REVIEW

New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework

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Abstract: Terrestrial ecosystems that were rare before human colonisation of New Zealand often have highly specialised and diverse flora and fauna characterised by endemic and nationally rare species. Although many of these ecosystems are under threat from anthropogenic modification and their biodiversity values are declining, they still are not adequately identified by current land classifications. We compiled a list of 72 rare ecosystems from the literature and by canvassing New Zealand ecologists and land managers. Rare ecosystems are defined as those having a total extent less than 0.5% (i.e. < 134 000 ha) of New Zealand's total area (268 680 km^2), and the resultant list includes both well-recognised and less well known ecosystems. To define the ecosystems in a robust fashion we developed a framework based on descriptors of physical environments that distinguish rare ecosystems from each other and from more common ecosystems. Using this framework the 72 rare ecosystems are defined using pertinent environmental descriptors selected from soil age, parent material, soil chemistry and particle size, landform, drainage regime, disturbance, and climate. For each ecosystem, an example locality and the dominant vegetation structural type are also given.

Keywords: ecological classification; New Zealand; rarity; threatened terrestrial ecosystems

Introduction

New Zealand's complex topography and climate have created a diverse array of terrestrial ecosystems. Many of these are small, widely dispersed, and often lack trees due to extreme environments. These distinctive ecosystems may exhibit corresponding extremes of biotic diversity (i.e. have diverse flora or fauna or be particularly depauperate), may have high national endemism (e.g. *Carex ophiolithica* and *Coprosma spathulata* subsp. *hikuruana* and other endemics on ultrabasic cliffs in Northland), and may support specialised life forms (e.g. halophytes in salt pans, tropical taxa in geothermal areas). Furthermore, these ecosystems often provide important refuges for native plant and animal species within highly modified landscapes (e.g. braided riverbeds – Williams & Wiser 2004; frost flats – Smale 1990; saline patches – Rogers et al. 2000; tors, cliffs and scarps – Rogers & Walker 2002).

Many of these ecosystems were historically rare, i.e. rare prior to human colonisation of New Zealand. They do not include ecosystems in common environments that are now rare because of stochastic events, however; for example, distinct tree species combinations on isolated mountain tops, or ecosystems largely destroyed during the human period, such as kahikatea (*Dacrycarpus dacrydioides*) forest on alluvium.

'Rare' encompasses ecosystems that are small in size (e.g. 100 m^2 to a few hundreds of hectares) but geographically widespread (e.g. dune deflation hollows along the New Zealand coast), to those that are larger (e.g. ten thousands of hectares) but geographically restricted (e.g. frost flats on the volcanic plateau) (cf. Rabinowitz 1981). We limit the total extent of any individual type of historically rare ecosystem to less than 0.5% (i.e. < 134 000 ha) of New Zealand's total area (268 680 km^2). Our geographic scope includes the main islands of New Zealand – North, South and Stewart. (More remote islands such as the Kermadec Islands, subantarctic islands, and the Chatham Islands are excluded.)

We use the definition of an ecosystem suggested in Henderson & Henderson (1963) as an ‘ecological system formed by the interaction of co-acting organisms and their environment’. An ecosystem type is therefore one type of ecological system that can be differentiated from another ecological system by one or more abiotic or biotic factors. Groups of organisms that co-occur within the ecosystem and interact through trophic or spatial relationships are considered to be communities (Lincoln et al. 1982). The microhabitats of individual organisms, such as logs on a forest floor, are at too fine a scale to be classed as ecosystems for our purposes.

Collectively, historically rare ecosystems contain half of New Zealand’s nationally threatened plant species (PA Williams unpubl., based on data of de Lange et al. 2004). Similarly, 38% of the 160 nationally threatened Lepidoptera live in ecosystems that are themselves limited in distribution nationally (e.g. Dugdale 2001). This rarity at different trophic levels increases both the intrinsic interest and the importance of rare ecosystems as foci for attention in biodiversity conservation initiatives (e.g. DOC & MfE 2000, 2007).

Historical and recent losses of indigenous cover have been well documented by Walker et al. (2006), but data pertaining to loss of individual rare ecosystems are lacking. Historically rare ecosystems face many threats, e.g. housing development (coastal sand dunes), weed invasions (braided riverbeds), and agricultural development (salt pan vegetation). Greater community and agency awareness of historically rare ecosystems and their importance will hopefully lead to greater protection and appropriate management that will arrest their decline.

To these ends we provide an initial list of historically rare ecosystems and a consistent framework for delineating and mapping them.

Existing classifications

Existing classifications can be grouped broadly into those based on abiotic criteria, vegetation, or ecosystems.

