: mesotrophic really has no more precise meaning than 'somewhere in the middle'. In practice, the nutrient status of a wetland is often simply estimated on the basis of landform setting, plant vigour, and other such indicators (Figs 115 and 116). A further term, used mainly in limnology, is dystrophic, describing water having significant dark staining from humic matter and an associated deficiency in nutrients.

One method for indicating nutrient status of wetland soil or water is by measuring conductivity, i.e. the degree to which a water solution will conduct an electrical current, this being indicative of the concentration of soluble ions which will include important plant nutrients, but also other salts which may be in high concentrations, such as sea salts in an estuarine or coastal site.

The pH of soil or water is an indicator of many wetland qualities, including, to an extent, nutrient availability. It is a measure of hydrogen ion concentration, expressed on a scale from 0 (acid) through 7 (neutral) to 14 (alkaline). The scale is logarithmic so each step on the scale represents a ten-fold difference in acidity / alkalinity. In general, the availability of plant nutrients in soils decreases below about pH 6, and this applies to most wetlands. Table 2 gives indicative pH values for wetland classes, based on a selection of published and unpublished New Zealand sources. Bogs are very acid, so have a low pH. The most alkaline of wetland soils are those of estuarine saltmarshes and inland saline sites; places having a lot of soluble

Fig. 115 Harakeke or flax (*Phormium tenax*) can grow in many wetland types, but its presence here in a Westland *Baumea* sedge fen as very scattered and stunted plants is an indicator that this wetland has relatively low fertility.

salts, mainly chlorides, sulphates, and carbonates of sodium, potassium, magnesium, and calcium.

The two nutrients likely to be most limiting for plant growth in wetlands are phosphorus (P) and nitrogen (N). Carnivorous plants such as sundews and bladderworts augment their nitrogen supply by trapping and digesting small invertebrates; these plants are indicators of wetland soils that are very infertile. Cyanobacteria ('blue-green algae') are able to 'fix' nitrogen from the air into a form available for plants; they can be common in wet places as free-living forms, but also in association with many lichens, and with some vascular plants of wetlands, notably *Gunnera*.

Fig. 116 High soil fertility may be indicated by lush plant growth or the presence of those plants otherwise familiar as farm or garden weeds. In this extreme example, a breeding colony of gulls on the coastal edge of the Awarua Plain, Southland, has killed the cushions in a formerly infertile bog, and so greatly increased the levels of N and P that the weedy grass *Poa annua* and rushes of *Juncus effusus* have taken over.

Chemical analyses of wetland soils and of plant tissues assist with understanding wetland types and with monitoring their nutrient status (Clarkson et al. 2003). Useful analyses include those for total carbon (C), total N, total P, and also available P which is a measure of the proportion of soil P that is effectively available to plants, other fractions being too tightly bound to soil materials. Often the ratio of one soil chemical to another, for example C : N, is used to help interpret aspects of wetland fertility. Chemical analyses have been used to help define wetland classes overseas, and to describe wetland variability in New Zealand, but much remains to be learned on this topic, and we are not yet in a position to delimit wetland types here on the basis of defined levels of soil chemistry.

4.3 Organic substrates and peat

Organic matter is derived from living organisms, whereas mineral (or inorganic) matter originates from rocks or their weathering products. Soil scientists recognise 'organic soils' as soils having 17% or more organic matter, and use the term 'peat' when organic content is 50% or more. Soils of 17–50% organic content can be described as 'peaty' (Taylor & Pohlen 1979). When organic matter is well decomposed it becomes the amorphous, dark brown to black material called humus, a component of almost all soils. Humus is typically concentrated in the uppermost soil layer, but can also be leached down to lower levels, and can darkly stain mineral materials, especially in saline soils, thus not all dark soils can be considered as peaty.

Peat is a deposit of the partially decomposed remains of plant foliage, stems, and roots, though some matter of animal or microbial origin may also be present. In constantly wet ground, oxygen is scarce, so that decomposing organisms – fungi and bacteria – are unable to fully break down organic matter. Acid conditions in most wetlands also retard decomposition, so that peat accumulates, often to depths of many metres, a process known as paludification. The term peatland is applied to all land having a peat substrate, irrespective of whether the land is wet or well-drained. The term mire embraces all peat-forming wetlands.

