



OIAD-639

Section 9(2)(a)

Dear Section 9(2)(a)

Thank you for your email of 30 April 2023 requesting the following under the Official Information Act 1982 (the Act):

I request any advice or reports that the Ministry received from Manaaki Whenua Landcare Research (including advice or reports written with other authors) in 2022, relating to resource management practice or law.

On 29 May 2023, the Ministry notified you of an extension of the time frame to respond to your request by 20 working days under section 15A(1)(b) of the Act, as consultations necessary to make a decision on the request were such that a proper response could not reasonably be made within the original timeframe.

The Ministry has identified five documents in scope of your request. Two of the documents are being released to you in full. One document is being released in part and one document is being withheld in full under section 9(2)(f)(iv), to maintain the constitutional conventions for the time being which protect the confidentiality of advice tendered by Ministers of the Crown and officials, and one document is being refused in full under section 18(d), as the information requested is publicly available.

In terms of section 9(1) of the Act, I am satisfied that, in the circumstances, the withholding of this information is not outweighed by other considerations that render it desirable to make the information available in the public interest.

You have the right to seek an investigation and review by the Office of the Ombudsman of my decision to withhold information relating to this request, in accordance with section 28(3) of the Act. The relevant details can be found on their website at:

www.ombudsman.parliament.nz.

Please note that due to the public interest in our work the Ministry for the Environment publishes responses to requests for official information on our [OIA responses page](#) shortly after the response has been sent. If you have any queries about this, please feel free to contact our Ministerial Services team: ministerials@mfe.govt.nz.

Yours sincerely

Clare Barton
Director - Science Strategy (Limits and Targets)

Document schedule

Document no.	Document date	Content	Decisions	OIA sections applied
1.	September 2022	25346_CawRpt_3818_Attributes of ecological integrity 2022_FINAL VERSION 30 Sep 2022__	Released in part	Section 9(2)(f)(iv)
2.	February 2022	Landcare Maori perspectives and Maturanga workshop Feb 2022	Released in full	N/A
3.	June 2022	LC4131 Landcare biodiversity offsets and compensation report	Released in full	N/A
4.	December 2022	[Title withheld under section 9(2)(f)(iv)]	Withheld in full	Section 9(2)(f)(iv)
5.	June 2022	LC4128_EcoSG V report	Refused in full	Section 18(d) www.envirolink.govt.nz/assets/2214-MLDC162-Exploring-the-implementation-of-ecological-soil-guideline-values-for-soil-contaminants.pdf

REPORT NO. 3818

**COMPILATION OF POTENTIAL ATTRIBUTES OF
ECOLOGICAL INTEGRITY FOR AOTEAROA NEW
ZEALAND**

**World-class science
for a better future.**

COMPILATION OF POTENTIAL ATTRIBUTES OF ECOLOGICAL INTEGRITY FOR AOTEAROA NEW ZEALAND

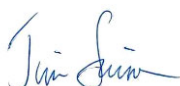
ANNA BERTHELSEN¹, JO CAVANAGH², JOANNE CLAPCOTT¹,
CARLOS CAMPOS¹, ADRIAN MCDONALD³, ROLAND EVELEENS¹,
KATE ORWIN², DUANE PELTZER²

1. CAWTHRON INSTITUTE
2. MANAAKI WHENUA – LANDCARE RESEARCH
3. UNIVERSITY OF CANTERBURY

Prepared for Ministry for the Environment

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Jim Sinner



APPROVED FOR RELEASE BY:
Grant Hopkins



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EXECUTIVE SUMMARY

The New Zealand Government plans to repeal the Resource Management Act 1991 (RMA) and replace it with three new pieces of legislation. One of these is the Natural and Built Environments Act (NBA, in draft¹), which specifies that environmental limits are to be prescribed in the National Planning Framework (NPF). To inform the NPF, the Ministry for the Environment (MfE) is seeking to identify indicators (or 'attributes') of ecological integrity (EI) that are suitable for setting environmental limits.

Attributes need to cover various environmental domains (Land [including Soil], Freshwater, Coastal and Seabed, Estuaries and Air), to consider indigenous biodiversity as a cross-domain theme and to relate to significant environmental issues. This requires compilation of potential attributes of EI in priority topic areas, as well as their assessment against key criteria in relation to management (including policy) and in a limit-setting context. MfE are also interested to know whether there are any gaps in their proposed definition of EI, which includes five components: ecological representation, composition, structure, function and resilience.

MfE contracted Cawthron Institute, Manaaki Whenua Landcare Research and University of Canterbury to carry out this work in two phases. Phase 1 (this report) focuses on compilation and synthesis of potential attributes (with no policy or management lens applied) as well as on identifying any gaps in the MfE-proposed definition of EI, Section 9(2)(f)(iv)

We conducted a literature search of thousands of published and unpublished articles across the five domains to identify potential attributes of EI. Our primary focus was on literature pertaining to Aotearoa New Zealand, but we also supplemented our findings using international monitoring frameworks and literature.

The literature yielded an overall abundance of potential attributes of EI across the domains: Land (subdomains: > 150 for Terrestrial and 245 for Soil), Freshwater (251), Coastal and Seabed, and Estuaries (> 580 combined), and Air (37), with indigenous biodiversity included as a cross-domain theme for all. Our approach developed a documented and repeatable search of the literature and provides a crucial summary of knowledge from published and unpublished sources. Key points from our across-domain synthesis for the EI components are as follows:

- Across all domains the attributes associated with composition and structure dominated; for Air, all attributes related to structure.
- Functional attributes were also quite common in all domains except for Air.

¹ <https://environment.govt.nz/assets/publications/Natural-and-Built-Environments-Bill-Exposure-Draft.pdf>

- Attributes for ecological representation and resilience were relatively few across the domains. Attributes for ecological representation were dominated by variations on broader environment or habitat extent with a greater number captured for the marine-related (Coastal and Seabed, and Estuaries) domains and terrestrial subdomain.
- Attributes specifically relating to indigenous species or indigenous biodiversity were identified for all domains except Air and the Soil subdomain. However, a number of biotic attributes did not distinguish between indigenous or non-indigenous species (e.g., coastal macroinvertebrate community abundance and diversity), and in this regard they technically do not meet the requirements under the EI definition provided. Some other attributes were specifically related to non-indigenous species (e.g., non-native species diversity).
- EI components are interrelated. Biotic structural components can be based on composition information, some composition attributes relate to function, and attributes relating to resilience are often measured by attributes associated with other EI components such as composition and function.
- The MfE definition of EI aligns in many respects with definitions used in the literature for the domains. However, the Freshwater and marine-related domain descriptions also include consideration of reference or baseline condition. For the Soil subdomain, EI is not used in the literature, but rather 'soil health' or 'soil quality', which can have a similar intent to the MfE EI definition, with the exception of the specification of 'indigenous biodiversity' in the MfE definition. For the Air domain, it was noted that the MfE EI definition could be strengthened to explicitly include climatic factors (rather than just abiotic physical factors) in the definition of structure.

Additional key points across domains were:

- A number of attributes were found to be connected across domains e.g., erosion or leaching, which traverse the land and water domains. Across-domain attributes also relate to domain boundaries e.g., riparian vegetation and tidal wetlands.
- Across domains, the development and/or use of attributes among different systems is uneven. For example, many of the Soil subdomain attributes are developed and applied in agroecosystems, whereas many Terrestrial subdomain metrics have been developed in indigenous forests and shrublands. Additionally, Freshwater attributes have been relatively well-developed into national scale monitoring frameworks. There was also unevenness across domains in relation to the type of attributes or threats they respond to. For example, there was a higher proportion of activities-based attributes (e.g., fishing-related) for the marine-related domains and a dominance of climate change-related attributes for the Air domain, while attributes relating to chemical contamination were common for most domains.

- Gaps in potential attributes for different EI components for Aotearoa New Zealand were identified through the international literature for all domains.
- A common theme for emergent attributes across the Terrestrial and Soil subdomains and Freshwater and marine-related domains is the use of eDNA or rRNA approaches to provide further detail on species presence and composition.

Section 9(2)(f)(iv)

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GLOSSARY

Potential attribute	A 'measurable characteristic (numeric, narrative, or both)'.
Coastal and Seabed	For the purposes of our report, Coastal and Seabed includes coastal waters and the underlying seabed. Coastal waters are defined in the NBA Exposure Draft as: '...seawater within the outer limits of the territorial sea and includes – (a) seawater with substantial freshwater component; and (b) seawater in estuaries, fiords, inlets, harbours, or embayments'. The landward boundary of coastal waters was identified as Mean High Water Springs.
Domain	The five domains are Land (including Soil), Freshwater, Coastal and Seabed, Estuaries and Air. Indigenous biodiversity is considered as a cross-domain theme' rather than a domain. Additionally, for the purposes of our report, Land (including Soil) was often considered as two separate subdomains: 'Terrestrial', which is the aboveground component, and 'Soils'.
Ecological integrity (MfE definition)	The ability of the natural environment to support and maintain the full range of indigenous biodiversity and ecosystem functioning, both within and across ecosystems. It requires supporting and maintaining: • ecological representation: the occurrence and extent of ecosystems and indigenous species and their habitats across the full range of environments • its composition: the natural diversity and abundance of indigenous species, habitats, and communities within and across ecosystems; and • its structure: the biotic and abiotic physical features and characteristics of ecosystems; and • its functions: the ecological and physical functions and processes of an ecosystem; and • its resilience: any other properties that contribute to the ecosystem's ability to recover from the adverse impacts of natural or human disturbances.
Ecosystem	As defined in the NBA: '... a system of organisms interacting with their physical environment and with each other'.

Estuaries	Partially enclosed water bodies where freshwater meets and mixes with saltwater from the sea. Additional notes on how estuaries were further defined for the purposes of our report: - the landward boundary was considered to be Mean High Water Springs and the seaward boundary was across the estuary entrance (e.g., prominent headlands) - overall, estuaries were included within the Coastal and Seabed domain boundary - our literature search terms for estuaries also included harbours, inlets, sounds and fiords.
Freshwater	As defined in the NBA exposure draft: 'all water except coastal water and geothermal water'.
Indigenous biodiversity	The variety of living organisms indigenous to New Zealand, the ecological complexes of which they are a part, including diversity within species, between species, and of ecosystems.
Land (including Soil)	For the purposes of our report, Land (including Soil) is the soil and underlying rock as well as the life (animals and vegetation) above and below ground. It includes ecosystems and life, but riverbeds and lakebeds are excluded. Land to the mean high water spring mark (e.g., sand dunes) is included.
NPF	National Planning Framework
NPSFM	National Policy Statement for Freshwater Management
NBA	Natural and Built Environments Act (still in draft as of the date of this report).
Natural environment	As defined in the NBA exposure draft: '(a) the resources of land, water, air, soil, minerals, energy, and all forms of plants, animals, and other living organisms (whether native to New Zealand or introduced) and their habitats; and (b) ecosystems and their constituent parts'.
River	As defined in the NBA exposure draft: '...a continually or intermittently flowing body of freshwater; and (b) includes a stream and modified watercourse; but (c) does not include an irrigation canal, a water supply race, a canal for the supply of water for electric power generation, a farm drainage canal, or any other artificial watercourse'.

1. INTRODUCTION

1.1. Background and report objectives

The New Zealand Government plans to repeal the Resource Management Act 1991 (RMA) and replace it with three new pieces of legislation. One of these is the Natural and Built Environments Act (NBA, in draft²), which aims to 'promote the protection and enhancement of the natural and built environment, while providing for housing and preparing for the effects of climate change'. This Act requires environmental limits to be prescribed in a new National Planning Framework (NPF), with the purpose of environmental limits being to protect either or both of the following: (a) the ecological integrity of the natural environment and (b) human health.

To inform the NPF, the Ministry for the Environment (MfE) is seeking to identify indicators (or 'attributes', as referred to in the National Policy Statement for Freshwater Management [NPSFM] 2020), of ecological integrity (EI) suitable for setting environmental limits. Attributes need to cover various environmental domains (Land [including Soil], Freshwater, Coastal and Seabed, Estuaries and Air), to consider indigenous biodiversity as across-domain theme and to relate to significant environmental issues. This work initially requires compilation of potential attributes of EI in priority topic areas, and, following this, their assessment against key criteria for use in management (including policy) and limit setting. MfE are also interested to know whether there are any gaps in their definition of EI.

MfE contracted Cawthron Institute, Manaaki Whenua Landcare Research and University of Canterbury to carry out this work in two phases. Phase 1 focuses on compilation of potential attributes and on identifying differences in the MfE definition of EI compared to how EI is defined in the literature. Section 9(2)(f)(iv)

This report encompasses Phase 1, with specific objectives being to:

- search the literature to compile a list of potential attributes of EI for each domain (considering indigenous biodiversity as a cross-domain theme) with respect to significant environmental issues. The intention here was to 'cast a wide net' to help ensure that all potentially relevant attributes were identified. Management (including policy) considerations are outside the scope of Phase 1. Therefore, even though all attributes identified in our report are relevant for EI, some attributes may not be appropriate for setting limits under the NBA.
- identify any key differences between the MfE definition of EI and how EI is defined in the literature for each of the domains.

² <https://environment.govt.nz/assets/publications/Natural-and-Built-Environments-Bill-Exposure-Draft.pdf>.

Note that consideration of any mātauranga Māori informed frameworks or cultural indicators is outside of the scope of our work. Considering attributes specifically related to human health was also outside the scope.

2. METHODS

We surveyed the literature to identify attributes relevant to EI (as defined by MfE) for Aotearoa New Zealand in four steps. First, we identified published literature within Aotearoa New Zealand relevant to EI for the five domains. Second, we used a combination of approaches to refine and filter this literature to those publications considered relevant to the domains and the development of attributes of EI applicable to the most significant environmental issues. Third, we used heuristic ad hoc searching of databases and obtained expert input across domains to determine if there are new, emerging or unpublished work within Aotearoa New Zealand relevant to this synthesis. Finally, we conducted a non-systematic 'rapid review' of the international literature on EI to supplement attributes that have not been adopted or applied within Aotearoa New Zealand (Booth et al. 2016). These four steps are described in more detail below. This is followed by details on how we recorded the literature review outputs and analysed the results.

2.1. Systematic literature review including refining and filtering (Steps 1 and 2)

2.1.1. Initial search

Our systematic review approach (Step 1) was based on aspects of the PRISMA³ framework, i.e., it involved a detailed plan and search strategy, but it did not include a meta-analysis component (O'Dea et al. 2021). Our search strategy considered a series of search strings in title, abstract, key words and author address fields, as follows:

('ecological integrity' OR 'ecosystem integrity' OR 'ecosystem condition' OR 'ecosystem health' OR 'community composition' OR 'community representativeness' OR 'community structure' OR 'ecological resilience' OR 'ecological function*') AND ('new zealand' OR 'aotearoa' or 'NZ').

Our search terms were designed to represent EI broadly, as well as to encompass the specific EI components as defined by MfE (i.e., composition, structure, function, resilience and representation). The strings reduced bias by helping us identify all relevant studies on a particular subject matter. Our searches were conducted on the Web of Science (WoS) core collection. A preliminary systematic search yielded 9,986 results (20 June 2022).

³ Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology.

2.1.2. Search for relevance

Using one search engine across all domains (WoS core collection), we then evaluated these results for relevance using the following criteria:

- domain-specific contributions (refer search terms in Table 1) AND
- responses to significant environmental issues (refer search terms in Table 2) AND
- relevance by including the search terms ('attribute*' OR 'indicator*' OR 'monitor*' OR 'management' OR 'application') AND
- exclusion terms (if used, these differed among domains as detailed in the results, refer Section 3).

Thus, to qualify for further assessment for a given domain, an item of literature had to meet each of the first three criteria and not be excluded by specific considerations (if any) for that domain. All fields (title, abstract, keywords and author address) were searched for text matching the above criteria.

After this process was completed, it became clear that attributes related to the Air domain are always secondary drivers of EI. None of the identified abstracts related purely to the Air domain. Thus, to identify attributes associated with the Air domain, an extra identification of the range of secondary domains was included for completeness. It should also be noted that the original search and the subsequent searches by domain missed a large amount of literature; hence, we also did ad hoc searching (detailed further below), which was particularly important for the Air domain.

The raw outputs of the literature search for each domain were saved in Excel file format and can be provided to MfE on request.

We then conducted further assessment of article relevance (Step 2), depending on the number of search results and additional considerations. This was based on expert evaluation of returned literature to identify studies relevant for attribute and metadata extraction based on title and abstract of studies. In some cases, the PDF was also obtained during this process so that further details in the article text could be examined to determine relevance. Factors for exclusion during this process included studies not relevant for Aotearoa New Zealand e.g., search identified Aotearoa New Zealand authors but article concerned another location. Exclusion factors also related to 'incorrect' domain (e.g., many freshwater studies were identified in the final returned literature search results for Land (including Soil)) or a focus on something other than a potential attribute (e.g., management, policy, governance, engineering, or conservation).

Following this, we obtained all article pdfs and any missing dois for all articles and extracted metadata from each article (i.e., populated our 'attribute list and metadata' data file); refer Section 2.4 'Recording literature search outputs' below.

Table 1. Terms used to define each of the domains for the systematic literature search. Note that indigenous biodiversity search terms (last row) were included in each domain-specific search.

Domain	Search Terms
Freshwater	Fresh Water, Freshwater, Groundwater, River, Stream, Lake, Wetland, Waterway, Glacier, Glacial
Coastal and Seabed	Coastal Waters, Coastal, Coast, Marine, Ocean, Seabed, Sea Floor
Estuaries	Estuar*, Harbour, Inlet, Sound, Fiord
Land (including Soil)	Soil, Soil Health, Land, Forest, Alpine, Agriculture, Urban, Vegetation, Terrestrial
Air	Air quality, Air pollution, Atmosphere, Climate, Climate Change, Weather, Meteorology
Indigenous biodiversity	Indigenous Biodiversity, Biodiversity, Biological diversity

Table 2. The significant environmental issues (SEI) for each domain. These were determined by the report authors to represent a range of environmental issues. Note that SEIs relating to indigenous biodiversity were considered for each of the domains.

Domain	Significant environmental issues
Land (including Soil)	Agriculture Biodiversity decline Biological invasion Climate change Contaminants (metals, organic contaminants) Contaminated land Diseases Disturbance Erosion Habitat loss Habitat modification Land fragmentation Land use change Land use intensity, compaction, leaching Mining Pests Soil acidification Salinisation Urban expansion/urbanisation including sealing Weeds
Freshwater	Climate change, flow regime, water temperature, water allocation, water abstraction Eutrophication, nutrient enrichment, nutrient loading Exploitation of resources Habitat modification, Habitat loss, Biodiversity loss Litter Non-indigenous species, invasive species Pollution, sedimentation, heavy metals Pathogens, toxins, emerging contaminants
Coastal and Seabed, and Estuaries	Climate change, acidification, water temperature, air temperature, sea level rise, increasing storm intensity, increasing flood intensity, increasing storm frequency, increasing flood frequency, shoreline erosion Eutrophication, nutrient enrichment, nutrient loading Exploitation of resources Habitat modification, Habitat loss, Biodiversity loss Human presence, human activity Hydrologic disruption, hydrodynamic disruption Litter Non-indigenous species, invasive species Pathogens, toxins, emerging contaminants Pollution, sedimentation, heavy metals
Air	Air Pollution/Air Quality: particulate matter, nitrogen dioxide, sulphur dioxide, carbon monoxide, surface ozone, airborne microplastics Attribution Climate change: temperature, precipitation. Wind, humidity, greenhouse gases (CO ₂ , CH ₄ , NO ₂) Climate variability: Southern Annular Mode, ENSO, natural variability Cold extremes: frost

Domain	Significant environmental issues
	Drought: precipitation, evaporation, wind, temperature Extreme events: could include drought, storms, heatwaves, cold spells and floods Floods Heat waves: temperature Storms: precipitation/rainfall, wind Weather patterns

2.2. Additional literature for Aotearoa New Zealand (Step 3)

Further ad hoc, heuristic searching was used to identify additional relevant publications, including unpublished 'grey literature' sources. Our ad hoc searches included several approaches:

- i) publications that cited or were cited by articles identified in the systematic literature searches in steps 1 and 2 above
- ii) expert knowledge of the authors
- iii) additional experts acting as 'critical friends' particularly to identify unpublished literature or additional attributes to consider
- iv) Google and Google Scholar searches were used to identify additional publications for assessment.

For the Air domain, it was clear that a large portion of the literature focusing on atmospheric science, air quality or climate change was missing from the initial search results. To mitigate this, additional targeted searches (using the Scopus search engine) were completed using attributes identified by the original literature search as further search terms to identify extra attributes and subsets of attributes. Expert knowledge was then used to add extra search terms. To ensure transparency, Table 3 identifies all the Air domain specific search terms used in targeted searching. In each case, the search was of the form ('Air [targeted search term]' and 'ecosystems') and then a subset was created to save only records which included 'Aotearoa' or 'New Zealand'. Each list of results was then examined to find relevant studies. The total of individual records collected was over 7500 and this resulted in the identification of just under 196 relevant Aotearoa New Zealand-based studies, though the number of unique records was smaller than this number as some records were found in multiple searches.

Table 3. Targeted Air domain search terms used in literature searches.

Targeted search term (explanatory note in brackets)	Number of studies identified	Number of relevant Aotearoa New Zealand studies found using search term	Total number of Aotearoa New Zealand studies found that were relevant to this search term from any source (only filled when different from previous number)	Comment
Ammonia	448	6	7	
Arsenic	347	4	8 (Heavy metals)	
Atmospheric nitrogen deposition	393	7	11	
Atmospheric particulate matter	55	1	4	
Atmospheric humidity	52	1		
Biomass burning	129	5		
Black carbon	96	1	0	Only reference really more relevant to particulate matter
Carbon Monoxide	30	1	2	
Climate indices	682	16		
Climate change	46	5		
CO (chemical symbol)	2000	24	2	Many references actually only related to CO ₂
Daily Temperature range (ETCCDI climate indices)	64	3		None specific to search term
Eddy covariance	22	11		
ENSO (teleconnection pattern)	9	3	5	
Fire	1376	27	23	Some only indirectly relevant to search term
Frost days	12	1		
Gaseous pollutants	140	2		
Greenhouse gases	54	17		
Heavy metals	15	1		
Herbicide and pesticide atmospheric transport	11	0		
Light pollutions	49	2		
Microplastics	144	3	5	All occurring in 2021

Targeted search term (explanatory note in brackets)	Number of studies identified	Number of relevant Aotearoa New Zealand studies found using search term	Total number of Aotearoa New Zealand studies found that were relevant to this search term from any source (only filled when different from previous number)	Comment
Number of summer days (ETCCDI climate indices)	50	1		
Noise pollution	72	2	1	Marine settings so questionable whether should be classified in AIR domain
Nox (chemical symbol)	43	2	11	
Ocean acidification	316	11		
Ozone	152	7	Tropospheric ozone depletion (3)- Stratospheric ozone depletion (6)	Number of found references refer to changes in atmospheric state variables (temperature, winds) indirectly related to ozone depletion
PAH (polynuclear aromatic hydrocarbons)	7	4	2	
Particulate matter	41	2	4	
PM2.5	23	2	4	
POPs (Persistent Organic Pollutants)	88	0	2	
PRCPTOT (ETCCDI climate indices for Precipitation total)	1	0		
Precipitation change	176	4	29	
Rainfall change	117	9	29	
SAM (teleconnection indices)	5	4	4	
Sensible heat flux	3	0	2	All connected to agriculture
Snowfall	36	1	6	
SO ₂ (chemical symbol)	39	2		

Targeted search term (explanatory note in brackets)	Number of studies identified	Number of relevant Aotearoa New Zealand studies found using search term	Total number of Aotearoa New Zealand studies found that were relevant to this search term from any source (only filled when different from previous number)	Comment
Sox (chemical symbol)	7	0		
Sulphur dioxide	39	0		
Temperature change	544	20	37	
Tropospheric ozone	10	2	3	
Wind or wind extremes	19	0	6	
Total	7517	196	216	

During our literature searches and refinement of articles for relevance, care was taken to ensure that there were no gaps in relation to sub-domains spanning domain borders (for example, wetlands, dune systems, riparian vegetation, air temperature).

In all cases, there were diminishing returns of investment in time or effort to discover additional attributes or records, but the systematic and ad hoc searches provided confidence that no major potential attributes developed or used in Aotearoa New Zealand were excluded.

2.3. International literature to supplement our findings (Step 4)

Steps 1–3 were focused on knowledge from Aotearoa New Zealand. For Step 4, we completed targeted searches of the international literature to identify additional potential attributes. Priority was given to identifying major reviews, syntheses or monitoring frameworks focused on regions where these approaches are most advanced including Australia, the United Kingdom, the United States and the European Union. A secondary goal of our international literature search was to identify attributes from additional sources to those listed above that could be used in Aotearoa New Zealand. These targeted searches were conducted based on expert knowledge of the authors, e.g., by searching for relevant key words in the literature and/or publications by authors or organisations active in particular domains. A systematic search of the international literature would have been an enormous task (> 1 million records), beyond the scope of the current work, and unlikely to yield major attributes not already considered in Aotearoa New Zealand or by international frameworks.

2.4. Recording literature search outputs

We recorded the number of search results across domains. For each record retained for further assessment (from systematic and ad hoc searches), we compiled potential attributes and associated metadata. When compiling the attributes, we aimed to be as granular as possible. However, in some cases (especially for the Coastal and Seabed, and Estuaries domains, and the Terrestrial subdomain) it was more practical to combine multiple attributes into one 'attribute topic' or focus on an attribute 'leader' given the volume of attributes or development of these in existing monitoring frameworks or research. The attribute and metadata information was compiled in 'potential attribute and metadata' files for the domains (see supplementary files, Appendix 1). The metadata recorded for each attribute (or attribute topic) included two types, described below.

2.4.1. Attribute-related metadata

Attribute-related metadata recorded are as follows:

- component of EI addressed (ecological representation, composition, structure, function, resilience) as per the MfE definition (refer Glossary). Assignment of a component/s to each attribute was based on an author's expert opinion and discussed amongst the project team for alignment purposes.
- potential attribute (or attribute topic) (i.e., name or high-level description).
- attribute 'method' (high level comments, not for all attributes).
- potential attribute 'group' (or 'class for Air) to provide a logical grouping for a set of related attributes e.g., 'fish' could be the group for fish-related attributes—this was done subjectively for individual domains based on expert judgement.
- domain (Land [including Soil] - also broken down into the subdomains Terrestrial and Soil, Freshwater, Coastal and Seabed, Estuaries, Air).
- subdomain i.e., key habitat, ecosystem or community within the domain that the attribute relates to (if relevant, not for all attributes). No additional information was provided in this respect for the Soil and Terrestrial subdomains (listed above).
- commonly used attributes (i.e. that were high in prevalence). These were found in more than ten publications (in the systematic search) or considered to be commonly used in Aotearoa New Zealand based on authors' professional judgement (in the ad hoc search). Additional information (i.e., regarding moderate and low prevalence) was also provided.
- source of attribute: 'NZ' if attribute was encountered in the systematic or ad hoc review of NZ literature, or 'international' if acquired from ad hoc overseas literature search.
- attribute scale and units of measurement; details of the study system and methods used; and threats, drivers or environmental issue addressed by the study (for

some domains or subdomains only, Section 9(2)(f)(iv)

We also noted any definitions of EI used in the literature returned by the searches.

2.4.2. Reference metadata

Reference-related metadata recorded are as follows:

- key reference/s for each potential attribute (including year of publication).
- literature search type for each record (Aotearoa New Zealand (NZ) systematic, NZ ad hoc, or international).

2.5. Summarising compiled attributes

We summarised our compiled potential attributes in two ways. First, we provided a summary of commonly used potential attributes for each domain (in text and tables) for each of the EI components defined by MfE. It is important to note that while it was helpful for summarising our findings, ‘common usage’ of attributes doesn’t necessarily indicate usefulness in a management, policy or limit setting context and vice versa—attributes not commonly used could potentially be useful. Thus, to provide additional information, we separately provided summaries of emerging attributes identified from the Aotearoa New Zealand literature and of additional international attributes in the text. Second, we discussed differences in the MfE definition of EI in comparison to how EI has been defined in the literature for the domains. This was based on definitions of EI noted during compilation of attributes from the literature. However, we also supplemented this with other seminal reports on this topic for Aotearoa New Zealand (and also in some cases for overseas).

