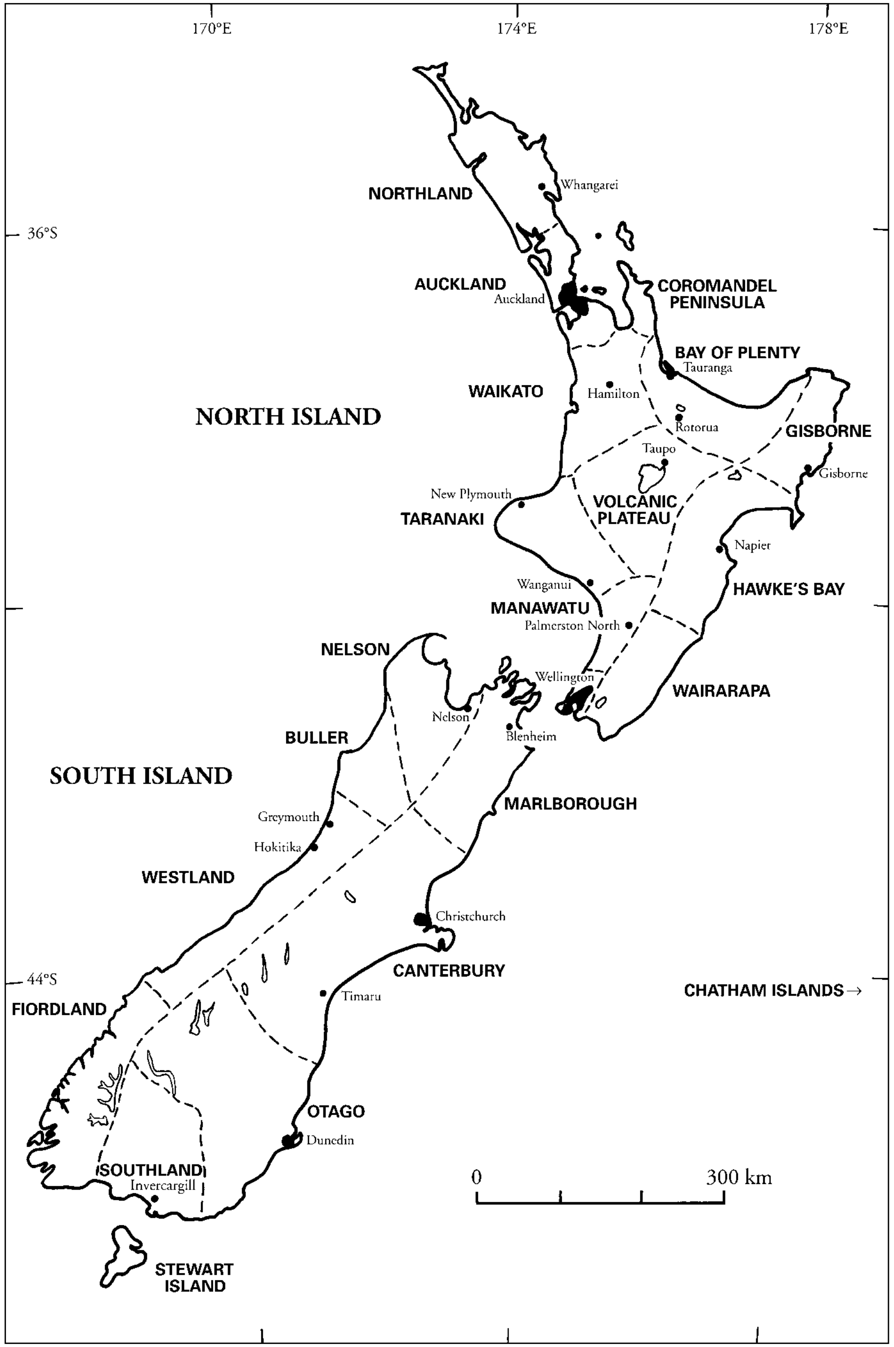

Wetland Types
in New Zealand

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Biodiversity
OUR LIVING TREASURE
HE KURA TAIAO

Department of Conservation
Te Papa Atawhai

Ministry for the
Environment
Manatū Mō Te Taiao
Sustainable Management Fund

Cover: Wetlands bordering Mahinapua Creek, Westland. The stream contains submerged aquatic plants and the floating foliage of water lily. Turf on the stream margin grades back to flax swamp then kahikatea forest swamp.

Inside covers: Map of New Zealand showing major localities and regions.

Publication was approved by the Manager, Science & Research Unit, Science Technology and Information Services, Department of Conservation, Wellington.

First published in 2004 by
Department of Conservation, Te Papa Atawhai
PO Box 10-420
Wellington

All photographs except Fig. 32 are by the authors.

ISBN: 0-478-22604-7

Design & layout by Bookpro
Cover design by Margaret Cochran
Printed by Astra Print, Wellington

Contents

Acknowledgements

This classification project was funded by the Sustainable Management Fund of the New Zealand Ministry for the Environment. We thank Pru Johnson for support with field work, Lance Shaw and Ruth Dalley of Fiordland Ecology Holidays for supporting the research describing fiord-head wetlands, and Kelvin Lloyd for use of the photo for Fig. 32. The following colleagues provided useful inputs of ideas and comments on the manuscript: Dave Campbell, Catherine Chagué-Goff, Bev Clarkson, Bruce Clarkson, Ron van Mierlo, Colin Ogle, Trevor Partridge, Katrina Rainey, Chris Richmond, Jonet Ward, Colin Webb, and Carol West. Then Jaap Jasperse (DOC Science Publishing) and Geoff Norman (Bookpro) helped turn the manuscript into a book. Its publication was funded from the Terrestrial and Freshwater Biodiversity Information System (TFBIS) Programme, the Government's Biodiversity Funding Package. The Ministry for the Environment does not endorse or support the content of the publication in any way.

SMF Project 5105 Supporters

Funding: Auckland Regional Council, Department of Conservation, Environment Canterbury, Environment Waikato, Southland Regional Council.

In kind: Auckland Regional Council, Department of Conservation, Environment Canterbury, Environment Waikato, Greater Wellington Regional Council, Lincoln University, Southland Regional Council, Taranaki Regional Council, University of Waikato, West Coast Regional Council.

ONE

Introduction

Wetlands are precisely that: wet lands. They are places of poor drainage or where water accumulates; sites where seepage or flooding is frequent; interfaces where land meets streams, rivers, lakes, and estuaries. Wetlands grade to aquatic habitats of deep water. Freshwater wetlands grade to brackish or saline wetlands of coastal estuaries and the sea itself. All forms of life need water, but wetland plants and animals are adapted to cope with an oversupply of wetness, and its consequences, such as nutrient shortages and the need to ensure a supply of oxygen to underwater parts. Each wetland organism lives in those particular places that match its own requirements, tolerances, and competitive ability. Some plant species are restricted to wetlands (obligate wetland plants), while others range also to dryland habitats (facultative wetland plants). Wetlands are diverse for many reasons, and New Zealand has many different sorts.

A definition of wetland for New Zealand purposes is provided in the Resource Management Act (1991): '"Wetland" includes permanently or intermittently wet areas, shallow water, and land water margins that support a natural ecosystem of plants and animals that are adapted to wet conditions.'

A wider definition of wetlands is provided by the Ramsar Convention on Wetlands, signed in Ramsar, Iran, in 1971, as an intergovernmental treaty to which New Zealand is a contracting party: '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.'

Classification of wetlands helps with the recognition of wetland types, so that each can be better understood, managed, and monitored. Although it is desirable to classify things into neatly defined boxes, wetlands do not make this easy for us. This is because wetlands vary along gradients of many environmental factors – such as dryness to wetness, infertile to fertile, acid to basic, fresh to saline – and although we may insightfully recognise many wetland types, the boundaries between them are not distinct realities of any natural laws of ecology.

Recognising wetlands and delimiting their boundaries on the ground can be tricky for several reasons. Wetland sites visible on the land surface are functionally connected to larger areas of water catchment and to an unseen extent of groundwater. Some wetlands can go unrecognised because they dry out in summer. Vegetation and plants typical of wetlands may extend onto relatively dry lands that have very infertile soils. And although the laying down of peat is correctly associated with many wetlands, there are also extensive peatlands that cannot be wholly regarded as wetlands.

Different sorts of wetlands result from their diversity of landform settings, origins, substrates, hydrology, nutrient status, and vegetation. A classification system may emphasise any one of these factors, but must be flexible enough in its application to recognise that wetland types grade into each other, and that wetlands are dynamic systems that change over time. Difficulties also arise with the names used for wetland categories because most terms have originated overseas where they have been defined and applied in sometimes conflicting ways. The current treatment represents one more step in the long-standing and difficult process of defining terms and using names in ways that suit New Zealand needs, while retaining some equivalence with international concepts.

In less than two centuries New Zealand wetlands have been severely reduced in extent: the figure of 10% is often quoted (unchallenged) for the area that now remains. The numerous values and uses of wetlands have been well documented and are not detailed again here. Suffice it to note that healthy wetlands are part of a healthy environment; yet wetlands continue to be lost, degraded, undervalued, ignored, and destroyed both deliberately and through ignorance. By being able to recognise wetland ecosystems, types, and features we are in a position to understand wetland functioning and processes. These in turn assist with the necessary business of wetland inventory, mapping, survey, and the monitoring of condition and extent, all of which are needed for protecting, managing, and enhancing our wetlands.

Every wetland visitor or researcher must expect a challenge in trying to work out how a wetland functions, and what type to call it. Future studies will allow for more watertight definitions and assessment of wetland types and features, as well as recognising new types. Until such time, be aware that even professional and experienced wetland ecologists spend much time arguing, disagreeing, and speculating about how any wetland system or site works. Wetlands do not reveal their secrets readily!

This book results from one of several goals of a Ministry for the Environment project on coordinated monitoring of New Zealand wetlands (Ward & Lambie 1998, 1999a,b; Downs et al. 2001; Harmsworth 2002; Clarkson et al. 2003). Our project has sought to develop a coordinated approach and standardised eco-classification to facilitate international reporting under the Ramsar Convention on Wetlands and national state-of-the-environment reporting under the Resource Management Act on changes in wetland extent and condition. One aspect of the project has been to develop a wetland classification system that is based primarily on wetland function (Gerbeaux & Richmond 1999; Partridge et al. 1999). This system allows for wetlands to be recognised at several sequential levels of a hierarchy, from broadly defined hydrosystems, to wetland classes, then structural classes of vegetation, and finally wetland 'types' distinguished by their composition of dominant plants. It should be noted that since Ward & Lambie (1999b) outlined this classification framework we have become aware of some inconsistencies and have sought to correct these and refine the circumscriptions of some wetland classes; these changes are noted in Section 2.2.

The emphasis of this book is on inland freshwater wetlands, those near coastal estuaries, and those of lake and river margins. Fully aquatic systems of lakes and rivers are covered in much less detail, these topics having their own complexity of literature in hydrology and limnology (e.g. Irwin 1975b). A draft structure for classification of geothermal and plutonic hydrosystems is set out as table 3 of Ward & Lambie (1999b) and of marine, lacustrine, and riverine hydrosystems in their table 4. An alternative classification of wetlands of all types was adopted by contracting parties to the Ramsar Convention in 1990, and although available on the Ramsar website, is currently under review.

Our main purpose is to describe and illustrate how wetland types can be recognised and named. Section 2 deals with the classification system, noting some of the background to wetland classification, and then describing the classification tiers. Section 3 demonstrates patterns in wetlands and shows how the classification system can be applied to them. Section 4 describes how wetlands function, especially in relation to the variables of hydrology, nutrients, and substrates, and discusses how wetlands change over time. Section 5 provides some direction on wetland survey methods, use of the classification system, and a guide to further information. A glossary of terms is provided at the end.

TWO

The classification system

2.1 Background to wetland types, terms, and classification

Systems for arranging types of New Zealand wetlands have variously given primary emphasis to vegetation, landforms, or substrates. Most wetland terms have come from other countries and have gradually been adopted here in both common and ecological usage. As an example, common parlance and the coining of place names for New Zealand wetlands often use the words bog and swamp almost interchangeably, whereas ecologists make a clear distinction between them: bogs are at the infertile end, while swamps are at the fertile end of a nutrient gradient in wetlands.

The pioneer plant ecologist Leonard Cockayne described New Zealand wetlands under headings of landform settings and vegetation, grouping most wetland types into the categories bog and swamp, but noting also the many transitions between these, and the gradations that occur between wetland and dryland, for example with his ‘semi-swamp forest’ (Cockayne 1928). For various forms of herbaceous wetlands he provides terms such as ‘salt-meadow’ (for estuarine sites), ‘coastal-moor’ (for coastal slopes), and ‘herb-moor’ (for upland sites).

The classification by Cranwell (1953) concentrates on peat types, their mode of deposition, topographic setting, the forms they create, and their general fertility. Her classification includes recognition in New Zealand of fens (in the sense used in the United Kingdom) as sedgy and woody vegetation on nearly neutral or only slightly acid substrates: i.e. something between bog and swamp.

In describing wetlands of Canterbury, South Island, uplands, Burrows (1969) describes flushes as distinct from bogs, as being sites that receive water and nutrients from upslope, and he recognises several types, such as 'wet flush', 'seepage flush', 'herb flush', and 'spring head flush'. In addition, Burrows distinguishes marshes as a further group of wetlands, distinctive in their substrate and vegetation.

The term mire has been increasingly used in New Zealand, mainly as a broad term that is more or less synonymous with 'peatland' (Thompson 1987), though there has also been a tendency to apply the term to a broader category of vegetated wetlands (e.g. Burrows 1990). Dobson (1979), describing mire types of New Zealand, provides a useful outline of wetland environmental factors, and a breakdown of types based mainly on floristics, with informative diagrams relating principal plant species to soil nutrient status, temperature, and pH.

In her overview of the mires of Australasia, Campbell (1983) also emphasises the dominant plants and vegetation structure. She recognises the category of fen as including several wet grassland and sedgeland communities, and also short alpine herbfield of snow patches. Recent studies of New Zealand wetlands (e.g. McQueen & Wilson 2000) have increasingly supported the recognition of fens as distinct from bogs. Campbell (1983) uses the term 'soak' for sloping seeps in mountain lands, and introduces to New Zealand the term 'wet heath', previously used in Australia.

Wardle (1991) gives further formality to the term wet heath for the traditionally difficult-to-categorise pakihi and gumland types that occur on ultra-infertile, impervious soils, these being at the wet end of a more general, sometimes dryland, category of heathland (having vegetation of stunted, small-leaved woody plants, wiry sedges, and ferns). Although Wardle does not use the term fen, his 'infertile swamp' is an equivalent.

Thompson (1987) notes that classification of wetland types may be based upon topography, floristics, substrate types, or nutrient status, but 'in practice, it is helpful to use all four methods'. Thompson outlines different concepts of wetland and peatland, and the factors of water supply, nutrient status, peat deposition, climate, and landform that influence the range of freshwater wetland types in New Zealand. He comments on the confused terminology within peatland literature, establishes some definitions, and discusses how overseas terms might be applicable to New Zealand situations, yet without necessarily recommending their adoption (Thompson in Davoren et al. 1978; Thompson 1987).

Whereas most New Zealand accounts of wetland vegetation types (e.g. Cockayne 1928; Cranwell 1953; Dobson 1979; Campbell 1983; Johnson & Brooke 1998; Wardle 1991) have been pragmatically descriptive and not overly concerned with producing a formal and definitive classification, a few attempts at a hierarchical classification have been made, but also with an element of tentativeness. At the 1974 New Zealand Ecological Society conference, Colin Burrows presented a tabulated preliminary classification of wetlands, and although not published in that form, his classification scheme was the principal contribution to that outlined by Keith Thompson in Stephenson et al. (1983), which classified wetlands according to these tiers of factors: fresh cf. salt waters; broad landform setting; nutrient status and wetland form; and vegetation structure. Stephenson et al. (1983) cautiously include fen in their classification scheme for New Zealand, and note the term marsh as having a particular meaning: 'usually shallow water, often seasonal, mineral substrate, herbaceous vegetation'. This concept of marsh is more akin to the sense in which it has been used in Britain, rather than in the American emphasis upon habitats having plants emergent from shallow water. The European term carr has sometimes been used in New Zealand for fens dominated by woody vegetation (Sykes et al 1991).

It should be noted that although some northern hemisphere definitions of the terms bog, fen, swamp, and marsh include vegetation as a descriptive element, this is not the case in the current New Zealand classification exercise. Hence concepts such as a fen being bryophyte-dominated (Canada: Zoltai & Vitt 1995) or swamps being tree- or shrub-dominated (United States and Europe: Mitsch & Gosselink 2000) are not included here at the wetland class level.

We wish to emphasise the fact that classification is a conceptual exercise (Colin Webb, pers. comm.). As such, the number and scope of units chosen for recognition is to a large extent arbitrary. The units are not necessarily equal. They may be characterised by different properties of their overall nature, and not all properties need to carry the same weight. In relation to wetland classification it is important to realise that wetland units cannot be easily and rigidly defined. This is especially the case with wetland classes. Our approach is one of descriptively circumscribing the units so as to capture the essence of their distinctiveness.

2.2 Structure of the classification system

The wetland classification we are working with is based on that outlined by Ward & Lambie (1999b) and adopted by Clarkson et al. (2003), but with some modifications, as noted below.

Its overall structure emphasises functional aspects of wetlands, starting with the broad hydrological and landform setting, moving down to wetland classes based on substrate, water regime, and chemistry, and finally to the lowermost levels where vegetation becomes a defining factor. This method of classification is a 'top-down' one, starting at the highest level then allocating units to categories within defined levels lower in the hierarchy. Hence it is not a taxonomic or 'bottom-up' approach, which would start with recognised and named units at the finest scale, then link these by the similarities they share at whatever level. Whereas in an ideal hierarchical classification one could draw clear lines of linkage up and down the tree, and all units would be distinct from each other, this system should be regarded as semi-hierarchical, insofar as combinations of parameters are used for the groupings, both within and between levels (Gerbeaux & Richmond 1999; Partridge et al. 1999).

The six classification levels of increasing detail are outlined in Table 1. These classification levels and their units are further described in the following chapters. Although Table 1 attempts to show a neat separation between the units of hydrosystem and wetland class, the reality is that in each case there is considerable overlap between units, as shown conceptually in Figs 1 and 2.

Level I comprises nine hydrosystems, based upon broad hydrological and landform setting, salinity, and extremes of temperature. The four most important hydrosystems are estuarine, riverine, lacustrine, and palustrine. In practical terms, hydrosystems are of relevance for grouping wetlands over relatively large areas and on a regional basis. Hydrosystem boundaries cannot be expected to be clearly definable on the ground. Note that our definitions of hydrosystems differ from those in Ward & Lambie (1999b). We find their inclusion of emergent vegetation as one of the defining factors to be in conflict with the principle that hydrosystems should be based upon broad factors of hydrology and landform setting.

Level IA (subsystem) is a less formal, descriptive level, allowing for attention to be drawn to descriptors of water regime additional to those which contribute to the formulation of the wetland classes which follow.

Table 1 Outline of semi-hierarchical classification system for New Zealand wetlands

I. HYDROSYSTEM

(Based on broad hydrological and landform setting, salinity, temperature)

Marine | Estuarine | Riverine | Lacustrine | Palustrine | Inland saline | Plutonic | Geothermal | Nival

IA. SUBSYSTEM

(A descriptive level relating to water regime)

II. WETLAND CLASS

(Based on substrate, water regime, nutrients, pH)

Bog | Fen | Swamp | Marsh | Seepage | Shallow water | Ephemeral wetland | Pakihi and gumland | Saltmarsh

IIA. WETLAND FORM

- Landforms which wetlands occupy (e.g. slope, basin)
- Forms which wetlands create (e.g. domed bog, string fen)
- Forms or features which wetlands contain (e.g. pool, rand)

III. STRUCTURAL CLASS

- Structure of the vegetation (e.g. forest, rushland, herbfield), or:
- Predominant ground surface (e.g. rockfield, mudflat)

IV. COMPOSITION OF VEGETATION

- One or more dominant plants (e.g. bog pine, wire rush)

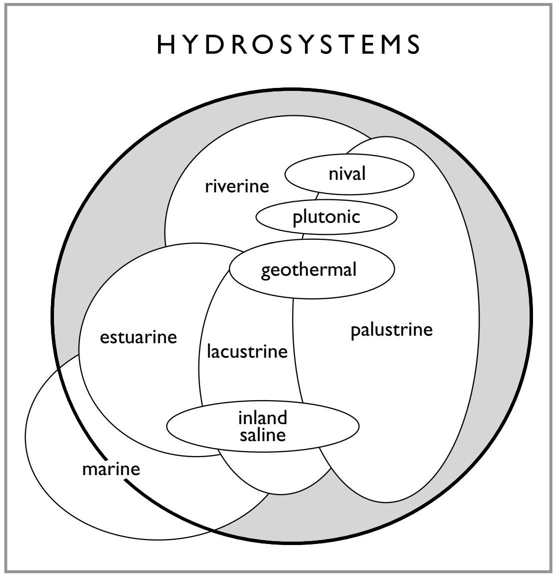


Fig. 1 A conceptual arrangement of hydrosystems in relation to 'wetland' as represented by the shaded circle.

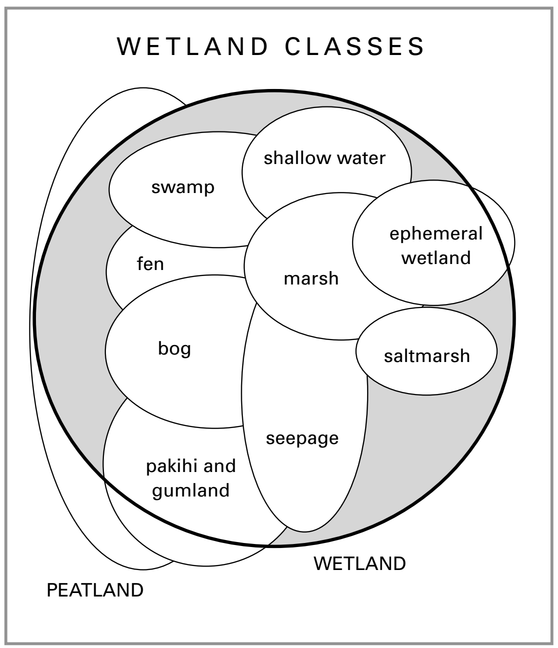


Fig. 2 A conceptual arrangement of wetland classes, their relationship to 'peatland' and to 'wetland' as represented by the shaded circle.

Level II comprises the nine wetland classes which are the units of central importance in mapping and documenting wetlands. Wetland classes may belong to one or more hydrosystems. Wetland classes are circumscribed by distinctive combinations of substrate factors, water regime, and consequent factors of nutrient status and pH (Table 2 on p. 38).

Note that we recognise three wetland classes additional to those listed by Ward & Lambie (1999b): shallow water, ephemeral wetland, and pakihi and gumland. We have adopted the wetland class term seepage to embrace 'seep' and 'flush', and regard saltmarsh as a class embracing most estuarine habitats.

Level IIA, wetland form, is a subsidiary set of descriptors of landforms which wetlands occupy, and forms that they create or contain.

Level III, structural class, is concerned with the general growth form or structure of the vegetation, or else the leading type of ground surface.

Level IV, composition of vegetation, is the lowermost level of the classification, allowing wetland types to be named from one or more of the dominant plants, in combination with a structural class.

2.3 Hydrosystems

Hydrosystems are the units of the uppermost level of wetland classification. They are based on general landform and broad hydrological settings, and distinctive features of water salinity, water chemistry, and temperature.

Nine hydrosystems are recognised. The four major ones are for wetlands associated with land, rivers, lakes, and coasts. Five minor hydrosystems accommodate habitats that are more specialised or localised, or of less relevance to the freshwater wetland theme: the open sea, inland salty places, underground, heated waters, and frozen habitats. The hydrosystems are described below in no particular order.