Peat types can be classified by broad factors of landform and climate, their mode of deposition, the plant materials that formed them, and their degree of decomposition (Taylor & Pohlen 1979). Provided a peat sample is not too decomposed it is possible to recognise its derivation from, for example, mosses, sedges, restiads, or wood. In many bogs and fens the most significant peat-forming plants are *Sphagnum* mosses (Figs 117 and 118) or wire rush (*Empodisma minus*; Figs 119 and 120). In a peat profile the upper horizons tend to be relatively uncompacted, with material recognisable as to its plant origin, while lower horizons are more decomposed and compacted, with finer and less fibrous peat texture. Degrees of peat decomposition can be assessed using the von Post index (Table 4). An example of how peat types and their decomposition stages can vary across a wetland is shown in Figs 121 to 123.

Two peat types can be distinguished on their manner of deposition. Sedentary peat (e.g. Fig. 127) accumulates where it was produced, from fallen litter, above-ground plant parts that die and remain attached, and from rhizomes and roots which also make a significant below-ground contribution to the peat mass. The second type – sedimentary peat – is deposited in water, perhaps distant from where it was produced, such as detritus that eventually settles onto a pool floor or lake bed. Transport and redeposition of sedimentary peat also takes place within fens and swamps, where hummock-and-hollow surface topography is typical, and where the hollows are usually a highly patterned system of elongated channels (see Fig. 26), wherein even the most sluggish-flowing water will move fine organic detritus from one part of the wetland to another.

Because wetlands are sensitive to climatic factors such as rainfall and temperature, they respond to climate change. Peat accumulation at a site may vary from fast to slow, or it may even cease altogether, during periods of different climate. In addition there can be phases of peat loss through accelerated decomposition, as well as by erosion agents such as water, slumping, or wind (Fig. 128). Being wet, anaerobic, and usually acid, peat is a good preservative. Well-preserved wood is often present as logs, limbs, or root plates: a reminder that many wetlands, now vegetated with non-woody plants, held a tree or shrub cover at some earlier time (Figs 124 to 126, 129). Buried charcoal is an indicator of former fire. The plant parts most resistant to decay are pollen grains, spores, and seeds. When identified from all the layers of a sampled peat column they yield a record of vegetation and climatic history for both the wetland site and its surrounding region, for which radiocarbon dating of wood or peat provides a time scale.

Blanket peat can cover extensive tracts of land of relatively low relief, irrespective of topography and slope (see Fig. 32). Climatic conditions conducive to blanket peat formation are cool temperatures, frequent cloud cover, high relative humidity, numerous raindays, and strong, often salt-laden winds. In combination, these factors have a direct effect in slowing the rate of organic matter decomposition; they also favour stunted and slow-growing vegetation with plants that produce acid litter. In the southernmost South Island, Stewart Island, Chatham Islands, and the subantarctic islands, many of the soils are blanket peat, though not all are formed by wetlands.

Table 4 The von Post index for assessing degrees of peat decomposition (from Taylor & Pohlen 1979)

The amount of decomposition is gauged in the field by assessing the distinctness of the structure of plant remains and the results of squeezing wet peat in the hand.

D1.	Undecomposed: plant structure unaltered. Yields only clear, colourless water.
D2.	Almost undecomposed: plant structure distinct. Yields only clear water coloured light yellow-brown.
D3.	Very weakly decomposed: plant structure distinct. Yields distinctly turbid brown water; no peat substance passes between the fingers, residue not mushy.
D4.	Weakly decomposed: plant structure distinct. Yields strongly turbid water; no peat substance escapes between the fingers, residue rather mushy.
D5.	Moderately decomposed: plant structure still clear but becoming indistinct. Yields much turbid brown water; some peat escapes between the fingers, residue very mushy.
D6.	Strongly decomposed: plant structure somewhat indistinct but clearer in the squeezed residue than in the undisturbed peat. About half the peat escapes between the fingers, residue strongly mushy.
D7.	Strongly decomposed: plant structure indistinct but still recognisable. About half the peat escapes between the fingers.
D8.	Very strongly decomposed: plant structure very indistinct. About two-thirds of the peat escapes between the fingers, residue consists almost entirely of resistant remnants such as root fibres and wood.
D9.	Almost completely decomposed: plant structure almost unrecognisable. Almost all the peat escapes between the fingers.
D10.	Completely decomposed: plant structure unrecognisable. All the peat escapes between the fingers.