While we aimed to standardise across domains, slightly different approaches (including levels of detail) for reporting and summarising the results were taken in some cases for the domains. For example, for the Air domain, all attributes identified were included in the attribute summary in the report (rather than just the commonly used ones), given the relatively small number of attributes identified for this domain overall. Reasons for this include how well developed the monitoring frameworks (and thus associated attributes) are across domains and the volume of attributes identified, and that different domains sometimes approach the same things slightly differently.

3. LITERATURE SEARCH AND ATTRIBUTE COMPILATION SUMMARY

3.1. Search items

The number of search results for each domain (considering Terrestrial and Soil as subdomains) are detailed in Table 4. Key international monitoring frameworks retrieved during ad hoc searching are listed in Table 5. For ad hoc searching in particular, the intent was to fill gaps in potential attributes obtained from the systematic results rather than to identify all relevant publication records. The following sections provide a summary of attribute results for each domain.

Table 4. The number of individual articles (published or unpublished depending on the search type) relating to literature search results and refining for relevance for each domain. NZ = Aotearoa New Zealand.

Domain or subdomain	Overall number of systematic search results	Number of NZ systematic search results refined for relevance from which attributes were compiled	Number of NZ ad hoc articles from which attributes were compiled (to supplement attributes from systematic search)	Number of international ad hoc articles (including international monitoring frameworks) from which attributes were compiled (to supplement attributes from the systematic and NZ ad hoc searches)
Terrestrial	1516	266	46	8
Soil	1516	144	28	26
Freshwater	708	100	22	7
Coastal and Seabed	561	41 ^a	> 80	> 20
Estuaries	209	75		
Air	930 (+7517 ad hoc results)	67	196	

^a Coastal attributes were also compiled from the 'Estuaries' records list.

Table 5. Key international monitoring frameworks retrieved during ad hoc searches.

Framework	Domain or subdomain	Location	Description
Essential Biodiversity Variables (EBVs)	Terrestrial	International	A suite of measures deemed essential for measuring state and change in biodiversity (Pereira et al. 2013; see also Bellingham et al. 2020) for links to Aotearoa New Zealand implementation of EBVs).
The Group on Earth Observations Biodiversity Observation Network (GEOBON)	Terrestrial	International	Global networks of monitoring biodiversity and ecosystem state and change have been developed to support national and regional commitments to global obligations such as the Convention on Biological Diversity and Ramsar. Frameworks for data collection and interoperability that are scalable are well developed and published. EBVs have emerged as part of this network https://geobon.org/ . There are marine, freshwater and soil Biodiversity Observation Networks ('BONs').
Ecological Integrity of National Parks	Terrestrial	Canada	The Canada Parks system is one of the most well-cited uses of ecological integrity (EI) indicators for assessing the condition of parks where historical baselines are uncertain because of a deep history of human uses (Fraser et al. 2009; Parks Canada Agency 2011; see also discussion in McGlone et al. 2020). https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/ecological-integrity-national-parks.html .
National Park Service's (NPS) Vital Signs Monitoring Programme	Terrestrial	USA	Identified metrics of status and trend in structure, composition, and function of forests impacted by multiple agents of change. Developed for temperate forest systems (Tierney et al. 2009).
Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES)	Terrestrial	International	Many of the global and regional data associated with IPBES are relevant for EI, particularly monitoring of regional biodiversity change, and ecosystem functions. Two areas of specific strengths for NZ are the role of local and indigenous peoples in conservation, and the impact of biological invaders (https://ipbes.net/global-assessment).
Terrestrial Ecosystem Research Network (TERN)	Terrestrial	Australia	TERN is a land observatory that includes landscape observation, ecosystem observation, and ecosystem processes. Nationally structured data collection for vegetation, soils, remote sensing information and biodiversity across Australia across land uses. Well documented and open access methods and protocols are well developed. https://www.tern.org.au/ .
Forest Structural Condition Index Ecoregional Potential	Terrestrial	International	Emerging metric of forest EI combining GEOBON approaches of remote sensing with ground-based monitoring data. More general treatment and links with Convention on Biological Diversity (CBD) targets for reducing biodiversity loss through the Global Biodiversity Framework (GBF) are provided in Hansen et al. (2019, 2021).

Framework	Domain or subdomain	Location	Description
Comprehensive assessment of soil health (CASH)	Soil	USA	Cornell Soil Health Assessment Manual (Mobius-Clune et al. 2016).
Tier 1 Soil Health Indicators	Soil	USA	Soil Health Institute (National Soil Health Measurements to Accelerate Agricultural Transformation – Soil Health Institute).
Sustainable management assessment framework (SMAF)	Soil	USA	United States Department of Agriculture (USDA) (Andrews et al. 2004).
Soil Health Indicators	Soil	USA	USDA- Natural Resources Conservation Service (NCRS) (Stott et al. 2019).
Soil function assessment	Soil	EU	LANDMARK programme (https://landmark2020.eu/project-details/
Land Use/Land Cover Area Frame Survey (LUCAS)	Soil	EU	Jones et al. (2021).
United States Environmental Protection Agency (EPA) Recovery Potential Screening framework	Freshwater	United States of America (USA)	Countrywide framework for comparing watershed condition and the potential for ecosystem recovery following restoration.
Australian Integrated Ecosystem Condition Assessment Framework	Freshwater	Australia	Condition assessment framework designed for the integrated monitoring of aquatic ecosystems.
United Nations (UN) Sustainable Development Goal (SDG)	Freshwater	International	SDG seeking to ensure availability and sustainable management of water and sanitation for all. Includes targets and indicators for improving ambient water quality (Target 6.3) and protecting and restoring ecosystems (Target 6.6).
United States National Aquatic Resource Survey	Freshwater, Coastal and Seabed, Estuaries	USA	National collaborative program between EPA, states, and tribes to assess the quality of the nation's coastal waters, lakes and reservoirs, rivers and streams, and wetlands using statistically-based survey design.
European Union Water Framework Directive 2000 (WFD)	Freshwater, Coastal and Seabed, Estuaries	Europe	Cross-border framework to protect and enhance the health of aquatic ecosystems while maintaining socioeconomic systems.
Essential Ocean Variables (EOVs)	Coastal and Seabed, Estuaries	Global	Specific priority variables for monitoring life in the sea through the Global Ocean Observing System.
Integrated estuary assessment framework	Estuaries	Australia	Framework that can be used to assess the biophysical health of estuarine and coastal systems but which also links into the social and economic

Framework	Domain or subdomain	Location	Description
			values of such systems. An important part of this is to identify appropriate indicators of both ecosystem and economic and social values.
International Cooperative Programme on Assessment and Monitoring of the Effects of Air Pollution on Rivers and Lakes	Air	International	Assesses the degree and geographical extent of acidification of surface waters.
Essential Climate Variables	Air	Global	Specific priority variables for monitoring climate within the Global Climate Observing System.
Network for Detection of Atmospheric Composition Change	Air	Global	This network was established to collect long-term databases for detecting changes and trends in atmospheric composition and to understand their impacts on the atmosphere and to establish scientific links and feedbacks between changes in atmospheric composition, climate, and air quality.

3.2. Land (including Soil)

We have divided Land (including Soil) into two subdomains (Terrestrial and Soil) and, after the first section, discussed them separately below for clarity due to the different fields of expertise needed to evaluate the literature for each subdomain.

3.2.1. Summary of search results for Terrestrial

Our systematic search of the WoS core collection (see Section 2.1, Tables 1 and 2) yielded 1853 records. We next excluded disciplines not relevant to the Land (including Soil) domain (i.e., disciplines or publications that are clearly for other domains, i.e., marine, aquatic and meteorological journals) and retained 1516 records.

Additional domain-specific exclusion criteria were then applied to this long list to remove records not relevant for assessing attributes of EI; this required expert evaluation of individual records, particularly to exclude non-New Zealand studies (i.e., many records contained a contributor from this country, but the study itself was done elsewhere). Records were excluded for:

- studies based solely on in-lab or ex situ variables (i.e., of limited value as attributes of ecosystems)
- studies considering only pairwise interactions or within species effects (e.g., biocontrol agent selectivity on a host organisms)
- studies within agricultural systems that considered only the effects of one or few management treatments on productivity but included no wider evaluation of responses within the agroecosystem
- purely conceptual or policy-directed studies.

After these exclusions, 326 records were retained for more detailed evaluation. We then evaluated individual records to generate metadata for each record (supplementary file, Appendix 1). Records were next split into 'Terrestrial' and 'Soil' subdomains; results are summarised separately below.

3.2.2. Summary of potential attributes for Terrestrial

Our systematic search yielded 266 records for assessment of potential attributes for aboveground terrestrial systems. An additional 46 records were included through ad hoc searching as outlined in the methods above. Also included were selected international records ($n = 8$) that outline frameworks for collation and structuring of attributes. Leading attributes derived from this analysis are summarised in Table 6.

More than 150 potential attributes of EI for aboveground terrestrial systems were identified (see Appendix 1). Many additional attributes were discovered during the systematic and ad hoc searches, but their relevance as EI attributes together with the feasibility of summarising vast numbers of potential metrics here meant attributes were grouped under a leading attribute. For example, there are dozens of diversity metrics, but only few commonly reported metrics are listed in Table 6. Similarly, plant functional traits are widely used to assess both functional diversity and ecosystem functioning, but > 100 plant functional traits could contribute to potential attributes (see www.try-db.org/).

Many attributes of EI are well advanced through other frameworks, such as the global and Aotearoa New Zealand-specific implementation of several attributes known as essential biodiversity variables (EBVs; see Pereira et al. 2013; Bellingham et al. 2020). Finally, for many attributes, there are distinct taxon- or system-specific attributes used throughout the literature, and these are not exhaustively listed. As an example, 'dominance' of species can be determined from biomass, population density, cover, size, or frequency; so although identical metrics or data may not be collected across different taxa or systems, appropriate measures of dominance can be quantified. Overall, the majority of compiled attributes provide commonly used potential attributes for three components of EI (i.e., composition, structure, and function). There are few commonly used attributes for ecological representation and resilience.

Table 6. Commonly used Terrestrial potential attributes used in Aotearoa New Zealand, along with less commonly reported but potentially useful attributes (labelled 'other potential attributes'). Attributes were collated from a systematic search of peer-reviewed publications and an ad hoc review of Aotearoa New Zealand-based literature. 'Group' is based on logical grouping for a set of related attributes. A complete list of potential attributes and accompanying metadata are in Appendix 1 (supplementary file). Note that many attributes are used to answer study-specific questions; only a subset are used specifically for monitoring purposes. Attributes either represent individual attributes or attribute topics. EBV = Essential Biodiversity Variable.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Ecological Representation	Ecosystem Representativeness	Land Environmental Class (Land Environments of NZ (LENZ)) Land Environment (NZ Environmental Data Stack (NZEEnvDS))	Threatened Environments Classification (TEC) BioFRAG (habitat fragmentation) Restored Significance (Vital Sites and Actions)	Attributes are derived directly from spatial data layers, in this case multivariate maps of soil, climate and landform related to biological properties. Some metrics for fragmentation and edge effects on composition are available.
Composition	Species diversity	Native species diversity (EBV). Numerous metrics of diversity are available (richness, evenness, chao estimators, etc.)	Beta- and gamma diversity Slope of richness-area relationship Number of threatened species	Numerous methods and indicators are used to quantify species diversity. An EBV; See Bellingham et al. (2020), and https://geobon.org/ebvs/what-are-ebvs/ .
		Non-native species diversity	Numerous metrics of diversity are available (richness, evenness, chao estimators, etc.). Number of invasive species	Directly related to invasions as a threat and management activities. For many groups, invasion by non-native species is increasing through time and contributing to changes in diversity.
	Phylogenetic diversity	Phylogenetic diversity (EBV)	Net relatedness index	An EBV less commonly considered than taxonomic diversity. Rapid improvements in molecular and analytical tools are emerging.
	Species dominance	Native species dominance (EBV)	Native species density, biomass, cover, height or size	Dominance measures vary among taxa and systems but are commonly measured. An Essential Biodiversity Variable (EBV).
		Non-native species dominance	Non-native species density, biomass, cover, height or size Pest capture rates	Directly related to invasions as a threat and management activities.
	Species occupancy	Native species presence (EBV)	Native species distributions	An EBV. Requires spatial structure for sampling.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Composition, cont.		Non-native species presence	Non-native species distributions Pest capture rates (TCI)	Directly related to invasions as a threat. Requires spatial structure for sampling.
		Indicator species presence	Rare species presence Keystone species presence Presence of non-production species in agroecosystems	Widely used for rare/threatened species across different taxa and systems. Some work done on species combinations as indicators. Usually considered habitat quality.
	Community composition	Compositional dissimilarity (EBV) Biotic homogenisation Species co-occurrence	Multivariate axes of composition Quantitative vegetation classification Compositional nestedness	Essential well-established attribute internationally. Many similarity indices or multivariate methods are used (e.g., Jaccard, Bray-Curtis) to quantify compositional change. An EBV. Requires spatial structure across scales for sampling.
	Genetic diversity	Genetic diversity of species population (richness and heterozygosity)(EBV)	Genetic differentiation (number of genetic units and genetic distance) (EBV) Effective population size Holobiont composition	An EBV. Rapidly developing field. Focused on few species targeted for population recovery.
	Composition of regenerating species	Species composition of early life stages	Fledging success of birds Seedling species composition Sapling species composition	Composition of recruitment is often a more sensitive or early indicator of restoration or threat than indicators for established populations.
	Trait diversity	Trait diversity (EBV) Trait richness	Feeding groups	Trait diversity has emerged as complimentary to taxonomic and phylogenetic diversity. An EBV.
	Interaction diversity	Interaction diversity (EBV)	Food web structure Network properties	Range of metrics are developed and published for food webs or networks. Analytically challenging. An EBV.
	Population abundance	Population size	Pest trap catch index Nesting density Invertebrate abundance	Often set as a target or limit for species. Most often applied to vertebrate pests or bird species in NZ.
Structure	Biomass	Carbon Species abundance (EBV)	Coarse Woody Debris (CWD) Exclosure effects on mass	Fundamental indicator for multiple purposes. Change in biomass indicates productivity or disturbance.
	Vertical structure	Ecosystem vertical profile (EBV)	Height frequency Tree height	Fundamental ecosystem property related to habitat provision, light capture and physical structure.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure, cont.	Vegetation cover	Live cover fraction (EBV)	Foliar Browse Index (FBI) Foliar Cover Index (FCI) Leaf Area Index (LAI)	Very widely collected information across vegetation-types.
	Population structure	Population size class distribution	Presence of large trees Juvenile survivorship Stand structure	Distributions of size, age and sex indicative of population processes. Applied across animals and plants.
	Landscape structure	Connectivity Fragmentation	Habitat equivalence Structural connectivity	Diverse set of attributes available describing ecosystem spatial structure, but few are deployed in NZ. This is a current gap for understanding biodiversity changes in modified landscapes.
	Ecosystem distribution	Ecosystem distribution (EBV)	LENZ Rare ecosystem cover Wetland extent Wetland condition	Fundamental information on the spatial distribution of ecosystems.
Function	Functional traits	Plant functional traits Feeding groups Functional diversity	Specific root length fine root dry matter content (DMC) Specific Leaf Area (SLA) Foliar N, P Body size Trophic position	Large body of knowledge and databases on functional traits are developed across taxa including plant functional traits, feeding groups of invertebrates. Collectively, these traits underpin the 'plant economics spectrum' used to predict nutrient use, growth, and other functions within species and at the community-scale.
	Primary Productivity	Aboveground Net Primary Production (ANPP) Ecosystem phenology	Tree growth Tree mortality Net gas exchange Pasture accumulation Net Ecosystem Exchange (NEE)	Fundamental measure of ecosystem energy capture. Underpins all functions. Essential, well-established attribute in NZ. All approaches used: plot-based, eco-physiological, models, remote sensing.
	Species functioning	Species phenology (EBV) Species morphology (EBV) Species physiology (EBV)	Species movement (EBV)	Multiple EBVs relate directly to species-population processes and functioning. This information varies widely among species and systems.
	Consumption	Diet selection Species palatability Invertebrate consumption	Selection consumption Pest irruption Stocking density	Includes herbivory and pathogens. A focus in NZ has been on the selective damage by pests, resource selection by native species, and pasture production.
	Species regeneration	Recruitment of juveniles	Tree recruitment Seedling recruitment Nesting success	Broad set of attributes often linked to population health, habitat quality or management activities.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Function, cont.	Native dominance	Dominance of ecological functioning	Per unit impacts on ecological process	Lee et al. (2005) and others; dominance of ecological process and function, not biomass per se.
	Toxicity	Contaminant presence in organism	Toxicity to individual (LD50)	Almost no records from systematic survey or associated with community or ecosystem-level responses. There is a large literature on toxicity screening and secondary poisoning of individual taxa within New Zealand (e.g., see Eason et al. 2013).
	Floral resources	Pollen production Nectar production	Flowering phenology Flower visitation rate Pollen limitation	Some work on seasonality and spatial available for bees. Fundamental data for native species largely unavailable.
	Fruit availability	Fruit produced	Species specific fruit production	Widely captured as a response variable to possum control.
	Propagule pressure	Seedfall Dispersal	Mast seeding	Generation of movement of seeds or juveniles. Variability through time crucial to consider.
	Ecosystem configuration	Matrix contrast Fragmentation impacts	Functional connectivity Rare ecosystem status Landscape resource diversity Edge effects	Diverse group of landscape metrics often linked to ecological process (e.g., habitat quality, species' movement)
	Soil fertility	Litterfall Litter decomposition	Litter carbon (C), nitrogen (N), phosphorus (P) content Soil C, N, P content Soil organic matter	Covered primarily in soil attribute summary (see Table 7).
	Interactions	Functional originality Dissimilarity of interactions	Parasitism rate Rate of attack Root mycorrhizal colonisation	Numerous food web and network metrics are available but require both intensive data collection and specialist expertise to analyse and interpret. Mutualisms included here.
	Ecosystem disturbance	Cultural disturbance Pathogen presence	Canopy cover Fire risk (flammability index) Stocking density Soil disturbance	Pests, pathogens attributes above are also potential drivers of disturbance.
	Regulating Ecosystem services	Water regulation Soil formation	Soil erosion control Climate regulation	More details in Dymond (2013) review.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Resilience	Resilience	Change in composition or structure attributes over time or in response to disturbance	Food web stability Stability of network properties	Resilience with respect to EI was nearly absent from the systematic search of NZ literature but could be derived from changes over time in other indicators.

3.2.3. Attribute results summary for Terrestrial

Brief comments for components of EI for the Terrestrial subdomain follow.

Ecological representation

Literature on ecological representation is complex and varied. Representation is a major underpinning measure for NHMS and biodiversity monitoring schemes (e.g., Lee et al. 2005; Bellingham et al. 2020; McGlone et al 2020; Walker et al. 2021). Some of the most widely adopted approaches are large-scale mapping of representative environments derived from multiple environmental, climatic and landscape features, but not diversity (e.g., LENZ, TEC, NZ data stack). Other approaches to ecosystem representation in Aotearoa New Zealand, such as the Ecosystem Classification system developed by Singers and Rogers (2014), rely primarily on botanical surveys and expert knowledge rather than quantitative multivariate estimates of representation. Hybrid approaches, such as the Vital Sites and Actions model (VSA, Overton et al. 2015), combine mapping with estimates of ecological uniqueness but have not been widely adopted to date. Overall, there are several complementary attributes for ecological representation available from regional to national scales. Greater inclusion of biodiversity into ecological representation is likely in the future, given this is an Essential Biodiversity Variable (EBV) (see also Schmeller et al. 2018).

Composition

Excellent compositional data have been collected nationally as a consequence of multiple long-term monitoring efforts for biodiversity, vegetation assessment, soil characterisation and carbon estimates. Attributes of composition typically involve assessing community composition, changes in composition or grouping using multivariate statistical methods. Reflecting the various ways in which composition data are collected, and differences among both taxa and ecosystems, there are no consistent analytical methods used across systems. Terrestrial vegetation is relatively well-characterised and quantitatively-derived community attributes are available (e.g., Wiser et al. 2011). Similarly, for bird communities, there is a nationally representative atlas and there are long-established monitoring protocols (e.g., 5-minute bird counts) that are frequently used to quantify species' occupancy and community composition alike. A particular requirement within Aotearoa New Zealand is characterisation of the presence and abundance of non-native species: this is crucial for many attributes including estimates of diversity, responses to management, or interactions with other drivers of change (e.g., see Vitousek et al. 1997; Simberloff 2019; Hulme 2020). However, there is a systematic underrepresentation of some taxa (e.g., invertebrates) or systems (e.g., urban environments, agroecosystems). Similarly, some EBVs such as phylogenetic and genetic diversity are rarely estimated.

Structure

Many structural attributes are collected at the same time as compositional data. Structure is driven across scales by abundance and dominance of plant species within

sites, reflected by numerous measures of biomass, vertical structure, and cover (including in height tiers). For other taxa, structure is reflected primarily as abundance-occupancy relationships (birds). Across these groups, population abundance and structure provide additional insights into population processes at site or larger spatial scales. For example, changes in tree size class distributions determine forest physical structure, habitat quality, effects of disturbance. Moreover, when size class distributions are considered together other data such as functional traits or additional attributes such as disturbance or pest species abundance, this provides greater insights in changes into many components of EI, and ability to assign responses to particularly drivers. Similarly, population size or structure is often used as a target or limit for species, both recovery of native species (e.g., minimum viable population size for bird species) and management of biological invaders (e.g., population density of pest mammals). Landscape-scale structure has been relatively well characterised for forests and wetlands, but not for many other systems including naturally rare or threatened ecosystems (Williams et al. 2007; Holdaway et al. 2017).

Function and process

Attributes for function and process are many and varied, including those related to belowground functions and soils processes (see Soil subdomain summary below). Species' functional traits are commonly used as indicators of ecological processes or ecosystem functions. This is part of a global move to better understand the role, function and importance of species and diversity in systems, or put another way, the consequences of species additions or removals from systems. For example, plant functional traits are widely collected to estimate functional diversity in communities. This diversity is related to resource use and thus energy flows and nutrient cycling in ecosystems and can be used to predict specific processes such as palatability to invasive herbivores or litter decomposability. Many traits also relate to EBVs including species phenology, morphology, and physiology.

Processes or functions can also be directly quantified or estimated. For example, Aboveground Net Primary Production (ANPP) is estimated from repeated measures of plots, models, or gas exchange measurements, or using remote sensing techniques. These approaches have different qualities and strengths as attributes that are not covered in further detail here but could form a good example of how multiple approaches could be deployed for some attributes. Regeneration of species and contributions to community structure are captured by a suite of attributes including timing, success and recruitment of propagules or offspring. For plants, some information is available for floral resources, mostly for understanding resource availability to honeybees or birds. Similarly, seed or fruit production is highly variable among species and sites but is linked to both regeneration processes and knock-on trophic consequences, such as mast seeding events driving pest mammal irruptions.

Processes at the ecosystem-level include landscape configuration and its effects on function, such as movement of species across boundaries, species-area relationships,

and provision of resources and habitat quality. Some international concepts, such as 'extinction debt' (i.e., the future declines in diversity driven by current changes to ecosystem area or condition) have not yet been considered in Aotearoa New Zealand. Many interactions or functions are captured by studies of food webs or networks. Although this approach provides numerous metrics of function such as interactions among species, plant-pollinator relationships, cascading effects of feeding groups, and functional niche of species or guilds, the intensive nature of data collection, analyses and interpretation likely limit the use of these metrics as attributes. Finally, the importance given to understanding ecosystem disturbance in Aotearoa New Zealand terrestrial environments is reflected by the large number of potential attributes spanning stocking density, fire risk, soil erosion, geological processes, pathogens, and cultural disturbance. Disturbance is also considered through changes in other attributes, for example, changes in tree size class distributions and foliar cover over time.

Resilience

Resilience rarely featured in the systematic literature review, and not as an attribute of EI. Most records related to resilience were on pasture production within agroecosystems, used manipulative experiments at small scales (e.g., to test ideas of biodiversity and stability), or used purely modelling approaches. Resilience as an attribute requires determining changes over time in other attributes spanning composition, structure and function. However, the relatively long history of monitoring, repeated measures of sites and plots, and interest in large-scale disturbances including climatic, geological and from fire mean that recovery of species populations, structure, composition and function could be assessed from an EI perspective despite a dearth of publications on this topic. Resilience has been explicitly considered for specific systems, including trajectories of wetland restoration, recovery of forest fragments, and major meta-analyses of plant, bird and invertebrate community responses to pest mammal management (e.g., Binny et al. [2021]; see also review by Gladstone-Gallagher et al. [2022] on linking NZ social-ecological resilience across domains).

Attribute gaps for Aotearoa New Zealand (supplemented by international literature)

International studies help to reveal gaps or underutilisation of some potentially excellent attributes of EI in Aotearoa New Zealand. For example, global efforts to develop a core suite of attributes for monitoring biodiversity (GEOBON) and Essential Biodiversity Variables (EBVs) reveal that genetic and phylogenetic diversity are rarely reported in Aotearoa New Zealand. Recent syntheses highlight the crucial importance of monitoring and reporting on genetic diversity within species (O'Brien et al. 2022), which is nearly absent from biodiversity monitoring and reporting in Aotearoa New Zealand (e.g., see Table 1 in Bellingham et al. 2020).

The effects of contaminants on integrity do not feature for terrestrial systems at least with respect to integrity. However, many studies were revealed in our search but were

typically based solely on in-lab or ex situ variables, considered only within species effects, and most were within agricultural systems and were thus considered of limited value as attributes of EI. As an example, the toxicity of several rodenticides and herbicides used in Aotearoa New Zealand were tested under lab conditions on the western fence lizard (*Sceloporus occidentalis*), a surrogate organism for native lizards. How such screening procedures might inform (Weir 2016). The relevance of such toxicity screening approaches for risk to populations, and potentially attributes of EI, is unresolved. Secondary contamination or toxicity to terrestrial organisms is possible, for example through trophic transfer of sodium monofluoroacetate (1080) to non-target species (Eason et al. 2013; Morriss et al. 2016). There is a large literature on non-target effects of these and other chemicals used in the environment that was not covered here. However, if species-specific effects of contaminants is considered within scopes, additional work is warranted linking studies of in situ impacts with population-level indicators such as population structure or juvenile survivorship.

Some international concepts that are reasonably well-established, such as ‘extinction debt’ (i.e., the future declines in diversity driven by current changes to ecosystem area or condition) have not yet been considered in Aotearoa New Zealand. Similarly, research into characterising and understanding changes in landscape structure are well advanced overseas and could be applied to help to overcome gaps in our knowledge and attributes of EI in, for example, biodiversity changes in modified landscapes.

Emerging attributes

The rapid development of new technologies and approaches to quantifying the state and trend of terrestrial environments provides opportunities for new attributes of EI. For example, eDNA and other molecular approaches complement current approaches to monitoring diversity and function (e.g., Holdaway et al. 2017; Dickie et al. 2018). Advances in and increasing use of LiDAR and remote sensing technologies are rapidly producing high quality and quantities of data that could be used to quantify structure, and in some cases, aspects of composition and function (e.g., Cavender-Bares et al. 2022). Similarly, major efforts internationally to better link remote sensing or earth observation data with plot or ground-based monitoring have generated several emerging indicators: these include the Forest Structure Condition Index, Lost Forest Configuration, and several community-scale indices like the Bioclimatic Ecosystem Resilience Index and Species Habitat Index (see summary of Hansen et al. 2021). In many cases the underpinning data needed to develop these attributes is available in Aotearoa New Zealand, it is a current gap in research effort and publication. The information produced by these technologies holds great promise for future monitoring including development or refinement of attributes of EI.

Similarly, major efforts internationally to better link remote sensing or earth observation data with plot or ground-based monitoring have generated several emerging attributes of EI (Hansen et al. 2021; see also TERN network protocols).

However, additional developments in data management, analytical approaches and interpretation are required to implement many of these emerging attributes. Genetic variation within and among species is both a gap in current attributes and an area with multiple emerging attributes. Genetic diversity is one of three levels of diversity recognised in the Convention on Biological Diversity (along with among species and ecosystems) and underpins species' adaptation and resilience to environmental changes. Both genetic approaches and non-genetic proxies (e.g., effective population size) could be deployed as attributes of genetic diversity. Moreover, these attributes can be summarised using consolidated scoring systems and can be scaled from local to national reporting (O'Brien et al. 2022; see also Hoban et al. 2022).

