Manaaki Whenua
Landcare Research

Road map to update the existing typology for terrestrial ecosystems

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Summary

Which domain does this report cover?

This report covers the terrestrial domain, as circumscribed by Collins (2024). It is a companion to a report investigating the adoption of a unifying typology for all of New Zealand (Sprague & Wiser 2024), and a set of equivalent reports for the remaining five domains (groundwater, lakes, marine and estuarine, rivers, and wetlands).

What typologies already exist?

Several typologies already exist for the terrestrial domain, some underpinned by data and others derived from expert opinion. We assessed four typologies against the set of end-user principles and requirements developed during collaborative workshops described in Collins 2024. These were the classifications of Singers and Rogers (2014), Wiser et al. (2011 and subsequent publications), *The Vegetative Cover of New Zealand* (Newsome 1987), and the naturally uncommon ecosystems (Williams et al. 2007). The New Zealand Land Use Information System was used as a basis for discussion on human-engineered systems.

Do existing typologies align with the principles and requirements?

All typologies align with one or another subset of the principles and requirements, but none align with all of them. The two more widely used ecosystem typologies (Wiser et al. 2011 and subsequent publications; Singers & Rogers 2014) could both be extended to be more comprehensive across a range of nested hierarchical levels, but neither has complete mapping for all of New Zealand. Documentation describing diagnostic criteria for assigning ecosystem types and mapping methodologies (including updates to maps) needs to be developed and made available. Accuracy assessments of maps implemented from the typologies are not consistently applied. Successional, urban and exotic-dominated ecotones, and human-dominated ecosystems, are also not consistently included in the existing typologies. This is due to these types either being out of scope of the typology or because they are not represented in the vegetation plot data underpinning the typology.

Do existing typologies align with the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET)?

The degree to which existing typologies align with the IUCN GET is variable. Most have either a one-to-one or one-to-many match to ecosystem functional groups (EFGs) from the IUCN GET, but in some cases types from the existing typologies only partially match to one IUCN GET EFG, indicating a missing unit from the global typology. Some of these cases result in extensive ecosystem types (e.g. black beech forest) only mapping partially to the IUCN GET. Some of the types from the IUCN GET intensive land-use biome encompass a wide range of environments (e.g. all of the New Zealand built environment class is included in a single IUCN GET unit).

What are the next steps for national ecosystem typologies in this domain?

We provide a road map to guide progress to a revised typology that meets the principles and requirements. This road map includes seven actions, followed by individual tasks required to complete each action. The recommendations specified by these actions are centred on the establishment of a governance structure, the adoption of a hierarchical structure for the typology, the development of diagnostic criteria for ecosystem types, the development of repeatable mapping methods, and improvement in the validation and comprehensiveness of the typology.

Finally, we recommend integrating the two main ecosystem typologies currently in use in New Zealand, drawing on the best points of each, with the ultimate goal of delivering a single revised typology for New Zealand's terrestrial ecosystems. This would require a collaborative effort between central government, regional councils, and researchers, with the support of adequate governance and database infrastructure.

1 Background

This report is part of a larger body of work aimed at guiding the development of a unified and overarching typology (see Keith et al. 2022) of ecosystems for New Zealand. It considers the terrestrial domain and provides a road map that sets out how an improved typology that fits with a unified national typology might be developed.

In developing the road map we first assess the existing typologies currently in use against a set of end-user principles and requirements (hereafter 'principles') developed during collaborative workshops (Collins 2024). Multiple typologies have been developed and used to describe New Zealand's terrestrial ecosystems; these have been most highly developed for forests and less developed for non-forest ecosystems. In the sections below we first describe the early typologies that underpin current typologies. We then focus on those typologies most in use that encompass vegetation of different types (e.g. forests, shrublands, grasslands, and other non-forested ecosystems).

Due to its complex geology, dynamic disturbance regimes, and relatively recent human habitation, the drivers of the composition of New Zealand's terrestrial ecosystems are complex. Much of the country's biota evolved in relative geographical isolation following its split from Gondwana c. 80 million years ago (Cooper & Millener 1993), after which it became one of the final land masses to be inhabited by humans in c. 1280 (Wilmshurst et al. 2008).

Before human arrival as much as 90% of the country was forested (McGlone 1989). Landscape changes were principally the result of geological disturbance (e.g. earthquakes, volcanic activity) and changes in climate (e.g. glacial advances and retreats), which had an imprint on the landscape-level patterns of terrestrial ecosystems (Cooper & Millener 1993). After human arrival, fire, once an uncommon element in the New Zealand landscape, was frequently induced by humans and resulted in a vast increase in the representation of non-woody and successional vegetation in the landscape (Perry et al. 2014).

Forest clearance continued following European settlement in c. 1840, and there was an increase in the intensification of human-dominated systems and the introduction of invasive predators, browsers, and weeds, and domesticated grazing animals. This has resulted in both a complex pattern of vegetation across the landscape and a complex conceptual problem in defining, mapping, and understanding what exists currently, what has the potential to exist, and what historically existed across a range of historical time points. This has influenced the typologies and maps currently in use in New Zealand, with some representing current patterns, and others potential patterns.

In this report we provide a summary of our assessment of terrestrial ecosystem typologies against the principles. We also provide an assessment of how the typologies align with the International Union for Conservation of Nature Global Ecosystem Typology (IUCN GET; Keith et al. 2013, 2022). Finally, we present a road map that outlines the steps required to achieve a revised ecosystem typology for the terrestrial domain that is consistent with the principles, and that nests under the IUCN GET.

1.1 Pre-existing foundational and relevant works

Below we provide a description of pre-existing foundational and relevant works that give valuable baseline information but were not designed to be comprehensive and exhaustive typologies. This is reflected in the thematic and spatial resolution considered. Many were one-off products, developed by a small number of individuals and without long-term funding to support their development or updates over time. Many aspects of these typologies underpin more recent typologies used in the terrestrial domain.

Forests class maps

From the 1950s, forest class maps were compiled at a scale of 1:250,000 (NZ Forest Service Mapping Series 6).[1] They provided almost national coverage (excluding Fiordland) of 18 broadly defined forest classes. These classes were defined qualitatively (McKelvey & Nicholls 1957; Nicholls 1976), and geographical variants within these classes were described. The maps were drawn using aerial photo interpretation, combined with ground-based assessments within each mapped class, using a mixture of quantitative data collected during the National Forest Survey spanning 1946–1955 (Thomson 1946; Masters et al. 1957), the North Island Forest Ecological Survey (McKelvey 1995), and regional descriptions. The forest class maps are still used for a range of purposes because they provide more granularity than products such as the Land Cover Database (LCDB) and *The Vegetative Cover of New Zealand* (Newsome 1987; see below).

Atkinson

Atkinson (1962, 1985) derived a system for naming and delineating vegetation classes that could be applied to all terrestrial ecosystems, with the primary aim of supporting vegetation mapping. It comprises two components: a structural name based on the proportion of plant growth forms, and a floristic name that indicates the identity of the major canopy layers. Structural names are based on a classification of growth forms and other surfaces provided in Atkinson 1962, such as 'forest', 'treeland', 'scrub', and 'shrubland'. Species are included in the names based on their dominance, and common names are used in preference to scientific names.

Although the Atkinson system is the most widely adopted naming system for New Zealand terrestrial ecosystems and provides enumeration of the different ecosystems occurring where it has been applied, it does not provide a New Zealand-wide typology.

Vegetation of New Zealand

Wardle (1991) published this seminal work, which was a comprehensive account of New Zealand's vegetation. It describes its origins, ecology, biogeography, and community structure. Each of the major categories of vegetation is described, including communities of both native and naturalised plants and the vegetation of the remote outlying islands.

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[1] Note that a small area of the North Island was mapped at 1:63,360, NZFSM Series 3.

Chapters focus on major physiognomic or ecological groups (e.g. forest, grassland and herbfield, wetlands), with the variation within these groups being described in terms of dominant taxa, geography, and major environmental gradients. No formal naming system, hierarchy or template for community descriptions was used, because the intent was not to produce a formal classification or typology.

EcoSAT

EcoSAT used satellite imagery to produce a land-cover classification at a 1:50,000 scale. Woody vegetation was further classified (EcoSAT Forests) using binary split rules initially developed from visual examination of typical spectral signatures (Dymond & Shepherd 2004), which matched mapped pixels to a selection of ground-based data (277 forest plots of 20 × 20 m). This classification reflected the proportions of *Nothofagus*, broadleaved species, and conifer species (i.e. podocarp species and *Agathis australis*) in the forest, as each has a unique spectral signature. The approach was then used to derive a national woody vegetation layer comprising nine classes. The more ecologically comprehensive depiction by EcoSAT was not published. Neither EcoSAT nor EcoSAT Forests has been ground-truthed.

Land Cover Database

The New Zealand Land Cover Database (LCDB; Manaaki Whenua – Landcare Research 2020) is a multi-temporal, thematic classification of New Zealand's land cover. It identifies 33 mainland land-cover classes (35 classes if the offshore Chatham Islands are included) based on satellite imagery. Of these, 16 represent naturally occurring vegetation, encompassing dominance by both indigenous and exotic species. The classification is periodically revised (currently version five), always with backward compatibility maintained. The nominal minimum mapping unit is 1 hectare, although features are regularly delineated below this threshold to identify significant land-cover types such as wetlands. LCDB is widely used for myriad purposes but is unsuitable for a national terrestrial ecosystem typology because the land-cover classes lack the granularity required for many purposes, including regional conservation planning. It is a critical layer, however, to aid mapping of the more granular typologies.

New Zealand Land Use Classification

An overview of the development of land-use classification in New Zealand is provided in Law et al. 2024. Classification of land use depends on attributes relevant to its use, and hence different land-use classifications (e.g. LUCAS LUM[2]) may be relevant for different purposes. The draft national land-use classification scheme, New Zealand Land Use Management (NZLUM) classification system (described in Law et al. 2024), is intended to be a 'general purpose' classification system for environmental management based on grouping land-use activities. The intent is for land to be classified according to its primary use, based on the primary land management objective of the landowner or manager, and

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[2] Land Use and Carbon Analysis System Land Use Map

additional secondary land uses can be captured separately. Some uses may only ever be secondary, so the proposed classification system necessarily includes some such uses; these secondary land uses are unlikely to significant influence the ecosystem associated with that of the primary land use. We used NZLUM as the basis for an assessment of how ecosystems modified by land-use map to the IUCN GET, particularly in relation to ecosystem functional groups identified under 'Intensive land-use biome' (T7). Consideration of land use will be required when human-engineered ecosystems are incorporated into a unified New Zealand ecosystem typology.

1.2 Typologies assessed against the principles

Here we describe the four existing typologies we assessed against the principles, chosen to support the development of a nationally standardised typology that meets the needs of multiple stakeholders, as defined in Collins 2024.

The Vegetative Cover of New Zealand

The Vegetative Cover of New Zealand (Newsome 1987) provided national coverage for all vegetation communities: 37 classes of indigenous-dominated vegetation were defined and categorised into seven groups. It was compiled for publication at the coarse scale of 1:1,000,000 and resolved vegetation communities with a reasonable degree of accuracy, but could only delineate map units greater than 500 ha in area. The underpinning data were primarily from the New Zealand Land Resource Information Survey (Blaschke et al. 1981) and were supplemented by regional vegetation maps with extensive ground-truthing. The maps are still used for some applications because they provide more physiognomic granularity in indigenous-dominated types than the LCDB.

Expert-based system of Singers and Rogers

This system (Singers & Rogers 2014), hereafter referred to as 'the expert-based system', was developed to address the need for an ecosystem typology that encompasses the structural and compositional variation in terrestrial ecosystems to provide a basis for conservation planning at regional and national scales. Higher-level types were defined based on climate (temperature and moisture availability), landforms, and soils. To accommodate communities where edaphic extremes or frequent disturbance are the primary drivers of composition (i.e. 'azonal' ecosystems), a separate abiotic framework representing these drivers was embedded above the zonal primary drivers. A literature review and expert opinion were used to align vegetation communities with the higher-level unit to which they are most frequently associated.