4.3.1 Important peat formers

Fig. 117 Sphagnum mosses retain moisture in the spaces among their main stems, side branches, and leaves, but most importantly within hollow leaf cells. As their cushions elevate and expand the older parts die and turn to peat. In favourable sites the main stems may grow 7–8 cm per year, as shown in this example from a lowland fen in Westland, the uprooted cushion of *Sphagnum cristatum* displaying dark bands that represent slower growth each winter.

Fig. 118 Sphagnum growth is relatively slow in cold climates. These peat cores are from a mountain bog at Lagoon Saddle, inland mid-Canterbury (see Fig. 59). Peat from under *Sphagnum cristatum* and wire rush (right) is relatively fluffy and pale; that from beneath nearby comb sedge (*Oreobolus pectinatus*; at left) is more compacted, and illustrates how its living reddish roots can penetrate the peat to some depth.

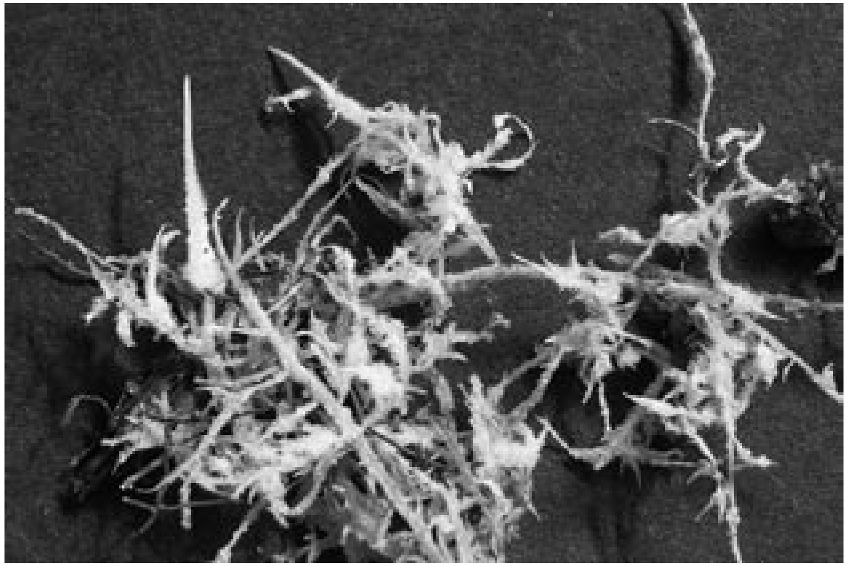

Fig. 119 Wire rush (*Empodisma minus*) produces masses of fine roots with numerous root hairs at the ground surface. These resist decay and accumulate as fibrous peat.