Because hydrosystems are a high category of classification, with very broadly circumscribed units, their practical application is most relevant for mapping at a coarse level and in grouping wetlands on a regional basis, across relatively large areas. At a detailed level of mapping it is often not possible to precisely demarcate boundaries between hydrosystems; this task becomes more practicable with the finer categories of wetland class. In wetland complexes that embrace a mixture of hydrosystems, the overall system is allocated by its dominant hydrosystem type. Examples of hydrosystems are shown in Sections 3.1 and 3.2.

2.3.1 Palustrine

All freshwater wetlands fed by rain, groundwater, or surface water, but not directly associated with estuaries, lakes, or rivers. The term palustrine derives from the Latin, *palus* = marsh. Most wetlands are palustrine, and it is this hydrosystem that includes the greatest range of wetland classes and vegetation types.

2.3.2 Riverine

Wetlands associated with rivers, streams, and other channels, where the dominant function is continually or intermittently flowing freshwater in open channels. The riverine hydrosystem includes open flowing waters and both the beds and margins (riparian zones) of channels. It embraces natural waterways and artificial ones such as canals, irrigation channels, and drains. Although many wetlands occupy landforms such as valley floors, floodplains, and deltas which owe their genesis to river processes, the riverine hydrosystem extends only so far as flowing channels retain a current influence, which can be defined as the extent covered by the mean annual flood. Towards its downstream end the riverine hydrosystem meets tidal influence and merges with the estuarine hydrosystem. The boundary can be defined as the place where estuarine salinity is 5‰ (5 parts per thousand).

2.3.3 Lacustrine

Wetlands associated with the waters, beds, and immediate margins of lakes and other bodies of open, predominantly freshwater which are large enough to be influenced by characteristic lake features and processes such as fluctuating water level, wave action, and usually permanent and often deep water that has nil or only slow flow. Lakes can be arbitrarily defined as having a major dimension of 0.5 km or more (Irwin 1975a; and see discussion in Section 2.6.3).

Fig. 3 Palustrine hydrosystem: wetlands occupying former outwash channels, Kennedys Creek, Westland.

Fig. 4 Riverine hydrosystem: flood-prone alluvium with toetoe (*Cortaderia richardii*) tussockland, Pyke River, Fiordland.

2.3.4 Estuarine

This hydrosystem embraces estuaries themselves, tidal reaches and mouths of coastal rivers, coastal lagoons, and wet habitats of open coasts where soil water is affected by sea salts. The dominant functions are the mixing of freshwater and seawater, and tidal fluctuation, both of which vary depending on degrees of direct access to the sea. The inland limit of the estuarine hydrosystem lies where salinity reaches a dilution of 5‰ marine salt concentration (Clarkson et al. 2003). The estuarine hydrosystem includes all areas of subtidal and intertidal zones in estuaries, and also wet ground in supratidal zones where surface water and groundwater receive saline contributions from wave splash, or airborne salt in sea spray; habitats which might otherwise be broadly termed coastal wetlands.

2.3.5 Marine

The saline waters of the open sea; this hydrosystem is not further considered in this book.

2.3.6 Inland saline

Inland sites in semi-arid climates where strong evaporation processes result in high concentrations of soluble salts in soil and groundwater, and where localised wetlands occur as seepages or in depressions; a minor hydrosystem in New Zealand, found mainly in the basins of inland Otago.

2.3.7 Plutonic

The plutonic hydrosystem includes all underground waterways and water bodies where light levels are too low to permit photosynthetic activity, and hence plant production, but where other inputs of energy allow for communities of fungi, microbes, insect larvae, and some fish species. Plutonic wetlands occur mainly as caves and underground streams in karst terrain (limestone and marble), but also as caves in volcanic lava, and as aquifers. Details of this hydrosystem are not further considered in this book.

Fig. 5 Lacustrine hydrosystem: wave action upon lake margin turf, Lake Wanaka, Otago.

Fig. 6 Estuarine hydrosystem: zones of seagrass (*Zostera novazelandica*), sedgeland, and rushland saltmarsh, abutting onto palustrine flaxland, Whanganui Inlet, Nelson.

Fig. 7 Marine hydrosystem: surge through kelp beds, Catlins coast, Otago.

Fig. 8 Inland saline hydrosystem: a partly dried salt pan, Maniototo basin, Otago.

Fig. 9 Plutonic hydrosystem: represented here by a stream exit from a limestone cave, Oparara, Buller.

Fig. 10 Geothermal hydrosystem: a steamy fumarole as a stream source, Waimangu Stream, Rotorua.

Fig. 11 Nival hydrosystem: snowfields at the head of the Whitbourn Glacier, Otago.

2.3.8 Geothermal

A hydrosystem where the dominant function is geothermal water (heated by volcanic activity to 30°C or more); geothermal wetlands may have water temperatures below this, yet be influenced by chemicals from current or former inputs of geothermal-derived water. Geothermal wetlands occur predominantly in the central North Island and include volcanically active habitats of fumarole margins, hot surface waters, heated soils that are permanently or intermittently wet, and shallow water at land margins. Details of this hydrosystem are not further considered in this book.

2.3.9 Nival

Snowfields and glaciers constitute a common though mostly frozen hydrosystem of the mountains, not generally thought of as a wetland habitat, but acknowledged here because snow and ice are indeed a habitat of algal communities, and because of the importance of melting snow and ice in nourishing vegetated wetlands.

Key to hydrosystems

1 Salinity 5‰ (5 parts per thousand) or more 2
Salinity less than 5‰ 4

2 Water regime not influenced by tidal water; situated in inland basins where salinity results from localised areas of saline soils associated with semi-arid climate . . . . . . **inland saline**
Water regime influenced by tidal water, and salinity due to marine-derived salt . . . 3

3 Partly enclosed by land but open to the sea, with evident tidal effects, or coastal land markedly affected by marine salt; salinity 5–35‰ . . . . **estuarine**
Little or no obstruction to open sea; salinity about 35‰ . . . . **marine**

4 Water regime affected by extreme temperatures (cold or hot) 5
Water regime not affected by extreme temperatures 6

5 Water mostly frozen . . . . **nival**
Water regime and chemistry influenced by geothermal activity with water being 30°C or more, or else affected by chemicals from current or former inputs of geothermally derived water . . . . **geothermal**

6 Water regime and chemistry associated with waterways and water bodies that run through cave systems formed mainly but not exclusively on limestone . . . . . . **plutonic**
Water regime not associated with waterways and water bodies that run through cave systems 7

7 Water regime not subject to surface inundation; wetland not immediately adjacent to flowing water or along the margins and shores of a lake; situated in topographically flat or in slightly concave, often not easily defined depressions, or in depressions at the edge of escarpments, or on slopes; sometimes occupying groundwater discharge zones . . . . **palustrine**
Water regime subject to surface inundation and resulting from marked water-level fluctuations; wetland immediately adjacent to flowing water or along the margins and shores of a lake 8

8 Situated in river or stream channels, or immediately adjacent to water courses; influenced by continuous or intermittently flowing water . . . . **riverine**
Not confined to channels or adjacent to water courses but situated in topographically defined depressions that retain inflowing surface runoff and groundwater originating from surrounding catchments or upslope sources; with presence of permanent non-flowing deep water 9

9 Major dimension of water body 0.5 km or more . . . . **lacustrine**
Major dimension of water body less than 0.5 km 10

10 Influenced by characteristic lake processes such as fluctuating water level and wave action . . . . **lacustrine**
Not influenced by any lake process . . . . **palustrine**

2.4 Subsystems

The subsystem is the second, and less formal, level of classification, allowing for attention to be drawn to particular descriptors of water regime (water source, movement, drainage, fluctuation, and periodicity of wetness) as outlined in Section 4.1 on hydrology. These water regime factors, considered in combination, and in conjunction with other wetland functions, give rise to the formulation of the wetland classes that follow. Note that the usefulness of particular water regime descriptors varies between hydrosystems. In the estuarine hydrosystem, tidal fluctuation is a predominant factor. In the riverine hydrosystem, rate and stability of water flow are important. In the lacustrine hydrosystem, fluctuation period and lake water stratification are strong descriptors.

2.5 Wetland classes

Wetland classes are governed by distinctive combinations of substrate factors, water regime, and the consequent factors of nutrient status and pH. Nine wetland classes are recognised: bog, fen, swamp, marsh, seepage, shallow water, ephemeral wetland, pakihi and gumland, and saltmarsh.

This third level of wetland classification is the most important one for the practical business of assigning a name to a functional wetland unit. Table 2 lists the characters of water regime, substrate, and chemistry. Note that there is much overlap of shared character states between wetland classes. Accordingly, each class is circumscribed by a particular combination of character states that are most distinctive to it.

Being based upon function – the ways in which wetlands work – wetland classes are not differentiated by the situations they occupy or the vegetation they contain. Nevertheless, particular landforms, vegetation structural classes, and plants are associated with each wetland class (Table 3 on p. 39). Note, however, that so far as the classification method is concerned, these features are secondary to the factors of physical and chemical environment which primarily delimit wetland classes.

Wetland classes fit beneath hydrosystems (Table 1). Most wetland classes can occur within more than one hydrosystem, and indeed some will actually span a hydrosystem boundary at particular sites. The wetland classes are described below in no particular order.

Fig. 12 Bog: a cushion bog with tussocks, a pool, and surrounding shrub and tree bog, Gorge Plateau, south Westland.

2.5.1 Bog

A peatland which receives its water supply only from precipitation, receiving neither groundwater nor any nutrients from adjacent or underlying mineral soils. Bogs are oligotrophic (nutrient-poor), poorly aerated, and usually markedly acid. Bog peat is poorly drained, having almost no water movement, and the water table is generally close to or just above the ground surface, and relatively constant.

Bogs occur most often on relatively level or very gently sloping ground, including hill crests, basins, terraces, and within other wetland types. Their vegetation types are very wide-ranging, dominants including mosses, lichens, cushion plants, sedges, grasses, restiads, ferns, shrubs, and trees.

Fig. 13 Fen: a gently sloping fen with a mixture of wire rushland, tussockland, and flaxland at National Park, Mt Ruapehu, Volcanic Plateau.

2.5.2 Fen

A wetland with a predominantly peat substrate that receives inputs of groundwater and nutrients from adjacent mineral soils. The water table is usually close to or just below the peat surface, and relatively constant. Water flow is slow to moderate. Fens have low to moderate acidity and are oligotrophic to mesotrophic.

Fens have slightly higher nutrient status than bogs, often because they occupy slight slopes, such as fans or the toes of hillsides (see Fig. 24) where they may grade downslope to swamp. Fens also occur on level ground where relatively shallow peat has not accumulated much above the influence of underlying mineral substrate, including situations around the margins of domed bogs. Fen vegetation is often composed of sedges, restiads, ferns, tall herbs, tussock grasses, or scrub.

Fig. 14 Swamp: a flax (*Phormium tenax*) - *Coprosma propinqua* / *Carex geminata* sedge swamp with leads of open water and indications of a fluctuating water level, Maher Swamp, Westland.

2.5.3 Swamp

A wetland that receives a relatively rich supply of nutrients and often also sediment via surface runoff and groundwater from adjacent land. Swamps usually have a combination of mineral and peat substrates. Leads of standing water or surface channels are often present, with gentle permanent or periodic internal flow, and the water table is usually permanently above some of the ground surface, or periodically above much of it.

Swamps usually occur in basins, and on valley floors, deltas, and plains. Vegetation cover is often sedge, rush, reed, flax, tall herb, or scrub types, often intermingled, and also forest.

2.5.4 Marsh

A mainly mineral wetland, having moderate to good drainage, fed by groundwater or surface water of slow to moderate flow, and characterised by moderate to great fluctuation of water table or water level. Marshes are often periodically inundated by standing or slowly moving water. They

Fig. 15 Marsh: a valley floor marsh with rush clumps, grasses, and herbfield, near Waihi Beach, Bay of Plenty.

are usually mesotrophic to eutrophic, and slightly acid to neutral in pH. Marshes differ from swamps by having better drainage, a generally lower water table, a usually more mineral substrate, and a higher pH.

Marshes occur mainly on slight to moderate slopes, especially on valley margins, valley floors, and alongside water bodies such as rivers and lakes. Vegetation is most often rushland, grassland, sedgeland, or herbfield.

2.5.5 Seepage

An area on a slope which carries a moderate to steady flow of groundwater, often also surface water, including water that has percolated to the land surface, the volume being less than that which would be considered as a stream or spring. Substrate ranges all the way from raw or well-developed mineral soil to peat; nutrient status and pH range from low to high; and the water table varies from just above the ground surface to a slight depth below. Seepages are located primarily where groundwater diffuses to the surface, especially at a change of slope, or where an impermeable basement raises the water table.

Fig. 16 Seepage: the toe-slope of a hillside with grazed sedgeland on a seepage carrying a moderate flow of groundwater and surface water, Greenstone Valley, Otago.

Flushes are considered here as falling within the wetland class of seepage. Flushing occurs when a periodic pulse of water, usually associated with rain (or seasonally with snow-melt), produces a sheet-flow of surface water, providing nutrients from higher ground, replenishing oxygen, and sometimes scouring the ground surface. Surface wetness is not always constant. Flushes are usually elongated downhill. The term flush has been commonly used in New Zealand for sloping wetlands in the mountains; it could validly be considered as a distinct wetland class.

Seepages (including flushes) are often relatively small and localised but occur both as stand-alone wetlands and as features which feed, drain, or are contained within other wetland classes. They intergrade with bogs and fens, but differ partly on the basis of their size and slope: seepages occupy sites of active water movement having enhanced aeration and nutrient supply. Vegetation is usually of low stature: moss, cushion, or sedge types; sometimes scrub or forest.

Fig. 17 Shallow water: a gently flowing river channel through a lowland swamp with submerged, bottom-rooted aquatic plants of pondweed (*Potamogeton pectinatus*) and starwort (*Callitriche petriei*), plus marginal floating foliage of giant sweetgrass (*Glyceria maxima*), Waipori River, Otago.

2.5.6 Shallow water

Aquatic habitats, generally less than a few metres deep, having standing water for most of the time. This wetland class accommodates the margins of lakes, rivers, and estuary waters, in which case the term 'shallow open water' is sometimes used to acknowledge the presence of an open body of water further from the shore. This wetland class also encompasses bodies of water that are not sufficiently large or lake-like in character to warrant lacustrine classification, yet of greater significance than just as water body forms contained within a wetland. The dominant unifying determinant is the presence of standing water. Nutrient and water chemistry factors are basically those of the water, rather than the substrate. In practice, the shallow water wetland class provides for habitats that 'land-based' wetland workers would meet with at land / water margins. For purposes of mapping or categorising fully aquatic habitats of lacustrine or riverine hydrosystems, the term 'deep open water' is available as an additional wetland class.

Fig. 18 Ephemeral wetland: the summer-drying phase of Julian's Pond, Taranaki.

2.5.7 Ephemeral wetland

A distinctive class most frequently found in closed depressions lacking a surface outlet, in climates where seasonal variation in rainfall and evaporation leads to ponding in winter and spring, and with fluctuation so pronounced that it can lead to complete drying in summer months or in dry years (Johnson & Rogers 2003). Water source is groundwater or an adjacent water body. Substrates are usually wholly mineral, upon an impervious underlying horizon. Water flow is slow to nil, nutrient status moderate, and pH neutral. Closed depressions occur especially on moraines, bedrock, dunes, and tephra. Vegetation is a characteristic marginal zone of turf and sward, and sometimes also rushland and scrub. Extreme cases of ephemeral wetland alternate between aquatic and terrestrial plants at different seasons.

2.5.8 Pakihi and gumland

Characterised by mature or skeletal soils of very low fertility and low pH, wholly mineral or sometimes with peat, rain-fed and with poor ability to transport water, frequently saturated but seasonally dry. Usually on level to rolling or sloping land in districts of high rainfall, the soils are old and severely leached of most nutrients.

This problematical wetland class embraces a medley of habitats including some, but not all, of the West Coast pakihi (Mew 1983) and Northland gumlands (e.g. Esler & Rumball 1975), but can extend also to sites having soils of extreme infertility because of their skeletal nature or lack of nutrients from inhospitable substrates such as ultramafic rock. Many of the peaty sites that have traditionally been referred to as pakihi can be classified as bog or fen. Nevertheless, the wetland class of pakihi and gumland is needed to accommodate habitats which may completely lack peat, and where wetness, sufficient for them to be regarded as a type of wetland, results in frequent soil waterlogging, even though this may alternate with periods when soils are relatively dry.

The wetland class pakihi and gumland is admittedly difficult to circumscribe on the basis of substrate and water regime. No simple and embracing name suggests itself for this wetland class and we are loath to confuse the issue by suggesting one. ‘Wet heath’ (e.g. Wardle 1991) might be a contender, but the vegetation connotation does not sit well with the wetland class level of the present classification system.

Despite these problems, the pakihi and gumland wetland class nevertheless has the unifying factors of a flora typical of wetlands, and vegetation that is usually heathland (shrubland in combination with restiads, sedges, and ferns; a mix of several vegetation structural classes, see Section 2.7). Such heathland, often fire-induced, poses difficulties for wetland classification because it can extend also to relatively dry habitats and also to blanket peatlands.

2.5.9 Saltmarsh

A wetland class embracing estuarine habitats of mainly mineral substrate in the intertidal and subtidal zones, but also including those habitats in the supratidal zone (such as wet coastal platforms) and in the inland saline

Fig. 19 Pakihi and gumland: represented here by the pakihi on German Terrace, near Westport, Buller, having typical fire-affected scrub of manuka (*Leptospermum scoparium*), and resprouting sedges and tangle fern (*Gleichenia dicarpa*).

Fig. 20 Saltmarsh intertidal zones of mangrove (*Avicennia marina* subsp. *australasica*) scrub, and rushlands of sea rush (*Juncus kraussii* subsp. *australiensis*) and oioi (*Apodasmia similis*), Whitianga, Coromandel Peninsula.

hydrosystem, which although non-tidal have similar saline substrates and constancy of soil moisture. Water source is from groundwater and adjacent saline or brackish estuary waters. The saltmarsh wetland class includes non-vegetated habitats such as mudflats, and the full range of vegetation types typical of the intertidal zone, from herbfield to rushland, scrub, and mangrove scrub or low forest.

2.5.10 Other wetland classes

The nine wetland classes outlined above should accommodate most of the broad level variants of palustrine, estuarine, and inland saline hydrosystems, along with those habitats associated with land / water margins of the riverine and lacustrine hydrosystems. Wetland workers may find the need to erect additional wetland classes, and this is valid as long as they are able to be circumscribed on the basis of distinctive combinations of substrate factors, water regime, nutrient status, and pH. It should be noted that our circumscription of the saltmarsh wetland class is a broader one than that outlined by Ward & Lambie (1999b). Their table 2 includes several additional wetland classes for the estuarine hydrosystem, such as seagrass meadow and algalflat: units which we treat as able to be described at the subsequent classification levels of structural class and composition of vegetation.

Although this book does not attempt to give any detailed coverage of wetland classes of lacustrine and riverine open waters, a draft classification of these is included in table 4 of Ward & Lambie (1999b). In summary, however, it can be noted that their lacustrine wetland classes are based upon combinations of two sets of descriptors, the first being nutrient status (oligotrophic, mesotrophic, eutrophic, dystrophic) and the second being the nature of lake stratification (monomictic, amictic, polymictic). These terms are discussed in Sections 2.6.3 and 4.2. For naming riverine wetland classes Ward & Lambie use descriptors concerned with the two factors of water flow (stable, variable, flashy) and channel gradient (steepland, midland, lowland). These terms are discussed in Section 4.1.2.

Ward and Lambie (1999b) also provide draft structures for classifying wetland classes in the geothermal, plutonic, and marine hydrosystems.

Key to wetland classes

1 Wetland ecosystem characterised by an accumulation of peat .... 2 **(peatland)**

Wetland ecosystem characterised by minimal or no peat accumulation, though layers of muck and a mix of mineral and organic muck may be present 4

2 Peatland often combining mineral and peat substrates; with moderate water flow and fluctuation and often the presence of leads of standing water or surface channels; water usually moderately acid (pH 4.8–6.3) and relatively rich in dissolved minerals .... **swamp**

Peatland with peat exclusively 3

3 Peatland with a surface raised or level with surrounding terrain; receiving water exclusively from precipitation and not influenced by groundwater or runoff water; water table generally at or slightly below the surface; water usually markedly acid (pH < 4.8) and low in dissolved minerals .... **bog**

Peatland receiving inputs of water and nutrients from adjacent mineral soils, with water flow on the surface and through the subsurface; fluctuating water table may at times be a few centimetres above or below the surface but under normal conditions is level with the land surface; water usually moderately acid (pH 4–6) and moderately rich in dissolved minerals .... **fen**

4 Mineral wetland on a slope which carries a moderate to steady flow of groundwater, often also surface water; located primarily where groundwater diffuses to the surface .... **seepage**

Mineral wetland not fitting above description 5

5 Water table persisting above or near ground surface for all or most of the year 6

Water table often below ground surface, and surface prone to temporary drying 8

6 Surface water near-permanent, to c. 2 m depth; tidal or not tidal .... **shallow water**

Surface water slight or tidal 7

7 Influenced by tidal water and / or where high soil salinity is a strong factor .... **saltmarsh**

Having low or nil soil salinity; often along the margins of lacustrine and riverine systems; sometimes in areas influenced by supratidal water in estuarine systems .... **swamp**

8 Wetland that lacks a permanent surface outlet and has a marked seasonal alternation between being ponded and dry .... **ephemeral wetland**

Wetland without marked seasonal alternation between being ponded and dry 9

9 Wetland characterised by ultra-infertile acidic soils with an impervious horizon, prone to temporary drought .... **pakihi and gumland**

Wetland with moderate to much water fluctuation, often on slight to moderate slope, or along the margins of lacustrine and riverine systems .... **marsh**

Table 2 Distinguishing features of New Zealand wetland classes

Wetland Class	Water origin (predominant)	Water flow	Drainage	Water table position cf. ground	Water fluctuation	Periodicity	Substrate	Nutrient status	pH
Bog	rain only	almost nil	poor	near surface	slight	wetness permanent	peat	low or very low	3–4.8
Fen	rain + groundwater	slow to moderate	poor	near surface	slight to moderate	wetness near-permanent	mainly peat	low to moderate	4–6
Swamp	mainly surface water + groundwater	moderate	poor	usually above surface in places	moderate to high	wetness permanent	peat and/or mineral	moderate to high	4.8–6.3
Marsh	groundwater + surface water	slow to moderate	moderate to good	usually below surface	moderate to high	may have temporary wetness or dryness	usually mineral	moderate to high	6–7
Seepage	surface water and/or groundwater	moderate to fast	moderate to good	slightly above to below surface	nil to moderate	permanent wetness to temporary dryness	peat, mineral, or rock	low to high	4–7
Shallow water	lake, river, etc., or adjacent groundwater	nil to fast	nil to good	well above surface: inundated	nil to high	wetness almost permanent	usually mineral	moderate	4–7
Ephemeral wetland	groundwater + rain	nil to slow	moderate to good	well above to well below surface	marked wet/dry alternation	seasonal, sometimes temporary wetness/dryness	mineral	moderate	5.5–7
Pakihi and gumland	mainly rain	almost nil	poor	below surface	slight to moderate	wetness near-permanent but prone to temporary drought	mineral or peat	very low to low	4.1–5
Saltmarsh	seawater, brackish water, salt spray, groundwater from land	moderate to slow	good	closely below surface between tides	tidal, or slight in supratidal zone	mainly tidal	mainly mineral	moderate	4.9–8

Table 3 Landforms, vegetation, and key indicator plants associated with wetland classes in New Zealand

Wetland Class	Predominant landforms	Common vegetation structural classes	Some key indicator plants
Bog	usually almost level ground, including hill crests, basins, terraces	wide range including moss, lichen, cushion, sedge, grass, restiad, fern, shrub, and forest types	*Sphagnum*, *Oreobolus*, *Baumea tenax*, *Sporadanthus*, *Empodisma*, *Dracophyllum*, *Epacris*, *Leptospermum*, *Halocarpus*
Fen	slight slopes of bog margins, swamp perimeters, hillside toe slopes, alluvial fans	usually sedge, restiad, rush, fern, tall herb, or scrub types	*Schoenus pauciflorus*, *S. brevifolius*, *Empodisma*, *Chionochloa rubra*, *Hebe odora*, *Baumea teretifolia*, *Leptospermum*
Swamp	mainly on valley floors, plains, deltas	usually sedge, rush, reed, tall herb, and scrub types, often intermingled, and including forest	*Phormium*, *Carex*, *Coprosma*, *Gahnia*, *Typha*, *Cordyline*, *Dacrycarpus*, *Laurelia*, *Syzygium*
Marsh	slight to moderate slopes, valley margins, edges of water bodies	typically rush, grass, sedge, or shrub types	*Juncus*, *Carex*, *Agrostis*, *Cortaderia*
Seepage	moderate to steep hill slopes, scarps; heads and sides of water courses	usually low-stature moss, cushion, or sedge types; sometimes scrub or forest	*Carpha alpina*, *Montia*, mosses
Shallow water	ponds, pools, streams; margins of lakes, lagoons, rivers	submerged, floating, or emergent aquatics	*Myriophyllum*, *Potamogeton*, *Azolla*, *Bolboschoenus*, *Baumea*, *Ruppia*, *Schoenoplectus*, *Isolepis*
Ephemeral wetland	closed depressions especially on moraines, bedrock, dunes, tephra	marginal zones of turf and sedge sward, sometimes rushland and scrub	*Glossostigma*, *Lilaeopsis*, *Myriophyllum*, *Pratia*, *Isolepis*, *Carex gaudichaudiana*, *Eleocharis*
Pakihi and gumland	level to rolling or sloping land having impervious soils, including pakihi, gumland, and formerly forested land	mixtures of heaths and other small-leaved woody plants with restiads, ferns, sedges, lichens, mosses	*Empodisma*, *Baumea tenax*, *Gleichenia*, *Schoenus*, *Leptospermum*, *Dracophyllum*, *Nothofagus*, *Dacrydium*
Saltmarsh	margins of estuaries; wet coastal platforms	seagrass meadow, turf, herbfield, rushland, scrub, mangroves	*Zostera*, *Sarcocornia*, *Samolus*, *Apodasmia*, *Plagianthus divaricatus*, *Avicennia*

2.6 Wetland forms

For palustrine and estuarine wetlands this category is a set of descriptors of landforms that wetlands occupy, and forms they create or contain. Other wetland forms are associated with standing open water, and flowing open water and channels.