Abiotic

Existing national environmental and land-cover classifications (e.g. Land Environments of New Zealand (LENZ; Leathwick et al. 2003) and the Land Cover Database (LCDB; Thompson et al. 2004) are applicable to common and dominant environments and vegetation. Nevertheless, some environments that we consider rare have been identified and mapped by these classifications. For example, LCDB2 identifies braided riverbeds and screes, and LENZ identifies ultrabasics and other areas within which rare or uncommon environments occur (e.g. sand dunes). These classifications based on abiotic criteria were not designed to identify historically rare environments, however. First, the current resolution (for LCDB2 and LENZ the minimum mapping units are 1 ha and 25 m, respectively) cannot detect environments such as ephemeral wetlands bordering karst lakes, which are patches only metres across. Second, there are aspects of the environment that are not represented by LENZ (e.g. geothermal environments). Third, planar maps of surface projections cannot depict subterranean systems and vertical surfaces, such as cliffs. Last, tools such as LENZ do not utilise biotic drivers (e.g. the effects of marine mammals) to identify rare environments such as those associated with seal colonies. Consequently, a system that is complementary to LENZ is required to define and name physical environments of terrestrial ecosystems that were historically rare in New Zealand.

Vegetation

The Atkinson (1985) system for naming and delineating vegetation types is widely used in New Zealand and is applicable to all terrestrial ecosystems. It comprises two components, species composition and vegetation structure (or substrate where vegetation is sparse or absent), and can be applied at a range of scales. Vegetation has often been used as a surrogate measure for biota in natural ecosystems as vegetation is immobile, easy to measure, and provides habitat for most other biota (Myers et al. 1987).

Ecosystem

Two of the better known New Zealand classification systems concern only forests (McKelvey 1984) and wetlands (Johnson & Gerbeaux 2004). However, a system developed to apply to the full array of ecosystem types evolved during the Protected Natural Areas Programme (PNAP) (Kelly & Park 1986; Myers et al. 1987). This classification was designed to identify representative examples of the full range of natural ecosystems within each ecological district, with the ultimate goal of enhancing biodiversity conservation (McEwen 1987). It is a hierarchical system and uses expert knowledge to subdivide each ecological district into ecological classes (defined by bioclimatic zone, hydrologic class, and land system and vegetation structure). Ecological classes are further subdivided into ecological units, which describe specifics of landforms, and vegetation (Atkinson 1985) types. The PNAP approach has provided some intuitively sound regional classifications (e.g. Courtney & Arand 1994), but no synthetic work has been done to enable classifications to be scaled up from a regional to national scale and hence to be applicable to rare ecosystems nationally.

A framework for defining the physical environments of historically rare ecosystems

We use a modular or multi-factor (sensu Corner et al. 2003) approach using physical and biotic factors to define and name the physical environments of historically rare ecosystem types. This approach provides maximum flexibility to define these environments and make changes or additions. The framework builds on the environmental drivers underpinning LENZ, the first level of the hierarchical approach used in the PNAP surveys (Myers et al. 1987), the biophysical component of Lawless et al. (1994, unpubl. draft report to the Department of Conservation), and the first level of the wetland classification, which is based primarily on hydrological and landform setting, salinity, and temperature (Johnson & Gerbeaux 2004).

Our framework specifically pertains to terrestrial ecosystems. We include only those wetland types (sensu Johnson & Gerbeaux 2004) dominated by terrestrial plants, or emergent hydrophytes as opposed to aquatic hydrophytes (Tiner 1991). Thus, we exclude permanent freshwater bodies such as ponds, lakes and lagoons, and the aquatic component of water channels and springs below the depth limit of rooted plants (littoral zone) such as the aquatic communities of braided rivers. Estuaries below mean minimum low water and marine systems below mean maximum high water are also excluded.

The drivers: factors that distinguish and differentiate environments

Soil types and their profiles provide an indication of factors influencing landscapes. Work by Hans Jenny (1941) described soil as the product both of biotic factors (plants and animals) and abiotic factors: climate (at a regional scale), parent material, topography (landform and drainage), and time since soil formation began. These ideas underpin the ecosystem concept used here, whereby the biotic factors become a function of abiotic factors. Rare ecosystems are often found in climatically or topographically extreme environments that may prevent or delay vegetation succession. For example, the chemistry of the soil parent material prevents an ultrabasic site below the treeline from developing into forest, whereas insufficient time for soil formation, because of parent material instability, prevents active sand dunes from supporting forest. In some situations, the factors may result in an induced vegetation type (sensu Kelly 1972) that may dominate for hundreds of years (e.g. frost flat heaths). However, shorter term successions on typical soils such as those on regularly eroding hill slopes are excluded from our classification.