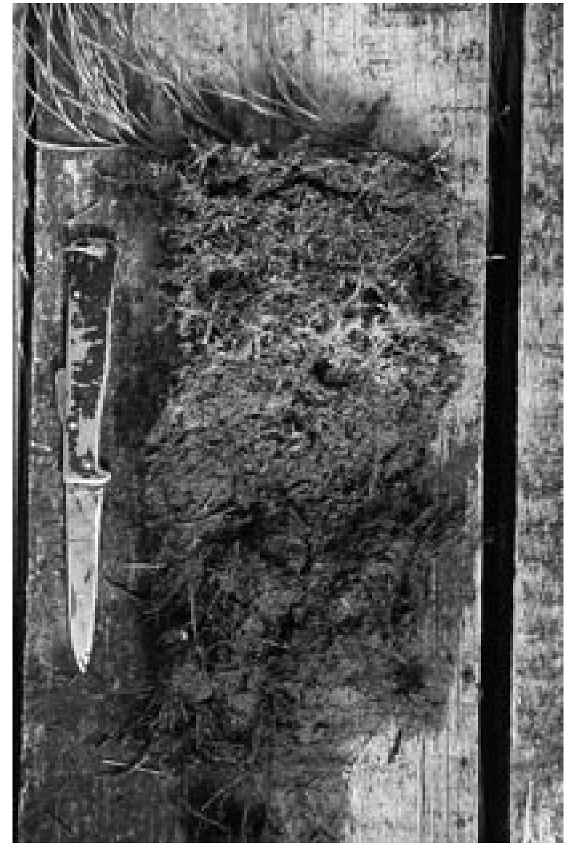

Fig. 120 Profile of peat developed under wire rush on the Whangamarino wetland, Waikato. The upper 15 cm of peat is pale, loose, and fibrous. Below this, at a level probably corresponding with the predominant water table, the peat has become darker, more decomposed, and more compacted.

4.3.2 Peat types across a bog system

Fig. 121 A red tussock (*Chionochloa rubra*) bog at Swampy Spur, east Otago. This wetland occupies a stream headwater basin of c. 250 × 100 m, at 620 m altitude, among hilly country having mountain flax, scrub, and tussockland. Peat depth in this bog reaches 6 m (Walker et al. 2001).

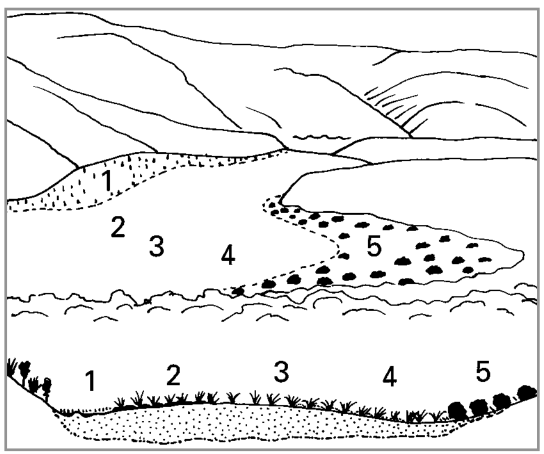

Fig. 122 Sketch and profile diagram relating to Fig. 121, showing numbered sources of the five peat types shown in Fig. 123.

Fig. 123 Cores from the upper 20 cm of peat under five vegetation / habitat types from a bog at Swampy Spur (Figs 121 and 122). The peat samples are (from left to right):

1. Slimy peat, well decomposed (von Post decomposition scale = D9), from lagg having very soft watery ground where toe of hillside meets bog: *Carex sinclairii - Holcus lanatus* sedge swamp with *Drepanocladus* moss;
2. Relatively undecomposed *Sphagnum* (D2), somewhat soft and moist, from red tussock bog having vigorous growth of *Sphagnum cristatum*;
3. Red-brown, fluffy, *Sphagnum* peat, partly decomposed (D5), from moderately firm ground beneath red tussock bog having abundant dwarf heaths and *Hypnum* moss;
4. Dark red-brown, compact peat, well-decomposed (D8), from relatively dry and firm, somewhat raised ground beneath red tussock bog having abundant coral lichens (*Cladia* spp.), dwarf heaths, and comb sedge;
5. Dark brown-black peat, compacted, slightly silty, and very well decomposed (D9) from moist but very firm ground of gentle hill slope having *Hebe odora* / *Carex geminata* shrub fen.

4.3.3 Peat growth in a mountain mire

Fig. 124 Sedgeland, fernland, and shrubland in a mire occupying a depression in the gently sloping, forested headwater of the Ongarue River, at 820 m altitude near the top of Mt Pureora, Volcanic Plateau.