Ecosystem types may differ in their granularity and may be named and described based on dominant taxa, structure or environment, in part based on the level of knowledge available. A modified version (fewer types) was incorporated into the Department of Conservation's management prioritisation process (Leathwick et al. 2012), and the typology has been widely used by regional councils (except Canterbury and Westland). The original intention was for this system to eventually transition to a quantitatively based approach:

Transition from this mainly qualitative ecosystem classification to quantitative approaches will occur as biodiversity databases and statistical modelling permit improved fits with national geographic patterns. (Singers & Rogers 2014)

Quantitative plot-based system of Wiser and collaborators

This system has been developed progressively to provide a national-scale (three major islands), quantitative plot-based vegetation classification of New Zealand (Wiser et al. 2011; Wiser & De Cáceres 2013; Wiser et al. 2016; Smale et al. 2018; Wiser & De Cáceres 2018; McCarthy et al. 2022; Wiser et al. 2022). Hereafter this is referred to as the 'quantitative plot-based system'.

The classification consists of two hierarchically nested levels: alliances and associations. Woody (forests, shrublands) and non-forested (herbaceous) classifications are differentiated by their use of cover abundance values versus relative species ranks to define vegetation types, respectively. A statistical approach called 'noise clustering' was used to define vegetation classes. This calculated the degree of fit of a plot to a defined vegetation type, so that a given plot record can either (1) be assigned to a single vegetation type; (2) be deemed transitional between more than one type; or (3) remain unassigned. An advantage of this approach is that it enables extensions of the classification by recognising that some plots in the current classification are best left unassigned until enough data are available to robustly define a vegetation type.

The system now incorporates data from over 20,000 plots, defining 32 alliances and 92 associations from forest and shrublands, 22 alliances and 50 associations from non-woody vegetation, and 14 associations from geothermal vegetation. However, this classification is largely restricted to areas and types of vegetation that have been sampled adequately with plots. Some well-known vegetation types with limited plot data (e.g. non-grassland alpine habitats, wetlands, coastal areas, urban and peri-urban areas) are currently less comprehensively represented in the system (Wiser & De Cáceres 2018). The classification has provided a framework for both basic and applied research.

Naturally uncommon ecosystems

Naturally uncommon ecosystems are defined as those having a total extent, before human arrival, of less than 0.5% (i.e. <134,000 ha) of New Zealand's total area (268,680 km^2). These ecosystems tend to occur in environments that are also rare and often have highly specialised and diverse assemblages of flora and fauna, characterised by endemic and rare species. The framework to define these ecosystems was 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 were defined using pertinent environmental descriptors selected from soil age, parent material, soil chemistry and particle size, landform, drainage regime, disturbance, and climate (Williams et al. 2007; Wiser et al. 2013). For each ecosystem, an example locality and the dominant vegetation structural type were also given. The IUCN's (then) draft ecosystem red-list criteria were applied to the 72 naturally uncommon ecosystems to assess each ecosystem's threat level (Holdaway et al. 2012). Naturally uncommon ecosystems are referenced in the National Policy Statement for Indigenous Biodiversity (Ministry for the Environment 2023) and are fully crosswalked (types translated between typologies) to the IUCN GET in the Output 1 report (Sprague & Wiser 2024), although not all have analogues.

1.3 Summary of relevant points from Collins 2024

In Collins 2024 there was no consensus on a candidate for a standard typology for terrestrial ecosystems. It was found that the expert-based system (Singers & Rogers 2014) has been adopted by most councils, but different regions have varying levels of detail in their resultant ecosystem maps. Other sectors use different typologies (e.g. the quantitative plot-based system, naturally uncommon ecosystems, LCDB). The agencies that contributed to this report stated that there are components of the existing typologies that work well for certain purposes, and suggested that, if possible, they could be compiled and integrated with each other and ultimately developed into something new. This system would need to be more comprehensive, able to integrate different levels of specificity, and be suitable for a range of applications. A hierarchical structure would be desirable, and it is important that the typology can be mapped, updated, and related to other typologies in use. The cost and practicality of developing a new system is an important consideration, as there is a tension between building on past investments versus looking beyond sunk costs to develop a system that meets long-term requirements.

There was nothing unique about terrestrial ecosystems that had not been raised in workshops focusing on other domains.

1.4 Unique challenges for the domain

The primary challenge for the terrestrial domain is that multiple typologies have been developed and are in use for different purposes, often by different communities. Although those using a particular typology often recognise some weaknesses, it is generally considered that at least some aspects of the system are adequate to meet their current needs (Collins 2024). Accordingly, stakeholders may be reluctant to endorse a solution that requires them to move too rapidly away from a familiar system.

This means that any solution to develop a single, unifying approach within the terrestrial domain will need to be progressive and enable users to continue meeting their needs during these developments. Any solution needs to be attractive to users and provide them with more and better capabilities than they currently have.

Also, some typologies present a dichotomy between 'vegetation' classifications and 'ecosystem' classifications, with the assumption that those based on floristic or physiognomic criteria do not represent ecosystems to the same degree as those that present vegetation communities in an environmental context. An alternative view is that vegetation types and ecosystem types are largely analogous. This is well expressed by Dayaram et al. (2021), who define vegetation types as 'landscape scale groups of plant communities that share functional processes within a biogeographically defined part of the landscape'.

This view is consistent with the concepts behind the IUCN GET, which emphasises characteristic biota, ecosystem function and ecological processes. Vegetation composition is an expression of environmental constraints on species distributions, disturbance regimes, dispersal limitation and biotic interactions, and creates the habitats within which other types of organisms exist. In an ecosystem classification it is important that functional processes be documented, and researched where not understood, to facilitate understanding of threats to these processes and thus to the ecosystem and its constituent biota. In the absence of data on the plant biota of an ecosystem, one may initially define it by environmental conditions (see *Land Environments of New Zealand*; Leathwick et al. 2002), with the ultimate goal of integrating biotic composition into the typology. This has been done for many naturally uncommon ecosystems.

1.5 Project objectives

- Assess existing domain typologies against the principles for a standardised typology.
- Recommend actions to update domain typologies to align with the principles and align with the IUCN GET.

2 Methods

2.1 Stakeholder meetings

We met with key stakeholders from the Ministry for the Environment (MfE), the Department of Conservation (DOC), and regional councils (Wellington, Otago) on 4 June 2024. The stakeholder group included:

- Anne-Gaelle Ausseil, MfE
- Amy Hawcroft, DOC
- Fiona Hodge, MfE
- Scott Jarvie, Otago Regional Council
- Meredith McKay, DOC
- Roger Uys, Greater Wellington Regional Council
- Elaine Wright, DOC.

Draft copies of our assessment of typologies against the principles, and our road map, were sent to the stakeholder group ahead of the meeting.

2.2 Assessment of how well the existing typologies meet the principles

We compiled an assessment of four terrestrial domain typologies against the principles. These typologies included:

1. the expert-based system (Singers & Rogers 2014)
2. the quantitative plot-based system (Wiser et al. 2011 and subsequent outputs)
3. *The Vegetation Cover of New Zealand* (Newsome 1987)
4. naturally uncommon ecosystems (Williams et al. 2007).

The Vegetation Cover of New Zealand was included because it is geographically and ecologically comprehensive, but it was never considered to be a candidate for the future typology because it is now dated, no longer updated, and was not considered by Collins (2024). Results were populated in an accompanying spreadsheet of the typologies against each of the principles, and these were discussed at our stakeholder meeting.

2.3 Assessment of how the existing typologies map to the IUCN GET

Of the 110 ecosystem functional groups (EFGs) in Level 3 of the IUCN GET, 34 are within the terrestrial core realm (IUCN GET Level 1). Thirteen of these EFGs are currently mapped as occurring in New Zealand,[3] with an additional 11 occurring in transitional realms, including a terrestrial component (Table 1).

We assessed whether the types defined by the expert-based system and the quantitative plot-based system could be nested in the IUCN GET. We did this by attempting to crosswalk types from the New Zealand typologies to IUCN GET EFGs. Seven ecosystem units were assessed from the expert-based system and eight associations were selected from the quantitative plot-based system. These were subjectively selected to cover a range of New Zealand terrestrial ecosystems. We also provide a crosswalk of the IUCN GET EFGs from the intensive land-use biome that are relevant to the draft national New Zealand Land Use Classification, NZLUM (Law et al. 2024). Note that a full crosswalk for the naturally uncommon ecosystems was completed for Output 1 (Sprague & Wiser 2024).

[3] Based on a spatial query completed on 8 July 2024 at https://global-ecosystems.org/analyse.

Table 1. IUCN GET ecosystem functional groups (EFGs) from the terrestrial realm (and transitional realms with a terrestrial component) present in New Zealand

Realm (IUCN GET Level 1)	Biome (IUCN GET Level 2)	EFG name (IUCN GET Level 3)	EFG ID
Terrestrial	Temperate-boreal forests and woodlands biome	Oceanic cool temperate rainforests	T2.3
Terrestrial	Temperate-boreal forests and woodlands biome	Warm temperate laurophyll forests	T2.4
Terrestrial	Shrublands and shrubby woodlands biome	Young rocky pavements, lava flows and screes	T3.4
Terrestrial	Savannas and grasslands biome	Temperate subhumid grasslands	T4.5
Terrestrial	Polar/alpine (cryogenic) biome	Ice sheets, glaciers and perennial snowfields	T6.1
Terrestrial	Polar/alpine (cryogenic) biome	Polar/alpine cliffs, screes, outcrops and lava flows	T6.2
Terrestrial	Polar/alpine (cryogenic) biome	Polar tundra and deserts	T6.3
Terrestrial	Polar/alpine (cryogenic) biome	Temperate alpine grasslands and shrublands	T6.4
Terrestrial	Intensive land-use biome	Annual croplands	T7.1
Terrestrial	Intensive land-use biome	Sown pastures and fields	T7.2
Terrestrial	Intensive land-use biome	Plantations	T7.3
Terrestrial	Intensive land-use biome	Urban and industrial ecosystems	T7.4
Terrestrial	Intensive land-use biome	Derived semi-natural pastures and old fields	T7.5
Marine-Freshwater-Terrestrial	Brackish tidal biome	Intertidal forests and shrublands	MFT1.2
Marine-Freshwater-Terrestrial	Brackish tidal biome	Coastal saltmarshes and reedbeds	MFT1.3
Marine-Terrestrial	Shorelines biome	Rocky shorelines	MT1.1
Marine-Terrestrial	Shorelines biome	Muddy shorelines	MT1.2
Marine-Terrestrial	Shorelines biome	Sandy shorelines	MT1.3
Marine-Terrestrial	Shorelines biome	Boulder and cobble shores	MT1.4
Marine-Terrestrial	Supralittoral coastal biome	Coastal shrublands and grasslands	MT2.1
Marine-Terrestrial	Anthropogenic shorelines biome	Artificial shorelines	MT3.1
Terrestrial-Freshwater	Palustrine wetlands biome	Subtropical/temperate forested wetlands	TF1.2
Terrestrial-Freshwater	Palustrine wetlands biome	Seasonal floodplain marshes	TF1.4
Terrestrial-Freshwater	Palustrine wetlands biome	Boreal, temperate and montane peat bogs	TF1.6

2.4 Road map of steps to transition existing typologies to meet the principles and align with the IUCN GET

A road map was developed based on the gaps and misalignments identified when we assessed the typologies against the principles. A draft of our road map was discussed at our stakeholder meeting and updated based on their comments.

2.5 Pathway options for developing a revised terrestrial typology

Before developing the road map we considered five pathways to the development of a national terrestrial typology:

1. adopt one of the existing typologies
2. transition the expert-based system such that it meets the principles
3. transition the quantitative plot-based system such that it meets the principles
4. integrate the above two systems, while transitioning each to ensure they meet the principles
5. propose a completely new approach.

3 Results and road map

3.1 Stakeholder meetings

Following are the key discussion points during our stakeholder meeting for the terrestrial domain.

1. There was some discussion about how we should be referring to the main terrestrial typologies. At present the typologies are usually referred to by the names of the authors who developed them. We suggested that names like 'expert-based system' for Singers & Rogers 2014 and 'quantitative plot-based system' for Wiser et al. 2011 and other outputs might allow us to better evaluate their merits, irrespective of who developed them. This was agreed upon by the stakeholders.
2. Our assessment of the typologies against the principles was circulated in advance for review by the stakeholders. A subset of the principles were discussed and minor clarifications – mainly related to mapping and the designation of new types in the expert-based system – were incorporated into the assessment.
3. Our original draft road map included a recommendation that a review of existing types of ecosystem typology hierarchies be completed, drawing on international examples, to decide on a suitable hierarchical structure for the future typology. The stakeholder group asked that a specific recommendation of a hierarchical structure be made as part of this review (rather than as part of a separate exercise to be completed in future).

4 Minor changes to the allocation of tasks among actions, and the order of their presentation, were suggested by the stakeholder group.