Our framework differentiates the physical environments of rare ecosystems from more common ecosystems and from each other by aggregating diagnostic classifiers (sensu Corner et al. 2003) of abiotic and biotic environmental factors into unique combinations (e.g. coastal sites, occurring on sand, having a depression landform and being excessively well drained). Comparable modular systems have been used to classify North American terrestrial systems (Corner et al. 2003). The choice of environmental factors and classifiers is critical to the success of the framework. First, they must enable the description and differentiation of treeless ecosystem types occurring below the treeline, e.g. on cliffs, sand dunes, and ephemeral wetlands. Second, they must enable the description of environments supporting ecosystem types that are rare in the alpine zone but not restricted to it (e.g. ultrabasic hills), as well as those that are restricted to the alpine environment (e.g. snow banks). Third, they must enable any rare forested ecosystem types occurring in extreme environments to be distinguished.

The following seven factors used in Tables 1 and 2, (1) soil age, (2) the nature of the parent material or the chemical environment of the soil, (3) the size of the particles making up the soil, (4) the landform on which the soil and its associated ecosystem is found, (5) the drainage regime of the landform, (6) any major disturbances influencing the system, and (7) the climate regime, are described in that order, based on their perceived power to discriminate systems. We do not presume, however, that a definitive hierarchy exists. For example, for ultrabasic or geothermal ecosystems, the parent material or chemical environment may be the primary aspect of their environment that distinguishes them from more common ecosystems, whereas sand dunes are formed from a wide range of parent rock types but their particle size and landform are their principal distinguishing features.

Soil age

The effective time since soil formation began has a major influence on organic matter accumulation and nutrient supply capacity of the soil. Plants are capable of growing on substrates with no organic matter, here termed raw soils (Hewitt 1992), e.g. fresh sand forming dunes under marram grass (*Ammophila arenaria*). If the substrate and vegetation are not disturbed, organic matter will accumulate in the upper part of the soil column, as indicated by dark staining, to form recent soils (Hewitt 1992), e.g. old sand dunes under scrub. Over time, in the order of thousands of years, and depending on the other soil-forming factors, a wide range of soils showing recognisable horizons may develop, e.g. yellow-brown earths (Taylor & Pohlen 1962). For convenience, these are termed mature soils. In the lowlands, these mostly supported forest in prehuman times. Eventually, however, if there are no inputs of fresh material into the soil column from the bedrock or other sources such as river alluvium, the soil may pass its peak of pedogenesis. The physical, chemical and biological properties of the soil–vegetation system will become so rundown (often in association with drainage-impeding subsurface pans of one sort or another) that the soil can no longer support tall forest, e.g. the pakihi soils of Westland. Such soils can be termed over-mature. Because historically rare ecosystems occur mostly at the extremes of environmental gradients, they mostly comprise raw, recent, or over-mature soils.

Parent material or chemical environment

Soil parent material, whether derived directly from the underlying rock or redeposited from elsewhere, is the primary determinant of soil fertility (i.e. its available P, cations, pH). The first diagnostic classifier describing parent material indicates chemical composition of the parent rock (Table 1). Parent rock types are grouped into five broad classes according to chemistry – quartzose, acidic, basic, ultrabasic, and calcareous – following Lilburne et al. (2004) and Barringer et al. (2006). Soil fertility tends to increase in the order listed above (quartzose to calcareous), but alkaline soils resulting from ultrabasic parent materials may have concentrations of heavy metals that are toxic to plants. To define the environments of historically rare ecosystem types, either the broad parent material class (e.g. acidic rock) or the more specific rock type (e.g. granite, sandstone, and basalt) is used. Parent materials may also include other substances such as loess, marine shell beds, and peat (Table 1).

Some ecosystem types are influenced by chemical factors that are not derived directly from the soil parent material but from groundwater (which may contain dissolved salts and heavy metals, for example), air (e.g. acid rain derived from geothermal activity, atmospheric salinity resulting from salt spray), or water movement (e.g. seepages and flushes carrying enhanced nutrients). These diagnostic classifiers are incorporated within parent material or chemical environment in Table 1.

Parent material particle size

The third diagnostic classifier describing parent material indicates dominant particle size (also called 'grain size'). Particle size influences local terrain (e.g. sand is blown to create dunes) and soil properties, particularly moisture availability and nutrient-exchange sites. Particle size follows the widely used Udden–Wentworth scale (Wentworth 1922; Table 1). More than one parent-material diagnostic classifier may be used, e.g. calcareous/boulders.