The main broad-scale landforms associated with wetlands are shown diagramatically in Figs 21 and 22. There is considerable scope for applying more detailed geomorphological concepts and terms in order to understand and classify New Zealand wetlands. Our diversity of basement geology, substrate materials, and processes, provide many landform settings and patterns of water movement for distinctive types of wetlands. These details are beyond the scope of this book; field workers should become aware, from general texts on geomorphology, and from geological and soil maps, of the regional landforms that occur in their particular study areas. The following outline is intended as a summary guide to readily observable landform features.

2.6.1 Landforms which wetlands occupy

Five basic landforms that act as the containers or hosts to wetlands are: flats (Fig. 23), channels, basins (Fig.24), slopes, and hills or highlands (Semeniuk & Semeniuk 1995). This simple classification can be used as an aid to the grouping of similar wetlands or to provide an additional descriptor in documenting a particular wetland site.

The general nature of the land surface is an informative feature to record. The movement of groundwater and surface water can often be inferred by observing whether the ground surface is concave, convex, or planar, in two dimensions: along the contour (across the slope) and in profile (up-and-down the slope). These can help in understanding how and where groundwater enters a wetland, and its likely contribution of nutrients.

Fluvial processes – the action of streams and rivers – create many landforms. A currently active river will have reaches of different gradient, places of erosion, and sites of deposition such as floodplains, levees, and deltas. The earlier courses of a river are evidenced by forms of similar sculpture, as abandoned channels or terrace remnants of former floodplains.

Key to wetland forms

1 Not influenced by tidal water 2
Influenced, at least for some time, by tidal water 13

2 Inland peatland, with surface raised above surrounding terrain 3
Inland peatland or mineral wetland, with surface not raised above surrounding terrain . . 5

3 Surface flat to irregular with sloping margins . . . . **plateau mire**
Surface convex 4

4 Convex surface small . . . . **cushion mire**
Convex surface often extensive (>100 m) . . . . **domed mire**

5 Adjacent to lakes and slow-flowing waters, with marked water fluctuations and periodic flooding 6
Not adjacent to lakes and slow-flowing waters 10

6 Floating . . . . **floating**
Not floating 7

7 Located along shores of lakes . . . . **shore**
Located near continuously flowing waters 8

8 Immediately alongside streams or rivers . . . . **riparian**
Not immediately adjacent to flowing water 9

9 In or along cut-off channels . . . . **channel**
Behind levees, on alluvial plains or terraces along valleys . . . . **floodplain**
In interfluvial basins, channels or levees on active deltas . . . . **delta**

10 Surface flat, topographically confined, with distinct slopes to the side 11
Surface flat to undulating, often appreciably sloping, peaty 12

11 Basin deposit, with greater depth in centre . . . . **basin**
Orientated in linear patterns, the hollows between beach ridges or interdunal depressions . . . . **swale**
Flat deposit, depth generally uniform, with water sometimes flowing into the middle . . . . **flat**

12 Surface pattern of ridges and pools distinct . . . . **string mire**
Surface pattern of pools generally absent . . . . **blanket mire**

13 Semi-enclosed body of water having a free connection with the open sea with channel complexes that drain during low tide . . . . **estuary**
An inland body of water, separated from the ocean by a barrier and situated in basins or embayments that do not drain during low tide . . . . 14 **(lagoon)**

14 Generally coast-parallel bodies of predominantly fresh water impounded by a long narrow spit formed by longshore drift offsetting at a river mouth . . . **river mouth lagoon (hapua)**
Exceedingly 'choked' with respect to exchanges of water with the ocean via an inlet or inlets, with openings to the sea rare and short-lived unless created by human action . . . . **coastal lake / lagoon**

(Note: many additional forms are associated with riverine, geothermal, and plutonic hydrosystems, but these are not within the scope of this book.)

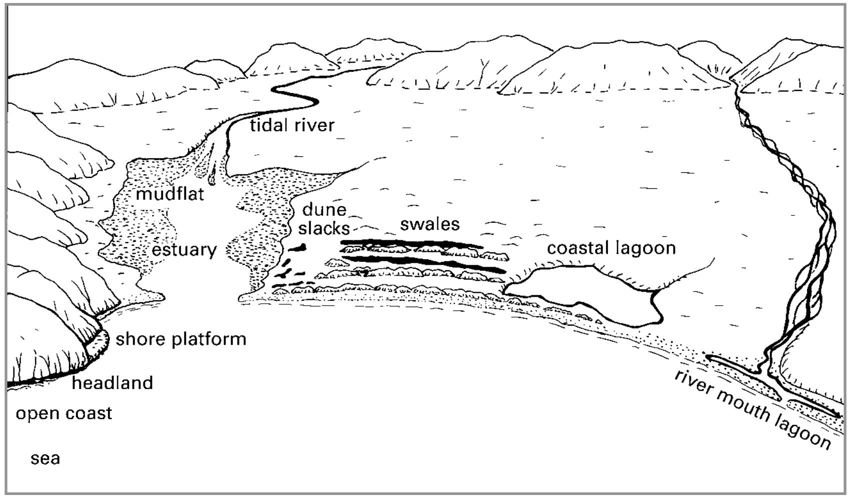


Fig. 21 Landforms of the estuarine hydrosystem.

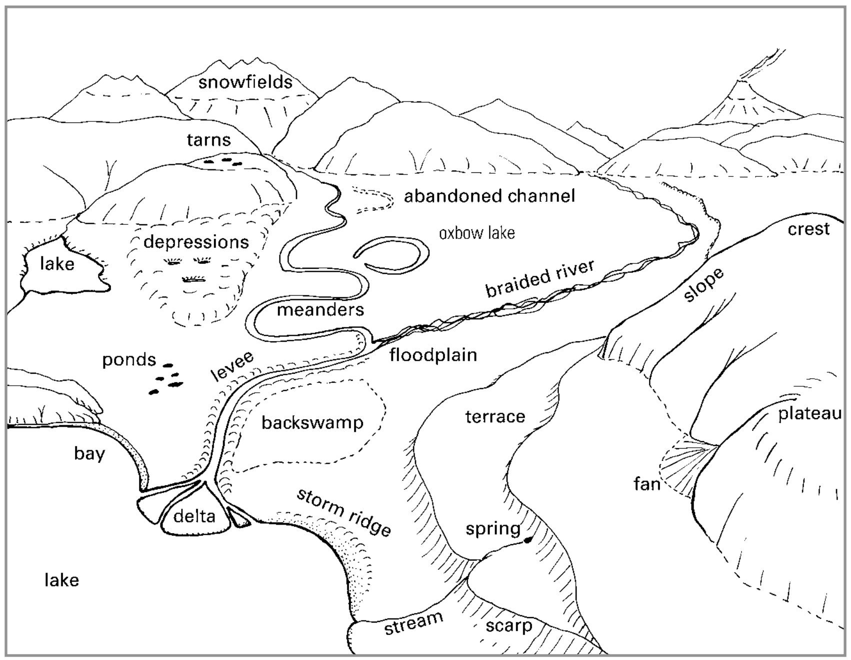


Fig. 22 Landforms of the palustrine and lacustrine hydrosystems.

Fig. 23 On a coastal plain near Haast, south Westland, wetlands occupy the elongated hollows, or swales, between old beach ridges, now forested, and formed in sequence as the land has risen relative to sea level and as the coast has built seaward. The youngest ridges and wetlands are those closest to the coast. These peaty wetlands receive some water flow and nutrients from the adjacent land and are therefore mainly fens, though the least fertile parts are bogs, including forest bog on the small 'islands' of slightly higher ground within the swales.

Many palustrine wetlands occur upon landforms that owe their origin to riverine systems yet are no longer actively affected by river or stream processes. Poorly drained parts of old river systems become marshes, swamps, and bogs. Many marshes occur along the inner margin of river terraces, where they are fed by seepages or springs from the foot of the scarp which lies below the next highest terrace. When in flood, sediment-carrying rivers tend to deposit some of their sandy and silty material close to the river margins, gradually building an elevated ridge, or levee; and whereas levees themselves are relatively well drained, the lower-lying land behind becomes progressively less so. A wetland that develops on a river terrace behind a levee is termed a backswamp. The development stages of

Fig. 24 Teviot Swamp occupies an upland basin on the Lammerlaw Range, Otago. Best classified as fen, the main peatland has developed upon a poorly drained fan that slopes gently to the right. The fen grades to seepages where water flow is more pronounced, both on the downslope margins and in the gullies upslope. The whole system is nourished by water that percolates from the deep soils of the adjacent tussock-grassland hills: a reminder that many wetlands are a surface expression of a whole catchment of groundwater.

river deposits and the relative ages of their wetlands can be gauged from aerial photos.

Coastal dune systems provide habitats for wetlands in the form of dune hollows which may hold seasonal or permanent water, more extensive damp sand plains, dune slacks (e.g. Sykes & Wilson 1987) which lie close to the sea and become ponded by rainfall or by incursions of the highest tides, and swales which are elongated depressions between beach ridges (Fig. 23).

Shore landforms are relevant for lakes, estuaries, and open coasts. A simple distinction can be drawn between headlands and bays; one an eroding environment exposed to wind, waves, and currents, and the other a more sheltered place where sediment is deposited. New Zealand has diverse examples of strongly indented coastlines – large estuarine harbours, sounds occupying drowned valleys, inlets, and fiords – which provide many sorts of sites for wetlands. Shore features demonstrate something that is important in relating all landforms to wetland types: that of scale. For example, wave erosion on a macro-scale can produce a cliffed headland on an open coast; on a meso-scale a steep bank on a tidal river; and on a micro-scale a winnowed scarp a few centimetres tall in a lake-edge marsh. Storms at times of high lake level produce raised storm ridges of gravel or sand – the lake equivalent of river levees – and these are responsible for the impeded drainage that can encourage some palustrine wetlands to develop closely adjacent to lakes.

Different zones of freshwater and tidal water bodies have a specialist terminology, the following being of most relevance in the context of wetland studies. In lakes and ponds the littoral zone is the zone which extends from uppermost water level to the depth limit of rooted plants. The eulittoral is the portion between highest and lowest water levels, while the infralittoral is the zone segment just below the water's edge where emergent or floating vegetation is prominent. Pelagic describes the open waters of a lake; benthic the bottom habitats. On tidal shores the main terms applied to zones are intertidal for the zone that spans the distance between highest and lowest tides, subtidal for the permanently submerged zone below this, and supratidal for the zone above the highest tide level where there is an influence of wave splash and salt spray.

2.6.2 Forms which wetlands create

The most creative of wetlands are bogs, fens, and swamps, in the sense that they can create features at a small scale and distinctive landforms at a large scale because of the ways in which they accumulate an ever-increasing depth of peat.

Undulations of hummock-and-hollow topography on a mire surface become accentuated over time because peat growth is slower in the water-holding hollows than upon the hummocks. A bog surface often has mini-hummocks (Fig. 25) or surface channels (Fig. 26), while the hummocks in a swamp can grow to be thickly vegetated pedestals that teeter a metre or more above the intervening dark runnels (Fig. 27).

Fig. 25 Many wetlands create a hummock-and-hollow surface, because plant growth and peat accumulation are favoured on any ground elevated above the water table. This bog in the Mararoa Valley, northern Southland, has developed cushion forms. On a larger scale, note the islands formed by the elevated trunks of *Carex secta* within the pool.

Fig. 26 Surface channels are common in peatlands, though often hidden by vegetation. In this Westland fen, fire has removed the former cover of plants and litter (these resprouting ferns and sedges are just 3 months old). A channel 10 cm deep is illustrated by the cutaway section of peat, revealing also that the water table, after a period without rain, lies somewhat below the channel base.

Fig. 27 A swamp pool in south Westland beneath trees and *Carex secta* tussocks, and covered with floating leaves of *Potamogeton suboblongus*: an example of how one wetland class (shallow water) can occur within another (swamp).

Fig. 28 Two flarks in an upland gully seepage, Lammermoor Range, Otago. Flarks are temporary ponds in peatland and they can become deeper, permanent pools as peat growth continues only on the vegetated margins.

Fig. 29 A string mire is a superb example of a form created by wetland processes. The 'strings' are the elongated ridges of peat that act as dams on slight slopes, creating a sequence of pools in terrace fashion. Peat growth is most active where the bog mosses and sedges are constantly moist yet not inundated, so that the surface level of both the pool rims and the small pedestal islands continue to elevate, Garvie Mountains, northern Southland.

On a sloping peatland, depressions that are temporarily ponded (called flarks; Fig. 28) develop into permanent pools as peat growth adds to the relative height of their impounding rims (or strings), to produce a large-scale pattern of numerous pools, their long axes aligned across the slope: a string mire (Fig. 29), which is an excellent example of a patterned wetland. Little attempt has yet been made to classify New Zealand wetlands in terms of their patterning of surface form, relief, and arrangement of water features.

One of the classic forms created by natural wetland processes is the domed bog (Figs 30 and 135), where peat has grown deepest in the most poorly drained centre, resulting in a convex surface that rises above the local topography and becomes progressively more isolated from inputs of nutrients from either the underlying mineral substrate or the surrounding

Fig. 30 A domed (or raised) bog is one having a convex surface, resulting from greatest peat growth in the most poorly drained central part. Lake Kini Pakihi in Westland is an example, though its dome, typically, is difficult to discern by eye.

land. It is also commonly called a raised bog, and in earlier terminology 'high-moor', as distinct from 'low-moor', the latter describing a relatively young wetland having a level or concave surface. A plateau bog is a form of raised bog having sloping margins but a plateau surface rather than a fully convex dome; the term does not refer to a bog upon an underlying plateau landform.

Fig. 31 A lagg stream: one which drains the perimeter of an extensive domed bog (see Fig. 30), Lake Kini Pakihi, Westland.

The convex nature of a domed bog is not always obvious to the eye, and may be confirmed only by accurate survey of the ground profile. The margins of a domed bog, more sloping, are where outward seepage can sometimes be discerned; these marginal slopes are referred to as the rand, and they typically drain down to a peripheral stream or swamp called a lagg (Fig. 31).

A blanket mire (or blanket bog if wholly rain-fed) is a peatland which extensively covers the crests, slopes, and hollows of an undulating landform, generally one of low relief (Fig. 32).

When several wetland classes or even more than one hydrosystem occur together, as indeed happens regularly, they form what is termed a wetland complex.

Fig. 32 Blanket peatland can cover large extents of gently sloping land, irrespective of topography, in districts with a cool, windy climate. Here on the West Cape table-lands in Fiordland, tussock bog covers the most poorly drained peat, and grades to shrub bog and tree bog where drainage and fertility are marginally better. (Photo by Kelvin Lloyd.)

There are many situations where the growth habit of wetland plants influences the small-scale forms in wetlands. Cushion (or bolster) plants can be common in upland mires, forming hard convex cushions which may fuse into gently undulating mosaics, forming what is called a cushion bog, though some cushion communities are on fens, or can occur on mineral and sometimes scarcely wet substrates. Many mosses, including some *Sphagnum* species, form soft cushions (see Fig. 53), eventually rising to a level that provides a drier surface that other plants colonise, the whole process resulting in a long-lasting hummocky topography. Large hummocks are formed by many sedges and grasses of tussock habit as they raise themselves upon a pedestal or short trunk of persistent rhizomes and roots.

By trapping inorganic sediment, marsh plants build pedestals or platforms that influence the arrangement of water channels, most notably in large expanses of saltmarsh rushland where distinctive patterns of vegetated and bare ground are largely caused by the plants themselves (Fig. 33).

Rafted (or floating) wetlands are produced by vegetation that starts as a water-surface mat, then becomes a buoyant platform of roots, rhizomes, and

Fig. 33 Distinctive forms created by oioi restiad rushland, New River Estuary, Southland. These 'pikelets' are elevating themselves above the level of mudflats and tidal channels as the rushes trap sediment. They are 50–80 m across, but still actively expanding at their margins.

emergent foliage (see Fig. 94). Organic matter settles into the thick soup of underlying water, but may also accumulate as sedentary peat on the surface, eventually leading to a domed bog, yet still with a body of water beneath.

2.6.3 Forms of standing open water

Depending on their size and setting, bodies of standing (i.e. non-flowing) open water can be wetland hydrosystems or classes in their own right, or they can be inclusions within other wetland classes (Fig. 34). Lakes are the largest and they can be arbitrarily defined by having a major dimension of 0.5 km or more, the criterion used by Irwin (1975a) in his checklist of New Zealand lakes. Nevertheless, many smaller bodies of water, including some dune lakes, kettle lakes, and oxbow lakes, could be validly referred to as lakes on the basis of depth, permanence, or the operation of typical lake processes such as stratification and wave-action. Thermal stratification

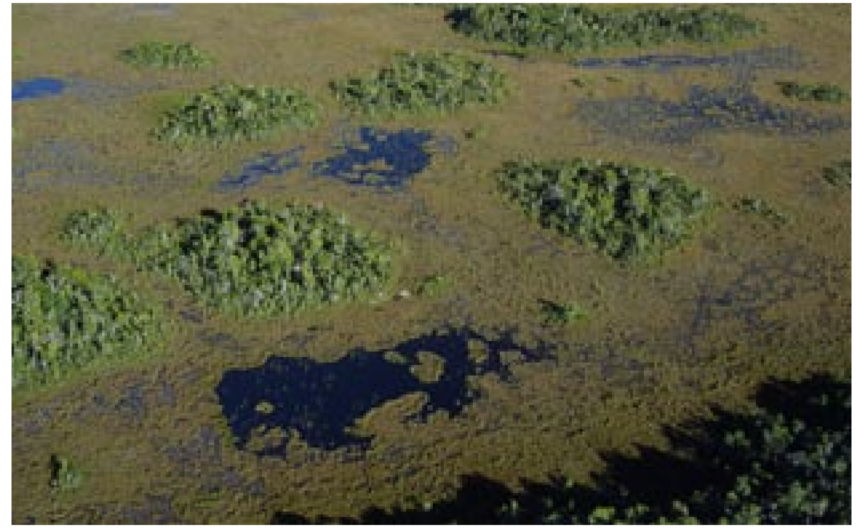


Fig. 34 Pools of shallow water are common in many palustrine wetlands, their shape, size, and distribution often being characteristic of particular wetland systems. These pools form part of a mosaic pattern with sedgeland, clumps and islands of reedland, and forested knolls in a Westland swamp system.

is the process whereby annual temperature cycles result in lake waters having horizontal layers of different densities. Monomictic lakes have a single period of stratification each year, generally in summer, alternating with a destratified period when mixing of the water layers, along with their nutrients and oxygen, is able to take place. Polymictic lakes have several periods of stratification and mixing each year. Amictic lakes are those which do not stratify.

A tarn is a small mountain lake (Fig. 35). A pond is an enclosed body of water, smaller than a lake, and often artificial, like the typical ponds of farmland. The term pool is applicable to an even smaller body of still water, often relatively stable in level, though it applies also, of course, to the deep and slow-flowing reaches of streams and rivers. The term peat pool is a useful one for pools within bogs and fens, these often having a characteristic rounded or oval shape, a relatively level base, and steep or overhanging peat margins.

A lagoon is a shallow lake, especially one that is permanently or periodically linked to a river, lake, or the sea. In New Zealand the term

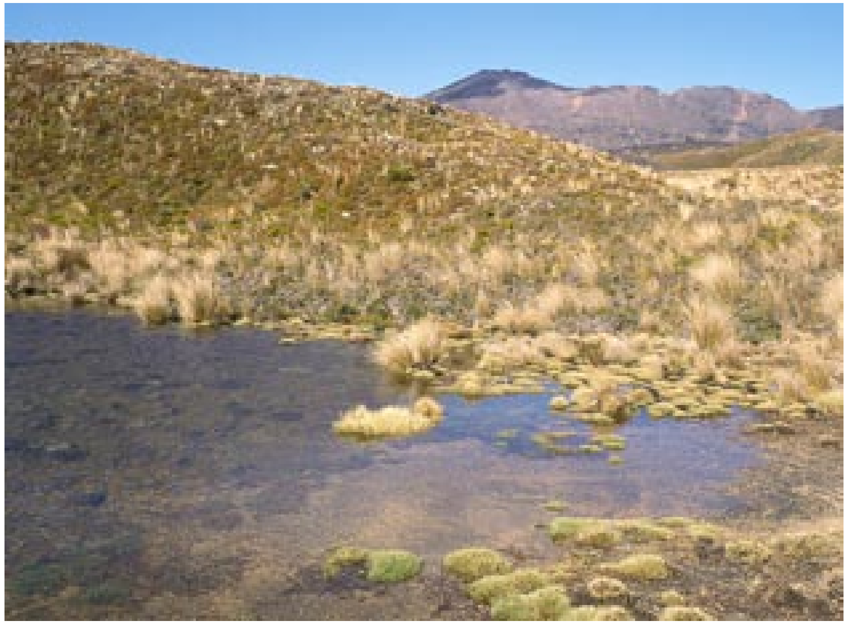


Fig. 35 An alpine tarn – or small lake – on the flanks of Mt Tongariro, Volcanic Plateau. This tarn has relatively little fluctuation, and is bordered by zones of cushion plants, tussockland, then shrubland.

lagoon is most often used for coastal lagoons (Fig. 36) but it is also used for inland examples. Coastal lagoons are separated from the sea by barriers of sand and gravel. They are usually shallow, often elongated parallel to the coast, with varying degrees of tidal prism and tidal mixing, and water that varies from fresh to brackish, and even to hypersaline where evaporation leads to salt concentrations (40‰ or more) exceeding than of oceanic water (c. 35‰). In the South Island, Kirk & Lauder (2000) recognise two distinct types of coastal lagoon: a 'hapua' type associated with the mouths of large braided rivers, having mainly freshwater but receiving some salt from spray and wash-over; and a 'Waituna' type (after Waituna Lagoon, Southland), more usually closed from the sea than open to it, having small inputs of river inflow, and with wind waves, currents, set-up, surge, and seiches as important mixing agents.