5 There was discussion about whether the future terrestrial typology should be expert-derived or based on a quantitively based approach, and how the two main typologies currently in use will inform the future typology. The merits of each were discussed: the expert-based system is in wide use among almost all regional councils (excluding Westland and Canterbury), but all seem aware of its weaknesses. The typology has also changed over time, so the council maps can't be simply combined to form a national map. The quantitative plot-based system approach is based on vegetation plot data, is more reproducible, and has diagnostic criteria for allocating types, but it is not widely adopted (or wall-to-wall mapped). The stakeholder group agreed that it would be preferable for the future typology to have quantitative underpinnings, but a pragmatic approach will be to build upon what is already available from the expert-based typology and transition it to a quantitatively based system (hereafter referred to as the 'revised typology'). It was agreed that the action points from the road map will reflect this.

3.2 Assessment of how well the existing typologies meet the principles

Our assessment of the terrestrial typologies against the principles are presented in Appendix 1, and as part of the Output 1 report, where the terrestrial typologies are presented alongside the other domains (Sprague & Wiser 2024). Below we provide a summary of how each typology assessed meets the principles, which can be read in conjunction with the full assessment.

Expert-based system

This typology's hierarchy is environmental, with composition informing the final ecosystem unit level. Levels are imperfectly nested, with 'zonal' and 'azonal' ecosystems sitting under different environmental frameworks, and ecosystem units can fit in several abiotic units. Maps of 'potential vegetation' have been produced using the system for all regional councils except Canterbury and Westland. Some ecosystem units have been modified over time, however, so it is not possible to combine these regional maps into a national map.

The mapping process is subjective and there are no criteria explaining how units are mapped or boundaries changed. New units and 'sub-units' have been added as required during the regional council mapping process, but these only apply to particular regions. There are no formal crosswalks between this typology and others, beyond stating they are 'equivalent' (but matches are often not one-to-one). Descriptions of ecosystem units are provided, but there are no diagnostic criteria, and the types were defined subjectively based on expert knowledge.

Some names are less informative than others and require users to know what an abbreviation in the code means to make an identification (e.g. BR = braided river). There has been no formal validation of the typology with external (e.g. plot) data. Exotic-dominated and successional forests are not included in the typology, and ecotones are not explicitly included (though some polygons are mapped as mosaics comprising multiple ecosystem units). The typology uses terminology and concepts familiar to New Zealand ecologists and conservation practitioners.

Quantitative plot-based system

This typology's hierarchy is biotic, with associations sitting in single alliances (perfect nesting, though links between the two were established after they were created). The types have been interpreted abiotically but are not defined by their abiotic characteristics. The typology is partially mapped, with over 20,000 plots mapped as points nationally. Forest maps have been produced using predictive modelling at Warawara and Russell Forests (both in Northland), with accuracy quantified but no independent verification (e.g. ground-truthing). National-scale spatial modelling has been trialled but remains unpublished.

The typology is flexible, with the noise clustering method allowing types to be defined, split, or combined while leaving the others intact. Crosswalks to other major typologies, including the expert-based system, have been done. Peer-reviewed and published quantitative analytical methods can be used to assign new plots to types, and names are unique, comprising dominant species and structural type. The typology includes successional ecosystems where sufficient plot data exist to define them, and ecotones can be captured based on the degree of membership of plots to multiple types. Vegetation types without sufficient plot data to define vegetation types (typically more than 10 plots; Wiser & De Cáceres 2013) are missing from the typology, so targeted efforts to adequately sample uncommon ecosystems and under-represented localities would be required.

The terminology describing ecosystems is familiar to New Zealand ecologists and conservation practitioners, but the names of levels (alliances, associations) are not in wide use in New Zealand (but are well known internationally). Analytical techniques will only be familiar to a subset of specialists with quantitative skills.

The Vegetative Cover of New Zealand

This typology's hierarchy is biotic and perfectly nested (vegetative cover classes sit within vegetative cover groups). The typology is mapped nationally but has not been updated since 1987. It was built on the New Zealand Land Resource Inventory (Blaschke et al. 1981) and the Nichols forest class maps, and was subject to extensive ground-truthing, but it only includes 47 types, all of which are quite broad. There are no diagnostic criteria for assigning types, just descriptions, but types are sufficiently broad that types can be readily identified. The typology includes successional ecosystems and exotic-dominated systems, but does not accommodate ecotones or rare types. The typology uses terminology and concepts familiar to New Zealand ecologists and conservation practitioners.

Naturally uncommon ecosystems

This expert-derived typology's hierarchy is largely environmental, with all types sitting within six broad types (e.g. coastal, geothermal). The typology is partially mapped, with broad occurrences (presences) mapped by regional and territorial authorities based on literature and expert knowledge. Ecosystem-level maps have been produced for close to half of the ecosystems. Maps can be updated by re-running the analysis or manually editing spatial features, and new types can be added. Diagnostic classifiers and descriptions exist for the identification of types, and the method has been peer reviewed and published (Williams et al. 2007). Successional and transformed ecosystems, and ecotones, are outside the scope of the typology so are not defined. The typology uses terminology and concepts familiar to New Zealand ecologists and conservation practitioners.

3.3 Assessment of how the existing typologies map to the IUCN GET

Our crosswalk examples are presented in Table 2.

The overall fit of the expert-based system was good, with most ecosystem types examined either mapping one-to-one to an IUCN GET EFG, or one-to-many IUCN GET EFGs. One of the expert-based system types (MF5: Black beech forest) only partially mapped to one IUCN GET EFG (T2.3 Oceanic cool temperate rainforests), which indicates there is a missing EFG from the IUCN GET typology. MF5 is defined as occurring in areas with a 'mild temperature' that are semi-arid (Singers & Rogers 2014). IUCN GET T2.3 is defined as occurring in cool temperate climates with a large water surplus, rarely with summer deficits. McGlone et al. (2016; cited in IUCN GET T2.3 factsheet) specifically exclude beech forest from oceanic temperate forests. There is no description applicable in the IUCN GET to these drier conditions where forests occur east of the main divide in New Zealand, but it should be noted that Chile mapped *Nothofagus* types into T2.3 (Appendix 3 of Keith et al. 2022).

Another of the expert-based system's types (VS4: Mānuka scrub) covers all of New Zealand so probably includes both IUCN GET shrubland EFGs T3.2 and T3.3 (but, in the case of T3.3, without being restricted to maritime environments). Where an ecosystem unit such as this spans multiple EFGs, this may indicate the unit is currently too broadly defined and could be partitioned according to the different EFGs.

The overall fit of the quantitative plot-based system was moderate. Most of the types examined (five out of seven) mapped to the IUCN GET either one-to-one, one-to-many, or many-to-one. Two of the types mapped only partially to one IUCN GET EFG, indicating that there is a missing EFG from the IUCN GET typology. A: PF1 Mountain neinei – Inanga low forest and subalpine shrubland from the quantitative plot-based system only partially matches the IUCN GET EFG T2.3, because its shrubland elements are not represented (naturally occurring subalpine shrublands are not represented in the IUCN GET). The beech type A: BF1 Black/mountain beech forest (subalpine) assessed in the quantitative plot-based system only partially matched the IUCN GET for the same reason as MF5 from the expert-based system (see above). There was no match for terrestrial geothermal ecosystems in the IUCN GET (only geothermal pools and wetlands are accommodated).

The IUCN GET EFGs from the intensive land-use biome generally mapped well to the human-modified ecosystems defined in the NZLUM (Appendix 2). However, there were some anomalies; for example, the use of 'annual' in IUCN GET T7.1 Annual croplands in reference to substrate modification and harvest is too restrictive, as more frequent substrate modification and harvest are likely to occur for many of the crops that would be captured in this category in the NZLUM classification 2.3.0 Short rotation and seasonal cropping. Both NZLUM categories 2.3.3 Extensive grazing and 1.3.3 Grazing native vegetation have a one-to-many relationship to IUCN GET T7.2, IUCN GET T7.5, and IUCN GET T4.4. The IUCN GET T7.4 Urban and industrial ecosystems captures a range of environments from mines to urban areas, so gives less visibility to the diversity of ecosystems it covers; most of the subclasses in the high-level built environment class of NZLUM would fall into this EFG (Law et al. 2024).

Table 2. Crosswalks between New Zealand terrestrial typologies (expert-based and quantitative plot-based systems) and the IUCN GET ecosystem functional groups (EFGs). Proportional fits are provided when New Zealand ecosystems fit in multiple EFGs.

Typology	Name in typology	EFG name (IUCN GET Level 3)	EFG fit
Expert-based system	WF11: Kauri, podocarp, broadleaved, beech forest	T2.4 Warm temperate laurophyll forests	–
Expert-based system	MF5: Black beech forest	T2.3 Oceanic cool temperate rainforests / no match	0.5 / 0.5
Expert-based system	CLF4: Kahikatea, tōtara, mataī forest	T2.3 Oceanic cool temperate rainforests	–
Expert-based system	AH3: Gravelfield/stonefield, mixed species cushionfield	T6.2 Polar/alpine cliffs, screes, outcrops and lava flows / T6.4 Temperate alpine grasslands and shrublands	0.5 / 0.5
Expert-based system	WL7: Tall tussock tussockland	TF1.6 Boreal, temperate and montane peat bogs / TF1.7 Boreal and temperate fens	0.5 / 0.5
Expert-based system	SA6: Kermadec ngaio scrub, mixed herbfield/loamfield	MT2.1 Coastal shrublands and grasslands / MT2.2 Large seabird and pinniped colonies	0.7 / 0.3
Expert-based system	VS4: Mānuka scrub	T3.2 Seasonally dry temperate heath and shrublands / T3.3 Cool temperate heathlands	0.5 / 0.5
Quantitative plot-based system	A: PF1 Mountain neinei – Inanga low forest and subalpine shrubland = *Dracophyllum traversii* – *D. longifolium* – *Coprosma pseudocuneata* – *Archeria traversii* low forest and subalpine shrubland	T2.3 Oceanic cool temperate rainforests / no match	0.5 / 0.5
Quantitative plot-based system	A: BF1 Black/mountain beech forest (subalpine) = *Nothofagus solandri* (*Peraxilla tetrapetala*) / *Coprosma pseudocuneata* subalpine forest	T2.3 Oceanic cool temperate rainforests / no match	0.5 / 0.5
Quantitative plot-based system	A: BBPF4 Kāmahi – silver fern forest = *Weinmannia racemosa* – *Cyathea dealbata* – *Knightia excelsa* (*Beilschmiedia tawa*) / *Leucopogon fasciculatus* forest	T2.4 Warm temperate laurophyll forests	–

Typology	Name in typology	EFG name (IUCN GET Level 3)	EFG fit
Quantitative plot-based system	A: S5 Turpentine scrub – *Gaultheria* montane shrubland = *Dracophyllum uniflorum* / *Gaultheria crassa* – *Poa colensoi* – *Festuca novae-zelandiae* montane shrubland	T7.5 Derived semi-natural pastures and old fields / T6.4 Temperate alpine grasslands and shrublands	0.7 / 0.3
Quantitative plot-based system	[T4] *Chionochloa pallens* / *Poa colensoi* – *Celmisia petriei* – *Schoenus pauciflorus* / *Wahlenbergia albomarginata* tussockland	T6.4 Temperate alpine grasslands and shrublands	–
Quantitative plot-based system	[G1] *Poa cita* – *Dactylis glomerata* / *Anthoxanthum odoratum* – *Trifolium repens* grassland	T7.5 Derived semi-natural pastures and old fields	–
Quantitative plot-based system	GEOm1 *Campylopus pyriformis* mossfield	No match	–
Quantitative plot-based system	Low elevation kauri forest of moist sites = *Pterophylla sylvicola* –*Beilschmiedia tarairi* – *Beilschmiedia tawa* – (*Didymocheton spectabilis* – *Agathis australis*) / *Freycinetia banksii* – *Dicksonia squarrosa* forest	T2.4 Warm temperate laurophyll forests	–

3.4 Road map of steps to amend, merge or replace existing typologies to meet the principles and align with the IUCN GET

Based on our assessment of the five pathways (see Appendix 4) to developing a national terrestrial typology, listed in the Methods, we proceeded with option (4): to integrate the two systems, while transitioning each to ensure they meet the principles. This provides a way to adopt the best features of the expert-based system's current level of mapping coverage, span of ecosystem coverage, and familiarity among end-users, and the quantitative plot-based system's quantitative and objective underpinnings, which are used by those needing frameworks to interpret and summarise vegetation plot data and are consistent with internationally accepted standards (Faber-Langendoen et al. 2014; De Cáceres et al. 2015).