Topography: landform and drainage

Topography has two components sensu Taylor & Pohlen (1962): landform (e.g. cliff), which determines the relief (e.g. slope), and drainage, which is the rate and degree of the removal of water. They have a multitude of effects ranging from preventing plant growth through instability and non-development of the soil substrate because of previous or ongoing steepness, to controlling the water-table level and soil drainage. We have adopted the landform terminology of Speight (1990). Where the drainage effect results in a permanently to seasonally high water table, or open water, and where plants and animals adapted to the wet conditions are present, the environment is classed as a wetland. For completeness, subterranean systems (e.g. caves), which support a unique and distinctive fauna, are included.

Disturbance regime

Disturbance of varying degrees is a universal feature of ecosystems. Ongoing disturbance is implied in several of the diagnostic classifiers associated with the factors described above (e.g. dune landforms). We use the term to describe only irregular disturbance that is not implied in other diagnostic classifiers but is required to maintain the ecosystem type. The diagnostic classifiers of abiotic disturbance regimes include periodic flooding and periodic fire. Braided riverbeds are maintained by periodic flooding, and periodic natural fires are a characteristic disturbance regime of some ecosystems such as the gumlands in Northland.

Native vertebrates may also generate disturbance that creates rare ecosystems. For example, seabird activity may result in soil disturbance caused by burrowing and trampling and high nutrient status through fertility imported in guano. Wetland turfs may develop in the presence of masses of waterfowl that trample, browse and fertilise. Seal activity can also create localised vegetation communities. Animal activity would have been widespread in New Zealand before human arrival and, combined with unusual topography or geology, may have supported a variety of rare environments.

Climate

Climate is a key determinant of plant growth via temperature, radiation, and precipitation. Coarse-scale climatic conditions are depicted in existing New Zealand climate and ecosystem classifications (e.g. Meurk 1984; Myers et al. 1987; Wardle 1991). Climate is used in two ways here. First, the climatic component of the above classifications is reduced to three coarse categories, 'coastal', 'inland' and 'alpine' to portray geographically where the listed physical environments typically occur. These geographical categories do not distinguish rare environments from common ones, however, so we use climate only as a diagnostic classifier (Table 1) when the physical environment of the rare ecosystem type is differentiated by a climatic factor that is extreme within the New Zealand context. Thus, climate may act on a regional scale, such as in the semi-arid zone of Central Otago where nationally unique ecosystem types occur (e.g. salt pans occurring on inland saline soils). More typically, climate may differentiate rare ecosystem types at a local scale; for example >200 frost days per year resulting from cold-air ponding differentiates frost flats from adjacent hillslope forests. Multiple diagnostic classifiers for climate are required to define the environment of a specific ecosystem type where climate combines diverse drivers (e.g. high cloud cover, a high number of frosts annually, extreme wind exposure).

Using diagnostic classifiers to define and name physical environments

Diagnostic classifiers from each or any of the seven classes of physical and biotic factors listed above (soil age, parent material or chemical environment, particle size, landform, drainage, disturbance regime, and climate) can be combined to define the physical

Table 1. Diagnostic classifiers that when combined distinguish the physical environments of historically rare ecosystem types from each other and more common environments. They comprise six classes of physical factors (soil age, parent material chemistry, particle size, landform, drainage, climate) and one class describing disturbance.

Soil age[1]	Parent material/chemical environment	Particle size (Udden–Wentworth scale)	Landform[2]	Drainage	Disturbance Regime	Climate
Raw Recent Mature Over-mature	**Quartzose rocks** Soft quartzitic sediments Quartzite **Acidic rocks** Mudstone (soft) Sandstone (soft Mudstone (hard) Sandstone (hard) – greywacke Rhyolite Granite and gneiss Schist **Basic rocks** Tuffaceous mudstone Tuffaceous sandstone Andesite Diorite Basalt Gabbro **Ultrabasic rocks** **Calcareous rocks** Limestone Marble **Other parent substrates** Alluvium and till Loess Shells Peat Dune sand[8] **Chemical environment** Groundwater salinity Atmospheric salinity Geothermal – acid rain Geothermal – acid soils, toxic elements Enhanced nutrients	Bedrock (in situ) Boulders >256 mm Cobbles 64–256 mm Gravel 2–64 mm Sand 62.5 µm–2 mm Silt and clay <62.5 µm	Hillslope[3] Hillcrest[5] Plain Terrace Fan Depression[6] *Gorge Doline Tor Cliff Scarp Talus *Moraine Beach ridge Beach Dune (comprised of dune crest and dune slope) *Cave entrance *Subterranean (e.g. caves and cracks) Estuary Lagoon *Dome	Excessive drainage Near permanently saturated (but water table not high) Permanently high water table Regularly high water table Seasonally high water table (periodically dry) Open water	**Abiotic** Periodic fire (including eruptions) Periodic flooding **Biotic** Seabirds – guano deposits Seabirds and marine mammals – trampling and grazing Seabirds – burrowing	**Coarse-scale[4]** Coastal Inland Alpine **Fine-scale** >200 frost days per year High water balance (high–very high monthly water balance ratio[7] High cloud cover (<1500 sunshine hours and >200 rain days p.a.) Semi-arid (high–very high annual water deficit)[7] Extreme wind exposure Late snowlie Geothermal – excessive heat Geothermal – superheated steam