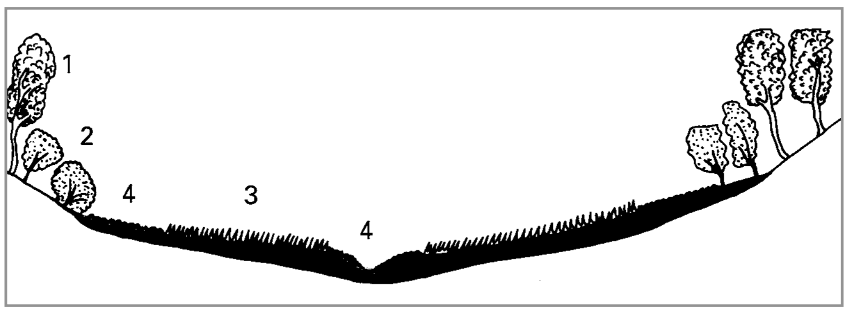

Fig. 125 Profile showing pattern of principal vegetation types:
1. Forest (surrounding): *Podocarpus hallii* and *Quintinia serrata*;
2. Bog pine (*Halocarpus bidwillii*) - mountain toatoa (*Phyllocladus alpinus*) scrub bog on relatively well-drained peat;
3. Fern bog on peat having little water movement: tangle fern, square sedge (*Lepidosperma australe*), *Carpha alpina*, and the moss *Dicranum robustum*;
4. Fern fen on wet peat with more water movement, near stream channels and on sloping upper sides of mire: tangle fern again but with much *Sphagnum cristatum* moss.

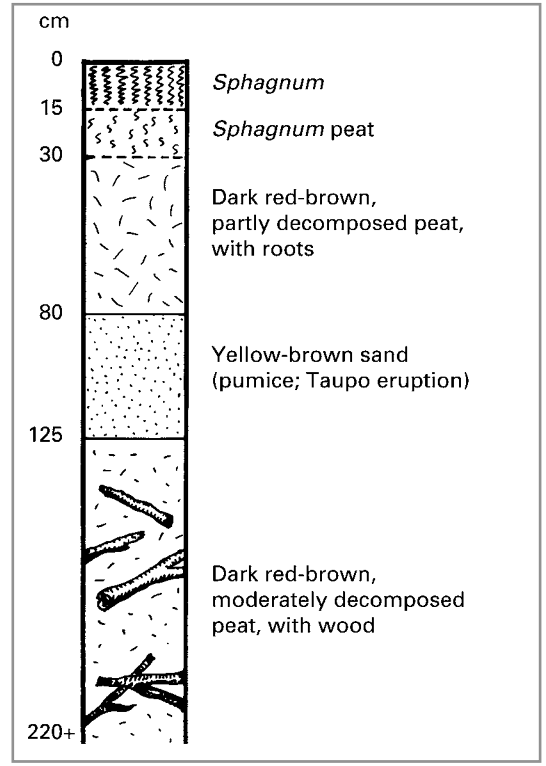

Fig. 126 Peat profile from Ongarue 'A' mire (simplified from Clarkson 1984). The peat in the lower part of the profile contains much wood, the remains of a wetland that had been dominated by bog pine and mountain toatoa. This is overlain by a deep layer of pumice sand, deposited by the Taupo eruption of about 1800 years ago, and a subsequent accumulation of 0.8 m depth of peat. The pH of the upper peat ranges from 4.5 to 5.7. This mire is relatively young. Much of it can be regarded as fen, with localised seepages. Those parts least affected by water draining in from surrounding slopes can be considered as bog, and this will probably become more the case in the future as areas of peat become somewhat raised, and as nutrient levels therefore decrease.

4.3.4 Peat structure and processes

Fig. 127 A shrub / tussock fen on a mountain slope near the treeline, its c. 1 m depth of peat and underlying bedrock exposed beside the tramping track to Key Summit, Fiordland.

Fig. 128 Peat is not always wet and slimy. If exposed to the air it can resume decomposition, or if dried out it can be resistant to rewetting, partly because of the concentration of waxes that would have come from the leaf cuticles of the original contributing plants. Wind-erosion of this dried peat patch reveals that this fen on the Garvie Mountains, northern Southland, has accumulated some 3 m depth of peat. Also revealed is part of an underground stream – a 'pipe' system of stream tunnels – such as would normally be unseen and unsuspected, yet a feature that may be quite common in sloping peatlands.