A single, accepted 'revised typology' would probably include types based on the expert-based system's units, the quantitative plot-based system types, as well as newly defined or reconfigured types. At the same time, a long-term goal should be to achieve the principle articulated by Faber-Langendoen et al. (2014, and references therein) that 'characterising and describing types is best accomplished using plot data'. To this end, collection of plot data using standard methods and established approaches to extend the quantitative plot-based system to formally define types now only represented in the expert-based system should be employed. The decision to integrate the two systems was endorsed by the stakeholder group.

Here we describe the series of actions required to do this, alongside a suggested sequence of activities. Some activities will need to be underway before others begin, whereas others can be progressed in parallel. Relevant principles from our assessment of the typologies are referenced within most of the actions, with this assessment presented in Appendix 1.

Figure 1 shows the relationship between actions and the principles, and Figure 2 gives a potential conceptual timeline covering the sequence of tasks to address the principles, dependencies among actions, and tasks that can take place concurrently. Our goal is for developments to be progressive and enable users to continue meeting their needs during developments. Any solution needs to be attractive to users and provide them with greater capabilities than they currently have.

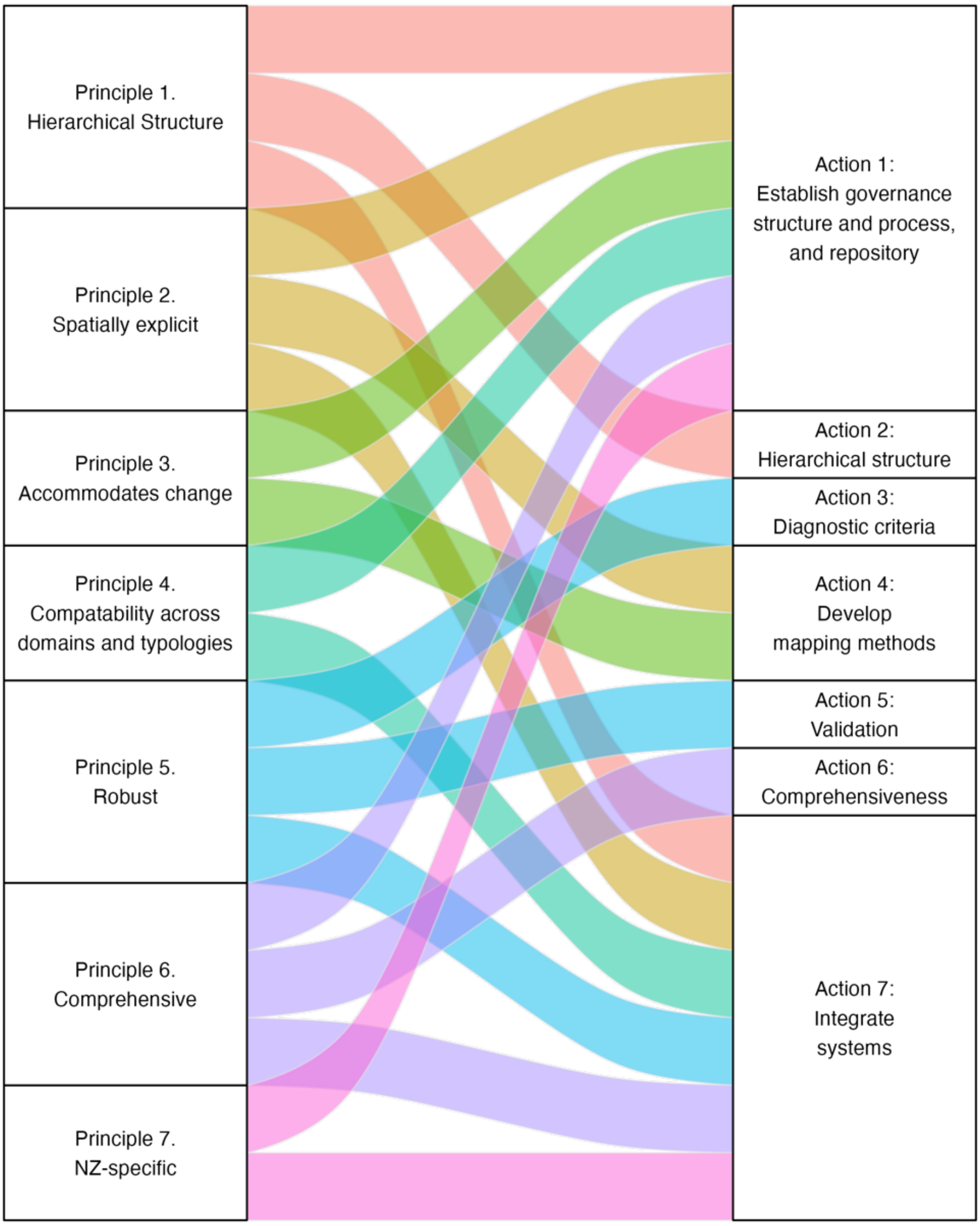

Figure 1. The relationship between the principles and our actions, which were recommended for a future typology for the terrestrial domain. Note that individual principles can be addressed by multiple actions.

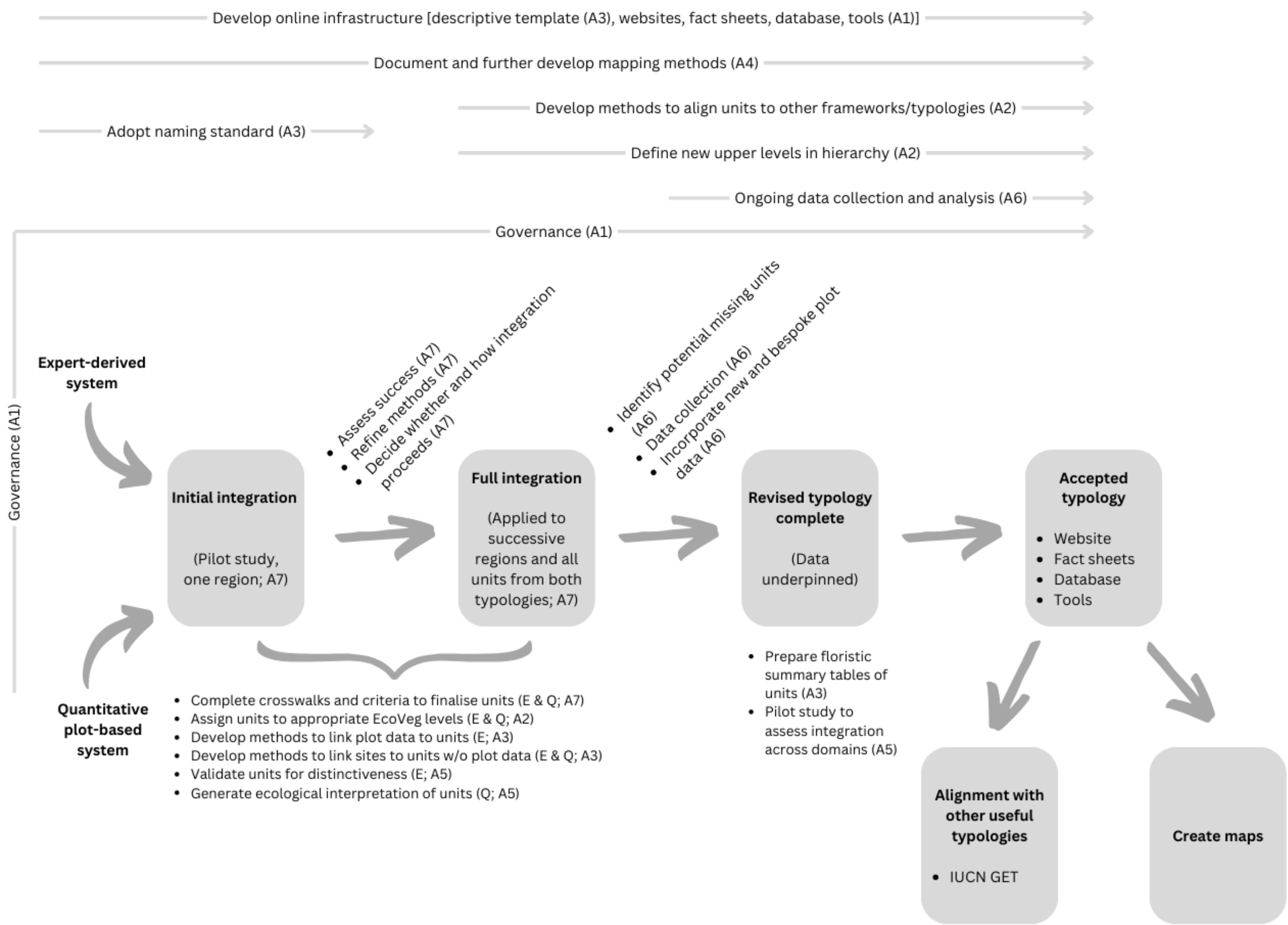

Figure 2. Conceptual timeline to achieve a future typology for the terrestrial domain, showing the sequence of tasks, their dependencies, and which tasks can be done concurrently to complete the recommended actions. Relevant action numbers (A) are stated alongside tasks, and expert-based and quantitative plot-based typologies are referred to as appropriate (E and Q, respectively).

3.4.1 Action 1: Establish a governance structure and process, and an accessible, managed repository for ecosystem typologies, associated products, and underpinning data

A governance framework should be developed to guide key decisions during the road map implementation and for managing ecosystem typologies, associated products (e.g. maps, factsheets, diagnostic tools) and underlying data. This would entail establishing a steering group for the terrestrial domain (see Output 1 report; Sprague & Wiser 2024). This will require a collaborative approach involving people from local and central government agencies, and research scientists from research institutes and academia.

At present, typologies and associated products are available as publications or unpublished reports (including reports for the expert-based typology mapping prepared for most regional councils) or on websites.[4] Maps and associated spatial data files are either curated by individual councils (for the expert-based system) or by individuals at Crown Research Institutes. In the latter case, versions of underpinning plot data and R scripts are also curated by individuals. This does not encourage a standardised process for managing a national terrestrial ecosystem typology, including creating and modifying ecosystem types, objective mapping and changing maps, and the collection and curation of underlying data and metadata.

As stated in the Output 1 report (Sprague & Wiser 2024), the responsibilities of the steering group would include addressing standards for data collection, analysis, classification, review, and archiving to meet the needs of that domain typology and related products (e.g. maps, websites). There is a range of international examples that articulate the features of successful governance structures and processes (Jennings et al. 2009; Peet & Roberts 2013, section 2.2.3; Dayaram et al. 2021, Part B); these works should be reviewed to help develop an equivalent in New Zealand.

Key tasks

- Generate the terms of reference for a governance group and define their roles and responsibilities.
- Establish a governance group.
- Develop a suite of open source programmes (e.g. R scripts with online hosting for version control) and source data to enable maps to be produced and updated (especially following the implementation of Action 7).
- Develop online infrastructure to support the revised typology and its users (see Action 7; e.g. keys and factsheets, typology database system, maps).
- Develop an ecosystem database linked to associated vegetation plot data. The North American VegBank 'Plant community' module provides an example of how this could be achieved.[5]

[4] e.g. https://www.landcareresearch.co.nz/publications/woody-ecosystem-types/

[5] See http://vegbank.org/vegbank/index.jsp

3.4.2 Action 2: Adopt a hierarchical structure for a terrestrial ecosystem typology to meet the need to move up and down different levels of specificity for different applications

Internationally many hierarchical systems have been adopted for national-scale terrestrial ecosystem and vegetation classifications (e.g. Rodwell 2006; Capotorti et al. 2023). We suggest adopting the EcoVeg system (Faber-Langendoen et al. 2014) for the proposed terrestrial ecosystem typology for New Zealand. EcoVeg provides detailed criteria for the classification of vegetation at different levels. It was originally developed out of the Americas and supports the International Vegetation Classification.

EcoVeg has five hierarchical levels below their Level 3 'Formation', which is equivalent to the IUCN GET Level 3 ecosystem functional groups. These five levels could be adopted for New Zealand in order to support a more information-rich typology than is required under the IUCN GET. The Level 3 'Formation' is the level where New Zealand ecosystems would align and integrate with the IUCN GET. It is likely that additional IUCN GET Level 3 groups would need to be defined (or existing ones broadened in scope) to accommodate all the country's terrestrial ecosystems (see above).