[1] Following Hewitt (1992) and Leathwick et al. (2003)
[2] A subset of those listed in Speight (1990). *= not listed in Speight
[3] Includes mountain slopes
[4] Coastal = coastal (within 1 km of the coast and with altitude <300 m); inland = lowland, montane, subalpine; alpine = lower alpine, upper alpine, nival – of Myers et al. (1987)
[5] Includes ridges and summits
[6] Includes hollows, basins and swales
[7] Following Leathwick et al. (2003)
[8] Derived from a combination of particle size and landform

environment of an individual ecosystem type (Table 2). Diagnostic classifiers are listed only if they are perceived by the authors as being critical to distinguish ecosystem types from each other. For example, a 'shingle beach' (such as occurs at Rarangi, Marlborough) is defined as being a (1) raw to recent soil (2) of gravel to cobbles (3) forming a beach (4) near the coast (raw–recent/gravel–cobbles/beach/coastal). Nearby, there may be a 'stony beach ridge' defined as (1) raw to recent (2) of gravel to cobbles (3) forming a beach ridge (4) near the coast (raw–recent/gravel–cobbles/beach ridge/coastal). In this example, only the landform differentiates these two systems. 'Coastal cliffs on basalt', such as those on Banks Peninsula, are defined as being (1) raw soil (2) of basic rock (3) forming cliffs (4) near the coast (raw/basic/cliffs/coastal). They are distinguished from 'calcareous coastal cliffs', such as those at Punakaiki, North Westland, by the nature of their parent rock, i.e. defined and named as raw/limestone rock/cliffs/coastal.

A few environments are so extreme that only one or two diagnostic classifiers are needed to separate them as an ecosystem type, e.g. (1) geothermal (2) acid rain systems (geothermal–acid rain), or (1) seabird guano deposits (2) near the coast (seabirds–guano deposits/coastal (numerous landforms)). In Table 2 information that is not part of the formal description but is important to further characterise the ecosystem type is presented in parentheses.

Where diagnostic classifiers are held in common, ecosystem types may be grouped together as is done in Table 2. This is an intuitive clustering procedure that serves to bring some order to the whole list. First, all rare environments having unique hydrological conditions and classified as wetlands by Johnson & Gerbeaux (2004) are separated out and listed at the end of Table 2. Next, all those with either extreme chemical/physical or biological factors are grouped and placed before wetlands. The biological group all have high disturbance and added nutrients and although mainly coastal, some seabird colonies are found well inland. Those environments characterised by limited light or no light, such as caves and underground systems, are grouped as semi-subterranean or subterranean, and geothermal environments are grouped together. Groupings of the remaining environments (the majority) start at the top of the table. They are grouped first by a coarse-scale climate classifier, or a range of climate classifiers. Within each group so defined, they are then listed according to whether they primarily have deposits of parent material (e.g. sand dunes, talus, moraines) or occur primarily on in situ parent rock (e.g. cliffs, scarps, tors). Last, environments within these groups are listed in order of increasing soil development, from raw to mature, and/or increasing particle size, from sand to boulders, or according to the chemical composition of the parent rock, whichever is applicable. For example, environments of ecosystem types on coastal sand are subdivided on the basis of soil development, whereas those on in situ parent rock are subdivided on the basis of rock chemistry.

The diagnostic classifiers in our classification are intentionally broad, and combine some of the finer distinctions in the biophysical categories of Myers et al. (1987) and Lawless et al. (1994, unpubl. draft report), for example. This was done both to simplify the list and to define the environments of the ecosystem types in fairly general terms, as the sources of variation within many of them are poorly understood. More specifically defined diagnostic classifiers (e.g. of bedrock types and degree of foliation or bedding, climate and landform) may eventually be required to describe how plant and animal communities vary within these environments.