An estuary is a coastal body of water, partly enclosed by land but open to the sea, where seawater is diluted by land drainage, and where tidal effects

Fig. 36 Part of a coastal lagoon (Te Whanga Lagoon, Chatham Island) that is periodically open to the sea. In the background, beyond fernland and scrubland on blanket peat, are two coastal lakes, separated from the sea by dunes.

are evident. Many estuaries are located at the widened funnel-shaped mouth of a river, while others receive their freshwater only from streams (Fig. 37) and inflowing groundwater. Tidal rivers are those lowermost reaches of rivers affected by tidal flow or backwater, though these effects may have an influence further up-river than the inland boundary of the estuarine hydrosystem, defined by the place where marine salt concentration is 5‰. Harbours, inlets, and bays that are open to the sea have oceanic water and belong to the marine hydrosystem, but the deep and elongated fiords of high-rainfall Fiordland are distinctive as they receive considerable inputs of freshwater which persists as a permanent surface layer of low-salinity water buoyant above deeper seawater.

Man-made bodies of standing open water come in many forms, including hydro-electric lakes, reservoirs for irrigation or domestic water supply,

Fig. 37 A tidal creek in a bush setting, Stewart Island: an estuarine wetland with shallow water and a saltmarsh of *Puccinellia* grassland, influenced by gentle tidal ebb and flood flow, and by the mixture of freshwater and seawater.

farm ponds, ponds used for aquaculture, ornamental ponds, borrow pits, and ponds for the settling, treatment, or oxidation of discharges from stormwater, quarrying, mining, industry, and sewage.

2.6.4 Forms of flowing open waters and channels

Many wetlands either contain, are fed by, or are almost wholly composed of areas of moving water. Flowing waters within relatively permanent and well-defined channels will usually be classified within the riverine hydrosystem. Different portions of streams and rivers can be described by terms such as fall, cascade, rapid, riffle, run, glide, pool, backwater, bed, braid, and delta. Riparian habitats are those that occur along the margins of streams and rivers. Channels range in gradient from steep to gentle, and they may at one extreme be confined within a gorge (Fig. 38), or at the other extreme, free to spread laterally across a floodplain.

A braided river is one which carries a high sediment load, the ever-deepening shingle causing the river to follow numerous channels which

Fig. 38 A gorge (appropriately, Gorge River, south Westland) where extremes of flood discourage tall plants but encourage a broad zone of seepages.

repeatedly branch and rejoin, with an intervening pattern of low islands and shallow bars (Fig. 39). A meandering river or stream occupies a valley of low gradient, where the main channel is able to swing across the full width of its floodplain in sinuous turns called meanders (Fig. 40). As the channel shifts course the abandoned meanders (or oxbows when the cut-off river bend returns almost upon itself) can develop to marshes, ephemeral wetlands, swamps, or oxbow lakes.

Water channels that occur within palustrine wetlands are often too small or too slow to be called streams, but they can nevertheless display on a small scale many of the same sorts of adjacent features that can be seen on their larger counterparts. Much of the flowing water in palustrine wetlands is not channelled, but percolates as groundwater, or as a sheet of surface water (see Fig. 82).

As described earlier, the term seepage is here adopted for one of the wetland classes. A seepage (Fig. 41) is an area where groundwater percolates

Fig. 39 A braided river: one having numerous channels and carrying a heavy load of sediment, Waimakariri River, Canterbury.

to the land surface, the flow being less than that which would be considered a spring. A flush is a type of seepage that carries a periodic flush of water across the ground surface (Fig. 42). A spring is a stream emerging to the surface from underground at a point source (Figs 43 and 44). Both springs and seepages can emerge either upslope of, within, or at the toe of sloping wetlands. Their occurrence within a fen, for example, can be caused by an upwelling of groundwater through hydrostatic pressure, producing localised areas, sometimes as raised pustules, of enhanced aeration and nutrient status (Fig. 45).

Fig. 40 Stream meanders and oxbows of former channels are typical of a valley having a gentle gradient and a wide floodplain. This upland valley in the Garvie Mountains, northern Southland, holds a mixture of bogs and fens on the valley floor, and of seepages and pools on the opposite hillside.

Fig. 41 A seepage complex on the Lammermoor Range, Otago, nourished both from the adjacent tussock grasslands and the peat-retained pool on right, showing how degrees of water movement and flushing have produced a fine-scale pattern of different vegetation types, distinguishable by their colours.

Fig. 42 A flush is a seepage that receives periodic pulses of water. This example, on a relatively steep mountainside, shows how heavy rain events have eroded a surface channel, and also deposited stones and gravel that are being incorporated in the peat, Garvie Mountains, northern Southland.

Fig. 43 A spring, where water emerges from the ground as a point source (left) on the side of the Ahuriri Valley, northern Otago. The stable stream margin and the tufts of vegetation upon stream stones are indicators of constant flow and an absence of scouring sediments.

Fig. 44 A spring-fed stream near Twizel, inland Canterbury, where lush growth of herbs on the margins is indicative of a constant flow of well-aerated water and a moderate supply of nutrients.

Fig. 45 Part of a fen on the Lammerlaw Range, Otago, where an upwelling of groundwater is producing a raised 'pustule', bright green from lush herbs and liverworts, that is more fertile and better aerated than the surrounding sedgeland. The soft peat of such sites can be a trap for animals, such as the cattle beast whose remains are visible in this pool.

Seepages occur in many different situations, ranging from drip-channels on cliffs, to the splash-nourished sides of steep streams and waterfalls (Fig. 46), and to all the places where water oozes from the ground because of a change in slope, a layer of impervious rock, or an iron pan. Many seepages occur in hill and mountain country. A snowbank is a site on a mountainside which accumulates snow, is usually late to thaw, typically has a predominantly mineral substrate, is fully saturated during the weeks or months of snow-melt, yet at other times may be dry (see Fig. 81). Many snowbanks feed seepages that merge with and nourish flushes and fens downslope.

Man-made channels include canals, irrigation channels, open drains, and ditches.

Fig. 46 Waterfalls produce gradations of habitats affected by water flow, splash, or spray; usually with herbfield or mossfield, and can mostly be classified as seepages, Tongariro National Park, Volcanic Plateau.

2.7 Structural classes

This classification level is concerned with the general growth form or structure (physiognomy) of the vegetation, or the leading type of ground surface. The structure of vegetation results from the spatial arrangement, stature, and relative abundance of plant growth forms. Structural classes are described without reference to particular plant species: this aspect of describing composition comes into play for the succeeding and lowermost level of the classification.

Most vegetation has several layers (or tiers), best displayed by forests where the uppermost continuous layer of foliage – the canopy – is formed by tree crowns which overtop subcanopy layers of small trees and shrubs, and layers of ground plants. In situations where the tallest layer of vegetation is not continuous and does not form a complete cover, the canopy is, in effect, shared between layers, as in many wetlands; it comprises that foliage which faces upwards to the sky and would be seen in 'bird's eye' view. Vegetation structural classes are distinguished on canopy cover, i.e. the percentage contribution of different growth forms to the total canopy area.

The main vegetation structural classes of wetland plants, plus the growth habits of aquatic plants are shown in Fig. 47. The following descriptions of structural classes are based on the diagnostic criteria developed by Atkinson (1985) for terrestrial vegetation, with some modifications and additions relevant to wetlands.

Forest Canopy cover of trees and shrubs >80%, with tree cover exceeding that of shrubs. Trees (including tree ferns) are those having a trunk ≥10 cm dbh (diameter at breast height).

Treeland Tree canopy cover 20–80%, tree cover exceeding that of any other growth form, but tree canopy discontinuous above lower non-woody vegetation.

Scrub Canopy cover of shrubs and trees >80%, with shrub cover exceeding that of trees. Shrubs are woody plants <10 cm dbh.

Shrubland Canopy cover of shrubs 20–80%, exceeding that of any other growth form.

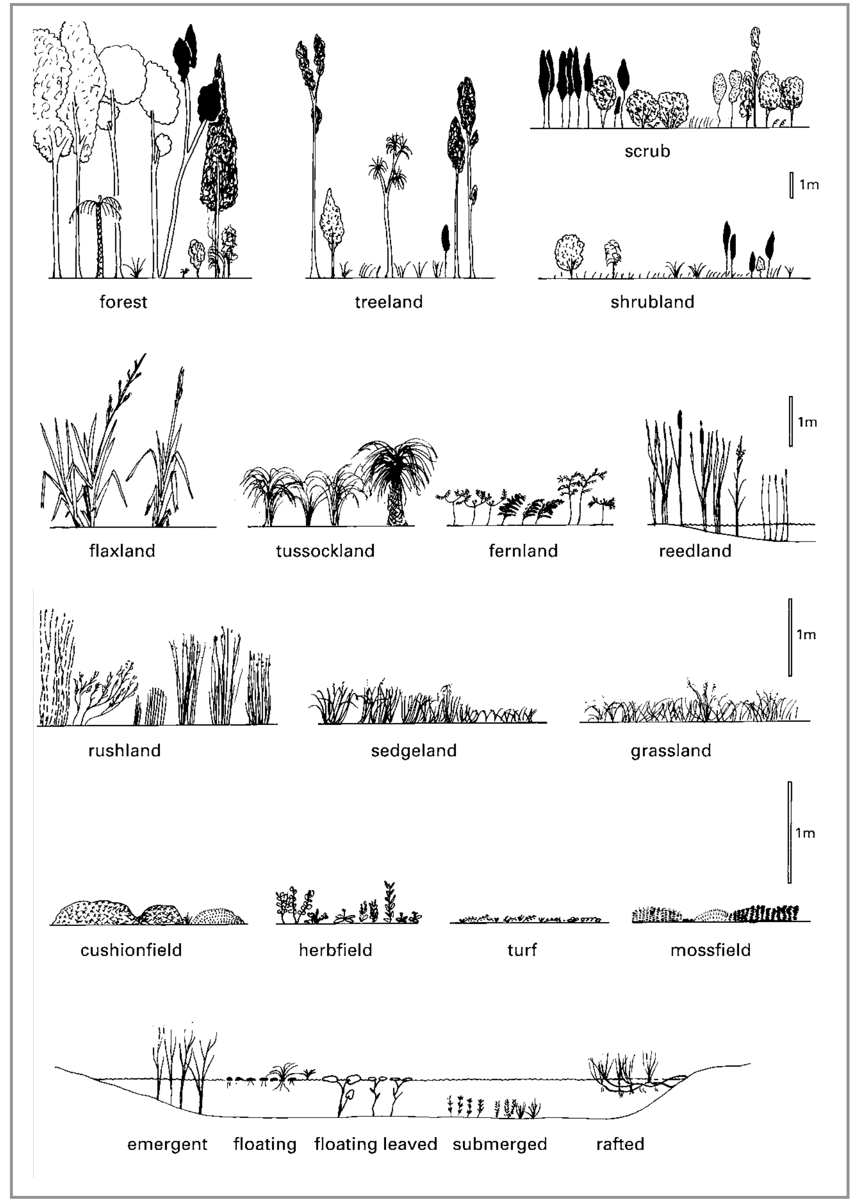


Fig. 47 Vegetation structural classes, and, at foot of diagram, growth habit of aquatic plants.

Flaxland Canopy cover of flax (*Phormium* spp.) 20–100%, exceeding that of any other growth form.

Tussockland Canopy cover of tussocks 20–100%, exceeding that of any other growth form. Tussocks include grasses and sedges >10 cm tall with fine linear leaves that arch upwards and outwards from a densely clumped base. Wetland tussocks include species of *Chionochloa*, *Cortaderia*, *Gahnia*, *Carex* (especially *C. secta*, *C. virgata*, *C. appressa*) and *Cyperus*, and *Schoenus pauciflorus*.

Fernland Canopy cover of ferns 20–100%, exceeding that of any other growth form.

Reedland Canopy cover of reeds 20–100%, exceeding that of any other growth form or open water. Reeds are tall erect herbs, emergent from shallow water, having unbranched leaves or stems that are either hollow or have a very spongy pith. Examples include *Typha*, *Bolboschoenus*, *Schoenoplectus*, *Phragmites*, *Phalaris*, *Zizania*, *Baumea articulata*, *Eleocharis sphacelata*, and *Glyceria maxima*.

Rushland Canopy cover of rushes 20–100%, exceeding that of any other growth form or bare ground. The rush growth form is characterised by those species of *Juncus* that have stiff, erect stems or similarly non-flattened leaves, but includes members of other genera (several *Baumea* and *Schoenus* spp., *Lepidosperma australe*, *Eleocharis acuta*, *Isolepis nodosa*) of similar growth form, and all species of the restiad genera *Sporadanthus*, *Empodisma*, and *Apodasmia*. The term restiad rushland may be used for vegetation dominated by these three genera, and wire rushland for that dominated by *Empodisma.*

Sedgeland Canopy cover of sedges 20–100%, exceeding that of any other growth form or bare ground. Sedges are members of the sedge family (Cyperaceae); the sedge growth form includes those plants having grass-like but usually coarser leaves, especially *Carex*, *Uncinia*, *Isolepis*, *Cyperus*, *Carpha*, and *Schoenus*. Note that several sedges belong in tussockland, reedland, rushland, and cushionfield.

Grassland Canopy cover of grasses 20–100%, exceeding that of any other growth form or bare ground. Tussock grasses belong in tussockland.

Cushionfield Cover of cushion plants 20–100%, exceeding that of any other growth form. Cushion plants include herbaceous, semi-woody, and woody plants with such dense branchlets and close-set leaves so as to form convex cushions. Cushion plants of wetlands include species of *Donatia*, *Gaimardia*, *Centrolepis*, *Oreobolus*, and *Phyllachne*.

Herbfield Cover of herbs 20–100%, exceeding that of any other growth form or bare ground. The herb growth form includes all herbaceous and low-growing semi-woody plants that are not separated as tussocks, ferns, reeds, rushes, sedges, grasses, cushion plants, mosses, or lichens.

Turf Herbfield of very low stature (generally <3 cm tall) of prostrate and tightly intertwined plants, typically composed of numerous species.

Mossfield Cover of mosses and / or liverworts 20–100%, exceeding that of any other growth form or bare ground.

Lichenfield Cover of lichens 20–100%, exceeding that of any other growth form or bare ground.

Algalfield Cover of algae 20–100%, exceeding that of any other growth form or bare ground.

2.7.1 Aquatic structural types

The growth habits of aquatic plants (Fig. 47) include those which are emergent, free-floating, bottom-rooted but with floating leaves, submerged, and rafted or sprawling (Coffey & Clayton 1988). These terms are all helpful when making a detailed description of aquatic vegetation structure. Wholly submerged vegetation attached to the substrate is often described in terms of being on the bed of a water body, hence algal bed or macrophyte bed. Extensive and unbroken beds of dense submerged plants are often referred to as some form of aquatic meadow, for example charophyte meadow (see Fig. 95).

2.7.2 Non-vegetated substrates

Diagnostic criteria for wholly or predominantly non-vegetated substrates are provided by Atkinson (1985). The categories of rockland, boulderfield, stonefield, gravelfield, sandfield, siltfield, clayfield, loamfield, and peatfield are each distinguished by having a greater area of any one of these substrate materials than of plants. Rockland has a predominance of residual bare rock. Definitions of particle sizes of substrate materials vary both within New Zealand and overseas, but the following are based on Milne et al. (1995): boulders exceed 200 mm diameter; stones (= very coarse gravel) 60–200 mm; gravel 2–60 mm; sand 0.06–2 mm; silt 0.002–0.06 mm; and clay <0.002 mm (see Fig. 130). Additional types of substrate and ground surface that occur in wetlands include driftwoodfield, bacteriafield, shellbeds, salt crust, and mudfield (mud being an unconsolidated and wetted mix of silt- and clay-sized particles).

2.7.3 Heathland

This term requires explanation because it is in common use; it does not appear in the formal list above because it is, in effect, a combination of several vegetation structural classes. Heath plants are trees, shrubs, or dwarf shrubs, typically slow-growing and often stunted. The leaves are small, scale-like or needle-like, and hard with a thick, waxy cuticle. The foliage tends to be flammable, and is also resistant to decay, producing acid litter. Many heath plants have very fine roots and shallow root systems. Heathland occurs on many substrates (Burrows et al. 1979). Heathland which occurs on wet substrates ('wet heath', e.g. Wardle 1991) usually comprises a mixture of shrubland or treeland with rush-like sedges, wire rush, and ferns. Such heathland, very often fire-induced, is the typical vegetation of pakihi and gumland, many blanket peatlands, some bogs and fens, and some non-wetland sites.

2.7.4 Use of structural class terms

The suffixes '-land' or '-field', allow the above terms to be used as stand-alone names, but when used in combination with a wetland class, a herbfield, for example, will usually be referred to as, say, a herb bog or herb marsh. When the combination of a structural class with a wetland class results in a clumsy name, it is appropriate to include the suffix, e.g. herbfield, shallow water. In practical usage many of the terms for non-vegetated substrates can be amended to acknowledge their landform setting: mudflat, boulder beach, sand bar, etc.

2.8 Composition of vegetation

This lowermost level of the classification allows wetland types to be named from one or more of the dominant plants in the vegetation.

A full description of vegetation at any site would include data on plant composition of all tiers, but for naming vegetation types and for mapping them it is usual to rely on the dominant canopy plants, these being what one would see in 'bird's-eye' view. The system of Atkinson (1985) has gained wide acceptance (see Clarkson et al. 2003). It is designed to convey as much information as possible about what is being named or mapped without becoming difficult to comprehend. The first step is to recognise the extent and boundaries of the vegetation unit according to the desired scale of description or mapping. The second step is to allocate a structural class name. Thirdly, the compositional name is determined. A vegetation type can usually be named from those plant species having 20% or more cover, a level of composition which means that seldom more than three species need to be named. If two or more species qualify, they are named in order of decreasing abundance. When no species reaches the 20% level the name is derived from the two most abundant species at the 15, 10, 5, or 1% level, whichever is appropriate. When plant cover is less than 1% the name applied is solely the type of ground surface, for example gravelfield.

The naming system of Atkinson also provides a format to convey height relationships between the named species. A hyphen (-) links species of similar height hence for example 'manuka - pink pine scrub bog'. A solidus (/) links a tall species with one from a lower layer, both being part of the canopy, as in 'cabbage tree / *Carex virgata* sedge swamp', indicating scattered cabbage trees within a sedge swamp dominated by *C. virgata*.

If required, a further degree of composition detail can also be incorporated in the vegetation type name using a format procedure to denote percentage plant cover ranges as in Table 10 of Atkinson (1985), viz. plant name underlined if >50% cover; without symbols if 20–49% cover; in round brackets ( ) if 10–19% cover; and in square brackets [ ] if 1–9% cover.

In some vegetation the presence of a plant species that is especially conspicuous will warrant its being included in the name for the vegetation type, in order to convey a realistic picture of the vegetation. Hence cabbage tree might be a conspicuous component of a flax swamp, yet present at only 15% cover, in which case the vegetation type can be named ('cabbage tree) / flax swamp'. It must be noted that although the Atkinson system for naming vegetation types is based upon canopy cover, there will be situations where it is desirable to distinguish and name a vegetation type by acknowledging a plant species which does not achieve 20% cover in the canopy yet is dominant and characteristic in one of the subcanopy layers. An example would be a desire to distinguish two types of closed-canopy manuka scrub fen, one having a dominant understorey of *Sphagnum* moss, and the other having wire rush. We suggest that by extending the Atkinson convention for conspicuous canopy plants to apply also to conspicuous or even dominant plants of the subcanopy, that the latter example could be named as 'manuka / [wire rush] scrub fen'.

Common names, when available, are ideal for brevity and are quite acceptable where their application to a plant species is unequivocal or explained. Scientific names are most accurately used by naming both genus and species, but naming the genus alone is equally clear when a genus has only one species in New Zealand, e.g. *Typha* (*orientalis*). If a plant can be identified only to the level of genus, then the uncertainty should be acknowledged (e.g. as *Baumea* sp. sedgeland). Situations also arise when relative abundance cannot be assessed for two or more similar species of a genus that are growing together, so the type must be named from the genus alone (e.g. *Baumea* spp. sedgeland; the abbreviation spp. indicating species in plural).

Section 5.1.7 expands on some issues commonly encountered when describing and mapping vegetation.

2.9 Wetland types

2.9.1 Examples of vegetation structure and dominant plants

The following illustrations of wetland types are described in a format that first emphasises the structural class (in bold type), notes the location (refer New Zealand map on inside front cover) and functional setting of the wetland, and then names the wetland type according to its dominant plants, structural class, wetland class, and hydrosystem.

Fig. 48 **Forest**. Arahaki Lagoon, Whirinaki, Volcanic Plateau; a depression upon volcanic ash (see soil profile, Fig. 131) where periodic ponding inundates the surrounding forest: kahikatea (*Dacrycarpus dacrydioides*) forest ephemeral wetland; palustrine.

Fig. 49 **Forest.** Waitangiroto, Westland; a lowland fen where sedgeland grades to a fringing zone of manuka scrub then silver pine (*Lagarostrobus colensoi*) forest bog; palustrine.

Fig. 50 **Forest**. Kaimai Range, Bay of Plenty; a hillside where mineral soils carry a flow of groundwater and surface water, evident from the wet sedgeland beside the vehicle track, and responsible also for the pale-green patch of pukatea (*Laurelia novae-zelandiae*) forest seepage; palustrine.

Fig. 51 **Forest.** Kopuatai, Hauraki Plain, Waikato; a modified area of the Kopuatai Peat Dome, adjacent to one of the major encircling drainage canals: grey willow (*Salix cinerea*) forest fen; palustrine.

Fig. 52 **Treeland.** Lake Wahapo, Westland; lowland swamp close to a lake, where a high water table allows for the presence of only scattered and stunted trees: kahikatea / flax tree swamp; lacustrine. Note that in this example, tree cover is only marginally sufficient for this to be called treeland rather than flaxland.

Fig. 53 **Treeland.** Maruia Valley, Buller; a gently sloping montane terrace having a high water table and constant flow of groundwater: mountain beech (*Nothofagus solandri* var. *cliffortioides*) / *Sphagnum australe* tree fen; palustrine.

Fig. 54 **Scrub.** Kopuatai, Hauraki Plain, Waikato; part of the fen that surrounds the bog of the Kopuatai Peat Dome (see also Figs 70, 140 and 141). Spindly manuka, 5–6 m tall, forms a mixture of shrubland (where its canopy cover is less than 80%) and of denser scrub: manuka / tangle fern - wire rush scrub fen; palustrine.

Figs 55 and 56 **Scrub.** Coromandel Harbour, Coromandel Peninsula; estuary mudflats and shell beds at two stages of the tide: mangrove (*Avicennia marina* subsp. *australasica*) scrub saltmarsh; estuarine.

Fig. 57 **Shrubland.** Longwood Range, western Southland; a hilltop bog set among silver beech (*Nothofagus menziesii*) forest: bog pine (*Halocarpus bidwillii*) / *Donatia novae-zelandiae* shrub / cushion bog; palustrine.

Fig. 58 **Flaxland.** Mahinapua, Westland; part of a swamp grading from a stream channel (foreground) to kahikatea forest (background): *Phormium tenax* - *Coprosma propinqua* flax swamp; palustrine.

Fig. 59 **Tussockland.** Lagoon Saddle, inland mid-Canterbury; moist peaty slopes leading down to peat pools in a montane valley head: red tussock (*Chionochloa rubra*) - *Hebe odora* tussock fen; palustrine.