Critically for New Zealand purposes, EcoVeg has a descriptive template with criteria to differentiate all levels of the hierarchy. These are based on biogeography and floristics, diagnostic species, ecological factors (climate, disturbance, edaphic/hydrology), and growth forms (see Appendix 3). The three upper levels have already been populated globally and a major effort to harmonise with the IUCN GET is largely completed, with a publication to support this currently in preparation.

It is not mandatory to populate all levels of the hierarchy. The most critical unit for New Zealand will be 'Level 8 – Association', defined as 'A characteristic range of species composition, diagnostic species occurrence, habitat conditions and physiognomy. Associations reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes.' This is equivalent to the granularity of many of the zonal ecosystem units of the expert-based system and the associations of the quantitative plot-based system, although this remains to be confirmed.

To identify which of the broader levels (Levels 4–7) would be useful for New Zealand, a first step would be to assign the types currently defined in both the expert-derived and quantitative plot-based typologies to the appropriate levels of EcoVeg. This would have the dual benefit of resolving the issue of unevenness of granularity in the types of these typologies. For example, vegetation types have yet to be described depicting the geographical variation within many naturally uncommon ecosystems (Williams et al. 2007) and between some equivalent azonal ecosystems of the expert-based system. Therefore, despite their currently limited geographical extent, different types of naturally uncommon and azonal ecosystems would fit best into one of the broader levels (Levels 4–6) of EcoVeg. This first step will also establish whether some naturally uncommon/azonal ecosystems may best be treated by the typology of another domain (e.g. some subterranean systems)

A challenge presented by the quantitative plot-based system is the lack of perfect nesting. This challenge could be resolved by applying cluster analysis to the associations to define new, higher (less granular) levels (Belbin 1987; Austin et al. 2000; Mucina et al., unpublished analysis of the New Zealand woody associations), essentially replacing the current alliances. This would also resolve the issue of significant differences in the ecological breadth of different alliances because of the multi-staged approach used to define them. To develop higher levels that are functionally based, clustering would be based on growth forms and functional traits of species rather than on species identity. This is consistent with EcoVeg Levels 4 and 5 and would facilitate linkage to the IUCN GET Level 3 EFGs.[6]

Adopting the EcoVeg system would enable perfect nesting and scalability and would not prevent us from aligning fundamental New Zealand ecosystem types to higher-level types of well-known New Zealand terrestrial biotic, biogeographical or environmental frameworks, depending on purposes. This can be useful to help understand the ecosystem types and facilitate mapping.

Frameworks to which the terrestrial ecosystem types in the proposed system could be usefully aligned include, but would not be limited to:

- LCDB
- Land Environments of New Zealand (LENZ; Leathwick et al. 2002)
- Land Use Classification Framework (NZLUM; Law et al. 2024)
- *Ecological Regions and Districts of New Zealand* (McEwen 1987)
- the ecosystem drivers of the expert-based system
- the naturally uncommon ecosystems framework of the naturally uncommon ecosystems (Williams et al. 2007).

Alignment could be achieved via geographical concordance between types of these typologies and locations from classified vegetation plots and other known occurrences of the terrestrial ecosystem unit, including those sourced from literature and expert knowledge. This would fulfill the requirement that the typology should be related to other typologies in use for the terrestrial environment (Collins 2024).

Key tasks

- The governance group confirms selection of the EcoVeg hierarchical framework for the terrestrial ecosystem typology for New Zealand.
- Assign types from both New Zealand typologies to their appropriate levels in EcoVeg.
- Define new, higher (less granular) levels for the revised typology.
- Align the revised typology to other useful frameworks (IUCN GET, LCDB, NZLUM, etc.).

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[6] One consequence of defining new alliances and replacing those currently in use is that existing products (e.g. factsheets) would also need to be replaced. End-users currently using the alliance level typology would need to transition to newly defined alliances. These end-users will need to be identified and brought into consultations about this transition and how best to continue to support their needs.

Relevant principles

Expert-based system

- Ecosystem units from this typology are imperfectly nested, with zonal and azonal ecosystems using different environmental frameworks (see Principles 1.1 and 1.2; Appendix 1). There is only one biotic level (the ecosystem units) in this typology. The abiotic framework within which individual ecosystem units are nested is indicative only: ecosystem units can occur outside these limits. As such, this typology does not satisfy DOC's need 'to be able to move up and down different levels of specificity for different applications within one framework' (Collins 2024).
- Different units have different levels of granularity (Principle 1.2): some descriptions comprise dominant species, others growth forms. These units and descriptions have not been widely validated.

Quantitative plot-based system

- There is imperfect nesting between alliance and association levels (Principle 1.1), because these were created in separate steps and the relationships between them were established subsequently.

3.4.3 Action 3: Develop and define diagnostic criteria, and improve descriptions, to support identification of ecosystem types

Quantitative methods exist to assign vegetation plots to ecosystem types based on their composition (Wiser & De Cáceres 2013; Tichý et al. 2014). This capability exists for types in the quantitative plot-based system because they were derived from compositional data, but it has yet to be developed for the expert-based system. This would require identifying vegetation plots that characterise an ecosystem unit and developing approaches to quantitatively compare additional plots to these to determine whether the new plots belong to that unit.

Complementary criteria to facilitate the assignment of sites to ecosystem types in both typologies in the absence of full plot data should also be developed. These could be formalised using explicit diagnostic species groups and dominance (e.g. Bruelheide 1997; Kočí et al. 2003; Janišová & Dúbravková 2010), or quantitatively defined combinations of indicator species (De Cáceres et al. 2012).

Related to this would be the development of a more traditional key whereby one could tease out the criteria (embedded in a set of plots for plot-based types) based on vegetation, environment, and geographical location (De Cáceres et al. 2012), somewhat analogous to a key for species identification. Both national and regional criteria would be useful. Existing methods of using formal logic to achieve this (e.g. the Cocktail method of Bruelheide 1997) should be evaluated. Indicator species combinations have been derived from plot data for alliances at the national scale in the quantitative plot-based system, but this remains to be done at the association level or at regional scales. The overall approach should be developed and tested on a representative set of ecosystem types as a pilot study.

A template for standard, comprehensive descriptions should be developed. These would build on the descriptions provided for the expert-based system, and the descriptions of alliances in factsheets[7] and publications supporting the quantitative plot-based system (e.g. Wiser et al. 2011). Ecosystem unit descriptions and names need to apply across their entire range. Box 2 of Jennings et al. 2009 provides an example template, and Faber-Langendoen et al. 2014 provide structured criteria for such descriptions. These are more suited to lower-level classes required by a terrestrial typology than the broad descriptions of EFGs in the IUCN GET. With time, this template should be followed to provide descriptions of all types retained in the revised typology.

A standard approach to deriving scientific, vernacular, and Māori names (for application when appropriate) for the types in the revised typology should be adopted. The expert-based system and the quantitative plot-based system have adopted slightly different standards, and either one could be selected or harmonised, or a new standard adopted. The naming standard will also reflect the level of the hierarchy to which the unit belongs.

Summary tables, often termed synoptic or constancy/abundance tables, that present the distribution and abundance of species with high dominance, frequency or diagnostic value in the types defined, usually accompany plot-based classifications (e.g. Wiser & Buxton 2009; Walker et al. 2011; Vynokurov et al. 2024). These allow users to quickly grasp the commonalities and distinctions between the types. For the quantitative plot-based system, such tables have been prepared at the alliance level, but they have yet to be prepared at the association level.

Key tasks

- Develop an approach to robustly relate plot data to the ecosystem units of the expert-based system. For the revised typology, develop quantitative, diagnostic criteria to allow identification of types by third parties. Consider how progressive updates to types will be tracked and/or versioned (related to the repository and products developed in Action 1).
- Develop complementary criteria to allow the identification of types without full plot data.
- Develop a template for standard, comprehensive descriptions of ecosystem types.
- Adopt a standard for naming ecosystem types.
- For the revised typology, prepare summary tables presenting the distribution and abundance of species with high dominance, frequency or diagnostic value in the types defined.

[7] https://www.landcareresearch.co.nz/publications/woody-ecosystem-types/

Relevant principles

Expert-based system

- It was found that there were no diagnostic criteria to allow the identification of ecosystem units (Principle 5.1.2). Instead, brief descriptions are provided, which are indicative but not diagnostic. Some names are not useful for identifying ecosystem units (e.g. 'WL Cushionfield').
- Feedback from Collins (2024) was that there is 'high judgement and low transparency in allocation of sites to ecosystem units'.

Quantitative plot-based system

- Alliance and association descriptions are present in publications, websites, and spreadsheets (Principle 5.1.1), but these are inconsistent and their comprehensiveness varies. Some associations are not formally described.
- Assignment of new sites to types requires vegetation plot data to be collected.

3.4.4 Action 4: Develop transparent, repeatable mapping methods and validate existing maps

A goal of this action is to develop rules for consistent mapping. Documentation describing the mapping process for the expert-based system, and how the maps are updated over time, should be developed to enable reproducibility of the mapping process. Further, the accuracy of these maps should be quantitatively assessed using vegetation plot data, employing the composition-based validation criteria developed in Action 3. These maps should also be updated to depict current vegetation (not just potential). A pilot study could be completed in the first instance on a single region.

Alternative mapping methodologies for the quantitative plot-based system should be reviewed and tested for accuracy. For wall-to-wall mapping, boosted regression trees based on environmental and remotely sensed predictors have been used, but alternative modelling frameworks (e.g. random forests) have not been attempted or assessed for accuracy. Polygon-based analyses have not been attempted but could be assessed (both Northland and draft national maps are pixel-based), possibly through predictive modelling into polygons defined by segmentation of remotely sensed data (aerial imagery, LiDAR). Mapping methodologies should be tested both regionally and nationally. A pilot study could focus on a small number (one to three) of regions with a reasonable density of recently measured vegetation plots. This exercise could include Northland, where there have been several efforts recently to collect plot data and produce vegetation maps. An exercise pairing this analysis with a comparison of results with maps from the expert-based system may be instructive.

Finally, a mechanism will need to be developed to define areas that are too data poor to have confidence in maps derived from plot data and to adopt a hybrid approach incorporating maps derived from the expert-based system and other sources (e.g. naturally uncommon ecosystem mapping).

Note that ecosystem mapping is a distinct process from defining ecosystem types and developing criteria to recognise them in the field. Mapping ecosystem types is constrained by scale and limitations imposed by ecosystem heterogeneity, which may restrict the ability to show all ecosystem types within a mapped area (Faber-Langendoen et al. 2014). One solution is to accept mapped polygons that represent mosaics of ecosystem types.

Key tasks

- Develop documentation describing the mapping process for the expert-based system.
- Assess the accuracy of the maps from the expert-based system using vegetation plot data (dependent on validation criteria from Action 3), initially with a pilot study focused on a single region.
- Assess and review alternative mapping methodologies for the quantitative plot-based system and test these, both regionally and nationally.
- Complete an analysis comparing vegetation maps produced with the expert-based system (updated to correspond to current vegetation, if required) and the quantitative plot-based system.
- Identify areas poor in plot data and devise a hybrid approach to mapping that incorporates maps derived from the expert-based system and other sources.

Relevant principles

Expert-based system

- Current maps usually depict potential vegetation, but maps of current vegetation are required (Principle 2.2). Some regional councils (e.g. Auckland, Waikato) have produced current vegetation maps, largely by clipping potential vegetation maps to natural classes in land-cover maps (e.g. LCDB; Manaaki Whenua – Landcare Research 2020), but the accuracy of this approach needs to be verified. For example, a polygon containing successional forest and classified as 'indigenous forest' by LCDB may get mapped incorrectly as a mature type based on the expert-based system's map of potential vegetation.
- It was found that mapping is largely complete using this typology (not completed for Canterbury and Westland Regional Councils; Principle 2.1.2), but the process is subjective (Principle 2.3). To be reproducible, thorough documentation and metadata are required to describe the mapping process.
- There has been no formal accuracy assessment of maps (Principle 2.1.2). This should be conducted using vegetation plots, while noting that this can only be done for the current distribution (most Singers and Rogers maps depict potential distribution). This requires a method to support the assessment of whether plot composition data or data collected for ground-truthing are consistent with the mapped unit (see Action 2).
- Criteria for changing boundaries or mapped unit attributes do not appear to have been developed (Principles 3.1.1 and 3.1.2), nor is there a mechanism to track any changes.