Fig. 129 A recently cleared drain through peatland on the Awarua Plain, Southland. Abundant buried tree trunks, limbs, and roots are proof that wood is well preserved within peat, and that this site had a former forest cover, probably as forest bog. Today's vegetation of flaxland and bracken fernland suggests that the former bog has become a fen, fertility and aeration having increased as a result of fires and drainage.

4.4 Mineral substrates

Bedrock provides the substrate for some wetlands, with perhaps a mere veneer of mineral or organic matter, in effect too thin and too young to be properly called a soil. The mineral component of a wetland soil can come from its underlying substrate and also from continuing inputs of materials carried by water, wind, or gravity. Substrate materials can be as diverse as river gravels, morainic till, volcanic ash, or dune sands, and these may initially be free-draining before wetland development begins. Much of the mineral material of wetlands is deposited by moving water. Depending on flow characteristics, sediments of different particle size such as gravel, sand, or silt are sorted and deposited in different places (Fig. 130). Particle size classes are described in Section 2.7.

Many North Island peatlands contain layers of ash deposited by airfall at times of volcanic eruption. A component of loess – wind-carried silt – is found in many South Island peats, especially in the lower parts of the peat profile that date from early post-glacial times when dusty, unvegetated outwash plains were widespread. Peatlands on dunes receive inputs of wind-blown sand. Mountain seepages and fens can be regularly nourished by nutrients from rockfall and avalanche debris (see Fig. 42).

Wetland soils derived from mineral parent materials undergo many characteristic physical, chemical, and biological processes as they mature. Like most soil types, they develop layers – or horizons – that become more distinctive over time, with surface litter and organic-rich topsoil overlying subsoil layers of weathering minerals. Examples of mineral wetland soils are shown in Figs 131 to 134.

As water percolates downwards through a soil, soluble matter and fine particles are leached from the upper layers and redeposited lower down. Leaching is most pronounced where rainfall is high, and strong leaching greatly reduces soil fertility by removing soluble nutrients to below the rooting zone of plants. A strongly leached soil can be recognised from the pale colour of its upper horizon of subsoil, resulting from the residual predominance of silica after removal of humus, iron and aluminium oxides, and clay. In soils which are saturated for prolonged periods the process of gleying imparts a grey or blue-grey colour to this horizon, a consequence of iron compounds being present in a state of chemical reduction, though the frequent presence of rusty mottling shows where re-oxidation of iron has occurred in better-aerated zones, such as around roots. When the products of leaching reach a lower subsoil level they precipitate as a dark colouration, often forming a thin, cemented pan of iron oxide and / or humus that then prevents drainage from the overlying soil.

Knowledge of soil structure, processes, and classification provide vital clues to understanding wetlands. Molloy (1998) gives a good introductory account of New Zealand soils, including those of wetlands. New Zealand handbooks on soil survey methods, description, and classification are provided by Taylor & Pohlen (1979), Milne et al. (1995), and Hewitt (1993). Published soil maps and surveys (e.g. NZ Soil Bureau 1954, 1968a,b) and land use capability maps can be a helpful source of information for the processes of location and inventory of wetland sites.

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4.4.1 Inorganic substrate materials

Fig. 130 An example of particle sizes, clockwise from top left: fine silt, silt, sand, coarse sand, gravel, coarse gravel. These are from a bay head at Lake Wanaka, Otago. Each square of material is 15 × 15 cm. The fine silt (top left) is dense and plastic, being originally glacial flour that settled on the bed of a former ice-snout lake. The silt at top centre is brownish from being partly weathered, and because it includes some humus material. The materials had been sorted to their respective particle sizes by the differential energies of wave action. Particle size of inorganic materials influences the drainage characteristics and fertility of many lacustrine, riverine, and estuarine wetlands. Many peatlands are underlain by one or more of these types of material.