3.2.4. Summary of search results and potential attributes for Soil

The systematic literature search on WoS resulted in 1561 articles for Land (including Soil) with 144 initially identified as specifically relevant for the Soil subdomain in Aotearoa New Zealand, noting that some of these papers include above and below-ground attributes. Review of these papers and ad hoc searches provided over 300 Soil subdomain attributes—this included attributes relevant to air, such as ammonia deposition, ammonia volatilisation and greenhouse-gas (CO₂, CH₄, N₂O) emissions; and water attributes, such as infiltration rate and surface run-off. We observed that the use of some attributes (particularly soil fauna) was strongly linked to individual researchers, and partially reflects the relatively small number of researchers working on these issues in this country. The search terms used were not particularly effective at finding literature related to erosion, compaction and leaching; this gap was filled by ad hoc searches. Review of Aotearoa New Zealand unpublished literature provided a useful cross-check on attributes identified through the systematic search of published literature; few additional attributes were identified in this way. A summary of Soil subdomain attributes used in Aotearoa New Zealand are provided in Table 7.

The targeted search of international literature (unpublished and published) demonstrated the extent to which soil indicators and measures of soil health are an active area of research in Europe and the USA, primarily in relation to agroecosystems. While a significant number of additional attributes could be added as a result of review of the international literature (e.g., Zwetsloot et al. [2022] includes a list of 289 measures used to assess soil biology and biological processes in soil, and an earlier European assessment of soil indicators identified 290 potential indicators related to 188 key issues for 9 soil threats [Huber et al. 2008]) we included only those that that addressed material gaps in the compiled attributes.

The national and international literature on soil quality/health measures is dominated by studies on agroecosystems, although some studies focused on soil quality in other systems (e.g., O'Neil et al. 2005). From a contaminant perspective, there is a wealth of literature on the assessment and management of soil contaminants. This literature includes remediation or rehabilitation of soils impacted by contamination, both within and outside of agricultural environments. However, these studies tend to have a more

limited range of soil attributes outside of contaminant concentrations or toxicity assessments and hence were not targeted in ad hoc searching.

Table 7. Commonly used Soil attributes used in Aotearoa New Zealand (NZ), along with less commonly used but potentially useful attributes (labelled 'other potential attributes'). Attributes were collated from a systematic and ad hoc review of Aotearoa New Zealand-based literature. 'Group' is based on logical grouping for a set of related attributes. Almost all attributes are used at a single time-point at a small spatial scale. For the full list of potential attributes and accompanying metadata, see Appendix 1 (supplementary file). Note that many attributes are used to answer study-specific questions; only a subset are used specifically for monitoring purposes. Attributes either represent individual attributes or attribute topics.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Ecological Representation		<i>No attributes found</i>		Note text commentary on representation.
Composition	Microbial	Bacterial community composition	Targeted functional groups (e.g., ammonia-oxidising bacteria and archaea)	
		Fungal community composition		
		Microbial biomass carbon	Archaeal community composition	
	Mesofauna	Nematode abundance	Mites, Collembola, enchytraeids	Many different groups, individual expertise.
		Nematode community composition		
		Nematode functional groups		
	Macrofauna	Earthworms	Gastropods, Araneae, Arthropods, etc.	The macrofauna groups targeted within NZ are variable and partly driven by individual expertise.
	Microbial diversity	Richness		
	Mesofauna diversity	Nematode richness	Other mesofauna richness	
	Macrofauna diversity	Richness		
Structure (biotic)	Microbial structure metrics	Fungal: bacterial ratio		Indicative of nutrient cycling rates.
		Gram positive: gram negative ratio		Indicative of changes in nutrient cycling or carbon and water availability.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (biotic), cont.	Mesofauna structure metrics		Plant parasite index	Nematode-based metrics give an indication of the relative abundance of different energy pathways within soil which relates to nutrient cycling pathways; other indices are indicative of community stability and resource enrichment.
		Nematode channel ratio Nematode maturity index	Enrichment index	
			Nematode Structure index	
Structure (chemical)	Carbon-related variables	% Carbon	Carbon stocks Labile carbon pools (e.g., hot and cold-water extractable carbon)	
			Particulate organic matter, mineral-associated organic matter	
	Nitrogen-related variables	% Nitrogen	Dissolved organic nitrogen	
		Ammonium and nitrate (mineral nitrogen)	Aerobic mineralisable nitrogen	
		Anaerobic mineralisable nitrogen	Hot-water extractable nitrogen	
			Nitrogen stocks	
	Phosphorus-related variables	Total phosphorus	Phosphorus fractions	
		Olsen phosphorus	Bray phosphorus	
		Phosphorus-retention (Anion-storage capacity)	Phosphorus stocks	
	Chemical Ratios	Carbon:Nitrogen ratio	Nitrogen:Phosphorus	
			Carbon:Phosphorus	
	Base cations	Cation Exchange Capacity	Base saturation	
		Individual cation concentrations		
	Sulphur	Concentration (Total, organic)		
	pH	pH		
	Electrical conductivity	Electrical conductivity		Measures soil salinity.

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (chemical), cont.	Sodium adsorption ratio	Sodium adsorption ratio		Primarily used in context of application of wastewater to land.
	Trace elements (TE)	Basic trace element contaminant suite	Extended TE suite, Selected TE e.g., iron, silica, aluminium, extractable TE e.g., Ca(Cl) ₂ , Mehlich-3	Specific studies can target specific TE or broader range of TE, primarily from a contaminant assessment but can also be for micronutrients and/or soil acidity/aluminium toxicity.
	Organic contaminants	Concentration		Study specific for a range of contaminants e.g., PAH, pesticides.
Structure (physical)	Macroporosity	Macroporosity @ -10kPa	Macroporosity @ other pressures	Used to assess compaction and also relevant for the assessment of soil hydraulic properties.
		Macroporosity @ -1500kPa (wilting point)	Total porosity	
	Bulk density	Bulk density ¹		Related to soil compaction.
	Soil texture	Particle size		Relates to sand, silt and clay contents.
	Water-related metrics	Water holding capacity	Near-saturated/Unsaturated hydraulic conductivity	Relevant attributes will be dependent on purpose for use.
		Gravimetric moisture content	Hydrophobicity	
		Other	Water table level	
			Mottling, Soil colour (Maunsell colour chart)	Colour and mottling relevant for hydric (wetland) soils.
			Continuous measurement via sensors	
			Critical source area (broader spatial scale)	
	Aggregates	Aggregate stability	Aggregate size distribution	Aggregate stability refers to the ability of aggregates to maintain structure when subjected to outside forces (typically water).
	Soil penetration resistance	Resistance		Relates to compaction
	Pedology	Soil classification	Stage of development	
			Parent material	
			Soil depth	

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (physical), cont.	Slope, altitude			Most relevant in context of erosion and / or conservation / indigenous environments.
	Soil temperature	Temperature		
	Litter layer	Depth		
	Sealing	% sealed		
Function	Measured carbon cycling rates	Basal respiration	qCO ₂ (metabolic quotient)	
		Decomposition rates in situ	Chamber-based respiration	
		Eddy covariance	Methane	Eddy covariance often not replicated across sites as it expensive. It is also used to estimate net primary productivity.
	Modelled carbon cycling	CenW		Models used are expertise related, CenW includes N and P cycling.
	Modelled GHG emissions, modelled N-leaching	Overseer		
	Measured nitrogen cycling rates	N mineralisation rates	Net or potential nitrification rate	
			Nitrous oxide emissions	
			Ammonia deposition and volatilisation	
			N isotopes	
			Denitrification rates	
			Nitrate and ammonium utilisation	
	Enzyme activity	Carbon, nitrogen and phosphorus enzymes	Sulphur enzymes	Various enzymes targeted depending on the study.
	Functional gene abundance	qPCR of specific genes	GeoChip	Variable genes targeted from carbon, nitrogen, phosphorus cycling to disease suppression, stress tolerance, plant growth regulatory genes.
	Catabolic activity	MicroResp	Biolog	
	Water-related rates	Infiltration	Water retention curve	
		Leaching		

Ecological integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Function, cont.	Water-related rates, cont.	Surface run-off	Evapotranspiration	
	Toxicity testing		e.g., Pollution induced community tolerance, Collembolan reproduction test	Study-driven methods, multiple standardised testing available.
	Erosion	Sediment yield, erosion rate		
Function (ecosystem services)	Provisioning services e.g., primary production	'bundles' of soil processes considered relevant for the different functions/services		Broader soil functions considered in the context of the delivery of ecosystem services.
	Regulating services e.g., flood mitigation, filtering of nutrients and contaminants			
Resilience	Resilience to drought	Lab-based resistance/resilience assay (drought)		

3.2.5. Attribute results summary for Soil

For the Soil subdomain, the EI components of composition, structure, and function dominated the literature. Ecological representation needs to be considered on a broader spatial scale than the Soil attributes are typically used for, and resilience is most often derived from the composition, structure, and/or function attributes and/or how data are collected (e.g., over time after researcher-initiated disturbance).

Attributes include those currently used for state-of-the-environment reporting by regional councils; these focus on soil chemistry (% carbon, % nitrogen, anaerobic mineralisable N, Olsen P, C:N ratios, pH, basic contaminants suite) and some physical variables (macroporosity, bulk density and aggregate stability) but no biological variables or direct measures of biological functions.

Ecological representation

With regards to ecological representation, the distribution of different soils across the landscape will differ due to natural variation in soil-forming factors and this will influence above-ground ecosystems and ecosystem functioning. Ecosystem representation (primarily of vegetation and associated fauna) is typically assumed to be captured through LENZ (which needs updating), while programmes such as S-Map or the Fundamental Soils layer provide coverage of the distribution of soil types across Aotearoa New Zealand. Other attributes such as Land Use Capability may also be useful to inform management activities. Soil type may influence the values measured by some attributes, although land use and associated land management activities will be the dominant influence.

Composition

Within Aotearoa New Zealand, studies on biotic composition are dominated by studies on microbial communities, with the use of other biota (e.g., meso- and macrofauna) largely researcher-driven. Studies on microbial community composition have mainly used phospholipid fatty acids (PLFA) in the past, but molecular approaches are now more commonly used as they provide more detailed information. Molecular approaches, and how best to interpret the resulting data, are currently very active areas of research. Visual identification and counting is primarily used for faunal species, although molecular approaches are also being evaluated.

Structure

There is overlap between biotic attributes of structure and composition where these attributes are based on biota e.g., bacteria, fungi, invertebrates, as structure attributes are often derived from composition data. Similarly, there are a number of biological indicators strongly linked to soil function, for example, various indices of nematode trophic structure and feeding groups. Some attributes that can be assigned as biotic attributes are perhaps more accurately considered as abiotic attributes e.g., soil organic carbon and anaerobic mineralisable nitrogen. Regardless, abiotic attributes dominate the attributes widely used for soil quality monitoring both nationally and

internationally and are often relevant for informing assessment of soil function and processes.

Function and processes

There is a wide range of attributes related to specific soil functions or processes with carbon and nitrogen mineralisation most commonly used. There is some variation in the methods used to assess the various functions or processes. Soil function can also be specified at a higher level to indicate ecosystem 'service' delivery (Dominati 2013); this approach is adopted to a greater extent in recent international literature (e.g., Buneman et al. 2018; Creamer et al. 2022).

Resilience

As noted for land, resilience rarely featured in the systematic literature review. Resilience is often calculated based on changes in composition, structure and function attributes through time after disturbance, including after human-induced disturbances. One laboratory-based assay for assessing resilience to drought was identified (Table 7).

Attribute gaps for Aotearoa New Zealand (supplemented by international literature)

There are multiple recent international studies that will be immensely valuable in the further assessment of attributes for use in Aotearoa New Zealand. For example, recent publications include the release of a recommended suite of indicators by the Soil Health Institute in the United States, which draws on an evaluation of soil indicators used across North America (Norris et al. 2022), and multiple papers and reports arising from the EU H2020-funded programme *Landmark* for which the overall scientific aim was to 'Comprehensively quantify the current and potential supply of soil functions across the EU, as determined by soil properties (soil diagnostic criteria), land use (arable, grassland, forestry) and soil management practices with relevance for farmers and farm advisors, legislators and policy-makers' (<https://landmark2020.eu/project-details/>).

The European Environment Agency has also released a draft report on indicators and thresholds for soil quality assessments in Europe with a specific focus on soil indicators relevant for assessing threats to soil, including soil erosion and soil sealing and includes a soil loss rate threshold of $2\text{t}\cdot\text{ha}^{-1}\cdot\text{y}^{-1}$ (Bartiz et al. 2021). Bagnall et al. (2022) provide an evaluation of soil hydraulic properties for the assessment of soil health; Lipztn et al. (2022) provides an evaluation of soil organic carbon indicators; Griffiths et al. (2018) and Zwetsloot et al. (2022) provide evaluation and approaches to the use of soil biological indicators. The Soil Health Institute has recently recommended that soil organic carbon concentration, carbon mineralisation potential, and aggregate stability provide the minimal suite of measurements be widely applied across North America (and likely beyond) for the assessment of soil health.

Wood et al. (2022) asked whether there is sufficient knowledge in the 'right' areas to effectively use soil health indicators, for example, is an increase in a soil health property good or bad? How much do desirable outcomes change when a soil property changes, and is the relationship between the two linear?

Emerging attributes

Methods used to quantify some variables are changing, with the use of molecular methods to measure soil biology and ecosystem functions increasing significantly, and the use of attributes such as hot water extractable carbon, and particulate organic matter:mineral-associated organic matter ratios are also increasing in popularity.

3.3. Freshwater

3.3.1. Summary of search results and potential attributes

The systematic literature search of the WoS core collection returned 708 results for Freshwater articles (Table 4). Screening of titles and abstracts for relevance to EI in Aotearoa New Zealand led to 145 relevant articles for Freshwater from which to compile attributes and metadata; this was further reduced to 100 articles on inspection of full texts. From these, 252 potential attributes with accompanying metadata were compiled, primarily related to biotic structure and composition (see Table 8).

The results from the systematic search were supplemented with further ad hoc searches of both Aotearoa New Zealand and international literature, which spanned published literature, grey literature and monitoring frameworks (Table 5), as well as expert knowledge from the authors. The ad hoc searches added 89 additional potential attributes including those related to wetlands, groundwater, and abiotic structure. These searches also identified different subdomains for 25 attributes already recorded from the systematic search, including attributes already used as limit-setting attributes within Aotearoa New Zealand. For example, while bacterial, dissolved organic carbon and nutrient concentrations were recorded for monitoring lakes and rivers multiple times in the published literature, the use of these attributes for monitoring groundwater was only recorded in the unpublished literature. Additionally, most attributes related to wetland condition, such as wetland extent or vegetation condition, were only found through the ad hoc searches. There was also a potential mismatch between the prevalence of some attributes in the published literature (vs the unpublished literature) and their relevance for defining limits or targets i.e., chlorophyll-a (chl-a) concentration and periphyton biomass are attributes that are already widely used for monitoring in Aotearoa New Zealand but did not feature frequently in the published literature.

Table 8. Commonly used Freshwater potential attributes in Aotearoa New Zealand, along with less commonly used but potentially useful attributes (labelled 'other potential attributes'). Attributes were collated from a systematic and ad hoc review of Aotearoa New Zealand-based literature. 'Group' is based on logical grouping for a set of related attributes. Almost all attributes are used at a single time-point at a small spatial scale. For the full list of potential attributes and accompanying metadata, see Appendix 1 (supplementary file). Note that many attributes are used to answer study-specific questions; only a subset are used specifically for monitoring purposes.

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Ecological representation		<i>No attributes found</i>		
Composition	Fish	Fish biomass		
		Fish Index of Biotic Integrity (Fish IBI)	Fish abundance, fish density	
	Invertebrates	% Ephemeroptera, Plecoptera, Trichoptera (EPT) density		
		% EPT richness		
		Average score per metric		
		Delta-15N of primary consumers		Metric calculated from food web isotope values.
		EPT density		
		EPT richness		
		Macroinvertebrate biomass		
		Macroinvertebrate community assemblage change		Differences in communities over space or time (beta diversity).
		Macroinvertebrate community composition		
		Macroinvertebrate Community Index (MCI)		
		Macroinvertebrate density		
		Macroinvertebrate diversity		Shannon or Simpson diversity calculated from species presence and abundance.
		Macroinvertebrate functional diversity		Diversity of functional groups e.g., functional feeding groups.
		Macroinvertebrate taxonomic richness		

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Composition		Macroinvertebrate trait composition		
		Quantitative Macroinvertebrate Community Index (QMCI)		
		Zooplankton community composition		
	Microbes	Bacterial community composition	Fungal community composition	Emerging attribute-- rRNA extraction used for taxa identification.
		Escherichia coli (<i>E. coli</i>) concentration		
		Faecal coliform concentration		
		Microbial community composition		Emerging attribute-- rRNA extraction used for taxa identification.
		Microbial diversity		Emerging attribute-- taxonomic richness and diversity assessed using eDNA or rRNA.
	Primary producers	Periphyton biomass	Periphyton accumulation	Assessed as either chlorophyll-a or total biomass.
		Periphyton taxonomic richness		
		Planktonic cyanobacterial biovolume		
Structure (abiotic)	Ecosystem intactness	Alteration of drainage		
		Connectivity barriers		Assessment of barriers preventing movement of water, resources, and animals between water bodies and with adjacent land ecosystems.
		Wetland extent		Component of the Wetland Condition Index, potentially falls under the land domain.
	Environmental tracers	Chlorofluorocarbons– 11, 12 & 13, Deuterium, Oxygen-18, Radon, Sulphur hexafluoride, Tritium		Generally considered descriptive attributes for ageing groundwater, but included as water quality measurements within the NEMS for Discrete Groundwater Quality.
	Habitat	Catchment erosion susceptibility		Potentially falls under the land domain.
		Degree of sedimentation/ erosion		Qualitative component of Wetland Condition Index.
		Fine sediment cover		

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (abiotic), cont	Habitat, cont	Fish spawning habitat extent		
		Habitat Quality Index		Qualitative rapid habitat assessment combining sedimentation, instream habitat and riparian vegetation
		Streambank erosion susceptibility		
		Substrate composition	Particle size, Substrate embeddedness	
	Hydraulic integrity	1 in 5-year low flow		
		7-day mean annual low flow (MALF)		
		Artificial impervious land cover		Potentially falls under the Land (including Soil) domain, component of wetland Index of Ecological Integrity.
		Bed movement	Instability Index	
		Discharge		
		Drainage alteration		Component of wetland Index of Ecological Integrity.
		Flow velocity		
		Frequency of events exceeding three times the median flow (FRE3)		
		Groundwater depletion		
		Groundwater discharge rate		
		River disturbance index		
		Groundwater level	Water table height	Also assessed within the Soil subdomain.
		Groundwater level variability		
		Groundwater recharge rate		
		Groundwater volume/flow		
		Mean flow		
		Mean flow in the naturally driest calendar month	Proportion of flow in February	

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (abiotic), cont.		Stream depth		
		Wetted width		
	Physico-chemical conditions	Ammonium nitrogen (NH ₄ -N)		
		Chlorophyll-a		
		Dissolved metals & trace ions (aluminium, arsenic, bicarbonate, bromide, cadmium, carbon dioxide, carbonate, chloride, chromium, copper, fluoride, iron, lead, magnesium, manganese, potassium, silica (reactive), sodium, sulphate, zinc)		
		Dissolved organic carbon		
		Dissolved oxygen		
		Dissolved Reactive Phosphorus (DRP)		
		Euphotic depth	Water clarity	Also referred to as Secchi depth.
		Nitrate (NO ₃ -N)		Key measure of nitrogen toxicity
		Nitrate leaching risk		Qualitative component of wetland Index of Ecological Integrity determined using catchment mapping.
		Nitrate-nitrite N (nOx-N)	Nitrite nitrogen (NO ₂ -N)	Key driver of periphyton biomass.
		pH		
		Soluble reactive phosphorus (SRP)		
		Specific conductivity		
		Total Nitrogen (TN)		Can be measured or modelled with catchment data (e.g., Freshwater Environments of New Zealand (FENZ) or Catchment Land Use for Environmental Sustainability (CLUES)).
		Total (dissolved) alkalinity		
		Total (dissolved) hardness		
		Total dissolved salts		
		Total dissolved solids		

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Structure (abiotic), cont.	Physico-chemical conditions	Total Oxidised Nitrogen (TON)		
		Total Phosphorus (TP)		Can be measured or modelled with catchment data (e.g., FENZ or CLUES).
		Total suspended solids		
		Trophic Lake index (TLI)		Calculated from Chlorophyll-a, euphotic depth, TN & TP.
		Turbidity		
		Water clarity		
		Water temperature		
	Sediment	Suspendable sediment		
Structure (biotic)	Browsing & predation	Damage by domestic or feral animals		Wetland specific, component of Wetland Condition Index.
		Introduced predator impacts on wildlife		Wetland specific, component of Wetland Condition Index.
	Ecosystem intactness	Fire damage		Wetland specific, component of Wetland Condition Index.
		Introduced fish presence		Component of the Wetland Condition Index.
		Wetland extent		Component of the Wetland Condition Index.
	Food webs	Carbon range, Food chain length, Nearest neighbour distance, Trophic area		Metric calculated from food web isotope values— likely impractical for regular monitoring.
	Primary producers	Algal traits		Life history, physiological and morphological traits of algal taxa present.
		Introduced plant canopy cover		Wetland specific, component of Wetland Condition Index.
		Introduced plant understorey cover		Wetland specific, component of Wetland Condition Index.
		Lake Submerged Plant Index— Native Condition Index		
		Lake Submerged Plant Index— Invasive Impact Index		
		Macrophyte cover		
		Natural vegetation cover		Specifically addressing wetlands.
		Riparian vegetation cover		

Ecological Integrity component	Group	Commonly used potential attributes	Other potential attributes	Further attribute details
Function		Ecosystem metabolism		Determined using open channel measurements of dissolved oxygen.
		Humification		Component of Wetland Condition Index indicating soil decomposition in wetlands— Potentially falls under the Land (including Soil) domain.
		Organic matter decomposition		
		Periphyton accumulation	Periphyton biomass	Assessed as either chlorophyll-a or total biomass accrued over time.
Resilience		<i>Change in composition/structure attributes over time or in response to disturbance</i>	<i>Food web stability</i>	<i>Uncommon</i>

3.3.2. Attribute results summary

Within the Freshwater domain, the systematic search returned an abundance of results relating to attributes of EI. From the initially high number of results, many papers were rejected based on having been done overseas (despite having Aotearoa New Zealand-based contributors or references), addressing other domains or not assessing ecological responses. Of the 252 potential attributes identified, most attributes related to the EI components of structure and composition, with some measures of function, few measures of resilience and no attributes relating to ecological representation. The majority of studies used fine-scale, single point measurements of EI attributes to assess ecosystem responses relative to reference conditions or between treatment groups, with minimal consideration given to defining EI.

Ecological representation

As with the Soil subdomain, ecological representation needs to be considered on a broader spatial scale than was directly assessed by Freshwater attributes we identified. No attributes of ecological representativeness were identified through either the systematic or the subsequent ad hoc searches. However, resources do exist for assessing representation. The Freshwater Environments of New Zealand data base (FENZ; Leathwick et al. 2010) and NZ Rivers Map interactive mapping tool (Whitehead & Booker 2019) provide information that classifies ecologically similar rivers and streams, lakes and wetlands, and predicts hydrology, habitat and biotic indices for all river reaches in Aotearoa New Zealand. In addition, the New Zealand Freshwater Fish Database offers a national scale public record of fish observations and distribution patterns.

Composition

Attributes related to composition employ measures of abundance and diversity, as well as multivariate analyses to assess differences in the diversity and abundance of algal, macroinvertebrate, macrophyte and microbial communities. Measures of composition incorporate all fish-, macroinvertebrate- and microbe-related attributes, including attributes used in existing regional and national monitoring programs. The complexity of attributes related to composition ranged from simple counts through to calculated indices employing species abundance and known tolerances (e.g., Fish IBI and MCI) and multivariate analyses. As a result, the specific attributes employed in a given study were selected to address the specific aims of that study. Measures of composition were employed across rivers, lakes, and wetlands to measure either how composition shifted over time or space in response to environmental variation or compare attribute results to pre-defined condition bands. Many measures of composition employed either visual or genetic identification of taxa, although some measures went beyond taxonomic identity to consider species function (i.e., trait composition).

Structure

Structural measures of habitat, hydraulic and physico-chemical conditions were very common. Further measures of introduced species impacts, food webs and primary producer characteristics were also found. This is very likely a reflection of the widespread use of abiotic structural measures (see Table 8) in existing regional and national monitoring programs, as these measures are a practical way to assess environmental conditions. Measures of biotic structure were focused around riparian and submerged vegetation cover, but also included food web characteristics and assessments of the impact of introduced species and fire. Alongside these specific attributes, aggregate indices that combine multiple variables into a single ecosystem condition value were also recorded (e.g., Trophic Lake Index, Wetland Condition Index).

In addition, many attributes related to hydraulic integrity were retrieved through the ad hoc search – due to attributes specifically addressing hydrology rather than ecology. The separation between ecological and hydraulic integrity attributes arose from the different time frames and approaches required to evaluate hydrological and ecological variables. While hydraulic integrity was identified as a relevant environmental issue in the ecological studies returned by the systematic search, these studies were mostly short-term assessments of ecological responses to artificially manipulated reductions in water flow or increases in water temperature studies. In contrast, the development of hydraulic attributes considered multi-year time series information on water quantity to characterise river flow regimes.

Function and processes

Functional attributes were focused on primary production and decomposition, with ecosystem metabolism, gross primary production and organic matter decomposition being most prevalent. As these attributes directly assess the supply and cycling of food resources and nutrients within ecosystems, they are highly relevant measures of ecosystem function. Other less prevalent measures of function were the retention of coarse particulate organic matter and sediment, the accumulation of periphyton, microbial activity and the dispersal of macroinvertebrates. Given that ecological functions are inherently processes, functional attributes tended to be measured over short time periods, with the resultant rates then extrapolated to longer time scales.

Resilience

Attributes relating to resilience were identified but not common. The resilience-related attributes were derived from assessing how structure or composition changed over time in response to disturbance e.g., changes in species richness or in the prevalence of specific traits. The attributes were identified from experimental studies of ecosystem responses to artificially manipulated environmental stressors.

Attribute gaps for Aotearoa New Zealand (supplemented by international literature)

Comparison of literature from Aotearoa New Zealand with overseas literature and monitoring frameworks identified gaps relating to wetlands, groundwater and hydrological attributes. While international frameworks largely employed similar attributes—because attributes of EI (and ecological health) are relatively well developed in the Freshwater domain (e.g., Clapcott et al. 2018), many attributes related to the wetland and groundwater subdomains were only found within the grey literature. In addition, a key suite of attributes relating to chemical contaminants (e.g., pesticides) was only found within international monitoring frameworks. Hydrological attributes were already assessed within the published literature from Aotearoa New Zealand, but articles seldom contained ecological components and hydrological indices were generally poorly utilised relative to other countries. For example, attributes of habitat and hydrological connectivity were only found in international literature. Additionally, attributes spanning the overlap between domains (e.g., the riparian zone) were rare and specific attributes relating to temporary waters (e.g., ephemeral stream or spring habitats) were not found. There was also little consideration of larger scale processes such as habitat connectivity or the persistence of cyclical patterns over time (e.g., fish spawning).

Emerging attributes

Molecular indicators for biotic structure and composition were identified as the main field of development for new EI attributes for freshwater. Specifically, eDNA or rRNA approaches were identified as potentially allowing a more complete assessment of taxonomic groups, or assessment of bacterial or fungal communities (Jackson et al. 2016; Wood et al. 2021).

3.4. Coastal and Seabed, and Estuaries

3.4.1. Summary of search results and potential attributes

The systematic literature search of the WoS core collection returned 561 results for Coastal and Seabed and 209 results for Estuaries (Table 4). An exclusion used in our search was for Atmosphere/Meteorological sciences in relation to discipline. Screening of titles and abstracts (and full texts in some cases) for relevance to EI in Aotearoa New Zealand led to 41 and 75 relevant articles for Coastal and Seabed, and Estuaries, respectively, from which to compile potential attributes and metadata. The results from the systematic search were supplemented with further ad hoc searches of both Aotearoa New Zealand and international literature, which spanned published and unpublished literature and monitoring frameworks (Table 5), as well as expert knowledge from the authors and additional experts (see Acknowledgements). The attributes compiled through ad hoc searches represented a high proportion of the potential attributes (more than half of those compiled, Aotearoa New Zealand and international combined). Information from attributes gained through ad hoc searching was also used to supplement metadata for attributes already compiled through the

systematic search (e.g., additional domains, subdomains, or methods) although this was not exhaustive. Additional information on subdomains may need to be obtained [Section 9\(2\)\(f\)\(iv\)](#), which could be done for a refined set of attributes. For example, additional subdomain information could be in relation to estuary 'type' (e.g., as in Hume et al. 2016) or whether the attribute is applicable to a subtidal or intertidal environment (if relevant).