Quantitative plot-based system

- It was found that wall-to-wall mapping is not complete, with maps produced for only two forests in Northland (Warawara and Russell Forests; Principle 2.1.2). These maps have not been validated with an independent data set or ground-truthed. More maps could be produced, but they would rely on a sufficient density of plots within the area being mapped. Mapping at the coarser alliance level may be feasible with a lower plot density, but this needs to be assessed. Whether alternative modelling frameworks would produce more accurate maps has not been assessed.

3.4.5 Action 5: Validation of typologies, and integration across domains

The ecosystem units from the expert-based system need to be validated for both distinctiveness from each other and for their alignment with the abiotic drivers. This could be achieved via the analysis using vegetation plot data (Action 3) by determining that plots are generally assigned to an appropriate unit and that these plots are located within the environment defined by the drivers associated with that unit.

For the association level of the quantitative plot-based system, it will be important to provide an ecological interpretation to independently validate the vegetation patterns therein and ensure the classification expresses key, known gradients. This has largely been done only at the alliance level, but this point does not reflect lack of adherence to any of the principles.

There will be interactions between the terrestrial typology and the typologies from neighbouring domains (wetlands, marine and estuary, etc.). In areas where there are shared types, workshops could be held with relevant domain experts to develop a shared solution that suits the needs of both domains. This could range from simple conversations for the resolution of shared types that are straightforward to resolve, to more extensive meetings with broader stakeholder engagement, including with Māori, if the resolution is not straightforward or is likely to be controversial. We recommend a pilot study in a representative area between a subset of domains with relatively resolved/advanced typologies as a first step towards testing how to manage this process.

Key tasks

- Validate ecosystem units from the expert-based system for distinctiveness from each other and for their alignment with the abiotic drivers.
- Generate ecological interpretations for associations in the quantitative plot-based system.
- Decide on a set of domains to carry out a pilot study on defining types from areas that are shared between multiple domains.

Relevant principles

Expert-based system

- There are no clearly diagnostic criteria or operationalised definitions of units, just descriptions (Principle 5.1.2).

Quantitative plot-based system

- Not all associations are described in terms of environmental or other ecological properties (Principle 5.1.1).

3.4.6 Action 6: Improve comprehensiveness (ecosystem coverage)

The goal of integrating the expert-based and quantitative plot-based systems anticipates an eventual system underpinned by plot data. So, when addressing gaps in the comprehensiveness of the current systems, focusing on the quantitative plot-based system first makes sense.

For the quantitative plot-based system, the utility of defining types missing from the typology from expert knowledge or under-sampled ecosystems should be assessed. Provisional types could be proposed using:

- the literature (the Singers & Rogers 2014 typology would be a good starting point)
- plots that are currently not classified due to their lack of compositional representation in the national vegetation plot data set
- naturally uncommon ecosystems (Williams et al. 2007) that are known to have never been sampled by vegetation plots (or were sampled and data are not available), or
- a customised sampling approach that cannot be incorporated into the plot-based system.

New plot data should be collected from under-sampled areas, followed by analysis to confirm provisional types. This system currently incorporates data only from the North, South and Stewart islands. Quantitative analysis can be conducted to extend the classification to define vegetation types from offshore islands from which plot data have been collected (e.g. Raoul Island, Anchor Island, Chatham Islands) to increase coverage.

Further attention needs to be paid to ensure that non-native and transitional ecosystems (successional, ecotone) that were not within the scope of the expert-based system are incorporated into the revised typology. These ecosystems are likely to become increasingly important and widespread through climate change, disturbance, introduced invasions, and large-scale afforestation. Examples should be gleaned from the literature and from experts. Again, this may entail defining provisional types, as described above. At the same time, the conclusion of Moore et al. (1976) that not all collections of co-occurring plants can or should be described as vegetation types needs to be considered, particularly where exotic species dominate and 'accidental' combinations of species occur that are unlikely to re-occur in time or space (Wiser et al. 2016).

Incorporation of human-engineered ecosystems, not currently covered by the expert-based or quantitative plot-based systems, should be considered alongside the further development and refinement of categories in the draft NZLUM, where these have relevance for defining ecosystems (Law et al. 2024). Consideration could be given to identifying the diverse ecosystems that can occur within urban environments.

Key tasks

- Identify potential types that are missing from both the quantitative plot-based and the expert-based systems that need to be incorporated at least as 'provisional' types in the revised typology. Confirm with new plot data and analysis.
- Evaluate the feasibility of incorporating vegetation plots collected using customised methods and vegetation plots collected more recently into the quantitative plot-based system. (See also a key task from Action 3: 'Develop complementary criteria to allow identification of types without full plot data').
- Extend the quantitative plot-based system to cover offshore islands from which plot data have been collected.
- Assess how the revised typology and land-use and land-cover mapping products describing human-engineered ecosystems (e.g. LCDB, NZLUM) can be incorporated to produce a typology and maps for all of New Zealand's land area.

Relevant principles

Expert-based system

- Typology (and maps) do not include secondary forests, urban, highly modified, or exotic-dominated ecosystems, or ecotones (Principles 6.1, 6.2, 6.4).

Quantitative plot-based system

- Over 20,000 vegetation plots have been classified (Principle 2.1.2), but types are only defined when sufficient plot data have been collected (Principles 6.3 and 6.4).

3.4.7 Action 7: Integrate the expert-based system with the quantitative plot-based system

Using this road map as a guide, integration of the best features of the expert-derived system with the quantitative plot-based classification should begin. Below we outline some activities that will be required to achieve this integration, but further details will need to be specified before work gets underway. We recommend a pilot study as a first step, focused on a region that (i) has been mapped using the expert plot-based system, and (ii) has a reasonable density of vegetation plot data that are as well distributed as possible (given the recognised limits to comprehensiveness of plot data) to represent the geographical and ecological variation present in the region.

An example could be Northland, where there have been several efforts recently to collect plot data and produce vegetation maps. This could be followed by progressive integration region by region. Integration will require that crosswalks have been completed between the ecosystem units of the expert-based system and the comparable level (likely associations) of the quantitative plot-based system. This would be best guided by unit descriptions, vegetation plot data associated with each unit, and the environmental and geographical extent of the respective units, and based on the validation procedures for ecosystem units developed in Actions 2 and 4. We list the specific tasks required to complete integration below.

As integration progresses from the first pilot study stage to successive regions, the success or failure of the approaches used in that phase will need to be evaluated. This evaluation will guide both the refinement of integration methods (as required) and decisions about whether and how integration should continue. For example, challenges to integration may reveal inherent weaknesses in one or the other of the two systems that can be overcome via additional work – and those that cannot. Further, whether ecosystem types proposed for adoption make sense in terms of planned applications (including mapping, monitoring to detect change, conservation planning and research) will need to be evaluated. This evaluation would inform revision of the integration plan to account for lessons learnt. Thus, the integration plan should be a 'living document' that can incorporate knowledge gains made throughout the process.

Because the long-term goal is to transition the current systems to a unified typology completely underpinned by plot-based types, with time the tools that capitalise on this will need to be developed. These would include:

- a website that is a 'one-stop shop' for the revised typology, including factsheets
- determination keys and online tools to assign new vegetation plots to the revised typology, as have been developed in New South Wales[8]
- time-stamped maps of current distributions of ecosystem types at regional and national scales.

Key tasks

- Decide on a candidate region to carry out a pilot study of integration.
- Complete crosswalks between expert-based and quantitative plot-based systems, starting in the pilot study region.
- Develop criteria to finalise types; e.g.:
  - individual units of the expert-derived system that largely equal individual types of the quantitative plot-based system, and which can be replaced directly with no or little loss of information
  - units of the expert-derived system that encompass ecosystem variability, represented by the quantitative plot-based system, and are insufficiently robust to be retained, and which can be replaced by types of the quantitative plot-based system

[8] https://www.environment.nsw.gov.au/topics/animals-and-plants/biodiversity/nsw-bionet/nsw-plant-community-type-classification/plot-to-pct-assignment-tool

    - units of the expert-derived system that encompass ecosystem variability that is not captured in the quantitative plot-based system, and which will need to be retained until sufficient plot data are collected to define that component of ecosystem variation
    - types of the plot-based typology that encompass ecosystem variability that is not captured in the plot-based typology (these will be retained).
- Assess the success of combining expert-based and quantitative plot-based systems in a suitable region.
- Complete for other regions, learning from the experience gained mapping prior regions.

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Appendix 1 – Assessment of four terrestrial typologies against the principles and requirements (from Collins 2024)

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
1. Hierarchical structure				
1.1 Level type	Environmental (primary hierarchy) then biotic (ecosystem unit level).	Biotic	Biotic	Environmental, nested within six broad types: coastal, inland & alpine, geothermal, induced by native vertebrates, subterranean or semi-subterranean, wetlands.
1.2 Nesting type	Imperfectly nested ('zonal' and 'azonal' ecosystems use different environmental frameworks); zonal ecosystem types are aligned with the abiotic unit where they most commonly occur, but they can occur outside of this unit. (Refer App. 11, DOC feedback, of Collins 2024: 'variable specificity/generality of types').	Perfect and imperfect. • Perfectly nested: all alliances perfectly nested into higher level groups. • Imperfectly nested: the alliance and association classifications were created in separate steps and relationships between them established subsequently. Most associations nest within alliances, but a small number of associations have no relationship to an alliance (the latter requires more plots). Also, a small proportion of the individual sample plots – especially those that are ecotonal – may be assigned to a different alliance than the association to which they belong. (Refer App. 12, DOC feedback, of Collins 2024: need to move up and down different levels of specificity for different applications within one framework).	Perfectly nested	Perfectly nested

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
2. Spatially explicit				
2.1.1 Is typology mapped?	Partially	Partially	Yes	Partially
2.1.2 Indicate extent, resolution, and accuracy.	Maps produced for all regional councils except Canterbury and West Coast. Scale, when stated (only some council reports), is approximately 1:10,000. Some units have been modified over time so it is not possible to combine regional-level maps into a national map. Maps are of potential vegetation (which is a hypothesis) so cannot be assessed for accuracy. Some councils have derived current distributions by intersecting with LCDB, but validation approaches (if any) were not reported in documentation provided to MWLR. DOC has mapped current distributions in some areas.	All 20,479 classified plots (woody, non-woody, geothermal) have associated location data and have been mapped as points nationally. (Refer App. 11, DOC feedback, of Collins report: 'high temporal/site specificity [of plots] can create poor congruence to existing national maps'). Woody associations have been mapped using predictive modelling (environment + remotely sensed predictors) at Warawara and Russell Forests (Northland) at 10 × 10 m resolution with accuracy also quantified during the modelling process but not independently verified (i.e. new data, ground-truthing). National-scale spatial modelling to map alliances based on environmental predictors was trialled from 2010 to 2016 with reasonable fits to pre-existing maps for some locations (e.g. Stewart Island) and to plot data in others (e.g. Northland). New, national-scale mapping was trialled in 2020 with higher-level groupings defined by classifying existing associations.	Mapped to 1:1,000,000 scale	Partially. Broad occurrence (presence) mapped by region and territorial authorities, based on literature and expert knowledge. Draft maps of 33 ecosystems produced by DOC and MWLR, with detailed metadata describing how these were constructed. Maps have not been ground-truthed. Some councils have mapped naturally uncommon ecosystems, particularly where such units are represented within the Singers and Rogers (2014) typology.
2.1.3 Also indicate how the ecosystem occurrence is represented (i.e. points, polygons, etc)	Polygons	Pixels (Warawara and Russell Forests; national maps) and points (vegetation plots)	Polygons	Mapped by DOC and MWLR – points, lines, and polygons

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
2.1.4 If not mapped, are there data that could be used to produce maps?	NA	Spatial modelling could be used to produce more regional-scale spatial predictions for associations (per methods used for Warawara and Russell Forests), though some areas may not have the density of plots required to produce accurate maps. To produce higher-quality national-scale maps, remote-sensing predictors could be used, in tandem with environmental predictors.	NA	Yes, in some instances. Work is progressing on this funded by Envirolink to MWLR.
2.2 Extent (current, historical, potential)	Potential (but see 2.1.2)	Current, although vegetation could have changed on some of the plots used in the classification that have not been measured in some years.	Current, though may be out of date (mapping dated 1987).	Mixture – where produced by combining spatial layers areas depicted may be greater than current occurrence. Where newly digitised, will reflect current distributions.
2.3 Are the methods used to map the typology sufficiently well described that they could be reproduced by a third party?	Partially – the process of mapping is described, but the person(s) creating the maps rely heavily on their local knowledge and that of selected experts. Unlikely to be reproducible by a third party.	Yes – methods are published in peer-reviewed articles or described in reports. R scripts and source data exist for all. Quantitative modelling skills required.	Yes	Yes, for broad-scale maps and those produced by DOC and MWLR.
2.4 Other comments	Mapping primarily completed by Nick Singers, with some (Otago, Southland) completed by Wildland Consultants (Kelvin Lloyd et al.)	Mapping and classification work done by MWLR primarily in contract to DOC, and also other funding mechanisms (e.g. MBIE Vision Mātauranga and Endeavour funding). Mapping method used was just one modelling approach, and others could be assessed and applied.	Only delineated map units greater than 500 ha in area	