Fig. 60 **Tussockland.** Longwood Range, western Southland (and Stewart Island in distance); shallow peatland on a poorly drained range crest, with some *Dracophyllum longifolium* shrubland, but otherwise *Chionochloa teretifolia* tussock bog; palustrine.

Fig. 61 **Tussockland.** Glenmore, Lake Tekapo, Canterbury; rolling moraine country with a gently sloping seepage in a stream head, the constantly wet valley floor having *Carex diandra* sedgeland while the more mineral and less saturated soils of the flanking slopes have *Schoenus pauciflorus* tussock seepage; palustrine.

Fig. 62 **Fernland.** Taramoa, Southland; a lowland plain domed bog, some parts of which have sufficient fern cover to be regarded as fernland: tangle fern (*Gleichenia dicarpa*) fern bog; palustrine.

Fig. 63 **Fernland.** Taia, Chatham Island; blanket peat on almost flat land bounded by sand dunes and the coastal lagoon of Te Whanga: bracken fern (*Pteridium esculentum*) bog (with restiads, lichens, mosses; modified by fire and livestock); palustrine.

Fig. 64 **Reedland.** Pukepuke Lagoon, Manawatu; a small lake among lowland sand plains, with marginal vegetation of raupo (*Typha orientalis*) reedland, shallow water; lacustrine (right), and in the foreground Mercer grass (*Paspalum distichum*) grassland.

Fig. 65 **Reedland.** Lake Ngatu, Northland; a dune lake with erect, emergent-aquatic sedges (*Baumea juncea* in foreground; *Eleocharis sphacelata* in deeper water beyond). These can be classified as reedlands in the wetland class of shallow water; lacustrine.

Fig. 66 **Reedland.** Tom Bowling Bay, Northland; a tidal creek: *Schoenoplectus validus* reedland, shallow water; estuarine.

Fig. 67 **Rushland.** Tongariro River delta, Volcanic Plateau (see Fig. 106); a moist valley floor with mineral soil that receives fresh silt deposits with floods (see Fig. 135): *Juncus effusus - J. edgariae* (centre of photo) rush marsh; riverine.

Fig. 68 **Rushland.** Kumara, Westland; a lowland terrace where forest has been felled for podocarp timber, the induced wetter ground favouring growth of *Sphagnum* moss, which is harvested from such sites: *Juncus canadensis / Sphagnum cristatum* rush fen; palustrine.

Fig. 69 **Restiad rushland.** Dismal Swamp, south Westland; part of a large lowland mire on a coastal plain, where frequent fire erodes the scrub and forest margins. The flexuose and bristly stems of wire rush scramble among and cling to each other, forming self-supporting tufts: *Empodisma minus* restiad rush bog; palustrine.

Fig. 70 **Restiad rushland.** Kopuatai Peat Dome, Hauraki Plain, Waikato (see also Figs 140 and 141). Kopuatai is the largest of the remaining northern New Zealand peat domes dominated by the tallest native restiad, cane rush (*Sporadanthus ferrugineus*). The dome crest receives water only from rain and is therefore bog. The photo shows vegetation dominated by *Sporadanthus* 2.2 m tall and about 30% cover, over wire rush (1 m tall, 50% cover), tangle fern (10%), and the sedge *Schoenus brevifolius* (10%). This can be classified as *Sporadanthus* / *Empodisma* restiad rush bog; palustrine.

Fig. 71 **Sedgeland.** Red Lagoon, near Lake Ohau, Canterbury; a broad depression in a valley floor of glacial outwash gravels where peat has accumulated beside a tarn. The water table is mostly above the ground surface, and the presence of raupo (middle distance) is an indicator of relatively high nutrient status, so this is a swamp. In foreground: *Carex sinclairii - C. diandra* sedge swamp; palustrine.

Fig. 72 **Sedgeland.** Lake Waikaremoana, Hawkes Bay; a sheltered bay with deep inorganic sediment on a gentle slope of moderate drainage that is inundated when the lake level is high: a *Carex* spp. sedge marsh; lacustrine. The marsh is dominated by *Carex geminata* (left distance), *C. virgata* tussocks (centre), and *C. sinclairii* (right foreground).

Fig. 73 **Grassland.** Kopuatai, Hauraki Plain, Waikato; a fen, modified by drainage, increased fertility, and weed invasion, for example by grey willow (*Salix cinerea*; background), and in foreground: Yorkshire fog (*Holcus lanatus*) grass fen; palustrine.

Fig. 74 **Grassland.** New River Estuary, Southland; mudflats in a large estuary invaded by one of the naturalised cord grasses (*Spartina anglica*): spartina grass saltmarsh; estuarine.

Fig. 75 **Grassland.** Maniototo basin, central Otago; a wide inland basin where former river meanders are influenced by salty mineral soils, and in this example, by increased fertility from dairy farming and its effluent. The wet (green) grassland zone is dominated by creeping bent (*Agrostis stolonifera*) and the moist zone (right) by squirrel tail grass (*Critesion jubatum*): an indicator plant of salty sites. These are grass marshes; inland saline.

Fig. 76 **Cushionfield.** Mararoa Valley, northern Southland; a montane valley floor where bog peat has accumulated on an almost level terrace, and where the hummock-and-pool topography has been created by the dense cushions – or bolsters – of comb sedge: *Oreobolus pectinatus* cushion bog; palustrine.

Fig. 77 **Herbfield.** Lower Waikato Valley, Waikato; a lowland floodplain, sometimes flooded and afterwards ponded, where agriculture has raised fertility of the mineral soil. Many naturalised plants are co-dominant; this could be described as willow weed - buttercup - dock herb marsh; riverine. In the background is treeland of crack willow (*Salix fragilis*) and alder (*Alnus glutinosa*) upon the levee adjoining a river channel.

Fig. 78 **Herbfield.** Taupo Swamp, Wellington; a roadside ditch stream of high nutrient status: water celery (*Apium nodiflorum*) - starwort (*Callitriche stagnalis*) herbfield, shallow water; riverine.

Fig. 79 **Herbfield.** Aramoana, Otago Harbour; an estuary where mudflats of the low intertidal zone have a ‘meadow’ of seagrass (*Zostera novazelandica*): this can be classified as seagrass herb saltmarsh; estuarine.

Fig. 80 **Herbfield.** Aramoana, Otago Harbour; estuary sandfields of the upper intertidal zones: glasswort (*Sarcocornia quinqueflora*) herb saltmarsh, grading (at left) to saltgrass (*Puccinellia*) grass saltmarsh, then knobby clubrush (*Isolepis nodosa*) rush saltmarsh on higher ground; estuarine.

Fig. 81 **Herbfield.** Garvie Mountains, northern Southland; the mid-summer remnant of an alpine snowbank. Stony mineral soils, revealed by the sheep tracks, are flushed with seasonal snow melt yet well drained and dry at other times. The brighter green stripes are seepages that are permanently wet and more peaty. Numerous plant species are co-dominant in the various communities, but they are all basically herbfield; palustrine.

Fig. 82 **Herbfield.** Old Man Range, Otago; an alpine seepage which can be regarded as a flush, seen here in early summer being inundated by a shallow, flowing sheet of snow-melt water. This community could be named from the characteristic presence of white caltha (*Psychrophila obtusa*), which bears conspicuous flowers immediately after the complete melt of its winter snow blanket: caltha herb seepage; palustrine.

Fig. 83 **Turf.** Awarua Bay, Southland; upper intertidal zones in the sheltered part of an estuary where the herbfield is of such low stature that it can be referred to as turf: *Selliera radicans - Samolus repens* turf saltmarsh; estuarine.

Fig. 84 **Turf.** Glenmore, Lake Tekapo, Canterbury; a depression with mineral soil in undulating moraines, lacking any inflowing stream or surface outlet, which ponds in winter and spring when groundwater input is high, then dries in summer. Different periods of inundation produce concentric zones of plant communities of numerous plant species, where composition varies over very short distances: turf ephemeral wetland; palustrine.

Fig. 85 **Mossfield.** Lammermoor Range, Otago; rolling land in the montane zone with snow tussock grassland. Peat accumulation in gully heads can vary in character between bog and fen: the red-brown patch in this small wetland is *Sphagnum cristatum* moss fen; palustrine.

Fig. 86 **Mossfield.** Tuku, Chatham Island; a very poorly drained hill crest on the blanket peat of the southern table-land, with low *Dracophyllum arboreum* forest beyond, and in foreground: *Sphagnum falcatulum* moss bog; palustrine.

Fig. 87 **Mossfield.** Hollyford Valley, Fiordland; a temporary stream channel with a silty base on a forested valley floor; ponded during and after rain storms, and sufficiently wet at other times to exclude woody plants but encourage tussocks of *Carex virgata* among *Hypnodendron marginatum* moss ephemeral wetland; palustrine.

Fig. 88 **Lichenfield.** Lammerlaw Range, Otago; an upland mire where upward growth of herb and moss cushions has raised their surface sufficiently above the water table for lichen dominance to be favoured by the frequent alternation of drying and wetting by rain and mist: *Alectoria - Cetraria* lichen bog; palustrine.

Fig. 89 **Algalfield.** Middlemarch, Otago; a stream in open grassy country at a time when low summer flow and warm temperature encourage rampant growth of filamentous green algae: algalfield, shallow water; riverine.

2.9.2 Examples of aquatic plant growth habit

The following illustrations show how the growth habit of aquatic plants, and where they grow in relation to water surface level and substrate, can be used as additional descriptors for shallow-water habitats.

Fig. 90 **Emergent aquatic.** Hamilton Lake, Waikato; the shallow margins of a small lake of relatively stable water level where bottom-rooted plants are emergent, holding their foliage above water level. Emergent lake clubrush (*Schoenoplectus validus*) - yellow flag (*Iris pseudacorus*) reedland, shallow water; lacustrine.

Fig. 91 **Floating aquatic.** Near Lake Wairarapa, southern North Island; an ephemeral wetland where a long period of shallow ponding and moderate to high fertility have fostered a phase of dense herbs and grasses. The red vegetation is a dense pool-surface coating of free-floating plates of retoreto along with tiny green platelets of duckweed. Floating retoreto (*Azolla filiculoides*) - duckweed (*Lemna minor*) fernland, ephemeral wetland; palustrine.

Fig. 92 **Floating aquatic.** Taramakau Valley, Westland; a swamp pool with pondweed (*Potamogeton cheesemanii*), its floating, water-repellant leaves held upon stems which are bottom-rooted, even at depths of 2 m or more. Floating pondweed herbfield, shallow water; palustrine.

Fig. 93 **Rafted aquatic.** Waihola–Waipori wetlands, east Otago; a swamp channel bordered by giant sweetgrass (*Glyceria maxima*), rooted on, or closely beneath, the shore, but with buoyant stems and foliage extending as a raft several metres across the water. Rafted giant sweetgrass grassland, shallow water; palustrine.

Fig. 94 **Rafted aquatic.** Birchfield Swamp, near Westport, Buller; a raft of swamp vegetation that cannot be walked upon and hides the deep pool of water beneath. The pool surface has been covered first by a mass of stems and foliage, partly emergent, of milfoil (*Myriophyllum robustum*; centre foreground). This has been colonised by the perching pale-green tufts of the sedge *Isolepis prolifer*. Rafted milfoil herbfield, shallow water; palustrine.

Fig. 95 **Submerged aquatic.** Kaimai Range, Bay of Plenty; a stream crossing an upland forested plateau, where the gentle gradient, steady flow, and relatively low sediment load allow for the growth of dense clumps of charophyte algae that are attached to stream bed gravels and permanently submerged. Submerged charophyte algalfield, shallow water; riverine.

Fig. 96 **Submerged aquatic.** Garvie Mountains, northern Southland; a stream head emanating from alpine seepages, the stream rocks being vegetated with black aquatic lichens (*Verrucaria* spp.) and the shallow margins with mosses, a demonstration that many groups of non-vascular plants contribute to submerged aquatic communities. Submerged *Verrucaria* lichenfield, shallow water; riverine.

Fig. 97 **Submerged aquatic.** Tongariro River, Volcanic Plateau; a shallow stony pool of a river flood channel where the living matter is composed of attached films and suspended masses of iron bacteria which gain their energy by decomposition of organic matter and oxidation of iron. Submerged bacteriafield, shallow water; riverine.

THREE

Wetland patterns

Most wetlands are not uniform but contain several different plant communities. Two or more wetland classes may occur adjacent to one another, or one class may be contained within another. Some wetland complexes can even extend over more than one hydrosystem.

The spatial arrangement of wetland classes, vegetation structural classes, and also wetland forms will often produce a readily discernible pattern. A wetland can be described as being patterned when its features are arrayed in a repeated fashion, often most obvious on aerial photos. Sequences of several vegetation structural classes, such as sedgeland to scrub to forest, can usually be interpreted as lying along some environmental gradient, in this example probably from wet to drier ground. One clear type of pattern is the zonation of vegetation types, as can be seen beside a lake or estuary, where water fluctuation is obviously the strongest environmental influence. When several environmental factors are interacting, the patterns of spatial distribution can be more complicated, and will often provide a challenge for interpreting how they have arisen.

Because factors such as substrate type, wetness, and nutrient status vary along gradients, the resulting vegetation types seldom have distinct boundaries, but instead merge with each other, the transition zones being called ecotones. Patterns can occur at many scales. Many wetland types are difficult to delimit or map because they occur as patches or fingers among a matrix of dryland vegetation, or else as narrow elongated strips adjoining a lake or river.

Some examples of wetland pattern have already been illustrated in Section 2.6 on wetland forms. The six further examples in Sections 3.1 to 3.6 have been selected to demonstrate the following points:

- the relationship between hydrosystems, wetland classes, and vegetation structural classes;
- correlations between substrates, hydrology, and vegetation types;
- working examples of how wetland patterns can be interpreted;
- the usefulness of vertical and oblique aerial photos for revealing wetland features;
- means of portraying patterns: habitat and vegetation maps, diagrams, profile drawings;
- patterns at both a broad and a fine scale.

3.1 Hydrosystems and wetland classes on a coastal plain

Vertical aerial photos are an ideal way to perceive broad-scale patterns of landforms, wetland patterns, and vegetation. Bodies of water usually show dark, with different tones depending on water depth and clarity. Vegetation types can be discerned from their textures, tones, and colours, though the last two of these can vary between seasons. This example (Fig. 98) shows a coastal plain where wetlands have developed behind a series of former beach ridges, laid down over several thousands of years, as the coastline has prograded – moved seawards – in conjunction with a relative drop in sea level. Boundaries of hydrosystems and wetland classes are shown in Figs 99 and 100.

Fig. 98 This vertical aerial view embraces 2 × 1.5 km of a wetland complex on the coastal plain near Haast, south Westland. Beach ridges with podocarp forest have parallel intervening swales of bog. On the inland side (right) are swamps associated with the dark meanders of the Maori River. The pale area (top right) is the bed of the more flood-prone and sediment-loaded Waita River.

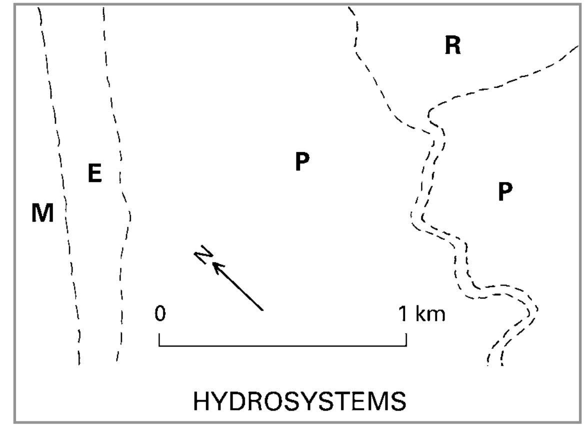


Fig. 99 Diagram relating to Fig. 98, showing the distribution of four hydrosystems: M = Marine; E = Estuarine; P = Palustrine; R = Riverine.

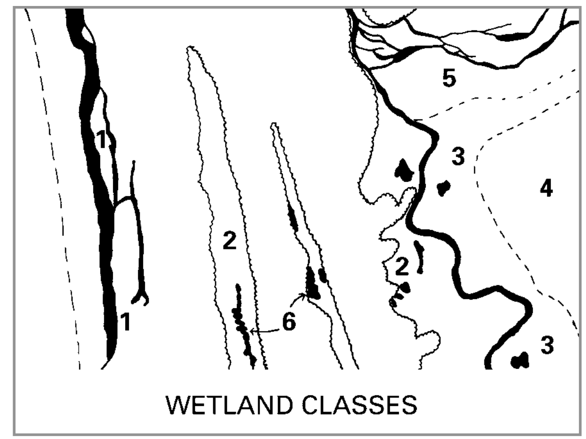
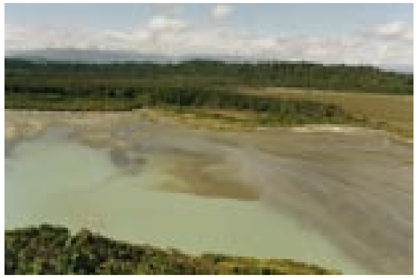


Fig. 100 Diagram relating to Fig. 98, showing the distribution of six wetland classes:
1. Saltmarsh on margins of river mouth lagoon;
2. Bog in swales between dune ridges;
3. Swamp infilling depression behind innermost dune ridge;
4. Fen on gentle slopes leading down to swamp;
5. Marsh on damp alluvium of river terraces;
6. Shallow water of bog and swamp pools, rivers, and coastal lagoon.

3.2 Linking hydrosystems to wetland classes and vegetation

Only a few wetland systems have a convenient nearby hill for an overview of the components. At the Wanganui River mouth in Westland the moraine hillock of Mt Oneone provides a panoramic view (Figs 101, 102, and 104) demonstrating hydrosystems, wetland classes, and structural classes.



Figs 101 and 102 The mouth of the Wanganui River and the gravel bar that encloses its small estuary. Note the patterns of water movement in the braided river and the various types of sediment in the estuary: a complexity that has its unseen counterparts in wetlands that are covered with vegetation.

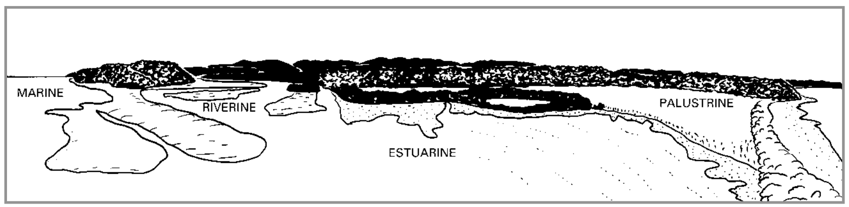


Fig. 103 Diagram showing the hydrosystems represented within Figs 101, 102, and 104.

Fig. 104 This palustrine wetland is called Doughboy Pakihi, but is best classified as fen plus swamp. It is a peat-filled hollow bounded by a coastal dune and the forested moraine ridge beyond.

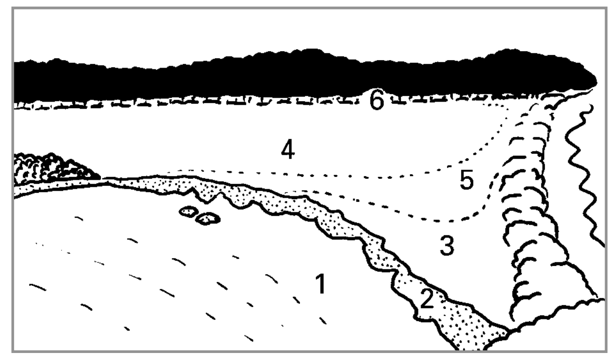


Fig. 105 Diagram relating to Fig. 104, showing the distribution of hydrosystems, wetland classes, and structural classes:

1. Estuarine mudflats;
2. Estuarine saltmarsh with zones of turf and rushland;
3. Palustrine swamp with flaxland;
4. Palustrine fen with sedgeland;
5. Palustrine fen with scrub (this zone recently burned);
6. Palustrine fen with treeland and forest.

3.3 Patterns on a river delta entering a lake

Most wetland patterns are a reflection not only of current environmental gradients, but also of landform genesis and human impacts. Lake Taupo is a huge, but relatively young lake, dating from the massive Taupo eruption of c. AD 186. Pushing into the south end of the lake, the Tongariro River has built a delta with coarse greywacke and pumice gravels on riverbank levees, and deposits of finer alluvium in the intervening hollows, where poor drainage is partly a result of ponding behind lake-shore storm-beach ridges.

Fig. 106 Wetlands on the delta of the Tongariro River, south end of Lake Taupo, with the town of Turangi just up-valley. There have been several human influences on this wetland system. Maori lived here, the Waitahanui Pa being situated on the left of the river's main mouth (left foreground). Farm development involved clearance of forest and scrub and attempts at drainage. Raising of Lake Taupo by c. 1 m in 1941 encouraged re-establishment of wetland vegetation. In the 1970s the Tokaanu Tailrace Canal was excavated through the wetland in right distance.

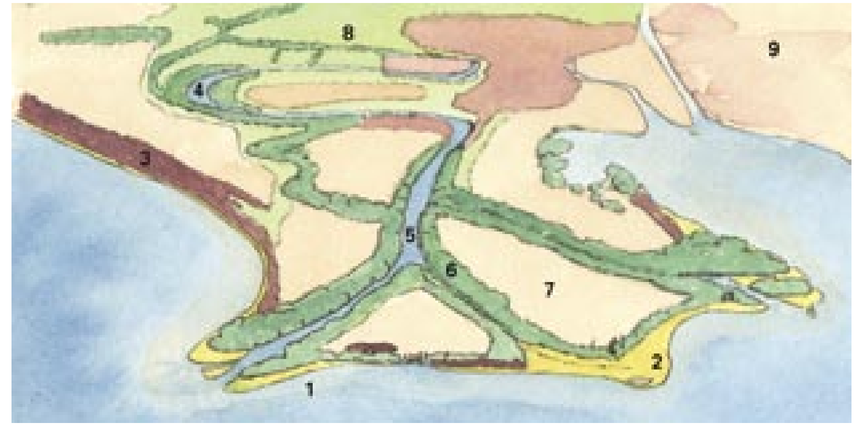


Fig. 107 Tongariro River delta: an interpretation relating to Fig. 106, showing the distribution of hydrosystems, wetland classes, landforms, structural classes, and vegetation:

1. Lacustrine shallow water, in bays and on delta shelf with submerged aquatic vegetation;
2. Lacustrine beach of bare pumice gravels, with turf and grassland;
3. Lacustrine storm beach with manuka scrub;
4. Riverine meander;
5. Riverine delta channel;
6. Riverine levee with crack willow forest;
7. Palustrine swamp with sedgeland, reedland, and flaxland;
8. Palustrine marsh with rushland and grassland;
9. Geothermal: localised fumaroles and hot pools near base of hill.

3.4 A dryland-to-wetland sequence on an alluvial plain

Patterns of wetland types are often caused by the way substrates of different-sized particles are deposited by gravity and along waterways. This example spans a sequence from dryland hillside habitats to progressively wetter wetlands. On a steep hillside large boulders and rocks tumble down to form well-drained talus slopes. During heavy rains, streams and rivers transport rocks and stones a certain distance down valley. Gravel, sand, and silt are carried a greater distance, to be deposited more slowly as substrates having progressively poorer drainage.

Fig. 108 Waiuna Lagoon, at Big Bay, south Westland, is a shallow, lowland lake that is being gradually infilled by the deltas of tributary rivers and streams.