Overall, > 580 potential attributes and/or attribute topics (Coastal and Seabed, and Estuaries combined) with accompanying metadata were compiled from search results (see Table 9 for commonly used attributes). For practicality, many of the potential attributes were grouped as 'attribute topics' for which multiple attributes were represented under one 'attribute topic'. If attributes were presented individually, the compiled list of these would be extremely large. Many of the compiled attributes related to both 'Coastal and Seabed' and 'Estuaries', given the environmental similarities between these domains. In some cases, the exact domain the attribute related to was not specified. To cater for this, we assigned these attributes under the 'Coastal' domain but only after we had judged that they didn't only apply to areas outside the seaward boundary of the coastal domain (if they did then they were not compiled in our attribute list). The 'Coastal' domain was also assigned if the attribute related to both coastal areas and estuaries; however, only the Estuaries domain was assigned if the attribute only related to estuaries and not also to Coastal. Other domains (Air, Land [including Soil]) were also noted (in Appendix 1) where the attributes were also applied in these domains.

Table 9. Commonly used Coastal and Seabed and Estuaries potential attributes used in Aotearoa New Zealand. Attributes were collated from a systematic and ad hoc review of New Zealand-based literature. 'Group' is based on logical grouping for a set of related attributes. For the full list of potential attributes and accompanying metadata, see Appendix 1 (supplementary file). Note that many attributes are used to answer study-specific questions; only a subset are used specifically for monitoring purposes. Attributes either represent individual attributes or attribute topics.

Ecological Integrity Component	Group	Commonly used potential attributes	Further attribute details	Domain (note the use of 'Coastal' here can include estuaries but 'Estuaries' means estuaries only)
Ecological Representation	Habitats or substrates	Habitat or substrate area or extent (broad-scale) <i>For example, in relation to intertidal and subtidal habitats, subtidal biotopes, biogenic habitats (including increasing or declining), dominant substrates, coastal wetland (seagrass, saltmarsh, mangrove), macroalgae including blooms, changes in spatial coverage of Submerged Aquatic Vegetation and Gross Nuisance Areas.</i>	Various attributes used across subdomains, but all use broad-scale methods to measure broad-scale area/extent	Coastal
	Human activities	Human activities area or extent (broad-scale) <i>For example, in relation to commercial coastal seabed trawling and dredging, activities and impacts (e.g., coastal hardening, coastal dredging, commercial fishing, recreational fishing and harvesting, aquaculture, shipping) and marine protected areas including compliance.</i>		Coastal
	Oceanographic	Oceanographic features area or extent (broad-scale) <i>For example, sea surface temperature, water column primary productivity (measured using remote sensing).</i>		Coastal
Composition	Algae	Microalgae (phytoplankton, microalgae, cyanobacteria) species: abundance of individuals <i>For example, cell counts and chlorophyll-a or fluorescence used as a proxy.</i>		Coastal
		Opportunistic Macroalgal Blooming Tool score	Index calculated from various parameters, including those relating to	Estuaries

Ecological Integrity Component	Group	Commonly used potential attributes	Further attribute details	Domain (note the use of 'Coastal' here can include estuaries but 'Estuaries' means estuaries only)
Composition, cont.			composition, structure and representation	
	Birds	Bird-related population measures <i>For example, indigenous shorebird numbers, assemblage metrics of sea and shore birds such as counts and assessment of species viability.</i>		Coastal
	Epibiota and epifauna (soft sediment)	Epibiotic and epifauna soft sediment communities; abundance and diversity		Coastal
	Fish	Fish abundance and diversity metrics <i>For example, abundance, diversity, and demographic attributes, community indices, changes in distribution, assemblage metrics of large predatory fish such as counts and assessment of species viability, fish functional richness, evenness, indices and modelling.</i>	Relate to various types of fish (e.g., reef, demersal) depending on the attribute	Coastal
	Fisheries stocks and bycatch	Fisheries-related measures of stocks and bycatch <i>For example, fish state of stocks and bycatch, scallop population indices, commercial catch, bycatch of protected seabird, sea lion and fur seal species.</i>		Coastal
	Habitat	Habitat types number and diversity		Coastal
	Marine mammals	Assemblage metrics of marine mammals e.g., based on counts and assessment of species viability.		Coastal
	Macroinvertebrates	Macroinvertebrate indices (multivariate and univariate) <i>For example, abundance, richness, evenness, NZ-AMBI, key taxa population structure, functional group metrics, Traits Based Index, National Benthic Health Models for mud and metals, community composition (multivariate analysis)</i>		Coastal
	Rocky reef	Intertidal and subtidal community abundance and diversity		Coastal

Ecological Integrity Component	Group	Commonly used potential attributes	Further attribute details	Domain (note the use of 'Coastal' here can include estuaries but 'Estuaries' means estuaries only)
Composition, cont.	Rocky reef, cont.	<i>For example, community indices for invertebrates and macroalgae.</i>		
	Species	Indigenous or non-indigenous (including high risk), key pest species. <i>For example, number of threatened/at risk/extinction status, outbreaks, richness, abundance, movement, Invasive species (presence or spread, outbreaks, number recognised as major threats)</i>		Coastal
	Microbial	Microbial (e.g., Faecal coliforms, Enterococci, <i>Escherichia coli</i>) concentrations in water		Coastal
Structure	Birds	Bird-related 'non-population' measures <i>For example, indigenous shorebird status, range and description of important breeding and non-breeding sites.</i>		Coastal
	Contamination or toxins in organisms	Contaminants or toxins in organisms <i>For example, organism (resident) contaminant levels, Faecal indicator bacteria, trace metals in mussel tissues, contamination in fish tissues, cyanobacteria toxin concentrations</i>		Coastal
	Eutrophication	Eutrophication and/or enrichment-related indices or assessment <i>For example, Enrichment Stage, Eutrophication indices or assessment</i>		Estuaries
	Litter	Litter-related (e.g., plastic, rubbish) measures <i>For example, beach litter density and percentage item count and weight per type</i>		Coastal
	Seagrass	Physical measures of seagrass		Coastal

Ecological Integrity Component	Group	Commonly used potential attributes	Further attribute details	Domain (note the use of 'Coastal' here can include estuaries but 'Estuaries' means estuaries only)
Structure, cont.	Seagrass, cont.	<i>For example, shoot and leaf density, leaf length, above ground biomass (leaves) and below ground biomass (rhizomes).</i>		
		Indirect indicators of seagrass health <i>For example, amount or presence of fungal wasting disease, fine-scale epiphyte/sediment/macroalgal cover.</i>		Coastal
	Sediment	Metals concentrations		Coastal
		Sediment characteristics (multivariate analysis)		Coastal
		Grain size composition, including percent mud		Coastal
		Nutrient concentrations		Coastal
		Organic content		Coastal
		Redox, including depth of/to redox discontinuity layer [RPD]		Coastal
		Sulphide concentrations		Estuaries
	Substrates and organisms (fine-scale area)	Substrates and organisms, area of (fine-scale) <i>For example, percent cover of sessile rocky reef organisms and substrates, or seagrass or soft sediment benthic macroalgae</i>		Coastal
	Water	Metals concentrations		Coastal
		Absorbance, colour, clarity		Coastal
		Oxygen-related measures <i>For example, dissolved or saturated oxygen, biological or biochemical oxygen demand</i>		Coastal
		Organic carbon or particulate carbon		Coastal
		Water level, e.g., sea level		Coastal

Ecological Integrity Component	Group	Commonly used potential attributes	Further attribute details	Domain (note the use of 'Coastal' here can include estuaries but 'Estuaries' means estuaries only)
Structure, cont.	Water, cont.	Light, including photosynthetically active radiation, irradiance		Coastal
		Nutrient concentrations, e.g., nitrogen and phosphorus and related species		Coastal
		Oxidation-reduction potential		Coastal
		pH		Coastal
		Salinity, conductivity		Coastal
		Temperature <i>For example, sea surface temperature and marine heatwave forecasting.</i>		Coastal
		Turbidity, also suspended particulate matter and suspended solids/sediments		Coastal
	Wave events	Extreme wave events		Coastal
Function	Benthic fluxes	Benthic fluxes <i>For example, nutrient- and oxygen-related</i>		Estuaries
	Nutrient, sediment and <i>E. coli</i> loads	Nutrient, sediment and <i>E. coli</i> loads <i>For example, modelled using Catchment Land Use for Environmental Sustainability (CLUES)</i>		Estuaries
	Sediment accumulation	Sediment accumulation rate		Estuaries
Resilience	Eutrophication	Eutrophic Susceptibility of estuaries <i>For example, various individual measures such as flushing potential, dilution potential, physical susceptibility or export potential, nutrient load threshold, nutrient load and closure period (for intermittently closed/open lakes and lagoons / estuaries)</i>		Estuaries

3.4.2. Attribute results summary

Our literature searches for the Coastal and Seabed, and Estuaries (i.e., marine-related) domains led to the compilation of a high number (> 580) of potential attributes of EI (including attribute topics). Most of these were from Aotearoa New Zealand, which aligns with the fact that marine environmental monitoring is regularly carried out at local and regional scales here (e.g., for state of the environment and resource consent-related purposes) (e.g., Hewitt et al. 2014; Zaiko et al. 2018). However, attributes of EI are generally not well developed (e.g., standardised) at the national level for Aotearoa New Zealand's coastal waters and estuaries (PCE 2020). Fisheries-related attributes, that are relevant to EI, for coastal waters and estuaries are also commonly used in Aotearoa New Zealand (e.g., as reported in Our Marine Environment 2019). Our compiled attributes primarily relate to the EI components composition and structure, followed by ecological representation and function and with very few relating directly to resilience. These results are discussed in more detail below in the context of each EI component, as well as in relation to potential attribute gaps for Aotearoa New Zealand and emerging developments.

Ecological representation

As with the Soil subdomain and Freshwater domain, ecological representation within the marine-related domains needs to be considered on a broader spatial scale than was directly assessed by most of the attributes. However, there is no definition for broad- vs fine-scale in this context. Furthermore, fine-scale data can often be aggregated and/or extrapolated into broad-scale data.

Nevertheless, a considerable number of commonly used attributes for these two domains were assigned to the 'ecological representation' component of EI. These were related to broad-scale area of habitat or substrates (subtidal or intertidal), and oceanographic features. They also related to the area of human activities such as commercial coastal seabed trawling and dredging, coastal hardening and dredging, commercial and recreational fishing, aquaculture and shipping (Our Marine Environment 2019). Note that ecological classifications, such as those previously summarised by MfE⁴, may also prove useful for developing and measuring attributes for ecological representation. Examples of classifications include the Land Cover Database (e.g., in relation to coastal wetlands), DOC's portal containing seagrass and mangrove area cover⁵, Coastal and Marine Habitat and Ecosystem Classification System (CMHEC) and the New Zealand Seafloor Community Classification (Stephenson et al. 2021).

⁴ <https://environment.govt.nz/publications/environment-new-zealand-2007/chapter-1-environmental-reporting/ecological-classifications/>

⁵ <https://www.doc.govt.nz/nature/habitats/estuaries/our-estuaries/seagrass-and-mangrove-extent/>

Composition

A high proportion of commonly used attributes relate to composition, which likely reflects the widespread use of many of these attributes in regional monitoring programmes (e.g., Robertson et al. 2002; Hewitt et al. 2014) and research. The attributes fitted within various biological groupings including algae, birds, epi-fauna or biota, fish, fisheries stocks and bycatch, habitats, marine mammals, soft sediment macroinvertebrates, rocky reef, indigenous and non-indigenous species and microbiology. Commonly used attributes identified in relation to 'fisheries stocks and bycatch' likely reflects the large impacts that fisheries-based activities can have on marine ecosystems and species in Aotearoa New Zealand (e.g., Our Marine Environment 2019, Durante et al. 2020, Edgar et al. 2017, Fisheries New Zealand 2022).

The 'composition' component is specifically defined by MfE as relating to species, habitats and communities that are indigenous only. Therefore, it was not obvious how to assign attributes for non-indigenous (e.g., invasive) species that related to composition (e.g., abundance and diversity). Furthermore, many commonly used composition attributes did not specifically relate to indigenous elements. For example, abundance and diversity indices for benthic macroinvertebrate communities encompass all taxa regardless of whether they are indigenous or not. In this regard, they therefore technically do not meet the composition requirements under the MfE EI definition. In terms of spatial scale, attributes relating to fine scales (e.g., percent cover of organisms or substrates in quadrats) were included under composition. However, as mentioned for ecological representation above, there was no cut-off for defining fine vs broad scales in this context.

Structure

Many of our compiled potential attributes of EI for the marine-related domains were assigned under the 'structure' component. As for composition, this likely reflects the widespread use of many attributes in regional monitoring programmes (e.g., Robertson et al. 2002; Hewitt et al. 2014) and research. Commonly used structural attributes related to the water column, sediment quality, contamination or toxins in organisms, litter (e.g., plastic or rubbish) and wave events. Other groupings, largely biotic, were seagrass, birds, substrates and organisms (fine-scale cover or area), as well as eutrophication.

Function and processes

Very few commonly used potential attributes were assigned under the 'function' component of EI. Those that were, related to sediment accumulation rate, benthic fluxes (e.g., in regards to oxygen and nutrients) and nutrient, *E. coli* and sediment loads in estuaries (e.g., based on catchment modelling). Primary productivity of phytoplankton (often measured by cell counts or using chl-a as a proxy) could also be considered under function; however, this was often measured 'point in time' (rather than as a rate over time) and therefore was considered to relate more directly to

composition or structure than function. The small number of commonly used function-related attributes may be due to the difficulty of study (they are often technically more complex or more time consuming to determine) relative to the attributes under ecological representation, composition and structure. Note that indices (e.g., the macroinvertebrate Traits Based Index [TBI]) that measure abundance and/or diversity of functional traits, species and groups were assigned under composition rather than under function.

Resilience

The only attribute for resilience considered to be commonly used in Aotearoa New Zealand was 'Eutrophication susceptibility of estuaries'. Some attributes assigned under other EI components can also be used to assess resilience. For example, the TBI indicates functional redundancy (a measure of resilience) but is constructed from the richness of macrofaunal taxa in seven functional groups (Rodil et al. 2013), and therefore was assigned under 'composition' (but, as mentioned above, it also relates to function). Another example of interrelatedness between resilience and other EI components is demonstrated by an experimental study on macrobenthic recovery processes following catastrophic sedimentation on estuarine sandflats (Thrush et al. 2003). This study measured recovery (which could be considered a measure of resilience) using compositional attributes such as macroinvertebrate abundance and numbers of taxa.

Gaps for Aotearoa New Zealand (supplemented by international literature)

We filled gaps in the list of potential attributes (or attribute topics) for Aotearoa New Zealand by supplementing from the international literature (monitoring frameworks). Examples of attributes used overseas but not used commonly or at all in Aotearoa New Zealand included size of hypoxic zone and soundscape mapping in relation to underwater noise (in relation to ecological representation), fish kills, litter-related (e.g., plastic, rubbish) deaths of marine animals and seagrass root microbiome (in relation to composition) and seagrass ecosystem function (including secondary production) and organic carbon metabolism (in relation to function). Also, functional traits analysis has been widely applied overseas to understand the functional response of biological communities to environmental and pressure gradients (Smit et al. 2021); however, this type of analysis was less common in the domestic literature we searched.

There were also many international multi-metric indices, especially in relation to eutrophication and/or macroinvertebrates but also to habitat quality, including wetland condition (e.g., wetland stress indices). Many of these comprised individual attributes similar to (or the same as) those already used in Aotearoa New Zealand. However, even aligned attribute terms can be represented by various attributes in terms of methods and metrics used. For example, in terms of methods, chl-a in the water column can be measured by instrument (i.e., fluorescence), satellite or laboratory analysis. In terms of metrics, for example, dissolved oxygen can be considered as a percentile (e.g., 10th percentile, Ferreira et al. 2011) or as an average (MPI 2019).

Refer to supplementary file for details on all international attributes compiled (Appendix 1).

Emerging attributes

Quite a few of the articles from which we compiled attributes were relatively recent (published in the past five years). These largely represented experimental and research studies not focused on developing monitoring indicators, although some did have this particular purpose. For example, newly developed potential attributes for Aotearoa New Zealand include the multivariate Benthic Health Models (Clark et al. 2020), which were recently included within an 'estuaries' module for Land, Air, Water Aotearoa (LAWA)⁶ for the purpose of monitoring the impacts of sediment mud content and trace metals. There has also been recent development of modelling approaches, for example, a Bayesian Network model to inform the management of multiple stressors (suspended sediment, sediment mud and metal content, and nitrogen inputs) on estuarine ecosystems (Bulmer et al. 2022).

Molecular eDNA indices for environmental monitoring are also under development for Aotearoa New Zealand, for example, for use in monitoring salmon farms in the Marlborough Sounds, Pochon et al. (2021) and estuaries (Clark et al. 2020). Furthermore, a recently funded Cawthron-led research project aims transform coastal monitoring by harnessing microbial communities (using eDNA methods) to disentangle multi-stressor impacts⁷. Another example is a non-invasive method to monitor marine pollution from bacterial DNA present in fish skin mucus (Montenegro et al. 2020).

Other emerging attributes applied in the coastal environment relate to 'contaminants of emerging concern' (Stewart et al. 2016), microplastics (Bridson et al. 2020; Clere et al. 2022) and monitoring of coastal suspended sediment using satellite remote sensing techniques over broad spatial and temporal scales (Pinkerton et al. 2022). Some of the emerging attributes (including approaches) relate to function. For example, the Aquatic Eddy Covariance technique can be used to quantify in situ seafloor metabolism over large areas (including across habitats) of benthic communities (e.g., Rodil et al. 2019⁸). Emerging carbon-related functional attributes include sediment carbon sequestration rate and greenhouse gas (GHG) fluxes of intertidal benthic habitats (Perez et al. 2017; Albot et al. in prep⁹, Hamilton et al. 2020) as well as Forensic Carbon Accounting to analyse carbon flows between the atmosphere and ocean, and into and out of seaweeds (Hurd et al. 2022).

⁶ <https://www.lawa.org.nz/learn/glossary/b/benthic-health-model/>

⁷ <https://www.mbie.govt.nz/science-and-technology/science-and-innovation/funding-information-and-opportunities/investment-funds/endeavour-fund/success-stories/>

⁸ Study conducted overseas but by authors that have ties to Aotearoa New Zealand.

⁹ Albot O, Levy R, Ratcliffe J, Naeher S, Ginnane C, Cooper J, Wood C, Dunbar G (in prep). Blue carbon soil stocks, sources and preservation within New Zealand saltmarshes.

3.5. Air

3.5.1. Summary of search results and potential attributes

The systematic literature search resulted in 936 articles related to the Air domain or subset terms already defined. Further screening for relevance reduced this to 67 articles, from which 15 attributes were identified. Further, targeted literature searches based on those 15 attributes and expert selection (see Table 3) helped to identify another 196 articles after a search through over 7500 records, which included additional metadata to bring the total number of attributes to 37. None of these attributes are specific to Air and each attribute currently identified has some relation to another domain (Freshwater, Land [including Soil] etc.); Table 10 identifies the relevant secondary domains in each case. In addition, the definitions of ecological representation, composition, structure and function provided by MfE mean that for the Air domain all attributes relate to ecological structure because they all are based on abiotic physical features. In addition to attributes that would formally be related to the AIR domain, we also identify a secondary set of confounding attributes that would be important to consider.

Table 10. Potential attributes identified for Air for Aotearoa New Zealand. Attributes were collated from a systematic and ad hoc review of Aotearoa New Zealand-based literature. Most attributes are used across a range of spatial scales and benefit from time series. For the full list of potential attributes and accompanying metadata, see Appendix 1 (supplementary file). Note that many attributes are used to answer study-specific questions; only a subset are used specifically for monitoring purposes. All attributes for the Air domain relate to the EI component 'structure'. Prevalence relates to usage of the attribute in the literature – see Section 2 Methods. Note that some attributes represent confounding factors, which would ideally be considered along with the more common Air attributes.

Attribute class	Potential attribute	Prevalence L=low M=moderate H=high	Secondary Domain/s
Surface pollutants	Particulate matter	L	All
	Airborne microplastics and nanoplastics	M	All
	Biogenic aerosol	L	All
	Tropospheric ozone pollution	L	Land (including Soil), and indigenous biodiversity
	Black carbon	L	Land (including Soil), and indigenous biodiversity
	Sulphur oxides (sOx)	M	Freshwater, Coastal and Seabed, Estuaries, and indigenous biodiversity
	Nitrogen oxides (nOx)	M	All
	Carbon monoxide	L	All
	Ammonia	M	Freshwater, Coastal and Seabed, Estuaries and indigenous biodiversity
	Heavy metals	M	All
	Polycyclic aromatic hydrocarbons (PAHs) and other hydrocarbons	M	All
Stratospheric Ozone Depletion	Stratospheric ozone depletion	H	All
	Ozone depleting substances (CFC11, CFC12, CFC13, HFCs, halons, etc.)	H	All
	Enhanced UV irradiance due to stratospheric ozone depletion	H	Estuaries, Land (including Soil), indigenous biodiversity
Confounding factor attributes			
Teleconnection	El Niño Southern Oscillation index	M	All
	Southern Annular Mode index	M	All
	Interdecadal Pacific Oscillation index	L	All
Light	Light Pollution	M	All
	Surface Solar Irradiance	H	All
	Photosynthetically Active Radiation	M	All
Climate change related attributes			
Temperature	Air temperature: change attributable to human-induced climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Air temperature seasonality: change attributable to human-induced climate change	M	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Reduction in cold weather extremes (e.g., frost days) attributable to climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Increase in hot weather extremes intensity and occurrence attributable to climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.

Attribute class	Potential attribute	Prevalence L=low M=moderate H=high	Secondary Domain/s
Temperature, cont.	Frost days (ETCCDI climate indices)	H	Land (including Soil), indigenous biodiversity.
Precipitation	Precipitation occurrence: change attributable to human-induced climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Precipitation Intensity: change attributable to human-induced climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Precipitation seasonality: change attributable to climate change	M	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Snowfall and snow line change	L	Land (including Soil), indigenous biodiversity.
Greenhouse gases	Carbon dioxide concentration: change attributable to human emissions	H	All
	Nitrous oxide concentration: change attributable to human emissions	M	All
	Methane concentration: change attributable to human emissions	M	All
Other confounding attributes			
	Noise pollution	L	Coastal and Seabed, Estuaries
	Fire indices: change attributable to climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Change in wind and wind extremes attributable to climate change	H	Freshwater, Estuaries, Land (including Soil), indigenous biodiversity.
	Latent Heat flux	H	Land (including Soil) and indigenous biodiversity
	Sensible Heat flux	H	Land (including Soil) and indigenous biodiversity

3.5.2. Attribute results summary

As noted above, based on MfE definitions of the EI components, all of the Air domain attributes we identified relate to *structure*. These metrics are all quantitative and have been studied based on existing networks within Aotearoa New Zealand or can be obtained from international data, such as satellite observations. With some additional collation and analysis, these attributes can be used in an EI context, noting that some datasets are already routinely collated by Statistics New Zealand.

The abiotic physical nature of every attribute identified in the Air domain potentially highlights a weakness when considering the Air domain in the context of EI as defined by MfE. In the atmospheric sciences it would be more common to think about composition attributes in terms of concentrations of chemical species, such as CO, CO₂, CH₄, O₃ and/or pollutants such as particulate matter. State attributes would represent the state of the atmosphere or climate, such as temperature, wind, precipitation, and irradiance.

To allow some grouping in the Air domain, attributes were assigned a prevalence level based on usage in the literature and also a class based on common root causes or impacts. The nine resulting attribute classes relate to a range of possible attributes, some of which may be considered confounding factors that would need to be monitored to be comprehensive or to examine interactions between various environmental issues. Additional commentary on each of these nine classes is provided in Appendix 2, Section 1.

Attribute gaps for Aotearoa New Zealand (supplemented by international literature)

Very little Aotearoa New Zealand based literature is available on issues of surface air pollutants, tropospheric ozone, acidification or eutrophication with a specific focus on how these attributes relate to ecosystems and EI. Other gaps include attributes for airborne microplastics, which are now recognised to be nearly ubiquitous globally and a potential threat to the marine-atmosphere environment (Allen et al. 2022), and noise pollution, which affects multiple domains but appears in the sampled Aotearoa New Zealand literature only in a marine context.

Emerging attributes

The most obvious emerging attribute identified in our literature review relates to airborne microplastics. The very small amount of literature found on microplastics for Aotearoa New Zealand that mentioned airborne sources was all post 2021. The most relevant work was De Bhowmick et al. (2021), which looked at current status and future directions for effort.

4. DEFINING ECOLOGICAL INTEGRITY

Below we discuss differences in the MfE definition of EI (as outlined in the Glossary) in comparison to how EI is defined in the literature for each domain.

4.1. Land (including Soils)

4.1.1. *Terrestrial*

For terrestrial systems, most studies use definitions of EI that are broadly consistent with the MfE definition, and this is crucial for linking national monitoring efforts and development of indicators with various international efforts or commitments such as Ramsar, CDB and IPBES (see also international frameworks in Table 5 above). These definitions are largely derived from Andreasen et al. (2001) and are widely used for ecological assessment and applications of EI internationally (e.g., Wurtzebach & Schultz 2016; Hansen et al. 2021; see also Brown and Williams 2016) and in New Zealand (McGlone et al. 2020). Some minor differences include the following:

- The widely cited Canada National Parks Act defines EI as 'a condition that is determined to be characteristic of its natural region and likely to persist, including abiotic components and the composition and abundance of native species and biological communities, rates of change and supporting processes'. This definition thus focuses on discrete areas (parks) and emphasises persistence of function.
- There is some debate on historic range of variation viz natural range of variation for defining EI, and this aspect of EI definition should be made more explicit for indicators. Preference is normally given to historic range of variation as a baseline (e.g., starting with Egan & Howell 2001).
- A somewhat distinct line of work on EI focuses on quantifying the effects of human pressure, or proxies of human-induced impacts. Here, the absence of human effects (i.e., intactness of a system) is considered to represent high EI (e.g., Theobald 2013; Beyer et al. 2020; see also McGlone et al. 2020). This approach continues to be used in some international studies, particularly for mapping or landscape-scale assessments (e.g., Theobald 2013).

Overall, there is a huge international literature on EI for terrestrial systems, most of which is broadly consistent with the definition used here. Crucially, many international commitments or networks (e.g., CDB, IPBES, GEOBON) use this definition of EI for monitoring and reporting at regional and international levels.

4.1.2. *Soil*

The term 'ecological integrity' is rarely used in discussion of soils. Instead, 'soil health' or 'soil quality' is typically used although there is debate in the literature about when

and where these terminologies might apply, and the real difference between these terms—with many authors considering the terms to be synonymous (see Buneman et al. 2018; Lehmann et al. 2020, and Creamer et al. 2022 for outlines of the debate over time). The simple definition of soil health as 'the continued capacity of a soil to function as a vital living ecosystem that sustains plants, animals and humans', originating from the USDA-NCRS¹⁰, has been used in several recent papers (e.g., Creamer et al. 2022; Liptzen et al. 2022). While this definition is conceptually similar to the MfE definition of EI, the specification of *indigenous* biodiversity in EI is a key point of difference. Specifically, no mention was made of indigenous biodiversity in any literature assessed for soils in the current project. This may be in part due to a dominant focus on the soil microbial community in soil health assessments (as compared to soil fauna), both because this community is exceptionally diverse and because truly indigenous species are challenging to identify. It is relevant to note that a recent study identified that protection of aboveground biodiversity may not sufficiently reduce threats to soil biodiversity (Cameron et al. 2019).