Definitions and names of historically rare ecosystems

The list of historically rare ecosystems (Table 2) was derived from those listed in Rogers & Walker (2002), Rogers et al. (2005), the environments and ecosystems listed in Wardle (1991), de Lange et al. (2004), suggestions offered following presentations made at the 2005 meetings of the Plant Conservation Network and the New Zealand Ecological Society, and our own knowledge. A draft ordered list (with accompanying text) was reviewed by 48 individuals including experts from the Department of Conservation, regional councils, universities and research institutes, private consultants, and retired researchers (see Acknowledgements). This process doubled the number of systems on the list, refined the diagnostic classifiers used, and increased the clarity of the rationale. A revised list was sent back to all the reviewers for a subsequent round of comments. The list now includes 17 wetland types, 3 types induced by native vertebrates, 5 subterranean types, and 5 geothermal types. The remainder include 11 exclusively coastal types and 30 types that may occur in inland or alpine areas. Nevertheless, it should be regarded as a first approximation and is undoubtedly an incomplete list, especially with regard to environments of historically rare forested ecosystem types and those restricted to alpine areas. The list errs on the side of including physical environments for ecosystem types that subsequently may be determined not to be historically rare (e.g. sand dunes), so as not to omit those whose original rarity is currently uncertain.

For each defined environment, the main vegetation structural units (adapted from Atkinson 1985) typical of the rare ecosystem types are given (Table 2).

Table 2. Physical environments and vegetation structure of New Zealand's historically rare ecosystems. The common name and definition describe the environment of the ecosystem type. Vegetation structure lists the main vegetation units across all occurrences of that ecosystem and uses categories adapted from Atkinson (1985) – forest, treeland, scrub, shrubland, tussockland, fernland, grassland, sedgeland, rushland, reedland, restiadland, cushionfield, herbfield, mossfield, lichenfield, and open land (includes rockland, boulderfield, stonefield/gravelfield, sandfield, loamfield/peatfield). * indicates that rarity at a national scale may be questionable. Information that is not part of the formal description but is important to further characterise the ecosystem type is given in parentheses.

Tentative common name	Definition (i.e. diagnostic classifiers) and notes	Vegetation structure	Example locality
Coastal			
*Active sand dunes	raw/sand/dune/coastal	grassland, sedgeland, open land	Himatangi, Manawatu
Dune deflation hollows	raw/sand/depression/excessive drainage/coastal	open land	Kaitorete Spit, Canterbury
Shell barrier beaches	raw/shells/plain/coastal	grassland, herbfield	Miranda Chenier Plain, Firth of Thames
Coastal turfs	raw/atmospheric salinity/coastal, extreme exposure	open land, herbfield	Westhaven Inlet, NW Nelson
Stony beach ridges	raw–recent/gravel–cobbles/beach ridge/coastal	scrub, shrubland, open land	Rarangi, Marlborough
Shingle beaches	raw–recent/gravel–cobbles /beach/coastal	open land	Rarangi, Marlborough
*Stable sand dunes	recent/sand/dune/coastal	shrubland, grassland, tussockland, herbfield, open land	Himatangi, Manawatu
Coastal rock stacks	raw/acidic rock/tor/coastal	open land, herbfield, lichenfield, shrubland	Cape Kidnappers, Hawke's Bay
Coastal cliffs on quartzose rocks	raw/quartzose rock/cliffs/coastal	open land, lichenfield, herbfield, scrub, shrubland tussockland	17 Mile Bluff, Westland
Coastal cliffs on acidic rocks	raw/acidic rock/cliffs/coastal	open land, lichenfield, herbfield, scrub, shrubland tussockland	Cape Turnagain, Wairarapa
Basic coastal cliffs	raw/basic rock/cliffs/coastal	open land, lichenfield, herbfield, scrub, shrubland tussockland	Coastal areas of Banks Peninsula,
Calcareous coastal cliffs	raw/limestone rock/cliffs/coastal	open land, lichenfield, herbfield, scrub, shrubland tussockland	Punakaiki, North Westland
Ultrabasic sea cliffs	raw/ultrabasic rock/cliffs/coastal	scrub, herbfield, lichenfield, open land	Western cliffs, D'Urville Island; Surville cliffs, Northland
Inland and alpine systems			
Volcanic dunes	raw/acidic rock (volcanics)/sand/dune	open land	Rangipo Desert, central North Island
*Screes of acidic rocks	raw/acidic rock/gravel–cobbles/talus/(excessive drainage–near permanently saturated; inland–alpine)	open land	Porters Pass, Canterbury
Calcareous screes	raw/calcareous rock/gravel–cobbles /talus/(excessive drainage–near permanently saturated; inland–alpine)	open land	Mt Arthur, Nelson
Ultrabasic screes	raw/ultrabasic rock/gravel–cobbles/talus /(excessive drainage–near permanently saturated)	open land, lichenfield, shrubland	Olivine Range, Southland
Young tephra (<500 years) plains and hillslopes	raw/acidic rock(volcanic) /sand–gravel/plains and hillslope	open land	Mt Tarawera, Rotorua
Recent lava flows (<1000 years)	raw/acidic rock (volcanic)/boulders–bedrock (numerous landforms)	scrub, shrubland, treeland, forest, herbfield, mossfield, open land	Rangitoto Island, Auckland
Old tephra (>500 years) plains (= frost flats)	acidic rock (volcanic)/depression/ seasonally fluctuating water table/inland, >200 frost days year	shrubland, scrub, tussockland	Kaingaroa, central North Island
Frost hollows	terrace/>200 frost days per year	shrubland, scrub	Buller River, Nelson
Boulderfields of acidic rocks (non-volcanic)	raw/acidic rock/boulders/talus	open land, lichenfield, shrubland	Iron Hill, western Nelson
Volcanic boulderfields	recent/acidic(volcanic)/boulders/talus/ excessive drainage	forest, scrub	Mt Eden, Auckland
Volcanic debris flows or lahars	recent/acidic rock(volcanic)/silt–cobbles	forest, scrub, mossfield	Maero debris flow, Mt Taranaki
*Moraines	raw–recent/cobbles–boulders/moraine/(various parent materials)	open land, shrubland, herbfield, tussockland	Murchison Valley, Canterbury
Boulderfields of calcareous rocks	raw/calcareous rock/boulders/talus	open land, lichenfield, shrubland	Mt Arthur, western Nelson
Ultrabasic boulderfields	raw/ultrabasic rock/boulders/talus	open land, lichenfield, shrubland	Red Hills, Southland
Cliffs, scarps and tors of quartzose rocks	raw/quartzose rock/bedrock/cliff, scarp and tor/inland–alpine	open land, herbfield, tussockland, shrubland	Lyell Range, Westland
*Cliffs, scarps and tors of acidic rocks	raw/acidic rock/bedrock/cliff, scarp and tor/inland–alpine	open land, herbfield, tussockland, shrubland	Mt Rolleston, Canterbury
Basic cliffs, scarps and tors	raw/basic rock/cliff, scarp and tor/inland–alpine	open land, herbfield, tussockland, shrubland	Mt Herbert, Banks Peninsula, Canterbury
Calcareous cliffs, scarps and tors	raw/calcareous rock/cliff, scarp and tor/inland–alpine	open land, herbfield, tussockland, shrubland	Mt Owen, Nelson
Ultrabasic cliffs, scarps and tors	raw/ultrabasic rock/cliff, scarp and tor/coastal–alpine	open land, herbfield, tussockland, shrubland	Olivine Range, Southland