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
3. Accommodates increased knowledge and change over time				
3.1.1 Spatial boundaries on maps can change over time?	Yes, spatial data are editable, though the process to decide whether or how boundaries are changed is not explained since reports are associated with the original mapping product. These are presumably maintained by the councils.	Yes (re-running analysis required)	Yes, spatial data are editable, though products are no longer maintained and haven't been updated for a long time.	Yes, by re-running spatial analysis and/or manually editing polygon spatial features.
3.1.2 Temporal changes can be made to mapped unit attributes?	Currently there are no attributes (e.g. condition) associated with the maps, other than those derived by the mapping process (e.g. area of each polygon).	Currently there are no attributes (e.g. condition) associated with the maps.	Currently there are no attributes (e.g. condition) associated with the maps, other than those derived by the mapping process (e.g. area of each polygon).	Currently there are no attributes (e.g. condition) associated with the maps, other than those derived by the mapping process (e.g. area of each polygon).
3.2.1 New ecosystem types can be added?	Theoretically yes, but we are not aware of this being done.	Yes – the noise clustering method allows new types to be defined while leaving the original units intact.	Theoretically yes, though the product is no longer maintained.	Yes, by either recognising a distinct combination of the diagnostic classifiers. Envirolink is currently funding MWLR to run a formal, consultative process to revise the typology by doing this.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
3.2.2 Ecosystems can be split or combined?	Yes (example in Southland and Otago reports, where new 'subunits' were added to Singers and Rogers classification). Since the typology and related maps are not centrally managed across councils, these updates aren't necessarily applied elsewhere. (Refer App. 11, Regional Council feedback, of Collins 2024: has been refined over time introducing inconsistency across councils).	Yes – ecosystems could be split by conducting a new cluster analysis on the units to be divided and ecosystems could be combined based on their compositional distance from each other.	Theoretically, yes, though the product is no longer maintained.	Yes, ecosystems could be combined by removing diagnostic classifiers from the ecosystem definitions that distinguished them or adding additional diagnostic classifiers to an existing definition.
3.2.3 Methods can be changed to better define ecosystem types?	No – the classification has been fixed and defined (except see 3.2.1 and 3.2.2)	No – markedly changing the analytical approach would create a new classification.	Theoretically, yes, though the product is no longer maintained.	No, this typology follows a specific theoretical construct and method.
3.3.1 Time span of underlying data and when typology created documented? Changes have been date-stamped?	Partial – the typology was published in 2014 based on literature review (varying publication dates) and knowledge of the authors (Singers & Rogers 2014). Although some of the source literature was based on data, the typology as a whole was not.	Yes, dates when underlying plot data were collected are known.	Maps were primarily derived from the NZ Land Resource Inventory, which has been updated over time, but the Newsome maps have not been updated. The data on which the original map was largely based were compiled from 1975 to 1979. Field checking took place before the map was published, but there is no explicit statement of which	The typology was published in 2007 and reflected the state of knowledge at that time. Typology not based on data.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
			period of time the maps apply to, nor any tracked updates to the maps over time.	
3.3.2 If maps have been created, is the time period of application documented? Have any changes been date-stamped?	Maps and classification describe ecosystem types 'as they potentially existed if people arrived today in New Zealand', and reports are dated. There is no evidence of changes or updates to the spatial product from spatial data supplied by councils.	Yes. All maps (Warawara and Russell Forests, national) were derived from vegetation plot data with known survey dates. Dates of all spatial layers used in predictive modelling are known. Documentation exists tracking plots that have been reassigned to a newly defined vegetation type, and where a selected subset of plots have been resurveyed and their vegetation type has changed.	There is no evidence that the maps or ecosystem typology have been updated over time.	Yes, for the broad maps and DOC/MWLR, this is documented in metadata.
4. Compatibility across domains and typologies				
4.1.1 Rationale behind typology structure clear?	Yes	Yes	Yes	Yes, by either recognising distinct combination of the diagnostic classifiers. Envirolink currently funding MWLR to run a formal, consultative process to revise the typology by doing this.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
4.1.2 Does it build on/acknowledge other typologies? Are relationships to units in other typologies explained?	Partial (acknowledges and describes relationships, but the units are newly defined). The descriptions of the units cite pre-existing literature, but the nature of the relationship of the unit to any descriptions provided in the literature is not stated beyond 'equivalent', even where the matches are not one-to-one (e.g. the same published ecosystem type may be listed as 'equivalent' to more than one ecosystem unit). No formal crosswalks to units in other typologies have been created. Yes, for maps. Tabular comparisons of ecosystem units have been provided in some cases (e.g. Table 1 in Nelson City Council report).	Partial (acknowledges and describes relationships, but the units are newly defined). Crosswalk of woody alliances to Forest Service Mapping Series 6, *The Vegetative Cover of New Zealand* (Newsome 1987) and EcoSAT Forests done based on locations of 1,177 nationally representative plots. All woody alliances crosswalked to Singers & Rogers 2014 and Wardle 1991 are based on descriptions therein. Relationships of non-woody alliances to all similar non-woody vegetation types are defined from data in earlier published literature described. Geothermal, Warawara, and Russell extensions do not describe relationships to units in earlier typologies.	Yes. Builds on the New Zealand Land Resource Inventory, which itself included existing information such as the Nichols forest class maps. Was also subject to extensive ground truthing. There is no clear description of the relationship between the units of this typology and others.	There was no existing formal typology delineating naturally uncommon ecosystems. The typology built on knowledge captured in publications and structured input from experts. Wetlands followed Johnson & Gerbeaux 2024.
4.1.3 Could the typology be cross-walked to other typologies in the domain?	Unknown: we are not aware of this being attempted, except see comments about maps in 4.1.2. (Refer App. 11, DOC feedback, of Collins (2024): 'many to many matches to other typologies').	Yes – see 4.1.2	Because it is mapped, could be cross-walked to any typology presented as mapped units or underpinned by vegetation plot data having known locations.	Yes

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
4.1.4 Other comments	Report from 2014 included 152 ecosystems	A total of 156 associations (finer-scale units) have been defined, comprising 92 woody, 50 non-woody, 14 geothermal.	Only includes 47 vegetation cover classes – fewer than other typologies assessed. All are quite broad.	Comprises 71 ecosystems
4.2.1 Describe whether and how taxonomic changes can be accommodated	Full composition of ecosystems units is not enumerated, so taxonomic changes only effect names of units and descriptions. The concepts associated with most names in the glossary appear to be stable, but this needs to be validated. Genera known to include species that have been 'split' recently are largely recognised at genus level (e.g. *Sophora*). Some genera (e.g. *Blechnum*) have been split, so their current meaning in names/descriptions requires determination. Compositional data from plots are at times used to inform mapping efforts, but only qualitatively.	Homotypic taxonomic changes (one-to-one name changes) can be accommodated through updates to names. Where different concepts may be signified by a name, the broadest taxonomic concept is associated with that name and records are aggregated accordingly.	Types are defined at a greater taxonomic resolution than species (no finer than genus level)	Vegetation structure defined using Atkinson structural types; no taxonomic names are used
4.2.2 Biotic names follow a reference taxonomy (e.g. NZOR). Please provide name of reference taxonomy	Common names follow Nicol 1997 and NZPCN (http://nzpcn.org.nz; but no date provided). Scientific names listed in their Appendix 1 but no reference taxonomy provided.	NZ Plant Names Database (http://nzflora.landcareresearch.co.nz/)	Not stated	N/A

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
5. Robust				
5.1.1 Detailed descriptions of units exist?	Primary and secondary ecosystem drivers described. Succinct descriptions of composition and current and historical distribution provided. Whether more detail is required could be evaluated.	Partial, all vegetation alliances and some associations are described (environment, dominant and distinguishing species) and mapped (points). For each alliance, synoptic tables showing species dominance and constancy are available, as well as online fact sheets (for woody ecosystems defined up to 2013). For the latter, spreadsheets exist which can be filtered based on various levels of the hierarchy.	Yes – distributions, characteristic landforms, and characteristic features are described in detail.	Structured descriptions are provided on web-based factsheets, with different levels of detail depending on existing knowledge.
5.1.2 Clearly applicable diagnostic criteria to allow identification of units	No, descriptions are provided rather than diagnostic criteria. (Refer App. 11, Regional Council feedback, of Collins 2024: definitions for many restricted ecosystem units not operationalised; DOC feedback: high judgement and low transparency in allocation of sites to ecosystem units).	Yes. Quantitative analysis can assign any new plot to the units. For woody alliances, combinations of species that are statistically significant indicators have been calculated.	No, descriptions are provided rather than diagnostic criteria	Theoretically, yes, based on the diagnostic classifiers. When more detail has been required to operationalise these definitions (e.g. to support mapping or select study sites for research) panels of experts developed additional diagnostic criteria.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
5.1.3 Do ecosystem names facilitate identification in the field?	Partial, where names include vegetation structure and dominant species. Some names require the user to know what the abbreviation in the code means to make an identification; for example, 'BR2: scabweed/gravelfield/stonefield' (it is not clear this includes braided river beds) and 'WL8: Herbfield/mossfield/sedgeland' (it is not clear what this is in comparison to other WL types).	Yes. Names are unique and comprise dominant species and structural type. Names are broad at high levels of the hierarchy (structural type), and become more specific at finer levels (incl. up to 4 or 6 species). Scientific plants names are used, with an equivalent name using vernacular names (woody classifications) and Māori names (Warawara and Russell forests) provided.	Yes – all types are sufficiently broad that units can be readily identified.	Common names are descriptive and reflect wide usage. Where the ecosystem has been referred to by multiple names, these are provided as synonyms on ecosystem factsheets.
5.1.4 Are the number of units manageable? Please specify the number of units at each level.	Zonal: 8 abiotic units ← 78 ecosystem units Azonal: 6 categories ← 11 divisions ← 74 ecosystem units (Refer App. 12 of Collins 2024: Bay of Plenty Regional Council noted that there are too many different types: 'We need something that's a bit higher level'). See also 1.2.	Woody: 7 structural types ← 32 alliances ← 92 associations Non-woody: 6 structural types ← 8 sub-groups ← 22 alliances ← 50 associations Geothermal: 14 associations	Yes: 8 vegetative cover groups ← 47 vegetative cover classes	Yes: 13 coastal; 30 inland and alpine; 5 geothermal; 3 induced by native vertebrates; 5 subterranean or semi-subterranean; 15 wetlands

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
5.2.1 Method to produce typology documented and independently reproducible?	No. The authors describe this aspect of their typology as follows: a subjective, theoretical framework of perceived environmental and physical drivers was created. Literature, pre-existing maps and expert opinion were used to align vegetation communities (defined from both literature and author knowledge) to units defined by the frameworks.	Yes, methods have been peer reviewed and published, original plot data are archived and R code is available. Note that fuzzy noise clustering uses a random seed, so repeat analyses will not produce completely identical results. Analytical skills are required to reproduce the analysis.	No, selection of criteria used to define classes was initially based on 'an analysis of the New Zealand Land Resource Inventory' (which is not described in detail), with subsequent modification based on recognised ecological importance and mapping practicalities.	Methods are documented, but whether another team of experts would define the same units can't be determined
5.2.2 If 5.2.1 is 'No', is the method defensible?	Partial – the framework is based on accumulated knowledge of the authors of NZ vegetation patterns, and published literature is cited and makes logical sense. However, the fit of the units into the framework and their descriptions have not been widely validated with external data. (Refer App. 11, DOC feedback, of Collins 2024: 'poor congruence to plot-level quantitative data').	N/A	Yes, based on the technology available at the time (1987).	Yes method was published in a peer-reviewed journal (*NZ Journal of Ecology*).
5.2.3 Was typology data derived, data underpinned, or expert-derived/qualitative?	Expert-derived/qualitative.	Data derived	Expert-derived/qualitative	Expert-derived/qualitative