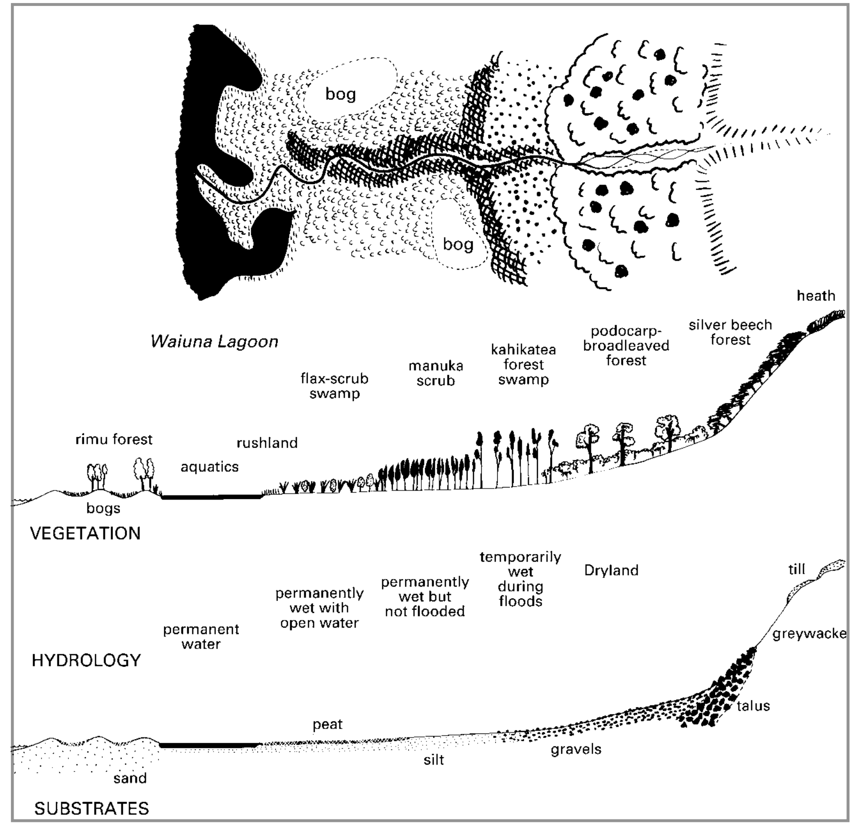


Fig. 109 Sketch map and profile diagrams of the alluvial plain and delta beside Waiuna Lagoon (see top right of Fig. 108). The gradient (right to left) of substrate materials and decreasing soil drainage is reflected in the sequence from forests to scrub swamp, bogs, marshes, then aquatic vegetation.

3.5 Zonation pattern on a lake shore

One of the more simple types of wetland pattern is a zonation, where a parallel sequence of wetland types arises in response to one dominant environmental influence. On lake shores strong zonation patterns are caused by water level fluctuation. Permanently aquatic zones are governed by the amount of light reaching different depths of water. Further upslope the zones relate to duration and frequency of submergence.

Fig. 110 Lacustrine shore zones, Lake Te Anau, Fiordland. This lake, glacial by origin, has a total fluctuation of 3.5 m. The turf zone (left) is under water about half the time. The zones of restiad rushes (centre), scrub, and forest (right) are submerged less often and for progressively shorter periods. At this site, stony shores of an exposed promontory meet the mobile gravels that belong to the end of a bay (foreground). These gravels display a stepwise set of low beach ridges, shaped by waves during successive storms through a period of falling lake level.

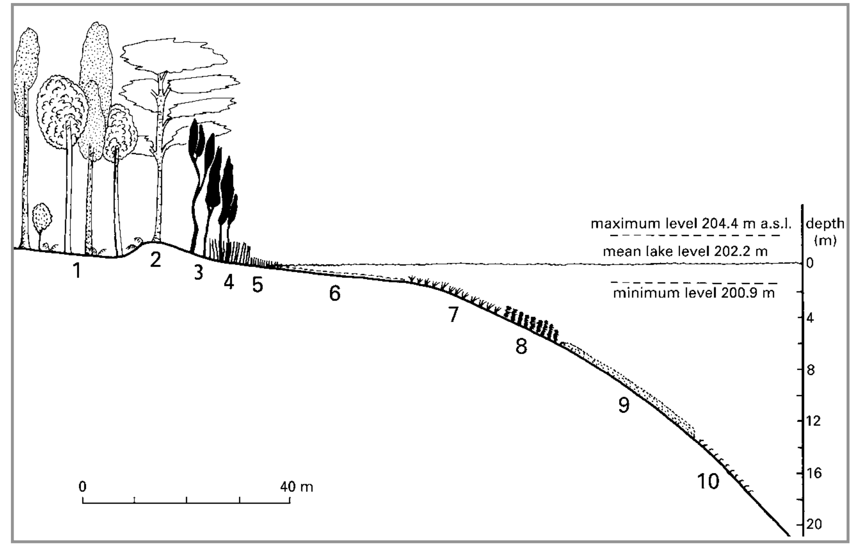


Fig. 111 Diagrammatic profile of a gentle, relatively sheltered shore at Lake Te Anau, Fiordland, showing the main vegetation zones in relation to fluctuating lake level:

1. Kahikatea (*Dacrycarpus dacrydioides*) - pokaka (*Elaeocarpus hookerianus*) forest swamp in poorly drained hollow behind storm ridge, sometimes ponded with floodwaters;
2. Beech (*Nothofagus*) forest on well-drained storm ridge, intolerant of inundation exceeding c. 50 days;
3. Manuka (*Leptospermum scoparium*) scrub marsh on silty gravels, tolerant of prolonged inundation by high lake levels;
4. Oioi (*Apodasmia similis*) restiad rush marsh;
5. *Carex gaudichaudiana* sedge marsh as a short sward;
6. Turf: several zones of turf marsh of different composition related to degrees of submergence and drying;
7. Aquatic herbfields: *Isoetes kirkii* beds and taller macrophytes (*Potamogeton* and *Myriophyllum* spp.), permanently submerged in the depth range of 2–8 m below mean lake level;
8. Canadian pondweed (*Elodea canadensis*) to 1.5 m tall, at 1–7 m depth;
9. Charophyte meadows: beds of *Chara* and *Nitella* spp. reaching 15 m depth;
10. Bryophytes: sparse mosses and liverworts to 17 m depth.

3.6 Pattern in a fiord-head marsh

Where a river enters the sea the pattern of wetland habitats is governed not only by river processes, channels, and sediments, but also by the gradient of salinity up the estuary and into the tidal stretch of river. In Fiordland the marshes at the heads of long fiord arms are less saline than in estuaries elsewhere. This is because the very high rainfall results in a surface layer of relatively fresh water that overlies, and does not readily mix with, the underlying seawater of the fiord.

Fig. 112 Estuarine saltmarsh where the Camelot River enters the head of Bradshaw Sound, Fiordland. The steep-sided valley was sculpted by a glacier. Since the end of the last glaciation, river alluvium has partly filled the valley floor and formed a delta at the fiord head. This photo was taken at about low tide.

Fig. 113 Map showing pattern of habitats and vegetation types at the Camelot River mouth, Fiordland.

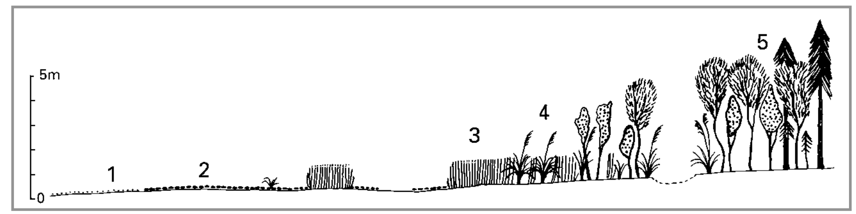


Fig. 114 Profile diagram showing habitats and vegetation types at the Camelot River mouth. The numbered features (see also Fig. 113) are:

1. Gravelly mudflats with algae in lower intertidal zone;
2. *Samolus repens* turf saltmarsh with *Poa astonii* tussocks, intertidal;
3. Oioi (*Apodasmia similis*) restiad rush saltmarsh, upper intertidal;
4. Toetoe (*Cortaderia richardii*) grass saltmarsh in uppermost intertidal zone;
5. Scrub marsh of *Carmichaelia australis*, *Coprosma propinqua*, and young kahikatea in supratidal zone, often flooded by river;
6. Forest of kahikatea, silver beech, and rimu (*Dacrydium cupressinum*) on river levees and alluvial flats;
7. Backswamp with flax - *Carex* spp. swamp;
8. Broadleaved forest (non-wetland) on steep stream fans;
9. Silver beech - kamahi (*Weinmannia racemosa*) forest (non-wetland) on very steep hillsides.

FOUR

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

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.

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).

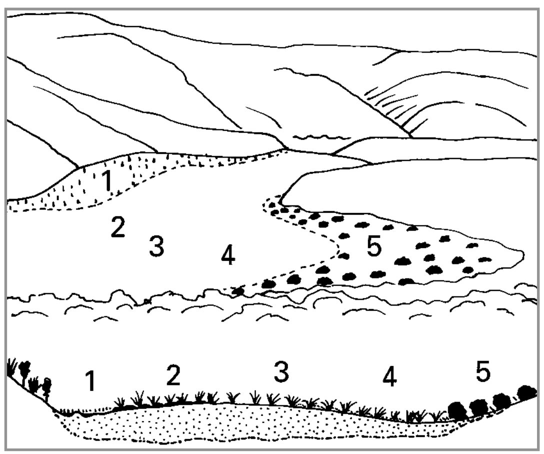


Fig. 122 Sketch and profile diagram relating to Fig. 121, showing numbered sources of the five peat types shown in Fig. 123.

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.

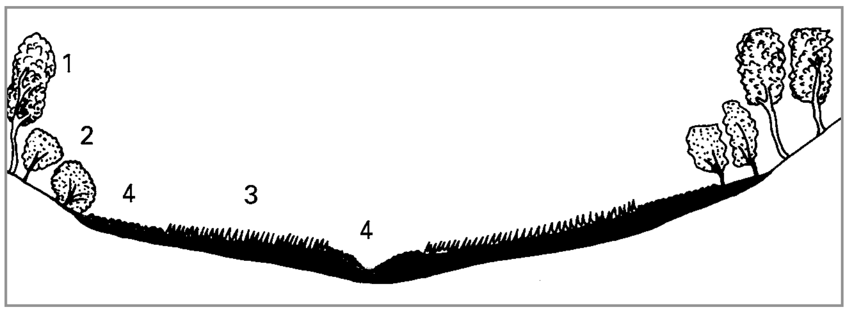


Fig. 125 Profile showing pattern of principal vegetation types:
1. Forest (surrounding): *Podocarpus hallii* and *Quintinia serrata*;
2. Bog pine (*Halocarpus bidwillii*) - mountain toatoa (*Phyllocladus alpinus*) scrub bog on relatively well-drained peat;
3. Fern bog on peat having little water movement: 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.

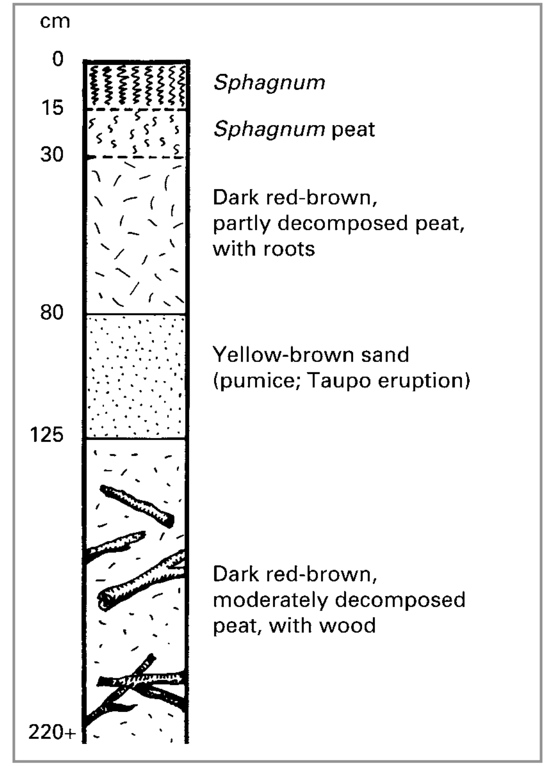


Fig. 126 Peat profile from Ongarue 'A' mire (simplified from Clarkson 1984). The peat in the lower part of the profile contains much wood, the remains of a wetland that had been dominated by bog pine and mountain toatoa. This is overlain by a deep layer of pumice sand, deposited by the Taupo eruption 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.

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.

4.4.2 Some mineral wetland soils

Fig. 131 An ephemeral wetland soil. Profile (to 30 cm depth) beneath turf in a seasonally ponded depression, Arahaki Lagoon, Whirinaki, Volcanic Plateau (see Fig. 48). The upper horizon is firm silt, dark-stained by humus though only slightly organic. This grades down to compacted and then looser pumice gravels. Drainage is relatively good and this soil becomes moderately dry over summer.

Fig. 132 A pakihi soil. Profile from an outwash surface, German Terrace, near Westport, Buller (see Fig. 19). A relatively uniform silty soil, highly infertile, from beneath tangle fern (*Gleichenia dicarpa) - Baumea teretifolia* fern pakihi. This soil allows for only very slow water movement, but can become quite dry at times of low rainfall if the underlying water table is lowered. The sampled core is not of sufficient depth to show the probable underlying iron-humus pan that is the main factor in restricting drainage.

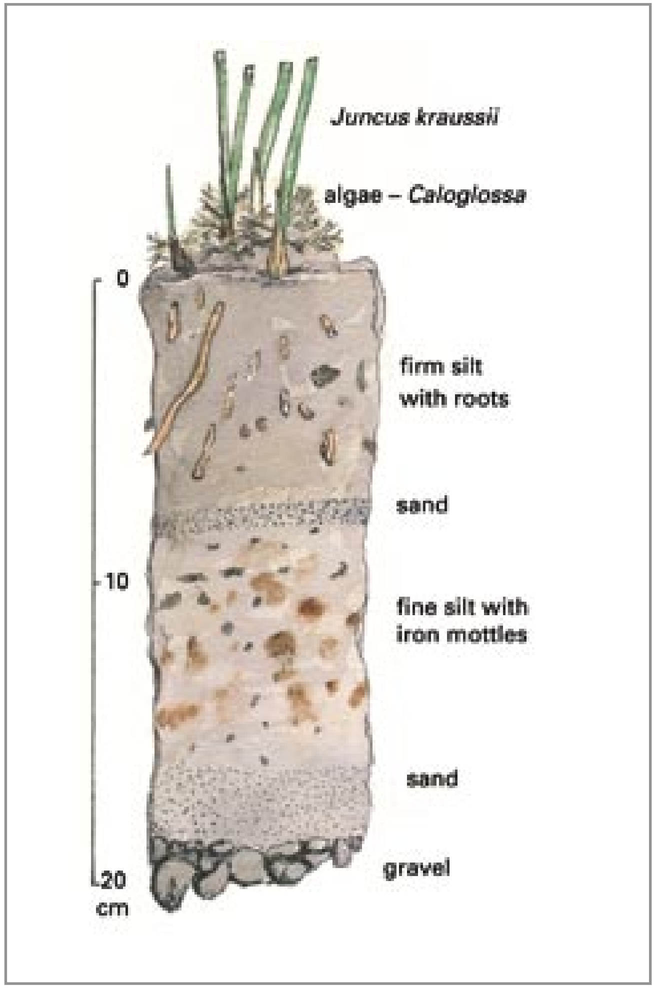


Fig. 133 An estuary soil from a tidal creek mouth. The varied deposition history is shown by layers of gravel, sand, and silt. The grey colour of the silt results from the process of gleying that occurs in wet soils where oxygen is scarce, and where iron compounds are present in their ferrous state, i.e. chemically reduced and often blackish. Rusty mottles and streaks are iron compounds in their ferric state, i.e. chemically oxidised. The mottles indicate places of better aeration. They can be common in soil horizons where the water table fluctuates. This soil, from Pauatahanui Inlet, Wellington, supports saltmarsh of sea rush (*Juncus kraussii* subsp. *australiensis*).

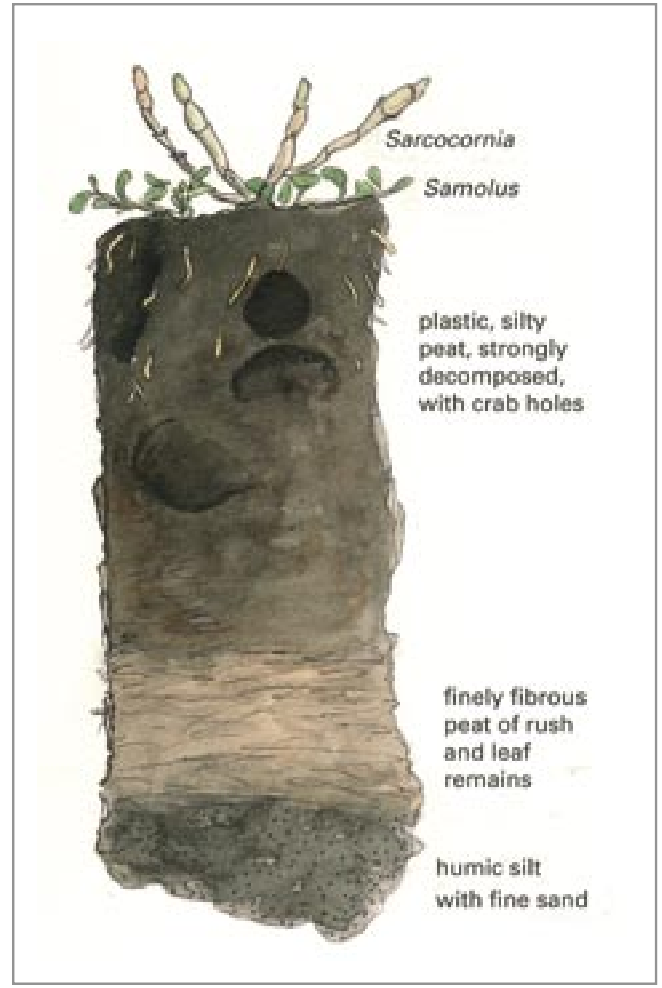


Fig. 134 A partly organic saltmarsh soil from an estuary margin behind a coastal dune. Note the large crab tunnels, a means by which much sand is continually mixed with the organic material. This is from a mid-tidal zone beneath glasswort (*Sarcocornia quinqueflora*) and sea primrose (*Samolus repens*) at Purakanui Inlet, Otago.

4.5 Sedimentation, deposition, and erosion

In places where sediment is carried by flowing water, any plant growth will act as an obstacle, reducing water flow and causing silt or sand particles to settle out. Most fens, swamps, and marshes receive ongoing inputs of water-borne sediment (Fig. 135). Submerged plants on a river margin can accumulate soft sediment around their stems, but this is usually liable to later erosion (Fig. 136). A saltmarsh can gradually elevate its ground surface with trapped sediment (Figs 33 and 137). Flowing water and wave action not only transport inorganic materials; but also deposit concentrations of organic matter (Fig. 138).

Fig. 135 Flooding of riverine marshes can bury and abrade the vegetation, yet provide fresh inputs of sediment and of nutrients. Here on the Tongariro River delta, Volcanic Plateau (see Fig. 106), recent disturbance clearly shows patterns of channel scouring and the deposition in different places of silt, sand, or gravel, creating microhabitats which will be reflected in the subsequent revegetating mix of sedge, rush, and grass patches.

Fig. 136 Sediment can have cycles of deposition and erosion. On the Clutha River, Otago, the Roxburgh Gorge was dammed for a hydro-electric lake, slowing both water flow and the carriage of sediment. Fine silt trapped by river-margin raupo (*Typha orientalis*) reedland is here being re-activated, for flushing downstream, by a deliberate lowering of lake level. Erosion reveals the thick rhizomes and the roots of the raupo, a reminder that wetland vegetation can produce much of its plant biomass underground and unseen.

Fig. 137 Sediment on a tidal river is moved by both the flood and the ebb tide. This is near the mouth of the Taieri River, Otago. Moving silt particles have settled out among the turf saltmarsh and oioi (*Apodasmia similis*) restiad rush saltmarsh, raising their platforms. The converse erosion part of the cycle is mostly by wave action undermining the miniature scarps, a process assisted by the burrowing holes of crabs, and by silt cohesiveness being weakened by the alternation of freshwater and seawater.

Fig. 138 Organic material can be carried and concentrated by moving water in many types of wetland. This is the shallow coastal lagoon of Waituna, Southland. Dislodged aquatic plants are being deposited by waves as a natural mulch among three-square (*Schoenoplectus pungens*) sedgeland and oioi (*Apodasmia similis*) restiad rushland.

4.6 Changes over time

All wetlands are dynamic, not static: they change naturally over both short and long time scales, and at rates that are not necessarily constant. Water channels change course, or become dammed. Land drainage can become impeded. Lakes and basins can fill with sediment. All these events are influenced by changes in climate. Peat accumulates and can raise the ground surface above the surrounds. The nature of a substrate and indeed a whole wetland can be determined by the plants that grow on it. A sequence of many stages may occur, for example a pond may infill with sediment, develop marsh vegetation, accumulate peat to become a swamp, then a fen, and finally a domed bog. As ground conditions change, so too does the vegetation: the process known as plant succession. Processes of vegetation change, including in wetlands, are described by Burrows (1990).

The following examples illustrate wetland change over three very different time scales.

4.6.1 Wetland change over millions of years

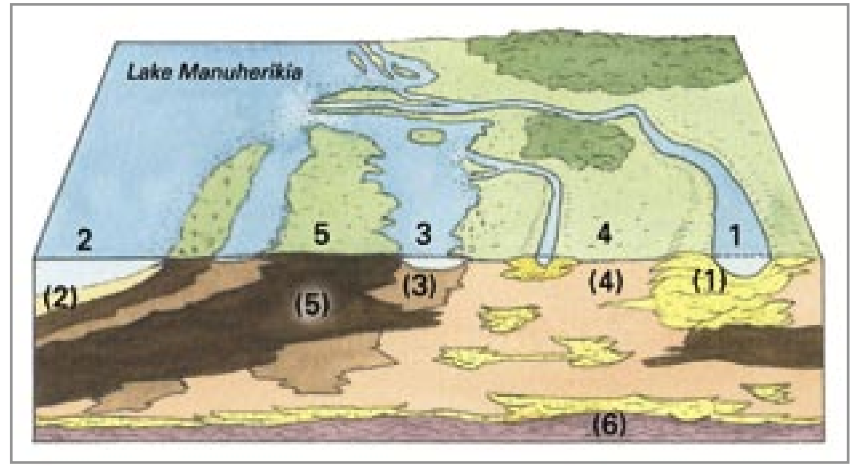


Fig. 139 A geologist's reconstruction (based on Douglas 1986) of part of the retrospectively named 'Lake Manuherikia' which extended across much of inland Otago in the mid-Miocene (c. 18–12 million years ago). This ancient wetland provides lessons for understanding modern wetland changes. Lake shore and alluvial plain wetlands have deposited peat and sediments in patterns which include: (a) pulses of sand deposition in riverbeds and on their levees; (b) lenses of sand where delta channels have changed course; and (c) diagonal patterns of organic beds caused by fluctuation and gradual rising of lake level.

Depositional environment	Materials
1. River beds and levees	(1) Sand and gravel
2. Open lake	(2) Non-carbonaceous mud, silt, sand
3. Lake bays	(3) Carbonaceous mud, silt, sand
4. Backswamps behind levees	(4) Carbonaceous mud / shale
5. Swamps (lake margin, alluvial plain)	(5) Peat turned to lignite
	(6) Underlying basement of weathered schist

Although 'Lake Manuherikia' and its wetlands existed for several million years, only fragments of their deposits remain today. Leaf and animal fossils tell a story of a period when New Zealand's climate was much warmer. However, the wetland cycle continues: parts of the ancient sedimentary sequence shown above are now again underwater; flooded by the man-made Lake Dunstan.