Internationally, an ecosystem services (also more recently considered as Nature's contribution to people [Diaz et al. 2018]) framework is increasingly used to assess soil quality and health. In this case, individual soil functions are grouped together to inform the extent to which soils are contributing to ecosystem services (Buneman et al. 2018) with Primary Productivity, Nutrient Cycling, Water Regulation and Purification, Carbon and Climate Regulation, and Habitat for above- and below-ground Biodiversity being considered important in agroecosystems (Shulte et al. 2014). Creamer et al. (2022) further sub-divided soil functions into sub-functions to link to specific processes and noted that some processes are relevant for multiple sub-functions or functions. An alternative approach adopted by the European Environmental Agency (Bartiz et al. 2021) gives greater consideration to the context in which soil indicators are likely to be used—in the management of land or soil to reduce soil degradation arising from soil threats including soil erosion, sealing, and contamination (including excess nutrients). Consideration of the specific contexts, i.e., the problems or threats the NBA and NPF are intended to address, will help to identify relevant attributes for Aotearoa New Zealand for a given domain.

4.2. Freshwater

Previous reviews of ecological assessment frameworks for freshwaters considering EI have identified consistent components of EI including addressing a range of biota and processes (Karr 1991), ecological structure and function (Rapport et al. 1998), physical, chemical, and biological integrity (Barbour et al. 2000) and that ecosystems are resilient to change (Clapcott et al. 2018). The components of EI are interrelated in that composition is usually inherent within structure, and function is not exclusive, i.e.,

¹⁰ <https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/soils/health/?cid=stelprdb1048783>

biological structure and function, physical structure and function, chemical structure and function are often linked.

Given that some freshwater ecosystems are now irreversibly modified, further definitions of EI have evolved to specifically include human modification. In considering the application of EI to freshwater management in Aotearoa New Zealand, Schallenberg et al. (2011) defined it as 'The degree to which the physical, chemical and biological components (including composition, structure and process) of an ecosystem and their relationships are present, functioning and maintained close to a reference condition reflecting negligible or minimal anthropogenic impacts'. Therefore, integrating the multiple components of EI within an assessment framework and selecting an adequate reference condition were both considered important for adequately characterising EI.

4.3. Marine

During attribute compilation in our study (refer Section 3.4.2), it was apparent that components of EI (as defined by MfE) can be interrelated, as also mentioned for the Freshwater domain above. Drawing on EI definitions from freshwater and terrestrial systems (i.e., Lee et al. 2005; Schallenberg et al. 2011), Thrush et al. (2011) outlined four pillars of EI for marine ecosystems: nativeness, pristineness, diversity and resilience. Contributing to aspects of these pillars, Thrush et al. (2011) also identified six features of EI for Aotearoa New Zealand marine ecosystems to include in marine EI monitoring. Four of these features were 'trophic structure', 'habitat structure and complexity', 'diversity' and 'resilience' (Thrush et al. 2011), all of which are generally encompassed within the MfE EI definition. The two additional features outlined by Thrush et al. (2011) were 'environmental context and history', which relates to knowledge of historical baselines and reference conditions, and 'disturbance regime', described as 'natural, human, intensity, extent, frequency'. Neither historical baselines nor reference conditions are included in the MfE definition of EI. Disturbance regime could potentially relate directly to the MfE component of function, although the inclusion of 'human' under disturbance regime deviates from this. Conversely, in contrast to the MfE EI definition, none of the descriptions of EI features outlined by Thrush et al. (2011) specifically mention indigenous biodiversity, however presumably 'nativeness' as an EI pillar aligns with this concept.

4.4. Air

The MfE definition of EI is comprehensive in many respects, but given that human-induced climate change represents one of the most important threats to ecosystems, the current definition could be adjusted to better reflect the interrelatedness of EI across domains, including the influence of climatic factors on all other domains. At

present, without some clarification, many of the attributes identified in the Air domain could be incorrectly interpreted as outside the EI definition. Additionally, research shows climate change will undermine many of the Sustainable Development Goals (SDGs) and that supporting the Paris Agreement commitments will conversely support the SDGs (Fuso Nerini et al. 2019). This reflects the interconnected nature of these two systems and that climate change again poses a major stress for all ecosystems. Griggs et al. (2021) has also identified that weather and climate information is currently underutilised in supporting the SDGs and therefore provides arguments why these attributes must be considered within analyses of EI. We also note that climate change is often identified as a threat multiplier, thus examination of attributes relevant to climate change are likely important to help understand whether other attributes are being impacted by this confounding factor. We also note that there is a considerable set of literature connecting air quality and climate change, which means that to be comprehensive, it may be advisable to include climate change-related confounding factors alongside air quality attributes. For example, work by Bytnerowicz et al. (2007) highlighted that the integrated effects of air pollution and climate change on forest ecosystems may significantly differ from the sum of the separate effects. More recent work by Fiore et al. (2015) has also identified the interplay between air quality and climate. We also note that state attributes of the atmosphere have significant impacts on air pollutants. For example, winds define the airborne transport of pollutants and thus define the regions exposed, while rainfall partially defines deposition. Thus, any changes in these variables due to climate change would significantly impact pollutant attributes.

Climate change represents a risk to ecosystem functioning resulting from the interaction of climate-related hazards, vulnerability and exposure (IPCC 2014). The climate hazard in this context can be defined by a number of attributes connected to abiotic physical features (structure), or more specifically to climatic features. Exposure would be defined by the variation of these features across Aotearoa New Zealand (representation). Quantification of vulnerability relates to the resilience aspect in the MfE EI definition. These three aspects and/or interconnections could be more explicitly identified within the MfE definition to recognise climate-related risks more clearly.

The dynamic adaptive policy pathway approach detailed in Haasnoot et al. (2013) has been highlighted in government documents (MfE 2022) as a useful decision-making tool for climate change policy and adaptation. This framework could be equally well used within the EI space to recognise the climate-ecosystem nexus. A strict application of the EI definition as currently specified to variables that directly represent ecosystem health would exclude several of the confounding attributes, limiting the application of many of the attributes within the pre-defined scope. Simply put, many of the other attributes considered are likely to interact or respond to the confounding attributes in a complex bi-direction way.

5. SYNTHESIS ACROSS DOMAINS

Overall, there was a large number of potential attributes for all domains identified in the literature, except for Air where direct connection to ecosystems was not as common within the relevant Aotearoa New Zealand literature. A synthesis across domains in respect to the EI components is as follows:

- Across all domains, attributes associated with composition and structure dominated; for Air, all attributes related to structure.
- Functional attributes were also quite common in all domains except for Air.
- Attributes for ecological representation and resilience were relatively few across the domains. Attributes for ecological representation were dominated by variations on broader environment or habitat extent (e.g., LENZ classes, threatened environments classification, FENZ classification of river reaches, coastal wetlands and substrates, human activities in coastal areas, and oceanographic features), with the marine-related (Coastal and Seabed, and Estuaries) domains and Terrestrial subdomain having the greatest number of such attributes. The presence or distribution of fine-scale features (e.g., keystone or indicator species) could also be used to provide a measure of representation especially if data were extrapolated across an area. Attributes relating to resilience were often measured by monitoring changes in an attribute associated with other EI components (e.g., composition or function) over time.
- Attributes specifically relating to indigenous species or indigenous biodiversity were identified for all domains except Air and the Soil subdomain. However, a number of biotic attributes, did not distinguish between indigenous or non-indigenous species (e.g., coastal macroinvertebrate community abundance and diversity), and in this regard, do not technically meet the requirements under the EI definition provided. Some other attributes were specifically related to non-indigenous species (e.g., non-native species diversity).
- EI components are interrelated. Biotic structural components can be based on composition information, some composition attributes relate to function, and attributes relating to resilience are often measured by attributes associated with other EI components such as composition and function.
- Similarities as well as some differences were identified between the MfE definition of EI and how EI is defined in the literature:
 - The MfE definition of EI aligned in many respects with EI definitions used in the literature for the Terrestrial subdomain and the Freshwater and marine-related domains. However, the Freshwater domain description also include consideration of reference condition, while 'knowledge of historical baselines' is included in the definition used for marine-related domains. For the Soil subdomain, EI is not used in the literature, but rather 'soil health' or 'soil quality', which can have a similar intent to the MfE EI definition, with the exception of the specification of 'indigenous biodiversity' in the MfE definition.

For the Air domain, it was also noted that the MfE EI definition could be strengthened to explicitly include climatic factors (rather than just abiotic physical factors) in the definition of structure.

Additional key points across domains are:

- A number of attributes are connected across domains. For example, erosion, compaction and leaching impact some form of water (ground, surface, coastal), vegetation cover can influence the extent to which erosion may occur; emissions of ammonia and greenhouse gases (CO₂, CH₄, N₂O) from soil affect air quality; and deposition of nitrogen-, sulphur- and contaminant-aerosols including dust can impact on all other domains. Across-domain attributes also relate to domain boundaries e.g., freshwater inputs are integrally linked with estuarine environments; coastal wetlands and dune environments can span below and above mean high water springs, and inland wetlands can span Freshwater and Land (including Soil) domains.
- Across domains, there was an unevenness in the development and use of attributes. For example, many of the Soil subdomain attributes are developed and applied in agroecosystems, whereas many Terrestrial subdomain metrics have been developed in indigenous forests and shrublands. Monitoring frameworks (and hence associated attributes) for Aotearoa New Zealand are well-developed at the national scale for the Freshwater domain in comparison to other domains generally. The marine-related (Coastal and Seabed, and Estuaries) domains include more activity-related metrics than the other domains, with many of these associated with fishing. For the Air domain, there was a dominance of climate-related attributes, which were also present in the literature for all other domains. Attributes relating to chemical contamination were common for most domains. Further, many systems are knowledge- or data-deficient, such as alpine areas, successional habitats, and naturally uncommon ecosystems. No attempt was made during our systematic search to quantify potential biases in the development and use of attributes.
- Gaps in potential attributes for different EI components for Aotearoa New Zealand were identified through the international literature for all domains.
- A common theme for emergent attributes across the Terrestrial and Soil subdomains and Freshwater and marine-related domains is the use eDNA or rRNA approaches, which potentially allow a more complete assessment of taxonomic groups or assessment of bacterial or fungal communities and in turn provide greater detail on composition and structure of those communities.

6. CONCLUSIONS

Our review of the literature yielded an abundance of potential attributes of EI. Our approach developed a documented and repeatable search of the literature and provides a crucial summary of knowledge from published and unpublished sources. Overall, there were a relatively high number of potential attributes identified for all domains except for Air. The number of attributes identified for each domain was Land (including Soil) (subdomains: > 150 for Terrestrial and 245 for Soil), Freshwater (251), Coastal and Seabed, and Estuaries (> 580 combined), and Air (37), with indigenous biodiversity considered as a cross-domain theme. Key points from our across-domain synthesis for the EI components are as follows:

- Across all domains, attributes associated with composition and structure dominated; for Air, all attributes related to structure.
- Functional attributes were also quite common in all domains except for Air.
- Attributes for ecological representation and resilience were relatively few across the domains. Attributes for ecological representation were dominated by variations on broader environment or habitat extent with a greater number captured for the marine-related (Coastal and Seabed, and Estuaries) domains and Terrestrial subdomain.
- Attributes specifically relating to indigenous species or indigenous biodiversity were identified for all domains except Air and the Soil subdomain. However, a number of biotic attributes did not distinguish between indigenous or non-indigenous species (e.g., coastal macroinvertebrate community abundance and diversity), and in this regard technically do not meet the requirements under the EI definition provided. Some other attributes were specifically related to non-indigenous species (e.g., non-native species diversity).
- EI components are interrelated. Biotic structural components can be based on composition information, some composition attributes relate to function, and attributes relating to resilience are often measured by attributes associated with other EI components such as composition and function.
- The MfE definition of EI aligned in many respects with definitions used in the literature for the domains. However, the Freshwater and marine-related domain descriptions also include consideration of reference or baseline condition. For the Soil subdomain, EI is not used in the literature, but rather 'soil health' or 'soil quality', which can have a similar intent to the MfE EI definition, with the exception of the specification of 'indigenous biodiversity' in the MfE definition. For the Air domain, it was also noted that the MfE EI definition could be strengthened to explicitly include climatic factors (rather than just abiotic physical factors) in the definition of structure.

Additional key points across domains were:

- A number of attributes were found to be connected across domains e.g., erosion or leaching, which traverse the land and water domains. Across-domain attributes also relate to domain boundaries e.g., riparian vegetation and tidal wetlands.
- Across domains, the development and/or use of attributes among different systems was uneven. For example, many of the Soil subdomain attributes are developed and applied in agroecosystems, whereas many Terrestrial subdomain metrics have been developed in indigenous forests and shrublands. Additionally, Freshwater attributes have been relatively well-developed into national scale monitoring frameworks. There was also unevenness across domains in relation to the type of attributes or threats they respond to. For example, there was a higher proportion of activities-based attributes (e.g., fishing-related) for the marine-related domains and a dominance of climate change related attributes for the Air domain, while attributes relating to chemical contamination were common for most domains.
- Gaps in potential attributes for different EI components for Aotearoa New Zealand were identified through the international literature for all domains.
- A common theme for emergent attributes across the Terrestrial and Soil subdomains and Freshwater and marine-related domains is the use eDNA or rRNA approaches to provide further detail on species presence and composition.

Section 9(2)(f)(iv)

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9. APPENDICES

Appendix 1. Lists of compiled potential attributes and associated metadata.

These are attached separately as supplementary files (excel, raw format) and titled as per the following:

- Terrestrial attributes_report format_20220930.xlsx
- Soil attributes_report format_20220930.xlsx
- Freshwater_attributes_report format_20220930.xlsx
- Coastal and Estuaries attributes_report format_20220930.xlsx
- Air attributes_report format_20220930.xlsx

Files containing Web of Science (WoS) literature search results can also be provided to MfE on request.

Appendix 2. This appendix contains additional information relevant to the Air domain.

Description of Attribute classes.

To allow some grouping in the Air domain, attributes were assigned a prevalence level based on usage in the literature and also a class based on common root causes or impacts. Additional information on each of these classes is as follows:

1. Surface pollutants: surprisingly, these attributes were not common within New Zealand studies. Ecosystems are impacted by surface pollutants, particularly sulphur and nitrogen oxides via deposition on water, vegetation and soils generally via wet deposition. Tropospheric ozone also affects the function and growth of vegetation. Acidification related to sulphur and nitrogen oxides affects nutrient cycling in ecosystems. Eutrophication, the process of accumulation of nutrients in water bodies, also often results from air pollution (see reviews by Bobbink et al. (2010), Pardo et al. (2011), Payne et al. (2017), and most comprehensively, US EPA (2020)). Recent international work detailed in Allen et al. (2022) also suggests that the prevalence of airborne microplastics is nearly ubiquitous globally and is therefore a potential threat for the marine-atmosphere environment worthy of monitoring. The general lack of literature in this space potentially highlights a knowledge gap which perhaps needs to be studied more broadly given the international literature.
2. Stratospheric ozone depletion attributes: the impacts of stratospheric ozone depletion on ecosystem function was also a relatively common theme. Metrics such as the concentration of ozone depleting substances allow an analysis of the effectiveness of global limits included within the Montreal Protocol. Note that many of the relevant attributes in this class are already monitored to support the Montreal Protocol.
3. Teleconnection related attributes: teleconnection indices related to El Niño Southern Oscillation, the Southern Annular mode and, less frequently, the Interdecadal Pacific Oscillation have been used by a number of studies as proxies to examine ecological sensitivity to natural climate variability. Note that these indices are already used and disseminated by Statistics New Zealand.
4. Light-related attributes: these attributes were either in the high or medium prevalence categories and some are collected commonly at meteorological observatories. However, many of the studies were at regional and/or local scales and would require additional monitoring for the attributes to be used nationally.
5. Temperature related attributes: temperature was the most commonly detailed abiotic physical feature used within the EI literature, with 68 separate references in the systematic and ad hoc searches combined. Various aspects of air temperature change attributable to human-induced climate change were identified, with indicators of changes in extreme temperatures being an important and high prevalence subset. These attributes must be considered within the EI context given the ecosystem-climate nexus. As for the precipitation class, the existing

- climate/weather monitoring networks provide reasonably good coverage of temperature attributes across the country.
6. Precipitation-related attributes: these connect to changing precipitation occurrence and intensity attributable to human-induced climate change and also to changing seasonality of precipitation. This class linked to high or medium prevalence attributes. These attributes must be considered within the EI context given the ecosystem-climate nexus. The existing weather monitoring networks across Aotearoa New Zealand provide a reasonably good coverage of precipitation attributes across the entire country, though the network is reducing in size and there are some areas of limited coverage, such as high elevation areas in South Island. There are also limited long-term time series available, which potentially limits attribution of cause and effect, but overall, long-term baseline data are available for use in identification of human-induced change throughout Aotearoa New Zealand.
 7. Greenhouse gas attributes: the impacts and mitigation possibilities related to greenhouse gases and ecosystems was also a common theme, though only carbon dioxide atmospheric concentrations meet the high prevalence criteria. The concentrations of these gases connect to the Paris Agreement and are common drivers used within modelling studies to predict human-induced climate change and thus provide useful attributes. Note that these attributes are already monitored across Aotearoa New Zealand to support climate change agreements.
 8. Other attributes: this class defines five other attributes which represent the potential impact of human-induced climate or other confounding factors on EI, namely the changing occurrence of wind extremes and changes in the frequency of weather conducive to wildfires as represented by fire indices. As for the precipitation class, the existing climate/weather monitoring networks provide reasonably good coverage of wind attributes across the country. The fire indices are also derived, collated and distributed via ongoing networks.

Note that the confounding factor classes relate to attributes that are very commonly identified in studies that discuss surface pollutants or stratospheric ozone depletion, or that relate to climate change related attributes which will likely act as threat multipliers.



Manaaki Whenua
Landcare Research

Te Ao Māori: Māori perspectives and mātauranga of soils

Soil guidelines Eco-SGV workshop, 9th February
2022.

Garth Harmsworth

(Te Arawa, Ngāti Tūwharetoa, Ngāti Raukawa)

Manaaki Whenua – Landcare Research, Private Bag 11-052, Palmerston
North

HarmsworthG@LandcareResearch.co.nz

Te Ao Māori: Key concepts for resource management, environmental management



- Tikanga, kawa (values, customary protocols, procedure, process)
- Whakapapa (ancestral layers, lineage, interconnections and interdependencies)
- Kaitiakitanga (to care for, guardianship, environmental responsibilities)
- Mana (prestige, authority), Wairua (spiritual dimension), Tapu (sacred, restricted use)
- Ritenga, tapu, rahui, noa (regulation, rules, management and use)
- Mauri (life force, vitality, essence, energy, spirit, quality)
- Taiao, taonga, taonga tuku iho (inter-generational use), tau utu utu – giving back
- Ora, oraanga, whaiora, hauora, mauriora, whenuaora (wellbeing, health – integral links between microbial health, plant health, animal health and human health)
- “Ki uta ki tai”, “Ngā maunga ki te ngutu awa”, Ngā maunga ki te moana” “ko te whenua ko au” “ko te awa ko au” – Mountains to sea approach (whole catchment, big picture, holistic)
- Te mana o te taiao, te mana o te wai, Te awa tupua (connections between land – papa, whenua, soil-oneone, water – wai, and atmosphere – hā, hau, hauora, kohauhau, huarere, āhuarangi)
- Te ao tūroa, whakapūmautanga, toitū, ū, tauriterite (finding permanence or balance in the system, equilibrium, sustainability)
- Maara kai, mahinga kai, hauanga kai (food, harvest sites)



Environment-ecosystems

Papatūānuku
Ranginui
Ātua

Wairua

Whanaungatanga

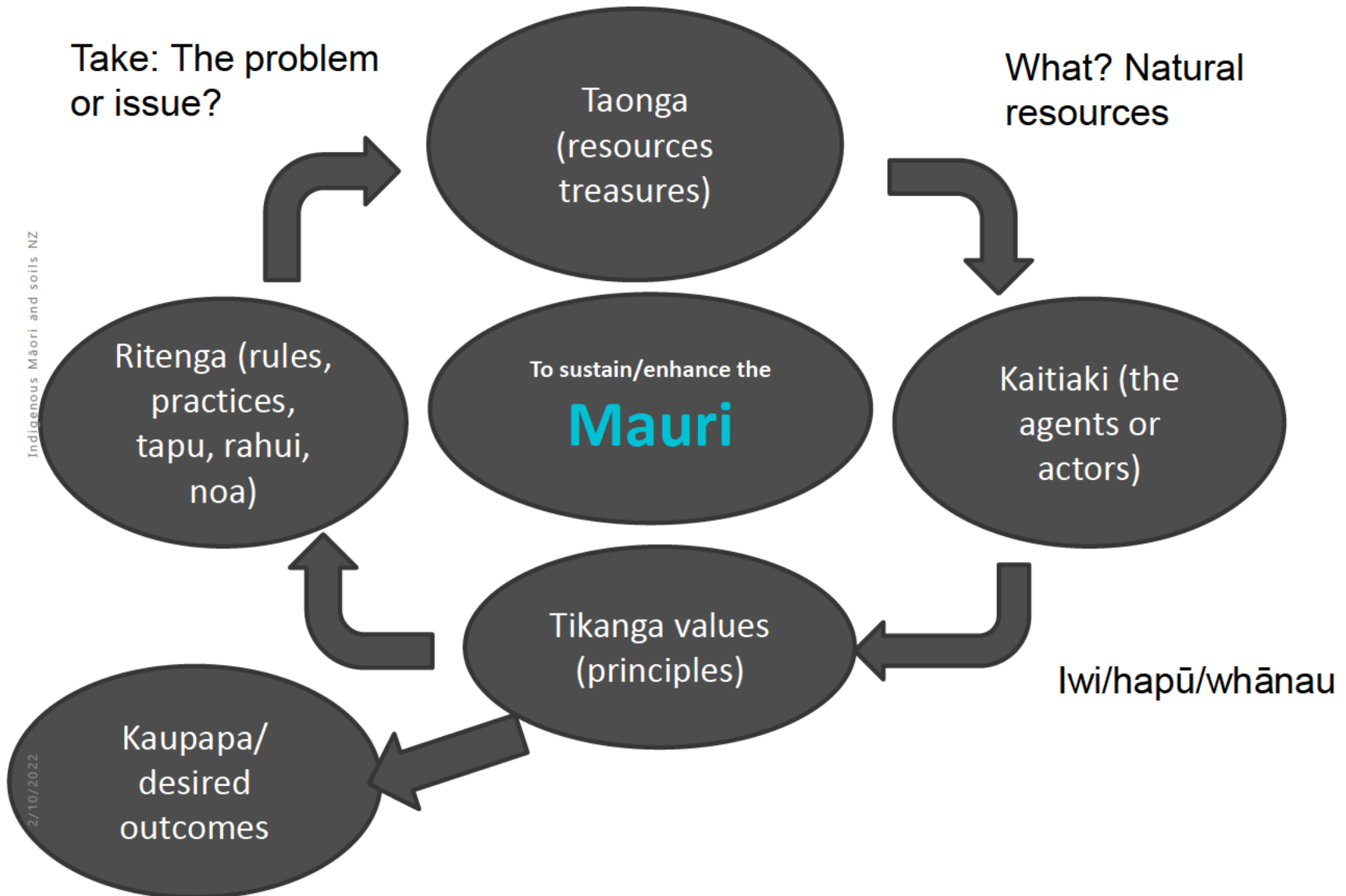
Hinengaro

Tinana

Physical
illness



Te Ao Māori conceptual framework (source: Hirini Matunga)





MBIE Soil Health Project (2016 – 2021)

Soil health: oneone ora, tangata ora

Full title: Soil ecosystem health and resilience – a pathway to prosperity and wellbeing

Three Main Objectives:

- I. Science excellence** – Soil Resilience (testing pedogenic thresholds) – Science approach/large scale field sampling and lab analysis
- II. Kaupapa Māori Research** – Develop Māori Soil Health concepts, frameworks, indicators, and soil management
- III. Integration, Management and Policy** – Develop an Integrated Soil Health Framework



Developing a longer term view of soil health

- Soil quality/health generally defined by dynamic soil characteristics (such as pH and soil nutrients) – largely inadequate to assess long-term changes to soil health and resilience.
- Currently soil resilience is poorly defined
- **Need to understand and explore the meaning of soil health from a kaupapa Māori perspective e.g. Māori values, principles, use inter-generational concepts of guardianship of land/whenua (e.g. kaitiakitanga, mana, mauri)**



Participatory research – who with?

- Māori researchers, iwi/hapū, Universities, CRIs, experts
- Iwi/Hapū/Kaitiaki groups, elders (e.g., Te Taitokerau, Rangitāne, Te Arawa, BOP-Tauranga, Waikato-Maniapoto, Taranaki, Te Waipounamu)
- Te Wharekura o Maniapoto (Rangatahi)
- Jessica Hutchings, Hua Parakore, Te Waka Kai Ora-Māori organics collective), Jo Smith – Victoria University
- Antoine and Shirley-Marie Coffin, Te Onewa consultants
- Teina Boasa Dean – Ngāi Tūhoe (PhD in mātauranga Māori and soils – Te Wānanga o Awanuiarangi, Whakatane
- Te Tumu Paeroa (largest Māori land manager in NZ)
- Māori land owners (Trusts/Incs)
- Māori businesses/industry groups
- Interviews, groups, hui/wānanga, workshops, field-days, surveys, etc.

Kaupapa Māori



Manaaki Whenua
Landcare Research

Present measures and indicators of soil health in Aotearoa-New Zealand do not recognise cultural perspectives or incorporate other knowledge systems, such as mātauranga Māori





Manaaki Whenua
Landcare Research

Kaupapa Māori Research Objectives

- Define Soil Health concepts and knowledge from a Māori perspective
- Local, Regional and National level Māori coordination and research
- Development of a Māori soil health framework and indicators
- Integration of key concepts and knowledge into a national assessment framework

Table 1: Complementary soil assessment/monitoring approaches



Kaupapa Māori soil assessments/indicators	Farm, community–technical & non-technical assessments	Science based – including professional scientific, technical assessments, and science based (statistical) sampling strategies
Kaupapa Māori based Mātauranga Māori knowledge based Based on Māori concepts and values <u>Examples:</u> Hua parakore (Maori organics) Kaitiaki assessments (pastoral, cropping, gardening, etc) Farm KPIs Rongo, whakatātare, kitenga, tiro (sensory assessments) Customary environmental indicators e.g. mahinga kai Cultural impact assessments Iwi/hapū/marae monitoring of contaminated sites Require in-depth Māori knowledge and understanding of particular environments and issues. Understanding of Māori values, goals, and aspirations. Kaupapa Māori approaches can include science and technical assessments. Examples: • Māori concepts, principles, and values • Kaupapa or mātauranga Māori based assessments and indicators • Traditional stories, narratives, gardening, maara kai, mahinga kai • Soil management guidelines, best practice • Land management, whenua, rongoā, kaitiakitanga Can include culturally based assessments for soil health and soil quality	<u>Examples:</u> • Can be subjective • Visual soil assessment (VSA) • Farm assessment • Farm indicators • Community based indicators (e.g. collectives) Can be subjective and practically based. Cost effective, relatively simple and short duration assessments linked to land management, soil management, farm operations, cropping, orchards, market gardens, hill country, etc. • Farmer, grower, orchardist, industry • Community values • Technical and non-technical assessments • School assessment programmes (soils and gardens) VSA pastoral, soil management, hill country, <u>Indicators:</u> • Soil structure and consistence • Soil porosity • Soil colour • Earthworm counts • Compaction–tillage pan, clod development • Soil erosion • Organic matter • Plant indicators	Scientific soil quality and soil health indicators: e.g., objective, measure 'soil quality' or 'soil health target range' <u>Example indicators measured</u> Organic reserves • Total carbon • Total nitrogen • Mineralisable nitrogen Fertility • Olsen phosphorus Acidity • pH Physical status • Bulk density • Macroporosity Trace elements Contaminated soils Use science based sampling strategy Laboratory analysis Require higher levels of technical input and skill, robust sampling strategies, analysis and interpretation, can be expensive and time-consuming.