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
6. Comprehensive				
6.1 Does it accommodate transformed ecosystems, including engineered, passed tipping point, successional, novel?	Incorporates some broadly circumscribed successional shrublands and grasslands. Exotic-dominated seral ecosystems are excluded. Secondary forests are omitted, as are some transformations (e.g. forests that have been selectively logged, 'mixed urban and exotic indigenous ecosystems' (Collins 2024, App. 12). Heavily engineered ecosystems (e.g. urban environments) are not included.	Yes, includes successional ecosystems and novel ecosystems, where plot data have been collected. Heavily engineered ecosystems (e.g. urban environments) are not included.	Yes, includes successional ecosystems, exotic forests, croplands, pasture, and urban areas.	No, these are outside the scope of the typology.
6.2 Does it accommodate ecotones?	Partial – in some councils (e.g. Wellington) polygons have been designated as mosaics comprising multiple ecosystem units.	Yes. The analytical process calculates values signifying the degree of membership of plots to units. An individual plot can be recognised as 'intermediate' between two or more units, signifying either a position along a compositional gradient or an ecotone. Incorporating uncertainty into Warawara and Russell maps allowed portrayal of ecotones.	No	No, these are outside the scope of the typology.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – *The Vegetative Cover of New Zealand*	Williams et al. (2007) – naturally uncommon ecosystems
6.3 Does it distinguish biotic (e.g. species) assemblages that are uncommon?	It captures 'azonal' types which are mostly naturally rare ecosystems responding to abiotic extremes and these may support biotic assemblages that are uncommon. Whether ecosystems that were once common and are now rare are captured requires evaluation. (Refer App. 11, regional council feedback, of Collins 2024: 'doesn't work well for restricted ecosystems').	Yes, where plot data have been collected (e.g. non-woody classification described gumland, coastal turf, braided river bed and granite gravel field associations).	No	It distinguishes environments that are uncommon, and these may support biotic assemblages that are also uncommon.
6.4 Is there any other form of ecosystem variation that is missing from the typology?	Needs evaluation. Although the literature underlying the typology is extensive, not all relevant literature sources were incorporated (e.g. Cuddihy 1977; Jane 1988; Reif & Allen 1988; Duncan et al. 1990), so there is potential for some ecosystem types to have been missed. (Feedback from Environment Canterbury to MWLR: Singers & Rogers 2014 doesn't 'really deal well with Canterbury's highly modified lowland area or dryland ecosystems').	Yes, ecosystems that have not been sampled by vegetation plots cannot be defined.	Yes, this broad typology does not include rare types by definition.	Yes, all ecosystems that are not naturally uncommon
7. NZ specific				
7.1 Reflects NZ ecological diversity and processes (if NO explain why)?	Yes	Yes	Yes, but not with much granularity.	Yes, those that are relevant to the scope of the typology.

Principles and requirements	Expert-based system	Quantitative plot-based system	Newsome (1987) – ***The Vegetative Cover of New Zealand***	Williams et al. (2007) – naturally uncommon ecosystems
7.2 Does the typology use terminology and concepts familiar to NZ ecologists and conservation practitioners?	Yes	Partial. Terminology describing ecosystems is familiar; names of levels (e.g. alliance, association) although in widespread use globally have been little used in NZ; analytical techniques will be familiar to a subset of specialists.	Yes	Yes
7.3 Takes account of te ao Māori?	No	Partial. Warawara and Russell forest extensions were developed in partnership with local hapū, and a name for each association using local Māori plant names was provided, alongside one using scientific names. However, the conceptual approach and analysis did not incorporate Māori views of the landscape.	No	No

Appendix 2 – Crosswalk of land-use categories identified in the NZLUM onto IUCN GET EFGs from the intensive land use biome

NZLUM classification(s)	EFG name (IUCN GET Level 3)	Comments
2.3.0 Short-rotation and seasonal cropping (sub-classes arable cropping, arable and livestock mixed cropping, short-rotation horticulture, seasonal flowers and bulbs and turf farms)	T7.1 Annual croplands	The IUCN GET specifically identifies 'annual' substrate modification and harvest; more frequent substrate modification and harvest are likely to occur for many of the crops that would be captured in this category.
2.2.0 Grazing modified pasture systems (with sub-classes dairy, intensive drystock and some areas of extensive dry stock)	T7.2 Sown pastures and fields	Extensive drystock land use in NZ covers a wide range in intensity of land use, and there are consequently varying degrees of modification of indigenous vegetation/ecosystems. Alternative IUCN GET classifications that may also be relevant for extensive dry stock are provided below. Furthermore, in NZ there is ongoing research and use of diverse pastures in high-productivity pastoral land, so the descriptor of these ecosystems being dominated by one or few grassland species doesn't necessarily fit for all NZ systems.
2.1.0 Plantation forests (sub-classes exotic forestry, indigenous forestry*, other production uses, planted environmental & infrastructure protection, permanent carbon forest 2.4.0 Perennial horticulture (sub-classes tree crops, vine-crops, other perennial crops)	T7.3 Plantations	The NZLUM plantation forests class includes plantations for pulpwood and saw-log production, as well as non-pulpwood production, such as oil, wildflowers, honey (e.g. kānuka/mānuka plantations). Mixed species may be used for environmental & infrastructure protection plantings in NZ, so alternative GET classes may be appropriate.
This effectively encompasses all of the sub-classes in the high-level Built Environment class on NZLUM.	T7.4 Urban and industrial ecosystems	The key 'challenge' in differentiating this EFG largely relates to the desired spatial resolution and the 'patch-size' of individual EFGs or ecosystems captured within a less spatially resolved EFG.
2.2.3 Extensive drystock	T7.4 Derived semi-natural pastures and old field	Identification of this ecosystem depends on the requirement for it to be defined by the removal or modification of woody plant components, and arguably the time-point of that removal; e.g. pre- or post-European arrival in NZ and/or introduction of large herbivores (by Europeans).
2.2.3 Extensive drystock 1.3.3 Grazing native vegetation	T4.5 Temperate subhumid grasslands	In the context of modified land uses, the large herbivores that graze these ecosystems are exotic livestock species, most often sheep. The extent of this EFG is in partly dependent on the time-point at which the ecosystem is considered to be the original ecosystem; e.g. is it before or after any deforestation and/or introduction of large herbivores by Europeans.
2.2.3 Extensive drystock 1.3.3 Grazing native vegetation	T4.4 Temperate woodlands	In the context of modified land uses, the large herbivores that graze these ecosystems are exotic livestock species.

* Indigenous forestry is included as a potential future land-use category; there are not known to be any current planted indigenous species for pulpwood and saw-log production.

Appendix 3 – EcoVeg example hierarchy

The table below is reproduced from Faber-Langendoen et al. 2014 (Table 2) and shows the hierarchical structure from the EcoVeg classification, with a worked example from North America. Table 4 in Faber-Langendoen et al. 2014 provides detailed guidelines for defining different levels of the hierarchy based on biogeography/floristics, diagnostic species, growth forms, climate, disturbance regimes/succession and edaphic/hydrology relationships.

Natural hierarchy	Definition	Example scientific names	Example colloquial names
Upper levels			
L1: Formation class	A broad combination of dominant general growth forms adapted to basic moisture, temperature, and/or substrate or aquatic conditions.	Mesomorphic Shrub and Herb Vegetation	Shrub and Herb Vegetation
L2: Formation subclass	A combination of general dominant and diagnostic growth forms that reflect global mega- or macroclimatic factors driven primarily by latitude and continental position or that reflect overriding substrate or aquatic conditions.	Temperate and Boreal Shrub and Herb Vegetation	Temperate and Boreal Grassland and Shrubland
L3: Formation*	A combination of dominant and diagnostic growth forms that reflect global macroclimatic conditions as modified by altitude, seasonality of precipitation, substrates, and hydrologic conditions.	Temperate Shrub and Herb Vegetation	Temperate Grassland and Shrubland
Mid levels			
L4: Division	A combination of dominant and diagnostic growth forms and a broad set of diagnostic plant species that reflect biogeographic differences in composition and continental differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.	*Andropogon* – *Stipa* – *Bouteloua* Grassland and Shrubland	Great Plains Grassland and Shrubland
L5: Macrogroup	A moderate set of diagnostic plant species and diagnostic growth forms that reflect biogeographic differences in composition and subcontinental to regional differences in mesoclimate, geology, substrates, hydrology, and disturbance regimes.	*Andropogon gerardii* – *Schizachyrium scoparium* – *Sorghastrum nutans* Grassland and Shrubland	Great Plains Tallgrass Prairie

Natural hierarchy	Definition	Example scientific names	Example colloquial names
L6: Group	A relatively narrow set of diagnostic plant species (including dominants and codominants), broadly similar composition, and diagnostic growth forms that reflect regional mesoclimate, geology, substrates, hydrology, and disturbance regimes.	*Andropogon gerardii* – *Heterostipa spartea* – *Muhlenbergia richardsonis* Grassland	Northern Great Plains Tallgrass Prairie
Lower levels			
L7: Alliance	A characteristic range of species composition, habitat conditions, physiognomy, and diagnostic species, typically at least one of which is found in the uppermost or dominant stratum of the vegetation. Alliances reflect regional to subregional climate, substrates, hydrology, moisture/ nutrient factors, and disturbance regimes.	*Andropogon gerardii* – *Sporobolus heterolepis* Grassland	Northern Mesic Tallgrass Prairie
L8: Association	A characteristic range of species composition, diagnostic species occurrence, habitat conditions, and physiognomy. Associations reflect topo-edaphic climate, substrates, hydrology, and disturbance regimes.	*Andropogon gerardii* – *Heterostipa spartea* – *Sporobolus heterolepis* Grassland	Northern Mesic Big Bluestem Prairie

* Broadly equivalent to the IUCN GET Level 3 (ecosystem functional groups).

Note: The name of the level can be added to the type name for clarity, where needed.

Appendix 4 – Assessment of five candidate pathways to the development of a terrestrial typology

Pathway option	Pros	Cons
1. Adopt one of the existing typologies	This is a the simplest approach, which would require minimal development for implementation. The typology used would be familiar to some of the end-user communities, and there would be little disruption for those who are already using it.	None of the existing typologies met all of the principles, so this pathway would not result in a typology that meets the needs of end-users.
2. Transition the expert-based system such that it meets the principles	This system is widely used already by regional councils, with only Canterbury and Westland yet to be mapped. This means there is widespread familiarity with the system across a range of end-users.	The process is inherently subjective (expert-derived) and qualitative, and there is variable specificity/generality of types. It also doesn't incorporate successional types. The process is currently unlikely to be repeatable by a third party, and so it would benefit from some quantitative and objective underpinnings, without which the system isn't consistent with internationally accepted standards (Faber-Langendoen et al. 2014; De Cáceres et al. 2015).
3. Transition the quantitative plot-based system such that it meets the principles	The typology has completely quantitative and objective underpinnings, is flexible, is peer-reviewed, and some end-users (e.g. DOC) are familiar with it. Crosswalks to other typologies have been done. It incorporates successional types, and can be extended to cover new types if plot data exist to define them. The system is consistent with internationally accepted standards that call for an incorporation of plot-based data (Faber-Langendoen et al. 2014; De Cáceres et al. 2015).	The system is not in widespread use by regional councils. At present the system is nested in two levels (associations within alliances), but both were created separately, with links between them established subsequently. Sufficient plot data need to be collected for new types to be defined. Mapping is limited to two forests in Northland. Terminology describing ecosystems is familiar to NZ specialists, but the names of levels (alliances, associations) are not in wide use. Analytical techniques will only be familiar to a subset of specialists with quantitative skills.
4. Integrate the two systems, while transitioning each to ensure they meet the principles	Provides an opportunity to incorporate the best aspects of (2) and (3), above. May be a more socially acceptable option, allowing people who have a preference for one of the two systems (over the other) to feel like their positive aspects will be present/preserved in the revised typology.	A moderate amount of work by trained experts would be required to integrate the two systems: probably more than (1) above, but less than (5) below. The amount of work compared to (2) and (3) would require further evaluation. Decisions and trade-offs along the way may mean that all of the principles are not fully met in the revised typology (i.e. if some of the cons of [2] and [3] are present, and cannot be resolved).
5. Propose a completely new approach	A typology can be developed from the ground up that aligns with all of the principles. There is the potential for it to incorporate the needs of all end-users, and also be consistent with international standards, using state-of-the-art techniques.	This pathway option would be the most costly option in terms of money and time. Substantial consultation with all stakeholders would be required while developing the new approach. There is considerable uncertainty over whether this would provide a solution superior to (4).