4.6.2 Wetland change over thousands of years

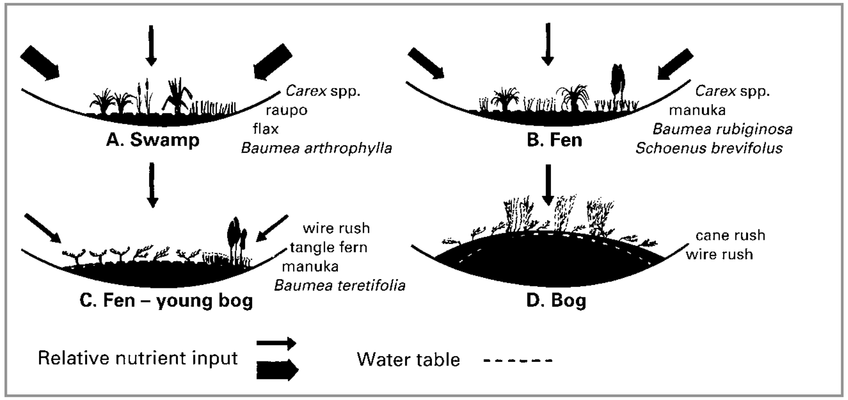


Fig. 140 Generalised sequence of bog development in the Waikato region over c. 10 000 years (based on Clarkson 2002).

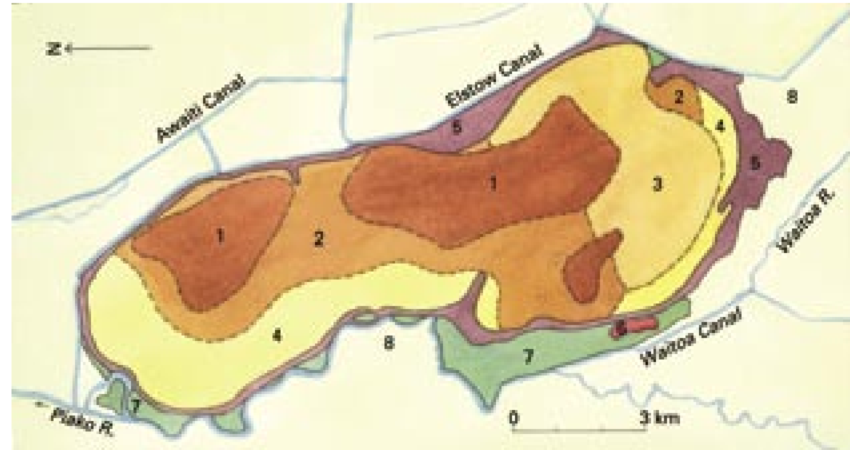


Fig. 141 Vegetation map (simplified from Irving et al. 1984) showing the modern wetland pattern on the Kopuatai Peat Dome. This is the largest New Zealand domed bog still in natural condition. The peat base lies at least 4 m below present sea level, and the highest point of the dome is only some 6 m above sea level. Although now surrounded by drainage canals and farmland developed from former peatlands, Kopuatai still shows a vegetation pattern that reflects water source, water movement, and hence nutrient status of the wetland types. The main vegetation types and habitats are:

1. *Sporadanthus ferrugineus* restiad rush bog on the rain-fed and least fertile dome crests;
2. *Schoenus brevifolius* - wire rush *(Empodisma minus)* rush bog surrounding the *Sporadanthus* communities;
3. *Baumea teretifolia - Empodisma* rush fen, typical of very wet areas in the south-east;
4. *Baumea teretifolia* - tangle fern (*Gleichenia dicarpa*) rush fen, fringing many margins of the dome and grading to the following;
5. Manuka scrub fen around the somewhat more fertile fringe of the peatland; this zone may be partly induced by the surrounding drainage and maybe also by fire;

6 Kahikatea forest swamp: one of the last remnants of a formerly widespread community;

7. Willow forest swamp, mainly grey willow (*Salix cinerea*), but also crack willow (*S. fragilis*) on wet mineral floodplain soils that were originally kahikatea forest swamp or flax - *Carex secta* swamp;
8. Surrounding farmland.

4.6.3 Wetland change: short-term cycles in an upland fen

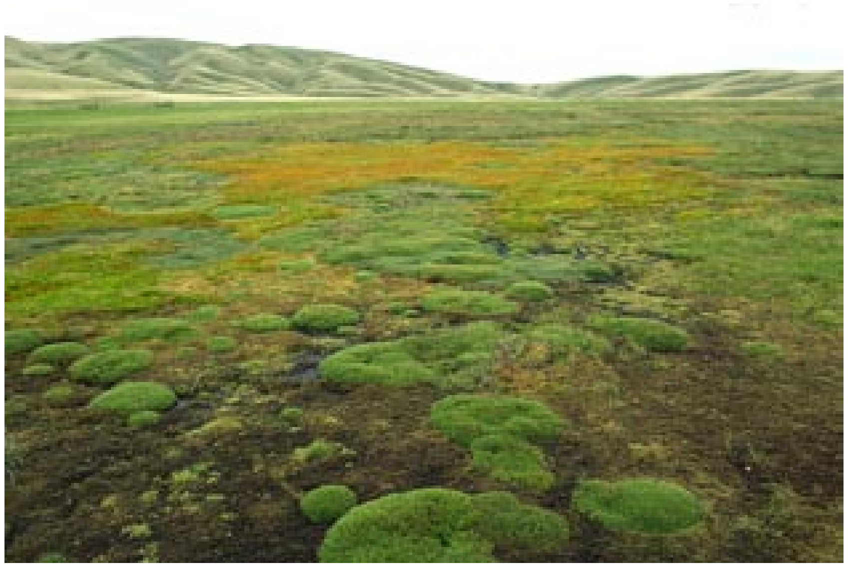


Fig. 142 Part of Teviot Swamp, Otago (see Fig. 24), a gently sloping fen nourished by groundwater that seeps from surrounding hills, and where slight changes in the rate and direction of downslope water movement cause short-term cycles in the dominant vegetation. At this site a slowing of drainage and a slight rise in water table have resulted in the demise and browning of sheets of *Sphagnum cristatum* moss, and their colonisation by young cushions of comb sedge (*Oreobolus pectinatus*). These cushions will rise above the water table, and themselves be invaded by other plants and lichens (see Fig. 88) during a phase when the hummocky ground becomes more bog-like.

Fig. 143 A portion of Teviot Swamp, where, in contrast to that in Fig. 142, the fen surface is receiving a re-invigorated supply of water. In response, *Sphagnum cristatum* is growing actively as a broad sheet, its vertical growth overwhelming an earlier phase of cushion plants, so that the foreground patches of *Phyllachne colensoi*, once convex cushions, are becoming saucer-like at their margins as the *Sphagnum* engulfs them. This phase of *Sphagnum* vigour is of benefit to the abundant flowering plants of *Gentiana amabilis*, growing upon the moss.

FIVE

Interpreting wetlands

Fig. 144 Working in a wetland; working out what it is: Shearer Swamp, Westland.

5.1 Use and application of the classification system

The New Zealand wetland classification system is designed for practical use by specialists and non-specialists alike. It seeks to circumscribe the units of classification, define terms, and standardise the naming of wetland types, in order to help unify wetland survey and management nationwide. As a scientific, functionally based classification system it is neither a taxonomic classification nor a regulatory one and does not focus on site evaluation related to environmental, social, cultural, or economic importance. The classification system is intended to complement the handbook on monitoring wetland condition by Clarkson et al. (2003) which outlines methods for recording wetland composition and for assessing condition and the impacts of changes.

The earlier sections of this book describe the units of classification and the ways in which wetlands function, at a level of detail intended to assist field workers to carry out relatively rapid survey and description of wetland sites, using mainly visual observations and simple recording techniques that are mostly qualitative or semi-quantitative, rather than involving systematic sampling or detailed analyses of data. The comments that follow are intended as additional introductory hints for efficient field studies of wetlands.

5.1.1 The question of scale

The sequential tiers of the classification allow for wetlands to be recognised and described at different levels of detail, depending on what applications are intended. The higher levels in the hierarchy apply to large regions and are most applicable to broad-scale inventory, survey, or mapping, to sort wetlands into meaningful groupings for data storage, retrieval, and interpretation, for example for State of the Environment monitoring. The lower levels are most useful for the evaluation of wetland values and benefits, the management of hydrology and wildlife habitat, and the conservation of threatened organisms.

Mapping scale is closely linked to the levels of wetland classification that can be mapped. A map scale of 1 : 100 000 would be appropriate only for hydrosystems. The scale of 1 : 50 000, as used for the topographic map series NZMS 262, is sufficient for showing location of wetland sites, and large areas of wetland classes. For many wetland systems a scale of 1 : 10 000 will be appropriate for mapping vegetation classes and also some degree of detail of vegetation structural classes, but note that at this scale it is often considered difficult to label areas smaller than 0.1 ha. For mapping vegetation types based on composition and structure of vegetation, a scale of 1 : 500 may be most useful, at least for a small wetland, or else to portray a selected window of detail of a larger mapped wetland.

5.1.2 Sources of background information

Field study of wetland sites for description and mapping will be most informative if available information is gathered beforehand. Location of wetland sites will be assisted by consulting topographic maps, aerial photographs, and GIS (Geographic Information System) information, as is available from the New Zealand Land Cover Database Version 2 (Thompson et al. 2004). The LENZ (Land Environments of New Zealand) database should prove to be a valuable tool for future wetland studies (Ministry for the Environment 2003). This enables individual sites to be evaluated within the context of a wider ecosystem classification based on climate, landform, and soil variables. Other sources of information include geological and soil maps, site field reports, and historical data, such as can often be obtained through discussion with local agencies and people.

5.1.3 Aerial photos

Aerial photos are a great help in planning a field inspection. Modern vertical aerial photos tend to be in colour, but older black-and-whites are equally or even more informative, having often been taken at relatively low altitude. Study of aerial photos taken in different years and seasons can reveal changes that have taken place in a wetland over time, and features such as fire boundaries, or patterns of surface water, that may be present only at certain times of year or after climatic events. The use of stereo pairs of photos, viewed in 3D under a stereoscope, is much more informative than looking at single photos.

Aerial photos help with understanding the landform setting, the surface catchment and drainage system, and often also, by inference, the nature of subsurface water movement. Patterns of vegetation can be identified by different tones, textures, and colours, though each of these can differ with the season of photography.

5.1.4 Field survey

Be prepared to get wet in a wetland! The margin of a wetland is often the wettest and most forbidding part, but also least representative of the main body of the wetland. Most wetlands can be walked or waded through; the main challenge is usually climbing through dense vegetation rather than extricating yourself from the wet or the muck.

It is often informative to visit the same site in different weather conditions. For instance, you are more likely to identify levels of inundation after heavy rain, or extreme low levels during dry spells. It is preferable to visit the site

during the same season that the aerial photo you are using was taken. Some plants, sedges in particular, are easier to identify when they are flowering or fruiting, during summer.

Wetland surveys do not require a great deal of equipment unless specialist studies are being pursued. Besides normal outdoor gear, useful items include compass, GPS, camera, notebook with waterproof paper, plot recording sheets, shovel and probe for looking at soil structure, pH and conductivity meters, field guides for identification of organisms, and plastic bags for soil or plant samples. When collecting plant specimens for identification, either later by yourself or for an opinion by an expert, make a point of collecting not just a foliage sample but also material that includes diagnostic features such as flowers or fruits, and in the case of many grasses, sedges, and rushes, a basal portion of stem that shows the growth habit.

5.1.5 Water regime

Observations on hydrology are essential for defining wetland classes. The source of water is a key criterion, for which landform setting and slope are the main indicators as to whether a wetland is fed by rain only, receives surface water or groundwater, or is associated with a lake, river, tidal river, or estuary. Direction of flow and drainage characteristics are useful features to assess on-site, and the nature of ground surface micro-topography can assist with this. Water table level can be gauged after it has reached equilibrium in an excavated hole. Water fluctuation regime can often be estimated by checking the level reached by debris or silt accumulation along river or lake margins and also within palustrine wetlands, and this can help in allocating boundaries between hydrosystems.

The firmness or otherwise of a peatland site is broadly correlated with degree of water content of the substrate. Jumping on a wetland surface can result in a quaking movement of up to several metres in radius, and this can indicate a substrate charged with moving groundwater, having unconsolidated sediments, or the presence of well-decomposed peat.

5.1.6 Substrates

The ease with which you can sink a probe will help to differentiate organic from mineral soils. A probe or auger will indicate depth of a substrate, and also the nature of underlying basement (e.g. rock, silt, sand) or the presence of buried wood or a hard pan in the profile. Peat can usually be recognised by its black or brownish colour. Its decomposition stage can be assessed using the von Post index (see Table 4). Inorganic matter in a substrate is usually paler, but may be dark from humus staining. Material that is of sand or larger particle size can be felt by its grittiness between the fingers. Finer silty material can be detected by its smooth and soapy feel, while clay is characteristically sticky, at least after some moistening and kneading. Soils that experience waterlogging may be detected by the presence of gleyed (greyish) horizons, various types of iron-mottling, and by sulphurous smells that indicate anaerobic processes.

Field measurement of conductivity is a general indicator of salinity and/or nutrient status, and field measurement of pH will help with assigning a wetland class name to a site (see Table 2). Sampling of soils for laboratory analysis of carbon and nutrient values will further confirm the class of wetland. Taste is a fair indicator of salinity. Hypersaline conditions, which occur in parts of estuaries subject to much evaporative drying, may be indicated by visible salt encrustations.

5.1.7 Describing and mapping vegetation

For the purposes of mapping wetland vegetation and undertaking rapid survey, the classification system provides the lowermost tiers of structural class (Section 2.7) and composition of vegetation (Section 2.8). Recognition of structural classes, i.e. the general growth form of vegetation or else the leading type of ground surface, is a straightforward exercise that does not require any detailed knowledge of plant identity. Likewise, composition of vegetation can be named with this system by being able to recognise just the dominant plants present in the canopy. So the entity we loosely refer to as a wetland type, being the combination of dominant plant with structural class, as in *Carex* sedgeland, is quite easy to recognise, and the system of Atkinson (1985) provides the diagnostic criteria and standard procedure for naming.

In practice, any vegetation study of a wetland, even at a general survey level, will involve recording vegetation at a level of detail somewhat beyond that required for naming and mapping wetland types. Thus the plot forms designed for use in assessing wetland condition (Clarkson et al. 2003)

prompt the recording of plant cover not only of canopy dominants, but also of subcanopy and ground layers.

Plant cover, usually expressed as a percentage, is one of several measures used for recording the composition of vegetation. Other measures include density (number of plants or stems per unit area), frequency (proportion of occurrences in a total number of samples), and biomass. There are several ways of measuring cover precisely, but for rapid survey it is simply estimated ‘by eye’. This can be done to a moderate degree of accuracy only, but a quick check can be done, before moving on from a study site, to see whether the recorded cover values add up to the 100% total expected of canopy cover, this being what one would see in ‘bird’s-eye’ view (see appendix VII in Clarkson et al. 2003). Note that if vegetation is being considered across several tiers of vegetation it is quite valid for the cover values of plant species to come to a total exceeding 100%. Note also that a subcanopy tier, considered alone, will very often have less than 100% cover, and that cover recorded for the ground tier is likely to include a proportion of unvegetated surface such as bare ground, litter, or standing water. Beware of the tendency to over-estimate the cover of plant species that are especially conspicuous, such as cabbage trees scattered through a sedgeland, and of plants having erect foliage or stems, such as some sedges and reeds, for while these may appear dense when seen from the ground in side view, the vertical view would show them to be less so.

Detailed ecological studies of wetlands would aim to use rigorous sampling and recording procedures, to produce data capable of statistical analysis. Such methodology is beyond what we are describing, but it should be noted that the wetland classification system can also be applied to the results of such studies.

Many wetlands are nearly flat so their features can be difficult to locate on the ground. A few wetlands can be viewed from adjacent high ground. Prominent landmarks are worth identifying before entering a wetland, and these can be located, with grid references, upon a laminated copy of an aerial photo, topographic map, or sketched base map, upon which annotations can be made with a wetland-proof marker pen. GPS (Geographic Positioning System) technology provides a modern aid to navigating around a wetland.

The approach commonly used for mapping involves the identification of areas of homogeneous cover that are then delineated as closed areas of whatever size and shape. A preliminary sketch map, usually based on an aerial photo, can be drawn to show prominent wetland features and the most obvious boundaries between map units. While some boundaries will be quite distinct, such as those between contrasting vegetation structural classes, others will be less so and must be mapped with less certainty, for example with a dotted line rather than a solid one. Quite often with wetlands, the intricate degree of patterning that can occur at many scales means that some units of mapping may need to be identified as mixtures of more than one vegetation or habitat type. However, by adopting the '80 / 20 rule', whereby the boundary of a relatively homogenous unit is demarcated in such a way that alien inclusions comprise less than 20% of the total, then the unit can be labelled as the dominant type.

The preliminary sketch map will help in the choice of sites to be visited for ground-truthing. Often this will take the form of planning routes that traverse what is believed to be a representative sample of the wetland diversity. Both on aerial photos and on the ground, look out for places where different types of habitat or vegetation abut, suggesting sites where a sequence of types can be most clearly related to environmental gradients. As noted above, the choice of mapping scale will dictate the level of detail that will be recorded in the field. However, a useful mapping record of a wetland site may often combine a broad-scale overall map with window maps of smaller areas to illustrate finer detail of typical or localised examples of patterns of wetland types. Profile diagrams are a good way to show examples of zonation patterns along particular environmental gradients.

Depending on the purpose of a wetland study, be it for biodiversity, assessment of habitat for birds or fish, catchment understanding, condition monitoring, or for values associated with traditional uses, recreation, education, or scenery, the observer will target observations on particular facets. But even when wetland inventory and mapping is the principal aim, field workers should look out for indicators of influences and processes that might affect how wetland types are interpreted.

Fire has affected many New Zealand wetlands, so that a wetland currently vegetated with, say, sedgeland, might have had a previous and originally more natural cover of forest or scrub, and might actually be in the process

of reverting to that vegetation. Some influences, such as drainage or an increase in nutrient status arising from adjacent land uses, may take many years to be fully reflected in the vegetation. One complication to interpreting wetland types from their vegetation is that some wetland sites can have enigmatic mixtures of plants that would otherwise be interpreted as indicating very different habitat conditions. Part of the reason for these situations can be if a wetland is undergoing a shift in plant composition, for whatever reason, and that this is happening relatively slowly, so that the observed plant cover is one which belongs to the past as well as the present.

A full record of a wetland site would include an attempt to note not only the vegetation, i.e. the composition, structure, and pattern of the vegetation types, but also the flora, i.e. a list of all plant species present in the area. This would include, and maybe highlight, any threatened plants and weeds.

Above all, make your own notes in your own style about what you see, irrespective of anyone else's style or templates. It is important, however, to always record standard data such as date, location, and observer. Much modern environmental emphasis is placed upon monitoring, yet some of the best monitoring is actually accomplished by the simple processes of thoughtful observation and careful recording. Environmental indicators are also in vogue, but this is not an exact science, and the best indicators are those organisms that tell a reliable story about what is happening in nature. This knowledge is gained by repeated looking, wondering, and surmising. Wetlands are great places for practising all three.

Give the wetland classification system a fair trial. Add to it and refine it as will inevitably be necessary. And argue about it, as we have.

5.2 Guide to further information

For full bibliographic references see Section 6.

Textbooks on wetlands

Haslam (2003)
Keddy (2000)
Mitsch & Gosselink (2000)
Tiner (1999)
US Army Corps of Engineers (1987)

Overseas wetland classification systems

Bridgham et al. (1996)
Brinson (1993)
British Environment Agency (1997)
Cowardin et al. (1979)
Farinha et al. (1996)
Ramsar (2000)
Semeniuk & Semeniuk (1995)
Warner & Rubec (1997)
Zoltai & Vitt (1995)

References on New Zealand wetlands

Burrows (1969)
Buxton (1991)
Campbell (1983)
Cockayne (1928)
Cranwell (1953)
Cromarty & Scott (1995)
Dobson (1979)
Irwin (1975b)
Johnson & Brooke (1998)
Mew (1983)
Stephenson (1986)
Stephenson et al. (1983)
Thompson (1987)
Vant (1987)
Ward & Lambie (1998, 1999a,b)
Wardle (1977, 1991)
Wilson (1987)

International internet sites

- The Ramsar Convention Secretariat (http://www.ramsar.org) is the organisation responsible for the International Convention on Wetlands, signed in the Iranian city of Ramsar in 1971. It has information about World Wetlands Day, wetlands of international significance, wetland inventory and monitoring, and international wetland issues. It also has a page on wetland centres around the world.
- http://www.ramsar.org/links_index.htm provides links with the key wetland websites around the world, including those of Ramsar's four international organisation partners (IUCN, WWF, Wetlands International, and BirdLife International), those of related convention secretariats, and those of all other important sites for wetland-related information (check the websites, and their links, of agencies such as the US Fish and Wildlife Service, Environment Canada, and MedWet for further information on national and regional wetland classification systems in North America and Europe).
- http://www.wetlandshelp-line.com provides a service designed to assist wetland managers, owners, and policy makers primarily from Australia, New Zealand, and the Pacific Island countries of the Oceania Region. It includes links with the key management agencies and NGOs of the region.

New Zealand internet sites

- The Department of Conservation (http://www.doc.govt.nz) has information on New Zealand wetlands of international significance and the New Zealand Wetland Conservation Awards, as well as many publications relating to New Zealand wetlands. Follow the link 'Publications' then 'Science and research'.
- Fish and Game New Zealand (http://www.fishandgame.org.nz) has information on World Wetlands Day, wetland wildlife, and tips for creating ponds for waterfowl. Follow the 'wetlands' link.
- Environment Waikato (http://www.ew.govt.nz) and Christchurch City Council (http://www.ccc.govt.nz) have pages on how to manage wetlands and streamsides.
- The Ministry for the Environment (http://www.mfe.govt.nz) has information on the State of the Environment, and provides access to wetland reference manuals.
- The Environmental Reporting Programme (http://www.environment.govt.nz) has published a series of reports that give metadata descriptions for environmental databases, classification systems, and spatial frameworks in New Zealand.
- The National Wetland Trust (http://www.wetlandtrust.org.nz) was established in 1999 to increase the appreciation of wetlands and their values by all New Zealanders. The objectives of the Trust are to increase public knowledge and appreciation of wetland values, to increase understanding of wetland functions and values, and proactive commitment to wetland protection, enhancement, and restoration.