Tentative common name	Definition (i.e. diagnostic classifiers) and notes	Vegetation structure	Example locality
Ultrabasic hills	ultrabasic rock/hillslope, hillcrest/(raw–mature)	open land, herbfield scrub, shrubland, tussockland, forest (very limited extent)	Red Hills, Marlborough
Inland sand dunes	raw–recent/sand/dune/inland	open land, scrub, tussockland, herbfield	Clutha Valley, Otago
Inland outwash gravels	raw–recent/sand–boulders/plain/inland	open land, herbfield, treeland	Pisa Flats, Clutha Valley
Braided riverbeds	raw–recent/sand–boulders/plain/periodically flooded ([2]JG, p. 56)	open land, herbfield	Waimakariri River
Granitic sand plains	raw/granite/sand–gravel/hillslope, hillcrest (mostly alpine)	open land	Lookout Range, Nelson
Granitic gravel fields	raw/granite/gravel/hillslope, hillcrest	open land	Mt Titiroa, Manapouri
Sandstone erosion pavements	raw/quartzose/bedrock/hillslope, hillcrest	open land	Mt Augustus, West Coast
Limestone erosion pavements	raw/calcareous/bedrock/hillslope, hillcrest/(alpine)	open land	Matiri Tops, western Nelson
Inland saline (salt pans)	ground water salinity/semi arid/depression ([2]JG, p. 20, 22)	herbfield, grassland	Maniototo Valley, Central Otago
Strongly leached terraces and plains ('Wilderness' vegetation)	over-mature/sand–gravel/ terrace–plain/inland	open land, herbfield, shrubland	The Wilderness, Southland
Cloud forests	high cloud cover (<1500 sunshine hours and >200 rain days p.a.)/inland	forest	Mt Manuoha, Urewera National Park; Waima Forest, western Northland
Geothermal systems			
Heated ground (dry)	geothermal – excessive heat	open land, mossfield, shrubland, scrub	Whakarewarewa, Rotorua
Hydrothermally altered ground (now cool)	geothermal – acid soils, toxic elements	open land, shrubland, scrub	Whakarewarewa, Rotorua
Acid rain systems	geothermal – acid rain	open land, scrub, treeland, forest	White Island, Bay of Plenty
Fumeroles	geothermal – superheated steam/acid rain/depression	open land, shrubland	Waimangu, Rotorua
Geothermal streamsides	geothermal – excessive heat/near permanently saturated (but water table not high)	open land to scrub	Waimangu, Rotorua
Induced by native vertebrates			
*Seabird guano deposits	seabirds – guano deposits/coastal/(numerous landforms)	open land, herbfield	Muriwai gannet colony, Auckland; South Bay, Kaikoura
*Seabird burrowed soils	seabirds – burrowing/coastal	open land to forest	Petrel colonies, Paparoas; Catlins Coast, SE Otago
Marine mammal haulouts	seabirds and marine mammals – trampling and grazing/coastal	open land to forest	Seal colonies, Westport
Subterranean or semi-subterranean			
Sinkholes	raw/limestone, marble, dolomite/doline	open land, shrubland, tussockland, flaxland	Thousand Acre Plateau, western Nelson
Cave entrances	raw/calcareous/cave entrance	open land, herbfield	Mangapu cave
Caves, and cracks in karst	calcareous/subterranean/coastal–alpine	none	Waitomo caves, Waikato
*Subterranean river gravels	raw/alluvium and till/gravel/subterranean/	none	Waimea Plains
Subterranean basalt fields	raw/basic rock (basalt)/subterranean	none	beneath Auckland city
Wetlands			
Lake margins	inland/regularly high water table/silt and clay–gravel/beach ([2]JG, p. 18)	open land, herbfield, rushland	Lake Te Anau, Fiordland
Cushion bogs	permanently high water table/peat/plain ([2]JG, p. 27)	cushionfield	Mararoa Valley, Southland
Ephemeral wetlands[1]	seasonally high water table/depression ([2]JG, p. 33)	herbfield, open land	Rangitaiki, Taupo
Gumlands (excludes those induced by anthropogenic fire)	over-mature soils/seasonally high water table/(peat or non-peat) ([2]JG, p. 34)	shrubland, fernland, sedgeland, forest	Ahipara Plateau; Spirits Bay, Northland
Pakihi	over-mature soils/regularly–permanently high water table/(peat or non-peat) ([2]JG, p. 34)	shrubland, fernland, sedgeland, forest	German Terrace, Westland
Damp sand plains	raw–recent/coastal/sand/plains/permanently high water table ([2]JG, p. 44)	open land, herbfield	Kaipara Heads, Northland
Dune slacks	raw–recent/coastal/sand/depression/ permanently or seasonally high water table ([2]JG, p. 44)	herbfield, open land	Himatangi, Manawatu
Domed bogs (*Sporadanthus*)	permanently high water table/peat/dome ([2]JG, pp. 48, 70)	restiadland, rushland, sedgeland, shrubland	Kopuatai Bog, Hauraki Plains
String mires	permanently high water table/ peat/depression on hillslope/open water ([2]JG, p. 48)	mossfield, sedgeland	Garvie Mountains, Southland