Ngā kupu Māori



Māori names and English description	Māori names and English description
Haumako – to be fertile, rich, productive Mōmona – rich fertile land, in good condition Whakamōmona – enrich, make fertile Opihi, pihi – the place of good growth, plants springing up Makurutanga – abundance, fertility Tāmata – a new cultivated site Whakapara, whakaparapara – burning woody remains for incorporation as ash; adding compost Pātohe – an abandoned cultivation site or fallow site Ngakinga – garden plots, cultivation Maara kai – gardens	Titōhea, hūiki, tohetea; hahore – land barren or exhausted through cultivation Pākihi – to be dried up, barren land Koraha – infertile, barren land Akeake – poor land, infertile land Pūtutu – stunted, barren land Tuakau – sterile land, wasteland, barren land Pākeka – land exhausted through cultivation Whenua pākeka – poor land Pūwhenua, taekai, pāhoahoa – exhausted lands, barren, infertile (cf. sterile) Tuakau – inferior lands, waste lands, bog Hahore – barren land, desolate, infertile, unproductive land Kīrea – land exhausted by frequent cropping Rake – bare or barren ground (whakarake – to make bare)



Māori gardeners had at least 100 names for types of soil

Maori names for soils	Maori names for soils
One-pū – sand One nui – rich soil, consisting of clay, sand and decayed organic material One-matua – typically loam One mata – dark fertile soil Tuatara wawata – brown friable fertile soil suitable for kūmara One-pārakiwai – silt One paraumu – very dark fertile soil, friable One hanahana – Dark soil mixed with gravel or small stones One haruru – Light but good soil; sand and loam	One hunga – sea sand, sandy beach, sometimes mixed with mud One kopuru – soil found in wet situations One kōkopu – gravel, or very gravelly soil One kura – reddish, poor soil One pākirikiri – soil containing gravel One parahuhu – alluvium (also parahua) One punga – light spongy soil One tai – sandy soil, near tidal flats, near beach One tea – white soil, sandy volcanic material One takataka – friable soil One tuatara – stiff brown soil, needing sand or gravel worked in



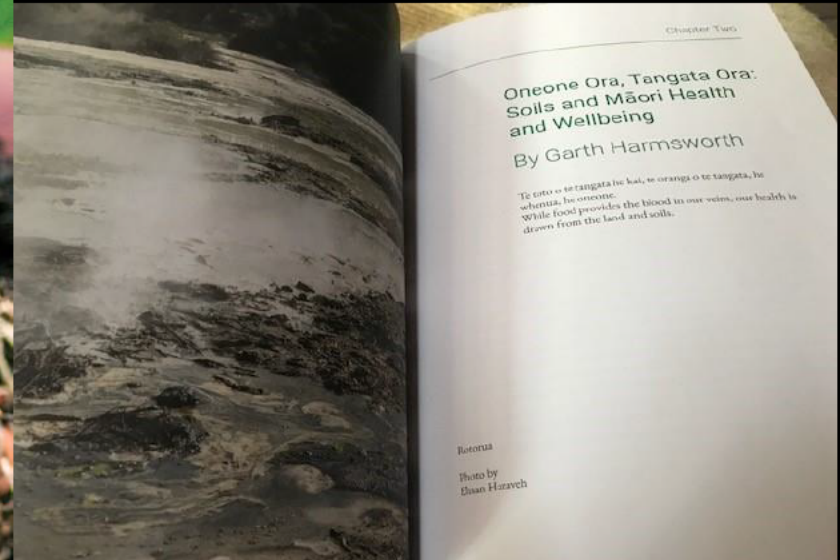
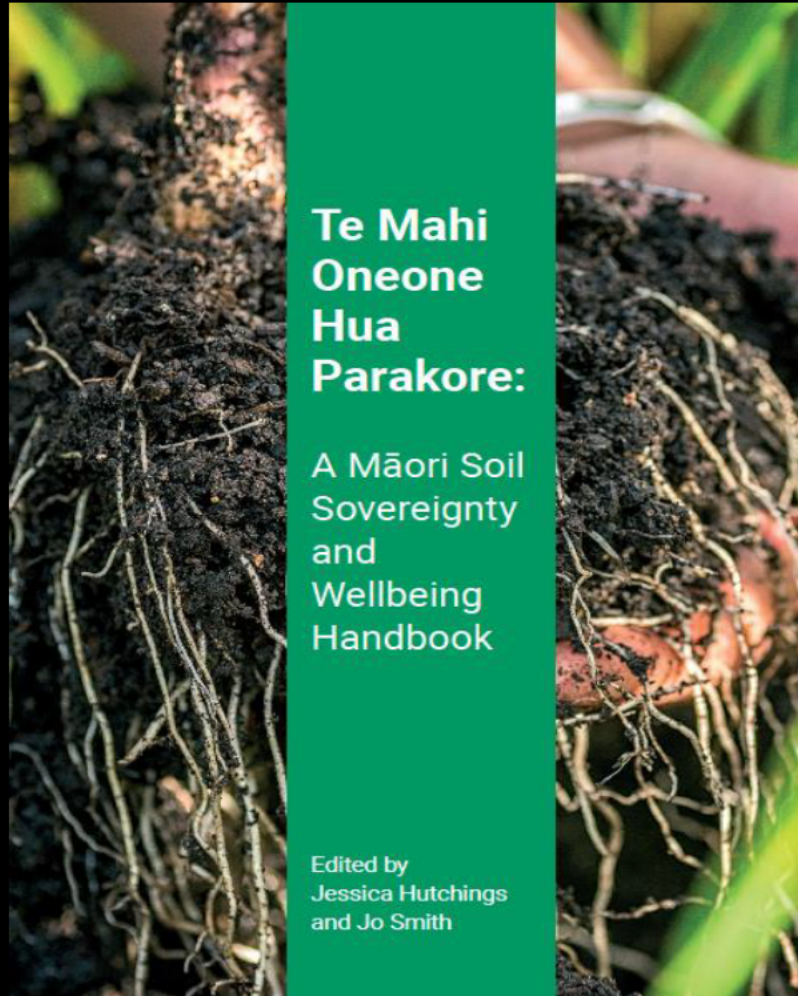
Maori names for soils	Maori names for soils
Kere was used as a prefix for some types of clay, including: keretū, kerematua and kerewhenua: Keretū - clay Kerematua – stiff clay Kerewhenua – yellow clay Kereone – sandy earth, e.g., near Morrinsville One wawata – lumpy soil Kirikiri tuatara – fertile brown soil	Kōtae – alluvial soil One tea – light sandy soil, near Dargaville. Kenepuru – sandy silt Kōtore – white clay Taioma – pipe clay Uku - unctous clay, white or bluish Uku whenua – plastic clay (old traditional name – KUPE AND NGAKE START FOR NEW ZEALAND JPS 1913. Matapaia – a clay when baked hard was used as a stone for cooking



<http://aotearoabooks.co.nz/te-mahi-oneone-hua-parakore-a-maori-soil-sovereignty-and-wellbeing-handbook/>

Māori soil health book

Hutchings J and Smith J. 2020. **Te Mahi Oneone Hua Parakore: A Māori Soil Sovereignty and Wellbeing Handbook**. 190p. ISBN 9780473516192. Free Range Press.



Visualising Māori Land

A prototype tool for accessing and interpreting environmental information about Māori land

[Home](#) [About](#) [Give Feedback](#) [Help](#) [Make an enquiry](#)

Nau Mai Haere mai - Welcome

This website is primarily intended to help Māori land owners and managers to find out more about the physical characteristics, constraints and potential of their Māori land blocks. To use this site either type the registered name of your land block in the search box above or using the map, zoom to the location of your land block and click on the land block's boundary. We welcome your thoughts and comments on the design of this tool.

Select a land parcel...

Terrain | Map | Satellite
Add an Overlay

Click on a Māori land parcel...

No overlay selected

You can select an overlay from the top left of the map

Limits for Taonga spp										
Taonga	Temp range °C	pH	T Nitrogen (ug/m³)	T Phosphorus (ug/m³)	Ammonia NH ₃ g/m³	Sediment (sensitivity)	DO(30 day mean) (mgL ⁻¹)	Habitat loss	Catchment condition	Predators (vulnerability)
Piharau (lamprey)	18-25	6.5-7.0	<0.7 <500	<20	Low-mod sensitivity	✓ (suspended)	>6.5 (>80%)	✓ v high	✓ (riparian, dams)	Humans
Tuna (eel)	22-25	6.5-7.0	<500	<20	Low-mod sensitivity	✓ (suspended)	>6.5 (>80%))	✓ v high	✓ (riparian, dams)	Humans
Toitoi (common bully)	20-22	8.7	<500	<20	High sensitivity	✓ not turbid	> 3mg/L ~6.0-9.0 (>80%)	✓ v high	✓	✓ (trout)
Kōaro	<13-20	7.6	<500	<20	High	✓ not turbid	8.0-9.0 (>80%)	✓ v high	✓ (loss of forest)	✓ (trout, smelt)
Banded kōkopu	12-18	6.5-7.0	<500	<20	High	✓ Most sensitive	8.0-9.0 (>80%)	✓ v high	✓	✓ (trout)
Giant kōkopu	11-15	6.0	<500	<20	High	✓ not turbid	8.0-9.0 (>80%)	✓ v high	✓ (loss of forest, dams)	✓ (trout)
Shortjaw kōkopu	12-18	8.3	<500	<20	High	✓ not turbid	8.0-9.0 (>80%)	✓ v high	✓ (loss of forest, dams)	✓ (trout)
Inanga	17-20	9.5	<500	<20	Low-mod	✓ not turbid, 420 NTU	8.0-9.0 (>80%)	✓ v high	✓	✓ (trout)
Kōura	<16	7.0-7.5	<500	<20	V high sensitivity	✓ not turbid	8.0-9.0 (>80%)	✓ v high	✓	✓ (trout, catfish, perch, etc.)
Smelt	15-17	8-9	<500	<20	High sensitivity	✓ not turbid	8.0-9.0 (90%)	✓ v high	✓	✓ (e.g trout)
Kākahi		7.0-7.5	<500	<20	High sensitivity	✓ v high	8.0-9.0 (90%)	✓ v high	✓	✓ (parasites)
Invertebrates		7.0-7.5	<500	<20	<0.8g/m³	✓ v high	8.0-9.0 (>80%))	✓ v high	✓	✓

Mauri assessment (waterway health) – freshwater (adapted from Hawkes Bay Regional Council Report Tukituki Choices. p66).



Attributes of mauri	How mauri can be enhanced/restored
Water depth, minimum flow	Increase minimum flow, maintain flows
Mahinga kai quality and availability Abundance/presence/scarcity of taonga species	Improve habitat for species such as tuna, native fish, taonga
In-stream nutrients	Reduce nutrient load from point source discharge and diffuse pollution sources
Native fish species (abundance/presence/absence/scarcity)	Ensure in-stream water quality parameters/analytes – e.g., phosphorus, toxicity, nitrates – can support and sustain native species populations and desired condition
Natural flow and flow variability	Ensure water takes do not significantly alter river and stream flow levels and improve flow variability by reducing the length of time flows are at or near minimum flow
Health of waipuna (freshwater springs) and aquifer quantity and quality	Ensure groundwater abstraction is sustainable and mitigations are implemented to minimise nutrient leaching
Wetland health	Ensure water takes do not drop the water table too low as to adversely affect wetlands, retain and restore culturally significant wetlands
Inter-connections between awa and people (marae/whānau/hapū/iwi)	Strengthen and support connections between people and waterways through cultural activities such as: increase understanding of mātauranga Māori, cultural health monitoring, customary rights, customary activities, mahinga kai, and recreation



Finding balance in the system – the principle of mauri

“Traditionally Māori acknowledged a natural order to the universe, a dynamic system built around the living and the non-living. Any shift in a system, for example through human interactions and/or impacts, cause shifts in the mauri of immediately related components. As a result, the whole system eventually becomes affected and degraded.

All activities and relationships are bound up and governed by principles and ethics and regulated by an elaborate system of tikanga, ritenga or rules.

The process is still used by Māori to guide resource use and management. Therefore, a key outcome for kaitiakitanga is to restore balance back the whole system, to maintain or restore the mauri, and to ensure this balance is maintained between people and the natural and spiritual worlds”.



²⁰ The following values and principles have emerged as integral to the understanding of soil health from a Māori perspective:

Mana, mana whakahaere/rangatiratanga/ mana motuhake, Mauri, Mahinga kai/Maara kai, Oranga ora, whenua ora, oneone ora, Whakapapa, Wairua, Taonga Tuku Iho.

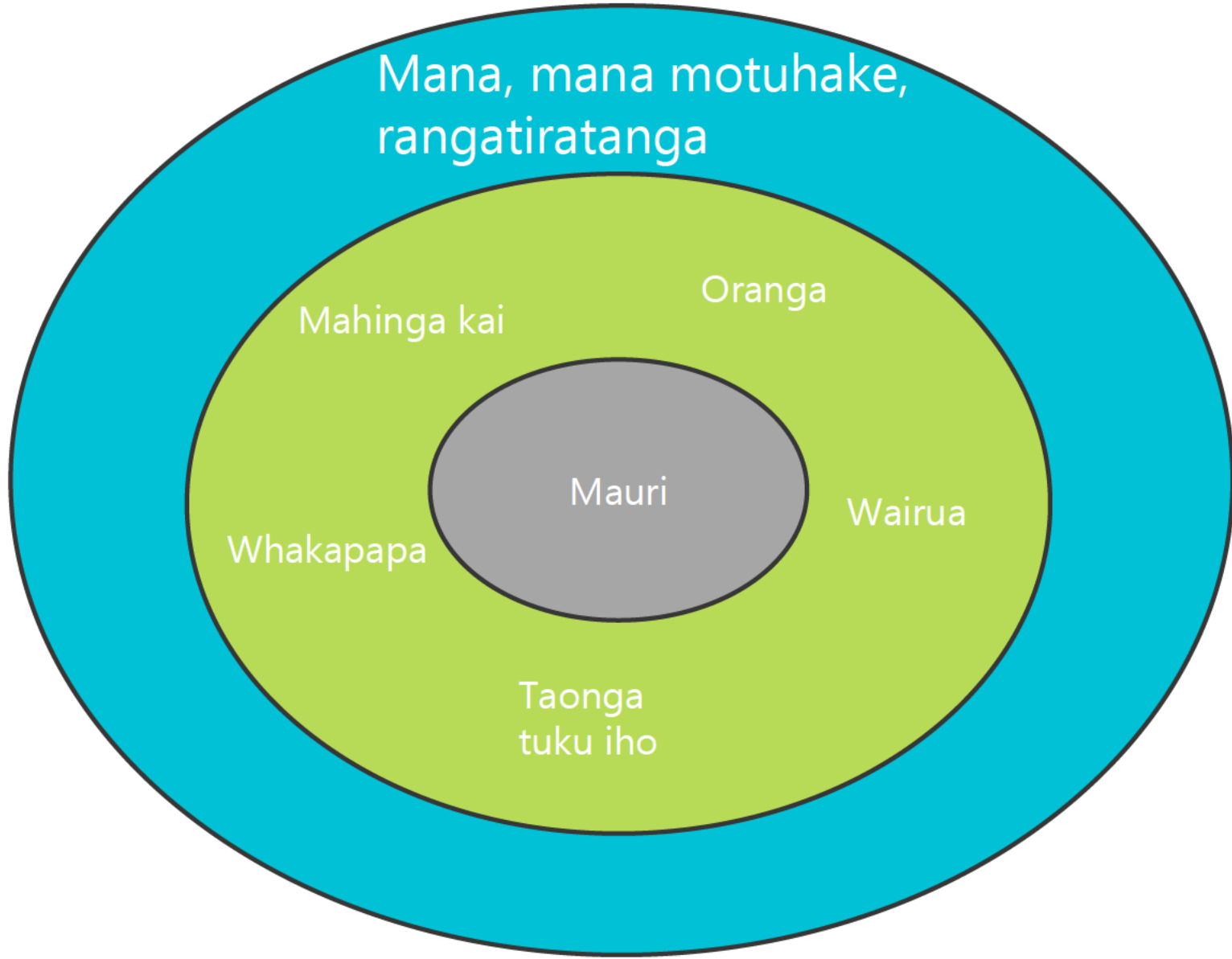
This provides the foundation for the development of evidence/datasets; finding the data required to establish if these principles are being met) and Māori soil indicators.



Maori soil health concepts and definition–*provisional*

(Soil health: oneone ora, tangata ora)

- Mauri (internal essence, life force, assessment, local knowledge) e.g. a healthy functioning soil fit for purpose and sustaining life, health, and prosperity, capacity of a soil to function as a living system to sustain mauri
- Mana (authority to manage and make decisions) also can imply the mana of a soil (as a living entity) – food sovereignty e.g. ability to make decisions over ones land, soil management guidelines and best practice
- Mahinga kai and Maara kai (the ability of the soil to provide sustenance, food sovereignty, and prosperity) e.g. area of soils that sustain gardening/organics
- Oranga, ora (measure of food safety and food health from soil) e.g. a soil free from pesticides and contaminants, meets food safety standards





Maori soil health concepts and early working definitions

“...the capacity of a soil as a living ecosystem to sustain and support all forms of life (to sustain microbes, plants, animals, humans and complex interconnections), through the maintenance of te mauri, to strengthen and enhance whakapapa, taonga tuku iho, mana, oranga, wairua, and whai rawa”

“capable of supporting, maintaining, and enhancing life and wellbeing”.

Soil health understood holistically (beliefs, whole ecosystem and interconnections – microbes to people)

Long term view of soil resilience (generational, “resilient soils, resilient people”)

“...Te Mana o te Whenua, te mana o te oneone, te mauri o te oneone”

“The mana of the land, the mana of the soil, the mauri of the soil”.



Māori soil health values and principles

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Core values/principles	Values/Principles – Description
Mana, mana whakahaere, rangatiratanga	Rights to manage land, soil, and resources, and exercise mana and kaitiakitanga over resources. Recognises the Treaty of Waitangi, Māori land versus tribal interests, iwi/hapū/whānau to express local through to national rights and interests (e.g. over resources, authority for decision-making, management).
Mauri	Life force, energy, vitality of the soil to sustain/support life and wellbeing. e.g. well-functioning soil ecosystems, full of soil biota, interconnections between physical, chemical, biological components and people.
Mahinga kai	Ability of soil to produce and sustain food for harvest and collection
Oranga ora, whenua ora, oneone ora	Ability of soil to provide and ensure health and wellbeing of people (ko au te whenua, ko au te oneone, ko te whenua/oneone ko au, ngā tangata), in accordance with tikanga and kawa, (e.g. no human waste) and supply healthy food. e.g., with no harmful contaminants, pathogens, pesticides, and free of toxicity. A well-functioning soil free of contaminants and waste in accordance with cultural values.
Whakapapa	Respect for ancestral links or lineage of the soil, connections back to ancestors, origins of Papatūānuku and Ranginui, Whenua, Ātua domains, also denotes family connections to place and between whānau/hapū/iwi.
Wairua	The spiritual domain or dimension. Conveys elements of whenua/soils to spiritual connections which bind the living to the non-living, the heavens to the earth, to give mauri and spiritual health which transcends through to people, food and resources.
Taonga Tuku Iho	Ability to sustain the soil resource for future generations, using concepts like kaitiakitanga and Te Ao Turoa. Intergenerational equity of the soil resource and its ability to provide for future generations. The soil resource is sustained, in as good or if not better condition for future generations.

Maori soil health datasets/evidence/indicators



Core values/principles	Types of data /evidence/indicators
Mana, mana whakahaere, rangatiratanga	Data/evidence that Māori are making decisions over their whenua, over their ngā oneone; This could be over tribal rohe (e.g. iwi /hapū management plans) or could be on specific land blocks/whenua where they have whakapapa and mana (e.g. kaitiaki, owners, beneficiaries). Decisions for enhanced soil health, using soil management guidelines, plans, and implementation of best practice on Māori land.
Mauri	Data/indicators which demonstrate the soil and people are in a healthy state and are connected, the system is in balance, indicators which show the vitality and energy of the soil resource, or the diminished state of the soil.
Mahinga kai	Data/attributes/indicators of mahinga kai, and that the mahinga kai is healthy and comes from healthy soils.
Oranga ora, whenua ora, oneone ora	Data/indicators of a healthy soil is providing healthy food, and healthy people. That practices for growing food from soil is following tikanga and guidelines for food sovereignty, food safety and food security. e.g., no harmful contaminants, pathogens, pesticides, free of toxicity. A well-functioning soil free of contaminants and waste in accordance with cultural values.
Whakapapa	Data/indicators which show the ancestral links between people and place, people and soils, and confers responsibility to those to manage soils for enhanced soil health and human survival and wellbeing
Wairua	Data/evidence that the wairua is intact, the spiritual health of the people is intact, and provides a connection between the spiritual and the physical, in order to sustain the soil in a healthy state. Binds the soil (like glue) to provide balance between mauri and mana.
Taonga Tuku Iho	Data/indicating a resilient healthy soil, that is able to provide opportunities for future generations. The soil is 'fit for purpose' in line with cultural values and Māori aspirations.

Maori soil health indicators (examples)



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Core values/principles	Soil health indicators
Mana, mana whakahaere, rangatiratanga	No. Iwi management /kaitiaki plans that refer to soils, soil health Land/soil management practices, to improve soils, implemented on Māori land Areal extent of healthy soils on Māori land % areal extent of land-uses/contaminated areas that reduce soil health on Māori land
Mauri	Mauri whenua ora/mauri being enhanced Soil ecosystems/soil biota that indicate well functioning soils (e.g. earthworms, porosity, OM) per (land area) High life supporting capacity, soil capacity/integrity high (land area) % area/tribal area: Strong connection between soils and people (e.g. area of soils used for gardening, cropping, mahinga kai, etc)
Mahinga kai	Mahinga kai areas are assessed as healthy with mauri intact, good-high People/whānau are healthy (proportion)
Oranga ora, whenua ora, oneone ora	Soil health is being maintained, within range, across all key indicators % proportion of food that is healthy and free of contaminants/pathogens/pesticides Human health/wellbeing is good to excellent (proportion of people v total)
Whakapapa	Whakapapa is recorded/transferred and known between people and whenua/soils, No. of wānanga/field studies on whenua/soils The ancestral links between people and place, is known Kaitiakitanga is practiced over natural resources, including soils
Wairua	The spiritual dimension/domain is important to local people Wairua is seen as part of maintaining/strengthening mana and mauri Wairua provides balance in the system, a well-balanced functioning soil ecosystem is achieved (e.g. kaitiakitanga and karakia practiced)
Taonga Tuku Iho	Soil health is maintained in areas for future generations Wise land use options are undertaken to maintain/enhance soil.

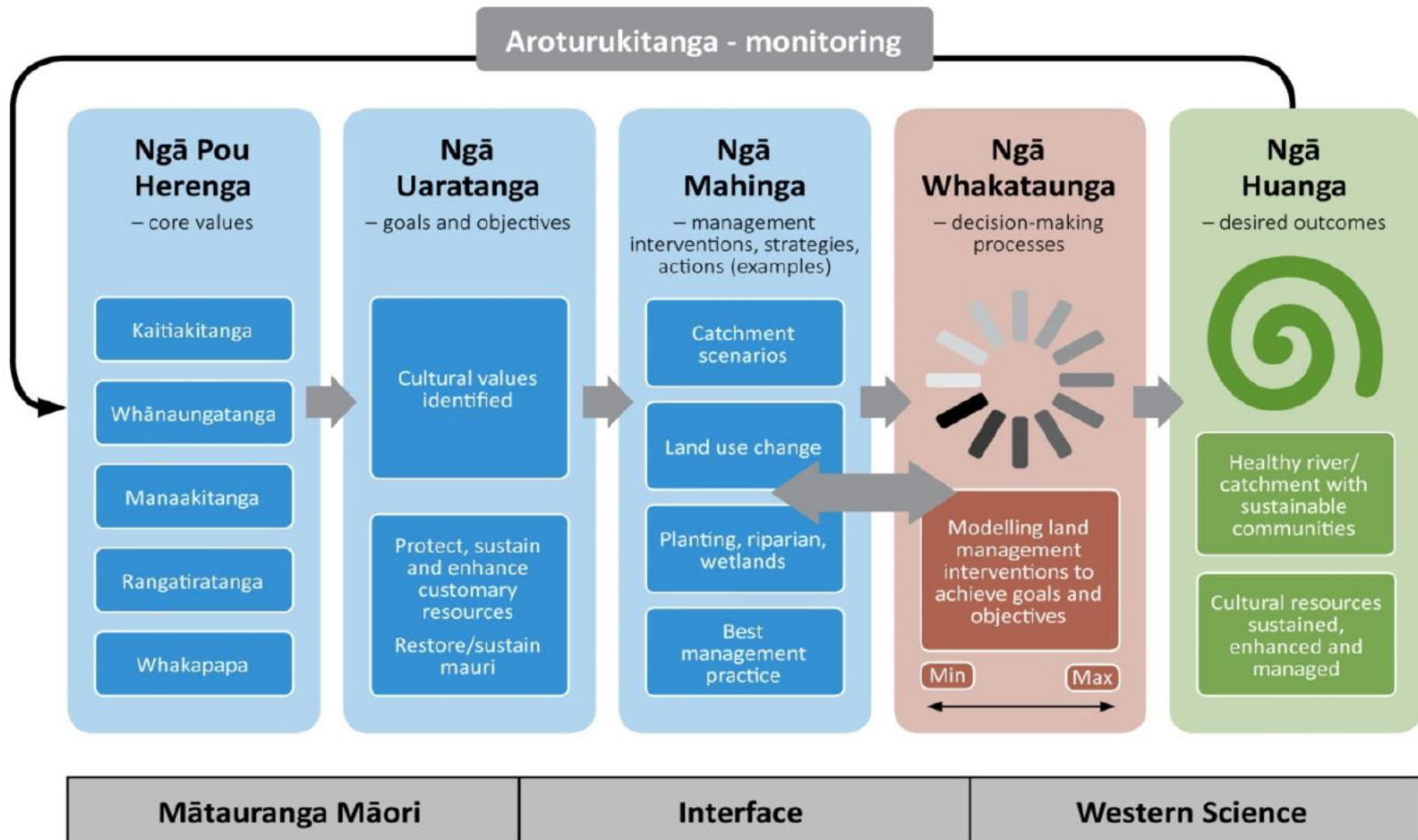
Soil indicators workshop

24/10/2022

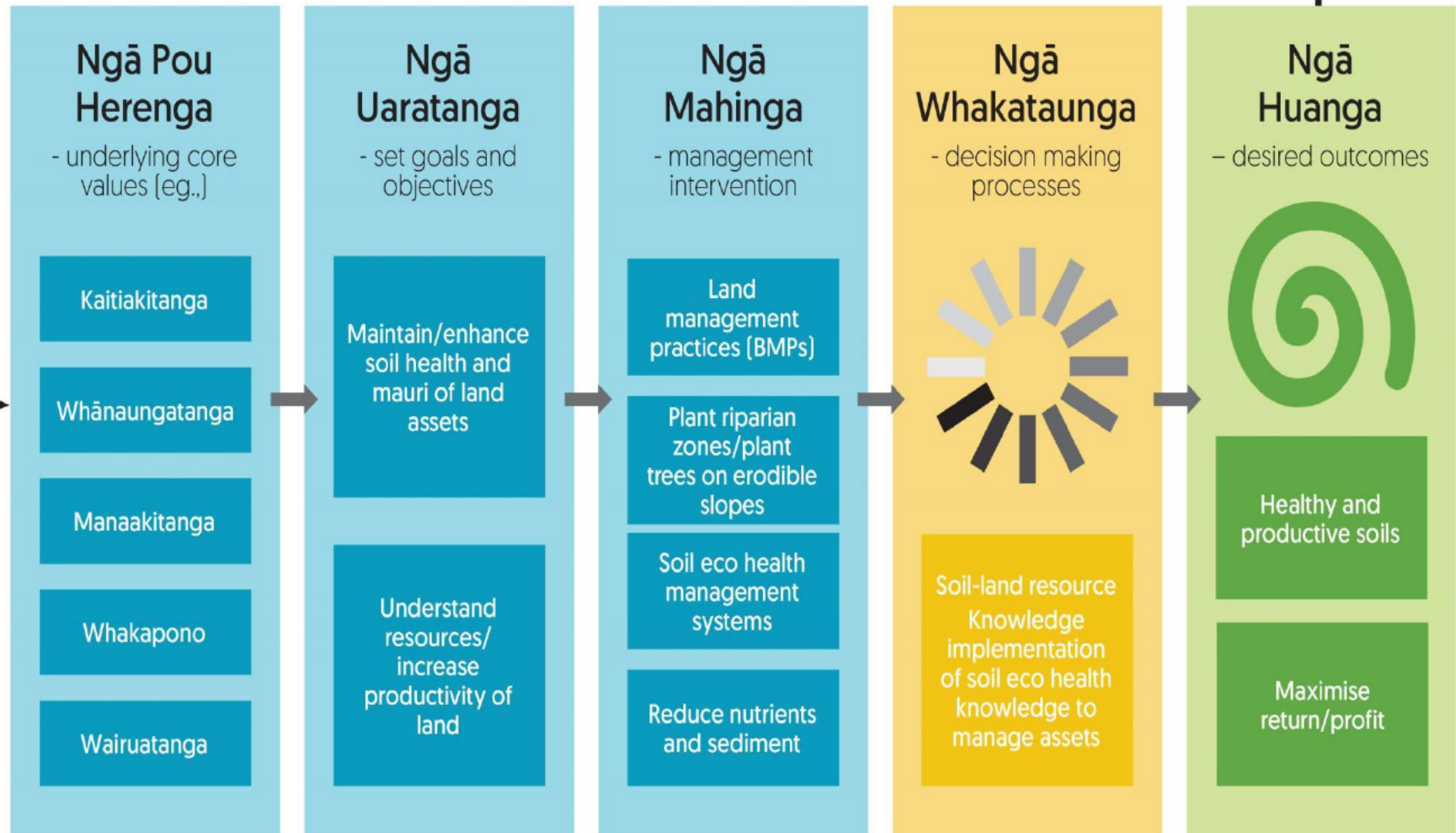
Kaupapa Māori modelling framework

Mātauranga Māori and science approaches can be used together to achieve iwi/hapū aspirational goals and outcomes/agreed outcomes

