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Processes: how wetlands function

The main drivers – or environmental functions – that govern wetland diversity are hydrology, nutrient status, and substrate. Hydrology is concerned with the origin and movement of water. Nutrient status refers to soil or water fertility in the sense of how much nutrient is available for plant growth. Wetland substrates or soil materials are composed of two classes of material: organic matter derived from living organisms which may accumulate as peat; and mineral (or inorganic) matter which originates from rocks or their weathering products. The nature of wetlands is also affected by 'feedback' from ecological processes happening within them. Furthermore, most wetlands change in character over both short and long time scales.

4.1 Hydrology

Wetland types and their vegetation are determined by combinations of four main hydrological factors: water source, movement, fluctuation, and periodicity of wetness. Together these can be referred to as the water regime.

4.1.1 Water source

Water precipitates from the atmosphere mainly as rain, but also as mist, drizzle, dew, snow, and hail. Water from these sources is generally very low in nutrients, but by no means devoid of them. The least fertile classes of wetland are solely rain-fed and they occur on hill crests, flat terraces, or parts of peatland that have developed a raised dome. Water that has been in contact with rock or mineral soil picks up dissolved nutrients, as well as suspended sediments, sufficient to make a significant difference to

the general fertility of any wetlands downslope or downstream. Runoff water can enter a wetland via stream or river channels, as surface flow across adjoining land, or else as subsurface groundwater, which may move not only downslope and laterally but also upwardly, when forced up by hydrostatic pressure from a lower level. For many wetlands their moisture source (or drainage impediment) is an adjacent water body such as a lake, pond, or river.

Terms concerning water source that appear in the literature and can be useful descriptors are: ombrogenous, for an entirely rain-fed wetland; soligenous, when water supply carries inputs of dissolved nutrients from adjacent land; and topogenous, for a wetland formed behind a topographic barrier that impedes drainage, especially in situations having a relatively small catchment and therefore receiving a water supply mainly from rainfall, such as a peatland between sand dunes.

4.1.2 Water movement

Characteristics of water flow and accumulation govern oxygenation, nutrient supply, sediment delivery, and erosion patterns in wetlands. Water flow is most familiar from the visible examples of headwater seepages and streams combining to become rivers which proceed downhill through rapids, past confluences, and around meanders, until they meet the ebb and flood of their tidal reaches, the mixing zone of the estuary, and finally the sea. This well-known part of the hydrological cycle also has its hidden equivalents below the ground surface, and it is important to realise that water is forever being exchanged in both directions between the surface and underground. Different parts of wetlands have areas of active flow, of water accumulation, and even of stagnation. Rates of water movement vary greatly, as does the direction of flow. Wetlands can be discharge areas or recharge areas for groundwater and this can change over time.

Water flow features are sometimes used to distinguish three broad units of wetlands: outflow wetlands that receive only precipitation (bogs, pakihi and gumland); throughflow wetlands (fens, swamps, marshes, seepages, rivers, and most lakes); and inflow wetlands that are a sink for water accumulation (especially ephemeral wetlands in depressions).

Ward & Lambie (1999b) provide descriptors of water movement for a draft classification of riverine wetland classes. Water flow can be stable (allowing attached macrophytes and mosses to persist from year to year), variable (allowing development and scouring of macroalgae), or flashy (allowing development of little more than microalgal felts). Channel gradients can be described as steepland (high gradient, producing well-aerated broken water surfaces), midland (overall flows of moderate gradient dominated by runs / riffles, or lowland (low gradient with slow runs and pools).

The exit of water from wetlands is governed by surface outlet levels, ground permeability, evaporation from soil, water, and wetted plant surfaces, and by transpiration of water from within plants through their foliage. The term evapotranspiration is used for the combined loss of water by evaporation plus transpiration.