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SEVEN

Glossary

algae (singular: alga) diverse plant groups of simple construction, including single-celled plankton, filamentous growth forms, charophytes, and the green, brown and red seaweeds.

algalfield a vegetation structural class having cover of algae 20–100%, exceeding that of any other growth form or bare ground.

amictic (of lake waters): having no periods of thermal stratification or mixing each year.

anaerobic of an organism, especially some bacteria, able to live in the absence of free oxygen; and of substrates where decay by such organisms often results in production of sulphur compounds.

backswamp a swamp located on a floodplain where drainage is poor behind a river levee.

backwater a body of relatively calm water, usually parallel with, and connected at its bottom end, to a river or stream.

blanket peat peatland which extensively covers much of the land, irrespective of underlying topography.

bed the floor of a lake, river, or other body of open water; a growth of plants upon such a substrate; also a layer of sediment or other deposited material (e.g. shell bed).

bog a wetland class: a peatland receiving its water supply only from precipitation, and therefore virtually unaffected by moving groundwater and nutrients from adjacent or underlying mineral soils; bogs are oligotrophic (nutrient-poor), usually markedly acid, and their water table is at or near the surface.

brackish water of intermediate salinity between seawater (c. 35‰ marine salts) and freshwater (<5‰ marine salts).

braided river a river with high sediment load having numerous channels which repeatedly branch and rejoin, forming a pattern of low islands and shallow bars.

bryophyte a general term embracing the non-vascular sporing plants mosses, liverworts, and hornworts.

canopy the layer or layers of uppermost plant crowns in vegetation, i.e. that foliage which faces upwards to the sky and would be seen in 'bird's eye' view.

carr a European term for a wetland dominated by woody vegetation.

cascade a section of a stream or river where water descends over steep rocks (steeper and less obstructed than rapids, less precipitous that a waterfall).

charophyte a member of the distinctive family of algae (Characeae) having erect stems and whorled branches, often important in freshwater aquatic habitats; New Zealand charophytes seldom become encrusted with lime so the term 'stonewort' is not relevant here.

clay chemically-weathered mineral fragments <0.002 mm diameter, i.e. finer than silt.

cushionfield a vegetation structural class having cover of cushion plants 20–100%, exceeding that of any other growth form. Cushion plants include herbaceous, semi-woody, and woody plants with such dense branchlets and close-set leaves as to form convex cushions. Cushion plants of wetlands include species of *Donatia*, *Gaimardia*, *Centrolepis*, *Oreobolus*, and *Phyllachne*.

cyanobacteria (Cyanophyta; formerly known as blue-green algae) simple plants including unicellular and filamentous forms, often with a mucilaginous covering; important as aquatics and on wetland soil surfaces.

delta a fan-shaped accumulation of alluvial sediment, usually with several water channels at a river or stream mouth.

domed bog a domed (or raised) bog has accumulated its greatest depth of peat in its most poorly drained and constantly wet centre, producing a convex surface.

dominant cover usually one or more dominant plants (e.g. bog pine, wire rush) but sometimes a bare substrate (e.g. mud, sand).

dune slack a vegetated depression between sand dune ridges where the water table is close to or above the sand surface; or a hollow between sandbanks which periodically holds slack – or scarcely flowing – water at times of highest tides.

dystrophic water having significant dark staining from humic matter and an associated deficiency in nutrients.

ecotone transition zone between plant communities.

emergent of aquatic plants, those which are rooted in water but have stems or foliage above the water surface; of terrestrial plants, those with a crown held above the level of the surrounding vegetation canopy.

ephemeral of a system that is a saturated or submerged wetland for some periods, yet becomes in effect a dry habitat for substantial alternate periods.

ephemeral wetland a wetland class, typically occupying a closed depression that lacks a permanent surface outlet channel, having mineral soil and a marked seasonal alternation between being ponded and dried, the wetness and the wetland tending therefore to be ephemeral.

episodic (of saturation or inundation): rarely, say once every few years.

estuarine a hydrosystem that includes the subtidal and intertidal zones of estuaries themselves, coastal river mouths, and coastal lagoons affected by the mixing of freshwater and seawater, tidal reaches of rivers, and supratidal zones of coasts affected by splash and spray. The inland boundary of the estuarine hydrosystem is where marine salt concentration measures 5‰.

estuary a coastal body of water, partly enclosed by land but open to the sea, where seawater is diluted by land drainage, and where tidal effects are evident; often located at the widened funnel-shaped mouth of a river.

eutrophic nutrient-rich, fertile.

evapotranspiration the total loss of water as water vapour, from ground and vegetation to the atmosphere, by the combination of evaporation and transpiration through the membranes or pores of plants.

facultative (of a wetland organism): occurring in wetland habitats but also in dryland ones (cf. obligate).

fall (waterfall): a steep section of a river or stream where the descent of water is precipitous.

fen a wetland class: a peatland receiving inputs of water and nutrients from adjacent mineral soils, and having the water table usually close to the peat surface; fens have low to moderate acidity and nutrient status.

fernland a vegetation structural class having canopy cover of ferns 20–100%, exceeding that of any other growth form.

flark a permanently or temporarily flooded depression within a peatland, occupied by sparse, weakly peat-forming vegetation.

flashy (of a riverine channel): having flows that allow development of little more than microalgal felts.

flaxland a vegetation structural class having canopy cover of flax (*Phormium* spp.) 20–100%, exceeding that of any other growth form.

flooding inundation by storm runoff from adjacent land, overflow from a stream or river, or the rise in water associated with tidal inflow (cf. ponding).

floodplain alluvial land adjacent to a river which continues to be affected by flood overflows from the present river.

flush a type of seepage which carries a periodic pulse of moving surface water from a higher level, as from a rain event or snow melt.

forest a vegetation structural class having >80% canopy cover of trees and shrubs, with tree cover exceeding that of shrubs. Trees (including tree ferns) are those having a trunk ≥10 cm dbh (diameter at breast height); cf. treeland.

geothermal a hydrosystem where volcanic activity produces hot surface waters, or heated wet soils (30ºC or more) or where geothermal chemistry affects wetland habitats.

gleying processes that occur in wet, poorly aerated soils, where chemical reduction especially of iron compounds produces grey zones, often with rusty mottling.

glide a gently flowing, unruffled reach of shallow water in a river or stream.

grass a member of the grass family (Poaceae = Gramineae), the leaves having a narrow blade and a sheath clasping a rounded hollow stem.

grassland a vegetation structural class having canopy cover of grasses 20–100%, exceeding that of any other growth form or bare ground. Tussock grasses belong in tussockland.

gravel fragments of rock 2–60 mm in diameter.

groundwater subsurface water that is in the saturated zone, including underground streams.

gumland land formerly occupied by forest of kauri (*Agathis australis*) in northern New Zealand, the soils once exploited for kauri gum, prone to waterlogging, and having heathland vegetation.

habit the external appearance or growth form of a plant.

habitat the environment occupied by an organism or community.

heathland a vegetation / habitat type characterised by a high proportion of heaths (strictly shrubs of the families Ericaceae and Epacridaceae, but also other woody plants having similar small leaves, persistent acid litter, and fine roots) usually in conjunction with ferns, sedges, and lichens.

herbfield a vegetation structural class having cover of herbs 20–100%, exceeding that of any other growth form or bare ground. The herb growth form includes all herbaceous and low-growing semi-woody plants that are not separated as tussocks, ferns, reeds, rushes, sedges, grasses, cushion plants, turf, mosses, or lichens.

humus dark brown to black, amorphous, well-decomposed organic matter in a soil or suspended in water.

hydrosystem wetland ecosystem differentiated by broad landform and hydrological settings, and by water salinity, water chemistry, and temperature.

hypersaline having salinity in excess of 40‰, i.e. higher than that of seawater (c. 35‰), such as can occur where wet soils or ponded water are subject to high evaporation rates.

inflow wetland a wetland which receives inflowing surface or groundwater but has no outflow (especially an ephemeral wetland in a depression; cf. outflow wetland, throughflow wetland).

inland saline a hydrosystem embracing sites in semi-arid climates in inland basins where localised areas of saline soils are associated with seasonally wet habitats.

inorganic derived from non-biological material; i.e. mineral matter (cf. organic).

intermittent (of inundation or saturation): in one or a series of wet years, but not every year.

intertidal the shore zone of marine and estuarine waters between highest and lowest tides.

kettle a depression, often bowl-shaped and usually without surface drainage, formed among glacial deposits at a time of glacial retreat.

lacustrine a hydrosystem associated with lakes and other bodies of open freshwater which are large enough to be influenced by characteristic lake processes such as permanent non-flowing deep water, fluctuating water level, and wave action.

lagg the marginal stream or swamp surrounding or fringing a domed bog.

lagoon a shallow lake, especially one near to and permanently or intermittently connected with a river, lake, or the sea; in New Zealand most often applied to coastal lagoons impounded behind beach ridges or associated with river mouths, but the term is also used for inland examples.

lake a large body of water surrounded by land, its major dimension generally 0.5 km or more, though smaller bodies of water can be validly referred to as lakes on the basis of depth, permanence, or local custom.

levee an embankment of flood alluvium built up alongside a river and typically with lower-lying land behind.

lichenfield a vegetation structural class having cover of lichens 20–100%, exceeding that of any other growth form or bare ground.

litter plant material (leaves, twigs, etc.) that has recently fallen to the ground surface.

littoral the shore zone of a lake or pond between uppermost water level and the depth limit of rooted plants; also the intertidal zone of coasts.

lowland (of a riverine channel): having a low gradient with slow runs and pools.

macrophyte a macroscopic plant, the term used mainly to distinguish relatively large aquatic plants from small algae and microscopic plants.

mangrove a tropical and subtropical saltmarsh community of shrubs or trees which typically produce erect aerial roots; in New Zealand the term is applied also to the only plant of this type which occurs here: manawa (*Avicennia marina* subsp. *australasica*).

marine a hydrosystem including saline open waters (c. 35‰ marine salts), the seabed, and the foreshore of open sea coasts.

marsh a wetland class: a mineral wetland which may have a peat component that is periodically inundated by standing or slowly moving water; water levels may fluctuate markedly. Marshes are usually of moderate to high nutrient status.

meander one of a series of sinuous turns produced by a mature stream or river as it swings and shifts course across its floodplain.

mesotrophic of moderate nutrient status; intermediate between oligotrophic and eutrophic.

midland (of a riverine channel): having overall flows of moderate gradient dominated by runs / riffles.

mineral of substrate materials that are inorganic; they may be bedrock, or sediments of particle size ranging from clay, silt, sand, gravel, to stones and boulders.

minerotrophic having relatively high nutrient status derived from mineral materials in the substrate or within groundwater inputs.

mire a general term that embraces all peat-forming wetlands.

monomictic (of lake waters): having a single period of thermal stratification and mixing each year.

mossfield a vegetation structural class having cover of mosses and / or liverworts 20–100%, exceeding that of any other growth form or bare ground.

mud a mix of silt- and / or clay-sized particles with water.

near-permanent (of saturation or inundation): throughout the growing seasons of most years.

nival a hydrosystem embracing snowfields and glaciers; a type of wetland insofar as snow and ice can be a habitat for algal communities.

obligate (of a wetland organism): confined to wetland habitats (cf. facultative).

oligotrophic nutrient-poor, infertile.

ombrogenous a wetland deriving its water supply entirely from rainfall.

ombrotrophic 'rain-fed', having low nutrient status as a result of receiving water only from rainfall.

organic living matter or material derived from it (cf. inorganic).

outflow wetland a wetland (mainly bog or pakihi) which receives water only from precipitation, and where flow of surface or groundwater is only outwards (cf. inflow wetland, throughflow wetland).

oxbow a river bend returning almost upon itself, forming an oxbow lake when the bend is cut off.

pakihi a general term for areas of flat to rolling land, mainly on the West Coast, having infertile mineral to organic soils of poor drainage and a fire-prone vegetation of scrub with ferns, sedges, and restiads.

pakihi and gumland a wetland class characterised by mineral or peat soils of very low fertility and poor drainage because of leached and impervious basement materials on land which is level or of low relief, with the water supply being mainly from precipitation.

paludification the process of peat accumulation.

palustrine a hydrosystem of all freshwater wetlands fed by rain, groundwater, or surface water, but not directly associated with estuaries, lakes, or rivers.

patterned wetland a wetland displaying recognisable and repeated pattern in the arrangement of vegetation and landform components.

peat an accumulation of partially decomposed remains of living organisms, mainly detritus from former plant growth.

peatland a general term embracing all land having peat substrates.

permanent (of saturation or inundation): always.

pH the reciprocal logarithm of hydrogen ion concentration, giving a scale where pH 7 is neutral, lower values indicate acidity, and higher values alkalinity.

physiognomy the characteristic appearance of a vegetation type or plant community.

piping the channelling in a tubular cavity of an underground stream.

plateau bog a form of raised bog having sloping margins but a plateau surface rather than a fully convex one; the term does not refer to a bog upon an underlying plateau landform.

plutonic a hydrosystem of underground wetlands, especially waterways that run through cave systems where lack of light excludes any plant production, but other organisms may be present.

polymictic (of lake waters): having several periods of thermal stratification and mixing each year.

pond a body of non-flowing freshwater, smaller than a lake but larger than a pool; natural but more often artificial.

ponding the process of water collecting in a depression or basin (cf. flooding).

pool a small body of still water; also a slow-flowing and relatively deep reach of a stream or river.

raised bog a raised (or domed) bog has accumulated its greatest depth of peat in its most poorly drained and constantly wet centre, producing a convex surface.

rand the sloping margin of a domed bog, typically leading down to a lagg.

rapid a section of a river or stream where water flows more swiftly than usual and the water surface is broken by obstructions.

reed a tall erect herb, emergent from shallow water, having unbranched leaves or stems that are either hollow or have very spongy pith. Examples include *Typha*, *Bolboschoenus*, *Schoenoplectus*, *Phragmites*, *Phalaris*, *Zizania*, *Baumea articulata*, *Eleocharis sphacelata*, and *Glyceria maxima*.

reedland a vegetation structural class having canopy cover of reeds 20–100%, exceeding that of any other growth form or open water.

restiad reed- or rush-like plants belonging to the family Restionaceae; the genera *Apodasmia*, *Empodisma*, and *Sporadanthus* occur in New Zealand.

rheotrophic 'flow-fed', having moderate nutrient status because of inputs of groundwater as well as rain.

riffle a shallow section of a river or stream where water flows swiftly and the water surface is broken into waves.

riparian situated along the immediate margin of a river or stream.

riverine a hydrosystem associated with rivers, streams, and other open channels, both natural and artificial, where the dominant function is continually or intermittently flowing freshwater. Although many wetlands occupy landforms such as valley floors, floodplains, and deltas which owe their genesis to river processes, the riverine hydrosystem extends only so far as flowing channels retain a current influence, which can be defined as the extent covered by the mean annual flood.

run a section of a river or stream where water flows swiftly.

rush strictly, any species of the plant genus *Juncus*, but applied also to other plants of similar form (see below).

rushland a vegetation structural class having canopy cover of rushes 20–100%, exceeding that of any other growth form or bare ground. The rush growth form is characterised by those species of *Juncus* that have stiff, erect stems or similarly non-flattened leaves, but includes members of other genera (some *Baumea* spp., *Lepidosperma australe*, *Eleocharis acuta*, *Isolepis nodosa*) of similar growth form, and all species of the restiad genera *Sporadanthus*, *Empodisma*, and *Apodasmia*. The term restiad rushland may be used for vegetation dominated by these three genera, and wire rushland for vegetation dominated by *Empodisma.*

salinity the quantity of dissolved salts in water, especially of seawater or its diluted products. Salinity is recorded, by convention, as parts per thousand (‰), i.e. grams of salts per litre of water.

saltmarsh a wetland class embracing estuarine habitats of mainly mineral substrate in the intertidal zone, but including those habitats in the supratidal zone and inland, which although non-tidal, have similar saline substrates and constancy of soil moisture.

sand grains of mineral detritus of particle size range 0.06–2 mm diameter.

saturation maximum water content: a soil or substrate is saturated when all the interstices are filled with water.

scrub a vegetation structural class having canopy cover of shrubs and trees >80%, with shrub cover exceeding that of trees. Shrubs are woody plants with stems <10 cm dbh (diameter at breast height).

seasonal (of saturation or inundation): during one or more seasons of the year.

sedentary peat peat accumulating *in situ*, beneath the plants which produced it; the term autochthonous – found in the place of origin – has also been used to describe sedentary peat.

sedge a member of the sedge family (Cyperaceae).

sedgeland a vegetation structural class having canopy cover of sedges 20–100%, exceeding that of any other growth form or bare ground. The sedge growth form includes those sedges having grass-like but usually coarser leaves, especially *Carex*, *Uncinia*, *Isolepis*, *Cyperus*, *Carpha*, and *Schoenus*. Note that several sedges belong in tussockland, reedland, rushland, and cushionfield.

sediment particulate materials that have settled out from suspension in water.

sedimentary peat peat which settles out as humic particles on the bed or margins of a water body such as a swamp pool or channel; the term allochthonous – material transported from outside the system – also describes sedimentary peat.

seepage a wetland class: an area on a slope which carries a moderate to steady flow of groundwater, often also surface water, including water that has percolated to the land surface, the volume being less than that which would be considered as a stream or spring.

shallow water a wetland class: aquatic habitats with water generally less than a few metres deep, having standing water for most of the time, and including the margins of lakes, streams, rivers, and estuarine waters plus small bodies of water which may occur within or adjacent to other wetland classes.

shrubland a vegetation structural class having canopy cover of shrubs 20–80%, exceeding that of any other growth form.

silt fragments of mineral material of particle size range 0.002–0.06 mm diameter.

snowbank a mountain site where accumulated snow thaws gradually during a relatively short growing season, to nourish mineral soils of downslope seepages; some snowbanks become seasonally dry while some are not saturated for long enough to be considered wetland.

soligenous a wetland where water supply is augmented by groundwater seepage or surface runoff that has been in contact with mineral materials in adjacent land and carries inputs of dissolved nutrients and often also suspended inorganic sediment.

spring a stream emerging to the surface from underground, as a single point source of groundwater discharge.

stable (of a riverine channel): having flows that allow attached macrophytes and mosses to persist from year to year.

steepland (of a riverine channel): having overall flows of high gradient, well-aerated with broken water surfaces.

storm beach a ridge of gravel or stones piled by storm waves on the upper shore of a beach on a coast or lake.

stratification (or thermal stratification): the process in a lake whereby changes in temperature at different depths, result in horizontal layers of different densities.

string mire a peatland of distinctive pattern where numerous pools are arranged stepwise downslope, their long axes often aligned across the slope, the pools being separated by ridges of raised peat – or strings.

structural class level III of the wetland classification, based on the general growth form or structure of the vegetation, or else the leading type of ground surface.

substrate the ground upon which vegetation grows or that underlying a non-vegetated wetland; a general term including rock, sediments, peat, or soil.

subsystem level IA of the wetland classification, which allows hydrosystems to be further described according to the water regime.

subtidal the shore zone of marine and estuarine hydrosystems below the level of lowest tide; permanently inundated.

succession the ecological process of community change over time, especially the progressive replacement of one vegetation type by another.

supratidal the shore zone above highest tide level of marine and estuarine waters; influenced by splash and spray, and including areas inundated by storm surges.

swale an elongated depression between coastal dunes or beach ridges, aligned roughly parallel to the coast.

swamp a wetland class: a soligenous wetland, usually combining mineral and peat substrates, having moderate water flow and fluctuation, and often the presence of leads of standing water or surface channels; swamps are relatively rich in nutrients.

sward vegetation of grasses or sedges of lawn-like stature.

tarn a small body of standing water in the mountains, often having no significant tributaries: the term tends to bridge the gap between pond and lake, and is a useful one for upland situations.

temporary (of saturation or inundation): for periods of about two weeks or less during the growing season.

throughflow wetland a wetland which both receives and produces flowing water (fens, swamps, rivers, and most lakes; cf. inflow wetland, outflow wetland).

tidal influenced by rise and fall of twice-daily tides, of bimonthly spring and neap tides, or by ebb and flow in tidal reaches of rivers.

topogenous a term occasionally used 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.

treeland a vegetation structural class having 20–80% canopy cover of trees, tree cover exceeding that of any other growth form, but tree canopy discontinuous above lower non-woody vegetation; cf. forest.

turf a vegetation structural type of low stature (generally <3 cm tall) of mainly herbaceous vascular plants forming a ground-hugging and often dense carpet of intertwined plants of numerous species.

tussock a densely tufted grass or sedge >10 cm tall with fine linear leaves that arch upwards and outwards from a densely clumped base; wetland tussocks include species of *Chionochloa*, *Cortaderia*, *Gahnia*, *Carex*, and *Cyperus*, and *Schoenus pauciflorus*.

tussockland a vegetation structural class having canopy cover of tussocks 20–100%, exceeding that of any other growth form.

variable (of a riverine channel): having flows that allow development and scouring of macroalgae.

water regime the combination of four main hydrological factors: water source, movement, fluctuation, and periodicity of wetness.

water table the level below which a substrate is fully saturated; the term is also commonly applied in New Zealand to roadside ditches.

wetland class level II of the wetland classification, where the units are differentiated by distinctive combinations of substrate factors, water regime, nutrient status, and pH.

wetland complex a wetland area comprising several adjoining wetland classes, or even more than one hydrosystem; many wetland sites are complexes; likewise mire complex, pool complex, etc.

wetland form level IIA of the wetland classification, being descriptors of landforms which wetlands occupy, or forms which they create or contain.

wire rushland rushland dominated by wire rush (*Empodisma minus*).

zonation the distribution of organisms or vegetation types in distinctive layers or zones.

Index

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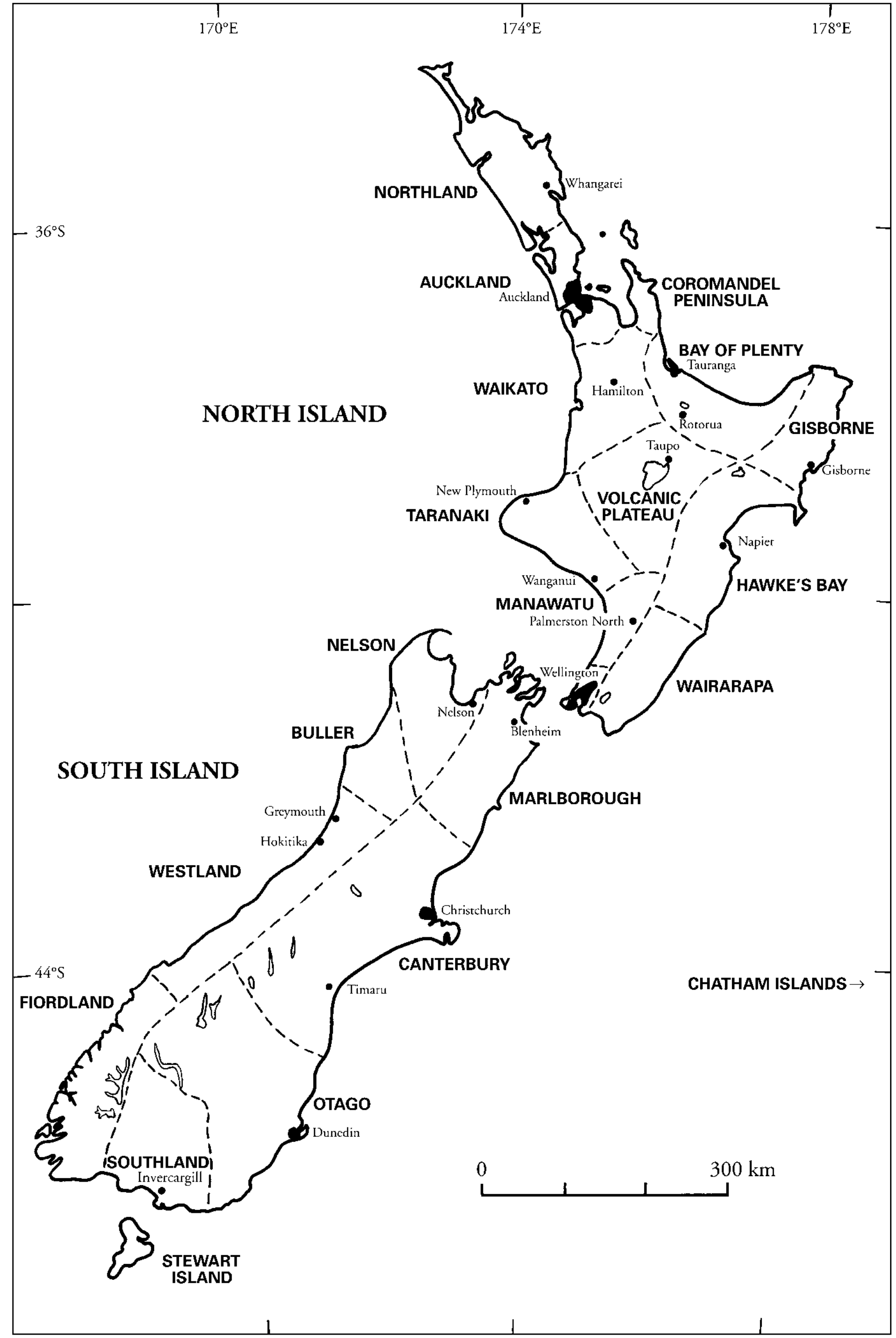
170°E
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NORTHLAND
Whangarei
AUCKLAND
Auckland
COROMANDEL PENINSULA
BAY OF PLENTY
Tauranga
WAIKATO
Hamilton
Rotorua
GISBORNE
Gisborne
NORTH ISLAND
Taupo
New Plymouth
TARANAKI
VOLCANIC PLATEAU
Napier
HAWKE'S BAY
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CHATHAM ISLANDS→
FIORDLAND
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STEWART ISLAND