Mātauranga Māori and Modelling Interface



Aroturukitanga - soil ecosystem monitoring

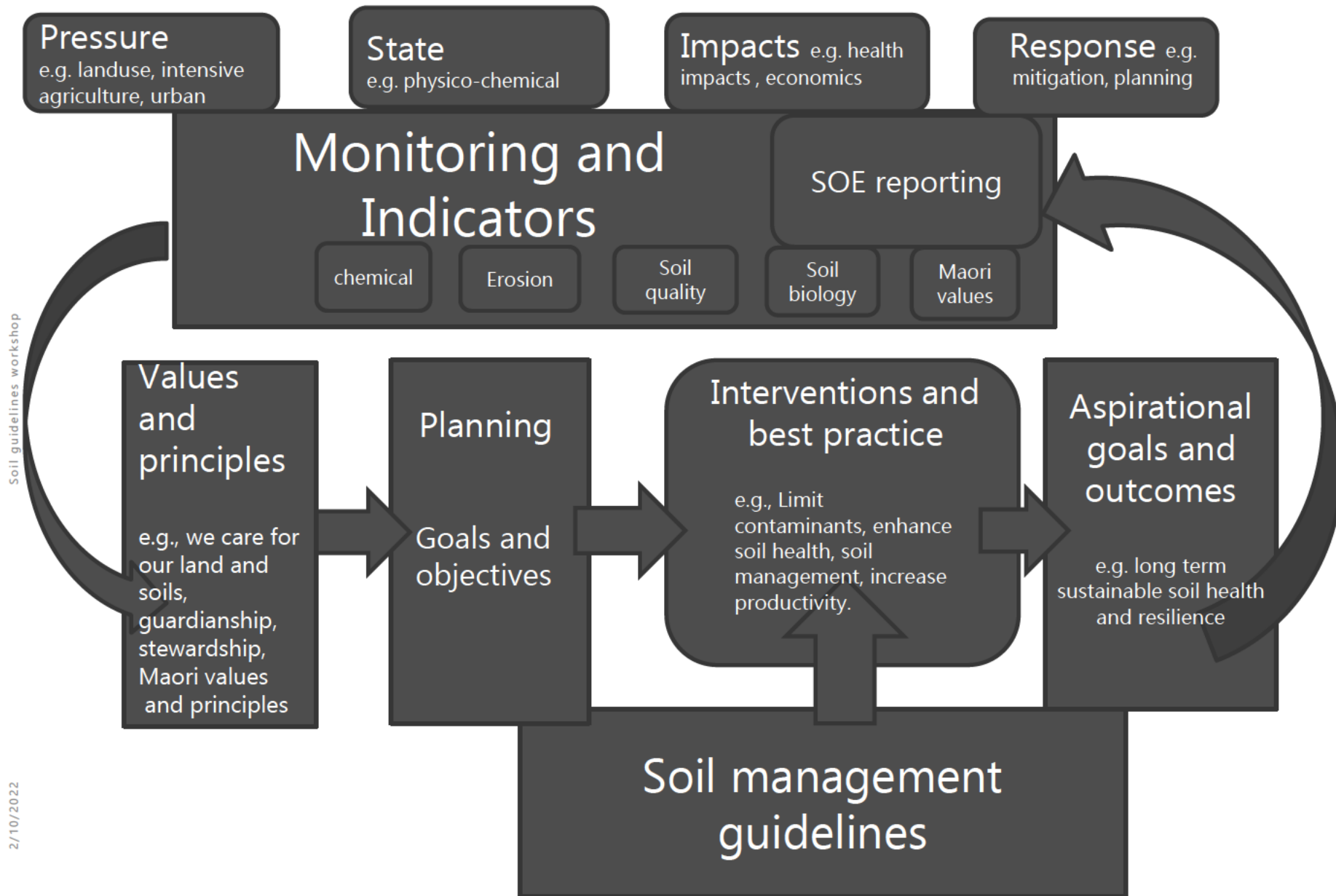


Mātauranga Māori

Interface

Western Science

An integrated soil health framework





A framework for Biodiversity Compensation and Offsets for harm to indigenous biodiversity in Aotearoa- New Zealand under the Natural and Built Environment Act

Prepared for: Ministry for the Environment

June 2022



A framework for Biodiversity Compensation and Offsets for harm to indigenous biodiversity in Aotearoa-New Zealand under the Natural and Built Environment Act

Contract Report: LC4131

Suzie Greenhalgh, Susan Walker and Robyn Simcock

Manaaki Whenua – Landcare Research

Sally Gepp, Madeleine Wright

Barristers

Reviewed by:

Dr William Lee (Independent)

Willie Shaw (Wildland Consultants Ltd)

Natasha Garvan (Bell Gully)

Dr Duane Peltzer (Manaaki Whenua)

Dr Olivia Burge (Manaaki Whenua)

Approved by:

Dr Geoff Kaine

Research Priority Area Leader

Manaaki Whenua – Landcare Research

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Summary

The Ministry for the Environment sought our advice on biodiversity offsetting and compensation to support the delivery of outcomes through the reformed resource management system. Consideration of and co-design with Māori was not part of our brief.

We propose a programmatic approach (as opposed to a piecemeal or project approach) for maintaining the ecological integrity of indigenous biodiversity for all Aotearoa-New Zealand's land except Māori Land. This Framework (Fig. S.1) is focused on terrestrial indigenous biodiversity, primarily on new activities. It takes account of the strengths, weaknesses, and failures of biodiversity offsetting schemes internationally, and of the unique characteristics and vulnerability of New Zealand's endemic and indigenous biodiversity. If our new resource management system fails to halt and reverse biodiversity loss, the species and ecosystems that are lost are lost globally. There is less margin for error here than in many countries.

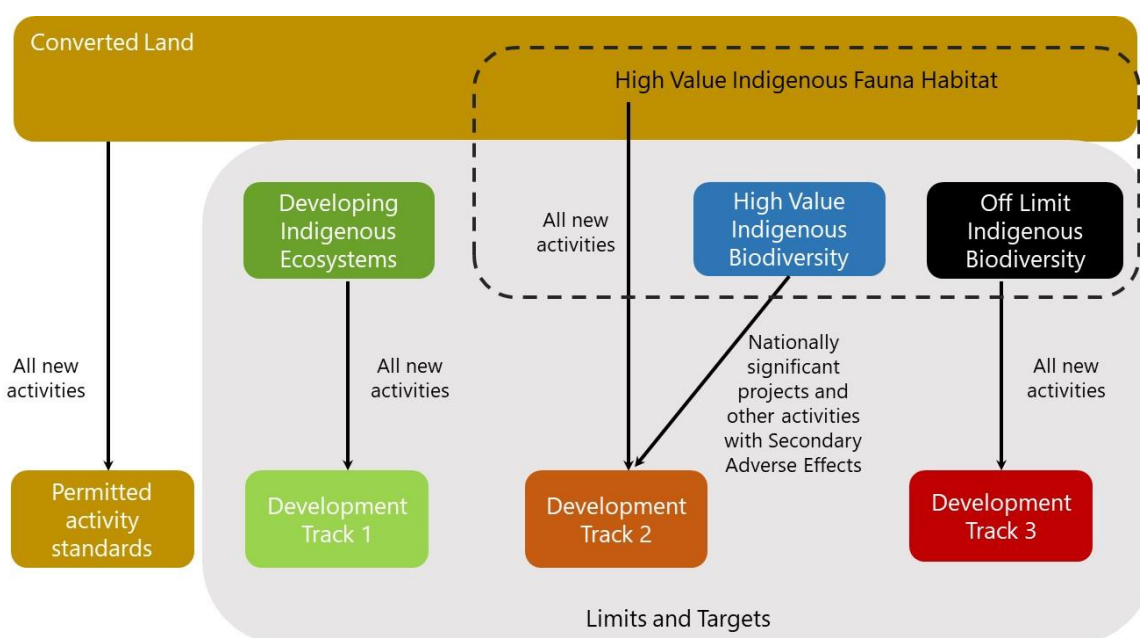


Figure S.1. Framework outlining Land Types and tracks for development.

The Framework divides land into four Land Types: Converted Land (c. 80% of all private land); Developing Indigenous Ecosystems (c. 10%); High Value Indigenous Biodiversity and Off Limit Indigenous Biodiversity (together c. 10%). A separate category of protected habitat for fauna is defined (High Value Indigenous Fauna Habitat) which can occur on any Land Type.

The four Land Types would be mapped by Regional Authorities. Limits and Targets for the land area of each Land Type would be set within Biodiversity Management Units defined by LENZ Land Environments. Within each Biodiversity Management Unit, activities would need to be controlled through permitted activity standards or a resource consent requirement to meet those Limits and Targets. High Value Indigenous Fauna Habitat would be mapped incrementally.

Three Development Tracks are proposed for effects management (Fig. S.1). Applying to all Development Tracks are: guiding principles for decision making; management of more than trivial **Adverse Effects** (as defined in Table S.1); distinctions between Primary and Secondary Adverse Effects; and avoidance where possible (where outright avoidance is not required). Development Track 1 has a different approach to managing more than trivial residual Adverse Effects than Development Tracks 2 and 3, and each has different requirements and implementation prerequisites.

Table S.1 Key definitions.

Adverse Effects: Adverse Effects describe a range of effects that negatively impact on indigenous biodiversity. Adverse Effects include but are not limited to the list below, which is divided into Primary Adverse Effects (1 to 4) and Secondary Adverse Effects (5 to 9).

Primary Adverse Effects

- a. Loss of ecosystem representation and extent
- b. Disruption to sequences, mosaics or ecosystem function
- c. Fragmentation or loss of buffering or connectivity
- d. A reduction in population size or occupancy of Threatened or At Risk species

Secondary Adverse Effects

- e. the degradation of mauri
- f. a reduction in the richness, abundance or viability of species in habitats and ecosystems
- g. pest vegetation or fauna incursions and changes that result in increased risk of incursions
- h. disruption to indigenous fauna by people and their pets and livestock and changes that increase the risk of disruption
- i. a reduction in people's ability to connect with and benefit from, indigenous biodiversity including from benefits such as
 - the historical, cultural or spiritual relationship of tangata whenua with their taonga; and
 - the scientific, educational, amenity, historical, cultural, landscape or natural character values of indigenous species and indigenous habitats; and
 - ecosystem services.

Biodiversity Compensation: an area-for-area based exchange for more than trivial residual Adverse Effects of an activity only on Developing Indigenous Ecosystems after applying the Effects Management Hierarchy, that meets the requirements in Section 6.3.1 of this report. Biodiversity Compensation can be provided either through a Biobank or through Developer-provided Compensation.

Note: Biodiversity Compensation has been designed to be a simple, low transaction cost approach. Developing Indigenous Ecosystems are the only ecosystems that can be exchanged in this way, because they comprise or include common and not-threatened indigenous species that can be replaced with reasonable certainty.

Biodiversity Offset: a bespoke set of actions undertaken in exchange for more than trivial residual Adverse Effects on High Value Indigenous Biodiversity, High Value Indigenous Fauna Habitats and Off Limit Indigenous Biodiversity that meets the requirements in Section 6.5.3 of this report. A Biodiversity Offset is undertaken only where avoidance of Primary Adverse Effects is not required, and after the Effects Management Hierarchy has been applied.

Note: Biodiversity Offsetting is more complex than Biodiversity Compensation, because it applies to indigenous biodiversity that is old, Threatened or At Risk, and cannot be readily or simply replaced, managed or monitored.

Effects Management Hierarchy: An approach to managing the Adverse Effects of subdivision, use and development that requires that:

- a. Adverse Effects are avoided where possible;
 - b. Adverse Effects that cannot demonstrably be avoided are remedied where possible; and
 - c. Adverse Effects that demonstrably cannot be remedied are mitigated where possible.
-

To prevent 'locking in' biodiversity decline, the Framework does not provide for exchanges of condition for area or number of species (i.e. 'averted loss' compensation and offsetting). To limit loss, it tightly restricts Adverse Effects on indigenous biodiversity that cannot be credibly replaced within a human generation, if at all. To limit interim loss, it requires enhancement actions to provide net gains while any new High Value or Off Limit Indigenous Biodiversity areas or populations mature.

Development Track 1 applies only to activities in Developing Indigenous Ecosystems (indigenous vegetation <25 years old). For all activities, more than trivial Adverse Effects are managed by applying the **Effects Management Hierarchy** followed by **Biodiversity Compensation** (as defined in Table S.1). All residual Adverse Effects on Developing Indigenous Ecosystems are exchanged for new areas of indigenous vegetation within third-party Biobanks or from Developer Provided Compensation, which are established and managed on Converted Land for the regeneration of indigenous vegetation. Biobank implementation is a priority for this system to work (Fig. S.2).

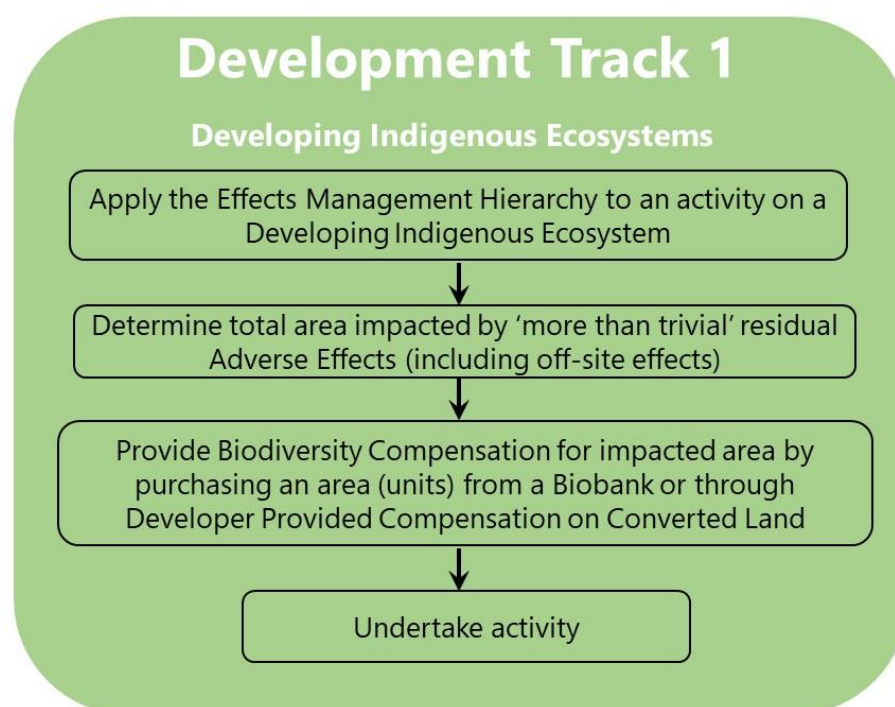


Figure S.2. Biodiversity Compensation process for Developing Indigenous Ecosystems.

Development Track 2 applies to different types of activities affecting High Value Indigenous Biodiversity. More than trivial Adverse Effects of Nationally Significant Projects and any activities affecting High Value Indigenous Fauna Habitat on Converted Land are managed by applying the Effects Management Hierarchy followed by **Biodiversity Offsetting** (as defined in Table S.1). All other activities must avoid Primary Adverse Effects and manage Secondary Adverse Effects by applying the Effects Management Hierarchy, followed by Biodiversity Offsetting (Fig. S.3).

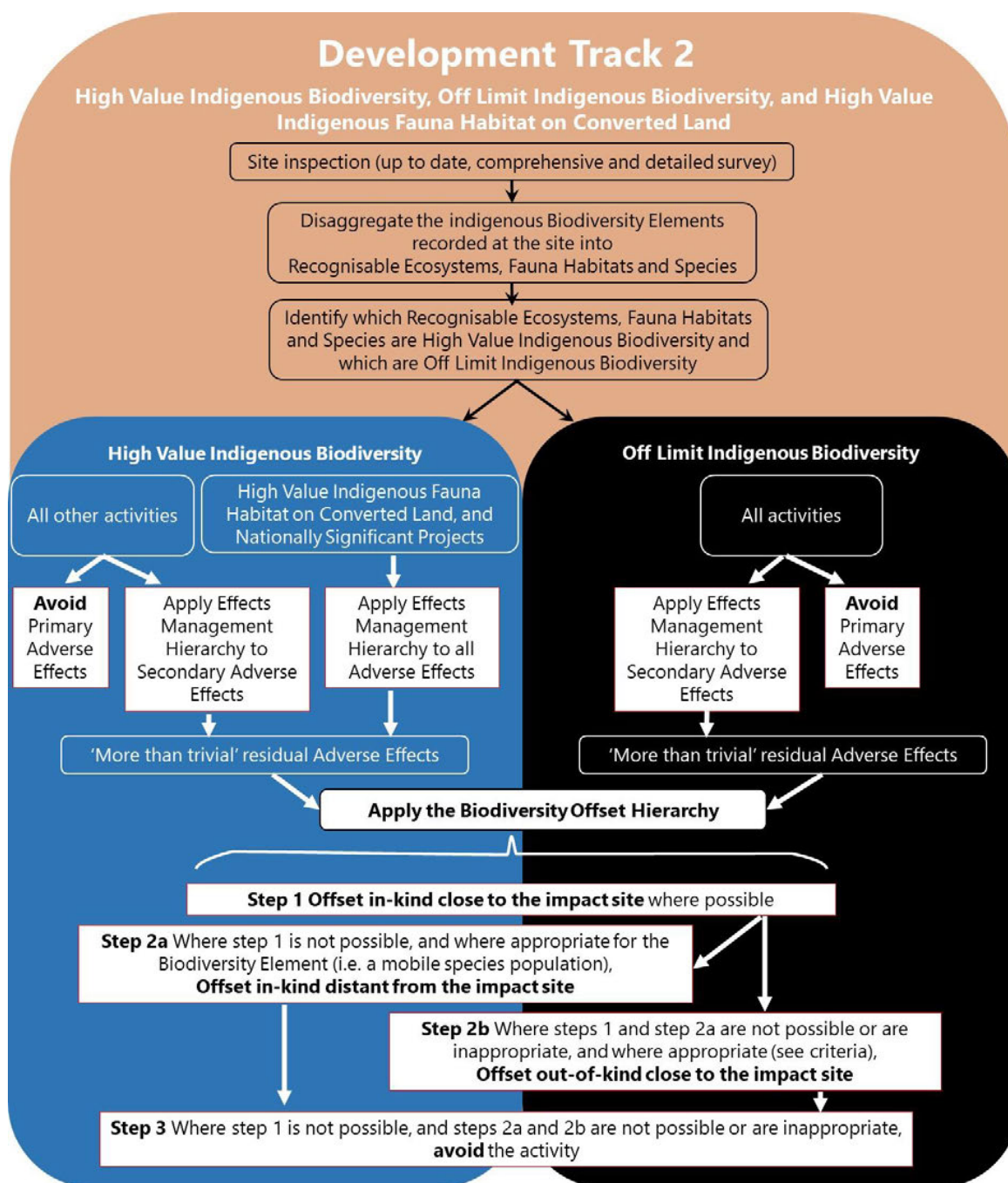


Figure S.3. Biodiversity Offset process for High Value Indigenous Biodiversity, Off Limit Indigenous Biodiversity and High Value Indigenous Fauna Habitat on Converted Land.

Development Track 3 applies to activities affecting Off Limit Indigenous Biodiversity, which is Aotearoa-New Zealand's most endangered Indigenous Biodiversity. There is effectively no way this biodiversity can be replaced if it is lost. All activities must avoid Primary Adverse Effects. Secondary Adverse Effects are managed by applying the Effects Management Hierarchy followed by Biodiversity Offsetting (Fig. S.3).

High Value Indigenous Fauna Habitat can occur on all four Land Types. Where it is located on an area that would otherwise be a Developing Indigenous Ecosystem, the area becomes High Value Indigenous Biodiversity. Where it is located on Converted Land, the Adverse Effects are managed by applying the Effects Management Hierarchy followed by Biodiversity Offsetting (Fig. S.3).

There is a hierarchy of Biodiversity Offsetting options. Under all options, all more than trivial residual Adverse Effects are exchanged for:

- new areas of indigenous ecosystems and species habitats established on Converted Land;
- new individuals of all impacted species populations (on Converted Land or in existing ecosystems); and
- enhancements in existing ecosystems to address interim loss.

In Biodiversity Offsetting, impacted Biodiversity Elements must be disaggregated, and bespoke sets of actions must achieve a net gain in all Recognisable Ecosystems, Fauna Habitat and Species.

Considerations pertaining to Public and Protected Land, new vs existing activities, and complementarity of the Framework to the NPS-FM and NPS-IB exposure draft (especially the identification and management of Significant Natural Areas by Territorial Authorities) are discussed at the end of the document.

Key technical requirements for implementing the Framework will be developing the data on Land Types; establishment of Biobanks; supporting additional expert capability in Councils; and effective monitoring and enforcement.

The success of this Framework in minimising further loss of indigenous biodiversity will depend on:

- how Limits, Targets and Biodiversity Management Units are defined and set,
- Nationally Significant Projects being constrained and clearly defined,
- whether multipliers are sufficient to discourage adverse effects on Developing Indigenous Ecosystems and (especially) High Value Indigenous Biodiversity and High Value Indigenous Fauna Habitat, which cannot easily be replaced (if at all).
- what monitoring and compliance mechanisms sit behind the Framework.

1 Introduction

The Government is in the process of reforming Aotearoa-New Zealand's resource management legislation. It plans to repeal the Resource Management Act 1991 (RMA) and replace it with three new pieces of legislation. The Natural and Built Environments Act (NBEA) will be the main replacement for the RMA. It will be supported by the Spatial Planning Act (SPA) which will require the development of regional spatial strategies and the Climate Adaptation Act. Through the NBEA, the Government seeks to create a single integrated National Planning Framework (NPF) that will incorporate the functions of existing National Direction. The NPF will be secondary legislation under the NBEA. The NPF will provide direction on matters of national significance and where national or sub-national consistency is desirable.

The Ministry for the Environment (MfE) is developing policy for biodiversity offsetting and compensation to support the delivery of outcomes through the reformed resource management system. It requires consideration of policy options for biodiversity offsetting and biodiversity compensation for developments with adverse effects on terrestrial, freshwater, and coastal/marine biodiversity. It intends that the work builds on the national directions set out in the National Policy Statement for Freshwater Management 2020 (NPS-FM) and Proposed National Policy Statement for Indigenous Biodiversity (NPS-IB), which were written in the context of the RMA. MfE requires that any policy for biodiversity offsetting and/or biodiversity compensation is fit for purpose under the reformed resource management system. Aspects of biodiversity offsetting and biodiversity compensation may be provided for in the NBEA itself, but the detail will likely be set out in the NPF.

This draft report responds to the above policy and legislative requirements and sets out a new proposed Framework to provide a robust system for biodiversity offsets and biodiversity compensation within the reformed resource management framework under development. Consideration of and co-design with Māori was not part of our brief.

The Framework has been prepared on the basis that it would be included in the NPF. The spatial identification of different indigenous biodiversity has been approached with Regional Spatial Strategies in mind. Some of the definitions, and comment on high-level matters such as use of the term 'trivial adverse effects' may influence the content of the NBEA itself.

Our analysis and recommendations focus on terrestrial ecosystems and terrestrial indigenous species. The requirements and high-level principles may be applicable to biodiversity offsetting and/or biodiversity compensation across all domains, but specific ecological factors in non-terrestrial domains would need further consideration. There are also existing statutory instruments (e.g. the New Zealand Coastal Policy Statement 2010 and the NPS-FM) that already set out policy relevant to biodiversity offsetting and biodiversity compensation within the coastal/marine and freshwater domains.

2 Background

2.1 International context summary

Biodiversity is declining in the sixth and potentially most extreme mass extinction globally, with a larger number of species going extinct at a faster rate than ever before. The main direct drivers of biodiversity loss are habitat transformation for development, overexploitation, invasive species, nutrient loading, and climate change.

As development has faced increasing pressure to avoid adverse effects on biodiversity in the last two decades, regulatory biodiversity offset programmes have become popular internationally (Bull & Strange 2018). However, environmental outcomes of offsets are rarely robustly monitored or reported on (Bull et al. 2013; Bezombes et al. 2019; Josephsson et al. 2021). Reported outcomes usually use simplistic outcome measures, such as aerial coverage or compliance with permit criteria (Marshall et al. 2020). Levels of compliance and enforcement with law, policies, and guidance pertaining to biodiversity offsets are low around the world (e.g. Fox & Nino-Murcia 2005 (USA); Quigley & Harper 2006a; Clare & Krogman 2013; Poulin et al. 2016 (Canada); Brownlie et al. 2017 (South Africa); May et al. 2018; Australian Auditor-General 2020 (Australia)) and the majority of measured outcomes fall short of stated objectives (e.g. Quigley & Harper 2006b; Poulin et al. 2016; May et al. 2017; Thorn et al. 2018; Gibbons et al. 2018; zu Ermgassen et al. 2019).

Biodiversity offsets and compensation often allow increased legal protection and/or new management of existing ecosystems to be exchanged for the permanent loss of others. The logic of this 'averted loss' (or 'avoided loss') paradigm and approach is that the protected or managed biodiversity might otherwise be lost in the future due to unregulated effects (e.g. through clearance, or through deterioration in the absence of management). International experience is that 'averted loss' biodiversity exchanges perversely 'lock in' or accelerate rates of habitat loss (Quétier & Lavorel, 2011; Bull et al. 2013; Maron et al. 2015; Simmonds et al. 2020), by providing for continued expansion of the footprint of development and further direct clearance or removal of indigenous flora and fauna species' habitat (e.g. Gibbons et al. 2018; zu Ermgassen et al. 2021). Because maintaining the extent of flora and fauna habitat is critical for maintaining the ecological integrity of indigenous biodiversity (Andren 1994; Tilman et al. 1994, Hanski 2005, Banks-Leite et al. 2020), an averted loss approach enables continued biodiversity decline.

If development continues to remove ecosystems, maintaining indigenous biodiversity depends – at a minimum – on creation of new ecosystems and species habitats to replace them, through ecological restoration. However, creation of new ecosystems has limitations, such as:

- Habitat clearance in advance of restoration will create time lags in habitat availability that compound adverse effects of past loss (Bekessy et al. 2010; Banks-Leite et al. 2020).
- While ecological restoration can enhance indigenous biodiversity, it rarely results in the full recovery of biodiversity, vegetation structure, or ecosystem services (Benayas et al. 2009).

- Over time, more rapidly developing ecosystems (e.g. restored herbaceous wetlands; e.g. Meli et al. 2014) are more likely to match intact reference states than slower-developing ecosystems (e.g. forests, Crouzeilles et al. 2016; Jones et al. 2018; forested wetlands, Shafer & Roberts 2008).
- In all ecosystems, success of ecological restoration depends not only on context (e.g. environment, type of past land use, propagule source) but also on what is measured (e.g. in restored wetlands, simple biodiversity metrics matched intact reference states, but biotic interactions, terrestrial and aquatic habitat measures, and biogeochemical cycles did not; Meli et al. 2014).

The outcomes of ecological restoration used to offset or compensate for development are similar. In a review of 32 reports of no net loss policies and individual biodiversity offset outcomes, zu Ermgassen (2019) found one-third (primarily in wetlands) reported achieving no net loss, although most studies used widely criticized area-based outcome measures (e.g. aerial coverage or compliance with permit criteria). No study had demonstrated success for forest habitats or species despite two-thirds of the world's biodiversity offsets being applied in forested ecosystems.