Tentative common name	Definition (i.e. diagnostic classifiers) and notes	Vegetation structure	Example locality
*Blanket mires	permanently high water table/peat/hillcrest, hillslopes, depressions (low relief) ([2]JG, p. 50)	rushland, mossfield, fernland, shrubland, scrub, forest	Southern Stewart Island
Tarns	open water/depression/alpine (usually) ([2]JG, p. 53)	tussockland, sedgeland, cushionfield	Glenmore moraines, Mackenzie Basin
*Estuaries	coastal/estuary ([2]JG, p. 54)	open land, sedgeland, rushland, reedland, herbfield, shrubland, scrub	Ohiwa Harbour, Bay of Plenty; Whangapoua estuary, Great Barrier Island
*Lagoons	coastal/lagoon ([2]JG, pp. 54–55)	open land, sedgeland, rushland, reedland, herbfield, shrubland, scrub	Lake Ellesmere, Canterbury
Seepages and flushes	permanently high water table/hillslope and fan/enhanced nutrients ([2]JG, pp. 57–58)	sedgeland, cushionfield, mossfield, scrub	Garvie Mountains, Southland
Snow banks	alpine/late snow-lie/seasonally high water table ([2]JG, p. 62)	tussockland, herbfield	Top of Kelly Range, Brunner Range

[1] May be usefully split into 'acidic' vs 'basic' to account for the very rare turfs surrounding karst lakes (e.g. Lake Koraha, Taumata Totara Forest)
[2] (JG) See Johnson & Gerbeaux (2004)

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