4.1.3 Water fluctuation

Fluctuation of level in open bodies of water is an obvious visible phenomenon. The highest level reached by water can often be inferred from the uppermost line of stranded litter, of silt deposited on plants, or erosion of soil. The amplitude of fluctuation in lakes and ponds can often be reckoned by observing how much separation there is between zones of wholly aquatic and typical terrestrial vegetation. Also very obvious is tidal fluctuation (see Figs 55 and 56), as a twice-daily event, though it must be remembered that every tide is different from the last. Spring tides have the greatest amplitude, occurring twice each month near the time of new moon and full moon, when gravitational pull of sun and moon is combined. Neap tides are those of least range in the intervening periods. Tidal amplitude in New Zealand is mainly 2–4 m, varying between different parts of the coast. Tidal fluctuation in the estuarine hydrosystem governs the distribution of subtidal, intertidal, and supratidal zones. Tidal reaches of rivers experience not only tidal fluctuation, but also the regular alternation of ebb and flood flow, both influences gradually decreasing upstream. Fluctuation in the level of flowing waters – rivers and streams – is accompanied by changes in the volume and rate of flow, and a flooding river will often greatly increase its channel width.

Much less obvious is the fluctuation of water level under the ground surface. It is measured by the position of the water table, below which the ground is saturated, and revealed by the level to which water accumulates in an excavated pit (see Figs 26 and 129). The water table is not necessarily

level like the surface of a lake; it can vary across the land depending on land contours and permeability. Some wetlands sit upon a perched water table, one that is held up by an impermeable soil horizon such as dense silt or an iron pan that prevents drainage, even though there may be permeable materials beneath. A perched water table can also be temporary, e.g. for a period following rain or surface flooding when an upper soil horizon becomes saturated, yet not to a depth sufficient to link with a much lower saturated horizon.

The water table tends to be high and relatively constant in bogs and fens, very high (i.e. above parts of the ground surface, but also variable) in swamps, widely variable in marshes, and extremely variable in ephemeral wetlands.

Types of wetness are important in understanding wetlands. Thus, a substrate may be moist (i.e. slightly wet), saturated (with all pores fully charged with water), or submerged (flooded or ponded). The term flooding is most specifically used to describe inundation by storm runoff from adjacent land, overflow from a stream or river, or the rise in water associated with tidal inflow. The term ponding is a better descriptor for water that collects in basins or depressions.

Rainfall at any season will cause regular minor fluctuations upon any general annual pattern, but unusually heavy rains, wet seasons, or wet years can fully recharge wetlands irrespective of time of year.

4.1.4 Periodicity

The effects of fluctuation are dependent on the time factors of duration (how long), frequency (how often), and timing (Tiner 1999). The following descriptors can be applied to conditions of flooding, ponding, and saturation, and conversely to situations of being emergent, dry, or droughted: permanent (always), near-permanent (throughout the growing seasons of most years), seasonal (during one or more seasons of the year), temporary (for periods of about 2 weeks or less during the growing season), intermittent (in one or a series of wet years but not every year), episodic (rarely, say once every few years), and tidal. The term ephemeral describes situations having a pronounced alternation between prolonged periods of both wetness and dryness.

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).

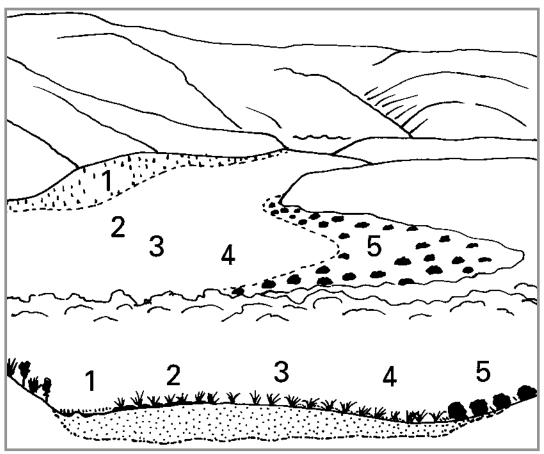

Fig. 122 Sketch and profile diagram relating to Fig. 121, showing numbered sources of the five peat types shown in Fig. 123.

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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.