Against that background, we agree with Maron et al. (2012) that biodiversity offsetting and compensation places substantial faith in the ability of ecological restoration to recover lost biodiversity; that most ecological expectations for restoration embedded in offset or compensation policies remain unsupported by evidence; and there are few ecosystems in which exchange of habitat removal for ecological restoration can potentially deliver 'no net loss'.

2.2 New Zealand context summary

Nature and state of indigenous biodiversity

Aotearoa-New Zealand's indigenous biodiversity is recognised internationally for its distinctive and unusual character, the vulnerability to extinction of numerous species, and the high rate of extinctions that followed human settlement in some groups (Walker et al. 2017). Remarkably high levels of endemism, presence of unusual and often ancient biota, and extraordinary diversity in particular groups are collectively unique to Aotearoa-New Zealand.

Aotearoa-New Zealand has, by international standards, a high proportion of its land area legally protected for natural heritage. However, the ecosystems that remain relatively intact, and that are well protected in public and private conservation areas, do not represent the full variety of ecosystems and hence indigenous biodiversity. Most terrestrial ecosystems and habitats for indigenous species in coastal, lowland, and mid-elevation environments have been substantially reduced and altered by human impacts. Little of the indigenous biodiversity remaining in these areas are securely protected against development and clearance (Cieraad et al. 2015). Of Aotearoa-New Zealand's 71 naturally uncommon ecosystems (Williams et al. 2007), 45 (63%) are classified as threatened, just 36% of ecosystem types – mainly those remote from or inaccessible to humans – are not currently considered to be threatened (Holdaway et al. 2012).

Successive State of Environment reports document a steady decline in indigenous biodiversity this century, in part due to the failure of the RMA to slow the three intertwined drivers of habitat loss (for vegetation and fauna), fragmentation, and degradation (collectively 'habitat transformation'; Banks-Leite et al. 2020). Habitat loss drives fragmentation, and vice versa, and both lead to degradation through edge effects (e.g. changes in the edge environment and ingress of nutrients, weeds, and pests) and changes to species composition and ecosystem functioning. These changes are usually very difficult to remedy and reverse (unlike, for example, effects of mammal predators on fauna; Walker et al. 2017).

Mitigating and reversing impacts of habitat transformation on indigenous biodiversity in Aotearoa-New Zealand will require a combination of preventing further habitat loss while simultaneously extending and repairing those habitats and ecosystems that remain. All three approaches are required, especially in landscapes where the least indigenous biodiversity remains. Many existing ecosystems will continue to degrade unless repaired (see for example Clarkson 2022). However, repairing some areas while enabling further clearance of habitat will compound habitat transformation and consequent indigenous biodiversity loss through fragmentation and edge effects. Hence it is a premise of this Framework that while enhancing existing and depleted areas is very important, maintaining indigenous biodiversity depends fundamentally on retaining and then expanding the extent of ecosystems that remain now to support indigenous biodiversity.

Ecosystems dominated by exotic species now provide essential habitat for a high proportion of Aotearoa-New Zealand's indigenous species, and retaining highly modified and exotic-dominated habitats is critical for maintaining Aotearoa-New Zealand's indigenous biodiversity. Especially in the flatter, low-elevation and drier landscapes where past habitat loss has been greatest, many species now depend for their persistence on vegetation that includes a very high proportion of exotic species. Further loss of the highly modified or exotic-dominated habitats of indigenous species in these landscapes would severely compound effects of past habitat loss, fragmentation, and degradation, driving many indigenous flora and fauna species to local extinction and threatening the viability of others.

Those characteristics that make Aotearoa-New Zealand's biota so highly unusual and threatened also make it especially poorly suited to replacement once lost to development. Exceptionally high rates of extinctions following human settlement, and exceptionally high numbers of threatened ecosystems and species today, reflect fundamentally slow growth rates and limited capacity for regeneration in many groups. An unusually high proportion of indigenous fauna have low mobility (e.g. flightless insects) so are slow to spread to new habitat. These factors mean that remediation or restoration of adverse effects on many terrestrial Aotearoa-New Zealand ecosystems and species is either not possible, very difficult, costly, and/or protracted, in contrast to most anthropogenic habitats (pasture, crops, and exotic forestry plantations) and many introduced species.

Current legal framework relating to biodiversity offsetting and biodiversity compensation

Biodiversity offsetting and biodiversity compensation are not expressly provided for under the RMA. The RMA does, however, include a requirement for consent authorities to have regard to measures proposed by a consent applicant to offset or compensate for residual adverse effects on the environment.

Many regional policy statements, or regional or district plans now provide for consideration of biodiversity offsets and biodiversity compensation. Some include a requirement for biodiversity offsetting or compensation in certain cases, others provide for one and not the other. The factors that must be met for a proposal to qualify as a biodiversity offset or biodiversity compensation (often referred to as principles) vary greatly around the country, although this has improved in second generation planning documents. Generally, the principles in place are beginning to reflect (if not perfectly) the principles set out in the international biodiversity offsetting principles (e.g. ten Kate et al. 2018).

Some aspects of current practice are relevant to this Framework and include:

- In some policy statements or plans, the biodiversity offsetting or compensation principles include 'limits' to offsetting.¹ These limits state when a biodiversity offset is not appropriate. Including limits to offsetting or compensation within the principles applying to them creates challenges for implementation because of uncertainty about the extent to which they should be determinative (i.e. if they cannot be met the proposed activity cannot be undertaken). Opposition to treating limits as determinative is often on the basis that if the areas or effects to which the limits relate were intended to be 'absolute no goes' they would have been identified as effects to be avoided, before getting to the point of looking at offsetting.
- Biodiversity compensation is sometimes defined to include actions like funding a community facility or research (e.g. a PhD) in response to loss of indigenous biodiversity being authorised. This does not align with achieving maintenance of the ecological integrity of indigenous biodiversity.
- Biodiversity offsets and biodiversity compensation often include a mix of actions focused on planting and establishing new areas of indigenous vegetation or habitat, and actions focused on protecting, managing, and enhancing existing areas of indigenous vegetation or habitat. The current practice of substituting enhancement for area (i.e. a form of averted loss) is discussed later in this report.

¹ See series of decisions confirming limits to biodiversity offsetting and compensation to be included in the Otago Regional Policy Statement: *Ocean Gold (NZ) Ltd v Otago Regional Council* [2020] NZEnvC 137; *Oceana Gold (NZ) Ltd v Otago Regional Council* [2020] NZHC 436; *Oceana Gold (NZ) Ltd v Otago Regional Council* [2019] NZEnvC 41.

3 Foundation of proposed Framework

3.1 Requirements to meet legislative intent

Ecological integrity goal, achieved through limits and targets

The goal of Biodiversity Offsets and Biodiversity Compensation is to help deliver on the outcomes for the natural environment sought through introduction of the NBEA. In particular:

- Protect and restore the 'ecological integrity' of the 'natural environment', including, specifically, the ecological integrity of indigenous biodiversity.
- Achieve the above through maintaining the current state of the 'natural environment' and in the longer term reaching a target state for the 'natural environment', at a defined Biodiversity Management Unit scale.
- Set the current state through identified Limits and the target state through identified Targets.
- Enable activities in such a way and/or within locations so that Limits (in the short term) and Targets (in the longer term) are met.

Biodiversity Offsets and Biodiversity Compensation must sit within a consistent wider Framework

If Limits and Targets are to be met, and ultimately to protect and/or restore ecological integrity, Biodiversity Offsets and Biodiversity Compensation must sit within a comprehensive resource management system. Therefore, in providing advice on Biodiversity Offset and Biodiversity Compensation it has been necessary to provide a more comprehensive Framework that addresses the management of effects of activities on terrestrial indigenous biodiversity in Aotearoa-New Zealand generally.

Specifically, within our Framework (Section 6) we have provided broader advice on

- Setting Limits and Targets, including:
 - What Limits and Targets should be (Section 6.2.1), including what is to be maintained through Limits and reached through Targets, and how 'maintain' for the purposes of 'maintaining' current state should be defined
 - What a Biodiversity Management Unit should comprise (Section 6.2.2)
- How adverse effects should be managed to meet Limits and Targets for indigenous biodiversity, including the requirements Biodiversity Compensation or a Biodiversity Offset must meet, and when and in what situations they should be available, or not.

Biodiversity Offset and Biodiversity Compensation must respond to lessons learned

Our Framework aims to minimise the negative outcomes for indigenous biodiversity seen in other jurisdictions, where biodiversity offsetting and biodiversity compensation have resulted in continued loss (Section 2.1). If problems with schemes that lead to continued loss are not corrected, Limits and Targets under the NBEA will not be met and indigenous biodiversity will continue to decline. Our Framework also builds on positive experiences and international research on what makes for a straightforward and effective biodiversity offsetting or biodiversity compensation scheme.

Offsetting and compensation must recognise the distinctive character of Aotearoa-New Zealand's indigenous biodiversity

Our Framework also accounts for the globally distinctive and unusual character of Aotearoa-New Zealand's indigenous biodiversity, especially its vulnerability and depletion, and its slow growth and limited capacity for regeneration (Section 2.2). It recognises that because of these unusual characteristics, scope for redressing adverse impacts on indigenous biodiversity is more limited in Aotearoa-New Zealand than in countries where biodiversity has coevolved with mammals (including humans over thousands of years, e.g. burning in North America and Australia; habitat clearance in Europe), and/or include a high proportion of species that have effective dispersal capabilities and rapid evolutionary adaptation.

3.2 Framework structure

In our Framework:

- Necessities for the Framework to achieve outcomes are provided as **requirements** rather than principles. These requirements must be met to give effect to the legislative intent. Principles, in our experience, are not always applied in practice nor seen as compulsory, which often leads to failure.
- The **principles** we do outline (Section 6.1) sit outside requirements and are provided solely to guide decisions where the context is not clear, and where there may be uncertainty around the decisions to be made.
- **Implementation guidance** provides recommendations for efficiently and effectively implementing the Framework to achieve the legislative intent, i.e. for meeting Limits and Targets within a Biodiversity Management Unit.
- More detailed implementation guidance is beyond the scope of this report and will require further development; we summarise these as **implementation prerequisites**.

3.3 Framework concepts

At the conceptual level, the Framework:

- 1 **Is designed so that all effects management actions directly link to meeting Limits and Targets for indigenous biodiversity.** In international literature this is called a **jurisdictional targets approach** (Simmonds et al. 2020); a minimum level of indigenous biodiversity is set within a specified spatial unit, and controls on activities aim to retain that minimum level. Importantly, a Limits and Targets approach requires a move away from 'averted loss' in biodiversity offsets and biodiversity compensation (Simmonds et al. 2020). In this Framework, we recommend that Limits and Targets are, at a minimum, defined in terms of indigenous vegetation extent (area) within a designated spatial unit (Biodiversity Management Unit), and that any loss of area must be exchanged for with (at least) a commensurate gain in area.
- 2 **Focuses on new activities and existing activities with increasing Adverse Effects on Indigenous Biodiversity.** It is these activities that primarily need to be controlled to maintain current state. Additional changes to existing activities may also be needed to support meeting Targets.
- 3 **Is premised on controlling Adverse Effects not specific activities.** This is because it is the nature of a particular effect that matters for maintaining ecological integrity, and not the type of activity causing the effect. As knowledge and understanding improves, description of and controls on Adverse Effects may change (e.g. controls on off-site effects on indigenous biodiversity). The Framework splits Adverse Effects into two categories – Primary Adverse Effects and Secondary Adverse Effects – and manages each differently, with Primary Adverse Effects being more stringently controlled.
- 4 **Requires all 'more than trivial' Adverse Effects on indigenous biodiversity to be controlled.** If Limits and Targets are to be met, more than trivial Primary and Secondary Adverse Effects of permitted, controlled, and discretionary activities will need to be managed, including by requiring Biodiversity Offsets or Biodiversity Compensation.
- 5 **Does not place undue reliance on Biodiversity Offsetting or Biodiversity Compensation to protect indigenous biodiversity.** For some ecosystems and habitats, it is either not possible, or very unlikely, that indigenous biodiversity that is lost can be replaced elsewhere in a way that will maintain ecological integrity. This Framework therefore identifies some ecosystems and habitats where Primary Adverse Effects need to be avoided altogether to maintain ecological integrity, and where Biodiversity Offsetting or Biodiversity Compensation are not available. This approach is necessary to meet Limits and Targets and is consistent with adopting a precautionary approach.
- 6 **Is based on all land within each Biodiversity Management Unit being classified as either (a) Converted Land; (b) a Developing Indigenous Ecosystem; (c) High Value Indigenous Biodiversity; or (d) Off Limit Indigenous Biodiversity** (See Section 5). Each of these four Land Types is able to be recognised and mapped by regional councils and this will make the Framework straightforward to apply. Under

this Framework, a different approach to managing Adverse Effects on indigenous biodiversity applies in each Land Type.

High Value Indigenous Fauna Habitat may occur on any Land Type. High Value Indigenous Fauna Habitat in a Developing Indigenous Ecosystem changes the Land Type to either High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity. High Value Indigenous Fauna Habitat on Converted Land is treated differently and has its own distinct effects management approach.

7 Prohibits Primary Adverse Effects on Off Limit Indigenous Biodiversity, restricts Primary Adverse Effects on High Value Indigenous Biodiversity and manages all Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land and on Developing Indigenous Ecosystems

- Off Limit Indigenous Biodiversity is Aotearoa-New Zealand's most vulnerable biodiversity and is very unlikely to be replaceable. All activities are therefore required to avoid Primary Adverse Effects on Off Limit Indigenous Biodiversity. Secondary Adverse Effects are managed using the Effects Management Hierarchy followed by Biodiversity Offsetting.
- High Value Indigenous Biodiversity cannot be replaced within 25 years, or at all. In these areas all activities except Nationally Significant Projects must avoid Primary Adverse Effects. Nationally Significant Projects may have recourse to Biodiversity Offsets after meeting the steps of the Effects Management Hierarchy for Primary Adverse Effects. For all activities, Secondary Adverse Effects are managed using the Effects Management Hierarchy followed by Biodiversity Offsetting.
- High Value Indigenous Fauna Habitat on Converted Land is habitat for Threatened and At Risk Species, which is important to replace if their persistence is not to be threatened. In these habitats, all activities may have recourse to Biodiversity Offsets after meeting the steps of the Effects Management Hierarchy for all Adverse Effects. Outside of these areas it is anticipated that Converted Land will generally not be subject to resource management controls for the purpose of protecting indigenous biodiversity, except as required to manage effects on the other three Land Types (e.g. to address edge effects).
- In Developing Indigenous Ecosystems all activities must manage more than trivial adverse effects through applying the Effects Management Hierarchy, followed by Biodiversity Compensation.

8 Applies a different method for exchanging more than trivial residual Adverse Effects to each Land Type

- Biodiversity Compensation is available for activities affecting Developing Indigenous Ecosystems. Biodiversity Offsetting is not available in these areas.
- Biodiversity Offsetting, but not Biodiversity Compensation, is available for:
 - All activities having more than trivial Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land
 - Nationally Significant Projects having Primary Adverse Effects on High Value Indigenous Biodiversity.

- All activities having Secondary Adverse Effects on High Value Indigenous Biodiversity
 - All activities having Secondary Adverse Effects on Off Limit Indigenous Biodiversity.
- 9 **Does not address controls on activities on Converted Land (other than in High Value indigenous Fauna Habitat) for the purpose of protecting indigenous biodiversity.** We recognise and advise that controls on many activities on Converted Land will be needed to meet Limits and Targets (for example, maintaining ecological integrity may require avoiding or minimizing the off-site effects of activities on, or discharges from, Converted Land) but they are beyond the scope of this report. Incentivising enhancement or regeneration as part of undertaking an activity on Converted Land will also be an important part of reaching Targets.
- 10 **Requires that Adverse Effects on Developing Indigenous Ecosystems are compensated for by creating new areas of indigenous biodiversity on Converted Land, which are initiated prior to an impact occurring.** Biodiversity Compensation requires that:
- the new areas of indigenous biodiversity should be provided through a Biobank or through Developer-provided Biodiversity Compensation.
 - the new areas of indigenous biodiversity are not located in Developing Indigenous Ecosystems (i.e. Biodiversity Compensation does not, as presented in this report, include enhancement of areas with existing indigenous biodiversity). If Biodiversity Compensation is undertaken within areas that are already regenerating this is 'averted loss' and will lead to drawdown (net loss) of indigenous biodiversity so that the current state of ecological integrity is not maintained.
 - new area is required even if the Adverse Effects do not cause physical loss of extent. In this instance, the total area subject to Adverse Effects is used to calculate the size of the new compensation area.
 - the spatial distribution of indigenous biodiversity is maintained (or improved) to ensure its persistence (e.g. policy must constrain 'hollowing out' of indigenous biodiversity on private land).
 - Biodiversity Compensation is in place prior to the activity with Adverse Effects being undertaken.
- 11 **Requires that Adverse Effects on High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity are offset by initiating the creation of new areas of indigenous biodiversity within areas of Converted Land, or new individuals of impacted species.** Actions must commence before an impact occurs, and after avoiding Primary Effects where required and after applying the Effects Management Hierarchy and Biodiversity Offset Hierarchy.
- 12 **Uses multipliers to ensure that Biodiversity Offsets and Biodiversity Compensation are consistent with meeting Limits and Targets and maintaining ecological integrity.** The greater the difference in type, time, space, and risk to biodiversity between the impacted area and the Biodiversity Offset or Biodiversity Compensation, the larger the multiplier. For example, larger multipliers

apply to ecosystems that take a long time to replace or are rare and threatened ecosystems. The multipliers must, at a minimum, be at a level that achieves a high degree of confidence that net gain will be achieved. Multipliers can also be used to create incentives for those undertaking activities affecting indigenous biodiversity to:

- exhaust the Effects Management Hierarchy before proceeding to Biodiversity Offsets or Biodiversity Compensation
- Create 'Offset in-kind' as opposed to 'Offset in-kind distant from the impact site' or 'Offset out-of-kind close to the impact site' for any more than trivial residual Adverse Effects.

- 13 **Requires that all offsets and compensation is additional to public conservation activities, and that these activities do not become dependent on, or driven by, continued development.** Compensation and offsets should not be used to fund or 'protect' an area or ecosystem that is already required to be protected and is already required to be managed. For example, compensation cannot fund the control of pests and weeds in an area which is required to be managed for pests and weeds, or to protect an area that is already required to be managed to allow persistence of indigenous vegetation under a lease agreement.
- 14 **Is based on a set of definitions that have been specifically developed** for the purpose of this Framework. Any changes in these definitions may have important implications in the intent and application of the Framework in practice.

The success of this Framework at minimising further loss of indigenous biodiversity in Aotearoa-New Zealand will depend on:

- how the Limits, Targets and Biodiversity Management Units are defined and set.
 - which Adverse Effects are prohibited in High Value and Off Limit Indigenous Biodiversity areas.
 - Nationally Significant Projects being clearly and narrowly defined within the NBEA or NPF.
 - whether multipliers are sufficient to discourage Adverse Effects on Developing Indigenous Ecosystems and (especially) High Value Indigenous Biodiversity and Secondary Adverse Effects on Off Limit Indigenous Biodiversity, which cannot be replaced.
 - what compliance mechanisms and resources sit behind the Framework. Compliance mechanisms are not discussed in detail in this report but should align with other work being undertaken by MfE on compliance.
- 15 **Applies to activities on all land regardless of tenure.** Activities proposed to be undertaken on public or Crown land are managed in the same way as activities proposed to be undertaken on private land.

4 Definitions

The definitions provided below were developed specifically for the implementation of the proposed Framework. However, the terms were defined in such a way they could be used within the NBEA and NPF.

Adaptive management:

- a a systematic and iterative process of decision making that operates throughout the duration of an activity, and aims to reduce and manage uncertainty about the environmental effects of an activity over time through:
 - monitoring the activity and its effects; and
 - making changes to management in response to the results of that monitoring; and
- b includes management by a staged development programme, each stage proceeding only when the monitoring of the biological or physical effects of the previous stage demonstrates that the adverse effects—
 - are within limits prescribed in the provisions of the [NPF/relevant plan or proposed plan]; and
 - are reversible.

Additional: Conservation gains that would not have resulted without new activities undertaken to compensate for or offset an adverse effect on indigenous biodiversity. In our Framework, a Biodiversity Offset or Biodiversity Compensation is additional if it is demonstrably a new activity and is undertaken or established on Converted Land that is not already protected for conservation or being managed for Biobanking for Biodiversity Compensation purposes or for a Biodiversity Offset.

Adverse Effects: Adverse Effects describe a range of effects that negatively impact on indigenous biodiversity. Adverse Effects include but are not limited to the list below, which is divided into Primary Adverse Effects (a to d) and Secondary Adverse Effects (e to i).

Primary Adverse Effects

- a Loss of ecosystem representation and extent
- b Disruption to sequences, mosaics or ecosystem function
- c Fragmentation or loss of buffering or connectivity
- d A reduction in population size or occupancy of Threatened or At Risk species

Secondary Adverse Effects

- e the degradation of mauri
- f a reduction in the richness, abundance or viability of species in habitats and ecosystems

- g pest vegetation or fauna incursions and changes that result in increased risk of incursions
- h disruption to indigenous fauna by people and their pets and livestock and changes that increase the risk of disruption
- i a reduction in people's ability to connect with and benefit from, indigenous biodiversity including from benefits such as
 - the historical, cultural or spiritual relationship of tangata whenua with their taonga; and
 - the scientific, educational, amenity, historical, cultural, landscape or natural character values of indigenous species and indigenous habitats; and
 - ecosystem services.

Note: More than trivial Adverse Effects is the bar where Biodiversity Compensation and Biodiversity Offset is required.

Biobank: A new and additional area of indigenous vegetation established on Converted Land to compensate for Adverse Effects on Developing Indigenous Ecosystems, that meets the requirements for Biodiversity Compensation in Section 6.3.1 and the requirements for a Biobank in Section 6.4.1.

Note: A Biobank is owned and managed by a third party, who can sell units of area in the Biobank. Developers will be required to purchase units from an appropriate Biobank in exchange for the area impacted by residual Adverse Effects of their activities on Developing Indigenous Biodiversity.

The establishment of a Biobank entails the registration of an area of Converted Land for the specific purpose of regeneration of indigenous vegetation. Allowing for natural regeneration is preferable to planting, but in some locations, planting may be required to assist natural regeneration. All Biobanks will need to meet management standards with respect to exclusion or control of ungulates and any weeds that threaten or slow indigenous vegetation regeneration. The types of management required for indigenous vegetation to regenerate depend on the environment, and Biobank standards will therefore vary between locations.

Biobanking: a market-based scheme that sets the rules of exchange for compensating for the Adverse Effects of development activities on Developing Indigenous Biodiversity.

Biodiversity: The variability among living organisms, and the ecological complexes of which they are a part, including diversity within species, between species, and of ecosystems.

Biodiversity Compensation: an area-for-area based exchange for more than trivial, residual Adverse Effects of an activity only on Developing Indigenous Ecosystems after applying the Effects Management Hierarchy, that meets the requirements in Section 6.3.1.

Biodiversity Compensation can be provided either through a Biobank or through Developer-provided Compensation.

Note: This definition differs to biodiversity compensation in other contexts, including the Exposure Draft NPS-IB, where biodiversity compensation is a final step in an effects management hierarchy, used when it is not possible to avoid, remedy, mitigate or offset the impacts of development.

In this Framework, Biodiversity Compensation has been designed to be a simple, low transaction cost approach, and is tied to the creation of Biobanks or Developer Provided Compensation with the same requirements as a Biobank. Developing Indigenous Ecosystems are the only ecosystems that can be exchanged in this way, because they comprise or include common and not-threatened indigenous species that can be replaced with reasonable certainty.

Biodiversity Element: A recognisable component of biodiversity subject to a Biodiversity Offset exchange. These elements must be quantified, for example as the percentage cover of plant species, measures of stem diameters of tree species, or the number of adult individuals or of breeding pairs of a species.

Biodiversity Management Unit: A spatially defined area of land that is the unit for the setting of Limits and Targets for indigenous biodiversity, and subsequent indigenous biodiversity management and accounting.

Biodiversity Offset: A bespoke set of actions undertaken in exchange for more than trivial, residual Adverse Effects on High Value Indigenous Biodiversity, High Value Indigenous Fauna Habitat and Off Limit Indigenous Biodiversity that meets the requirements in Section 6.5.3. A Biodiversity Offset is undertaken only where avoidance of Primary Adverse Effects is not required, and after the Effects Management Hierarchy has been applied.

Note: This Framework proposes a different definition and management hierarchy for a Biodiversity Offset to that in the Exposure Draft of the NPS-IB.

Buffer zone: a designated area used to protect areas of indigenous ecosystems from the adverse effects of pressures that originate outside those areas (e.g. drying effects of wind, or spillover of nutrients or seeds from intensively managed land nearby).

Connectivity: The degree to which the movement of species and processes is facilitated among and across habitats and ecosystems.

Controls: Controls are methods for achieving Limits and Targets including policies, standards, and rules in the NPF or a plan or proposed plan. They can specify requirements that a proposed activity must meet, or maximum levels of harm or level of effects.

Converted Land: An area of land

- a where indigenous vegetation has been fully removed, or
- b that is otherwise wholly exotic pasture, but matagouri, mānuka, kānuka and/or tauhinu (*Ozothamnus leptophyllus*) shrubs less than 25 years old and/or silver tussock are present, or
- c that is a plantation forest, or
- d where wilding conifers or other exotic trees achieved full canopy closure prior to the new NBEA being operative, or
- e where vegetation has been planted as part of a domestic garden, or as a shelterbelt, or for stormwater management or production purposes.

Note:

In clause c plantation forest is defined as in the NES-PF.

In clause d

- the date restriction prevents incentive to convert by neglect though passively enabling exotic tree invasion
- the word 'exotic trees' purposely excludes lower-statured closed canopies of broom and gorse which may be in the process of regeneration to indigenous dominance. Areas of Converted Land that have tall exotic tree canopies but regenerating indigenous understories will be able to be restored as Biobanks (e.g. through selective logging and enrichment planting).

In clause e

- production is intended to cover narrow circumstances such as when mānuka has been planted and is managed for honey production.

Core area of a Biobank: The area of a Biobank that is available to sell units, which will be surrounded by a buffer zone.

Currency/exchange currency: The unit used to measure the equivalence between indigenous biodiversity that is lost and a Biodiversity Offset or Biodiversity Compensation. There are three exchange currency types: simple, universal, and comprehensive (Salzman & Ruhl 2000). A simple currency adopts an explicit biodiversity-based measure such as area, number of individuals or habitat-hectares and accepts the logical shortcomings, perversities and inequities arising from any differences in the exchanged biodiversity. A comprehensive currency attempts to capture all aspects of the exchange that are of interest to the parties involved. A universal currency expresses disparate features in a common currency unit such as dollars. This Framework proposes a simple currency (hectares of land in a Land Type) is used for Biodiversity Compensation, and a comprehensive (and disaggregated) currency is used for Biodiversity Offsets.

Degradation: Deterioration or depletion of ecosystem properties, often directly or indirectly as a result anthropogenic activities, and including lack of management (neglect) that allows degradation by pest plants or pest animals or disease or 'edge effects'.

Developer Provided Compensation: Biodiversity Compensation that is provided by the person undertaking the activity with Adverse Effects on Developing Indigenous Ecosystems.

Note: Developer Provided Compensation entails the registration and management of Converted Land for the specific purpose of regeneration of indigenous vegetation, and has the same requirements, rules, and standards as a Biobank.

Developing Indigenous Ecosystem: An area of land that is indigenous vegetation which is less than 25 years old and is not one of the below

- a a naturally uncommon ecosystem
- b supporting an ecologically important emergent forest tree
- c a sand dune
- d a habitat of a Threatened plant species
- e a habitat of a Threatened or an At Risk animal species
- f a habitat of an indigenous plant or animal species at the geographic or environmental limit of its known natural range
- g Converted Land.

Note: Plant species and animal species are deliberately treated differently in clauses d and e (and in our other Land Type definitions). Animals are more vulnerable to rapid extinction than plants, which often have longer-lived and dormant life stages, and more options for reproduction such as vegetative propagation.

This definition depends on our definitions of habitat; of indigenous vegetation; on the threat classification of Holdaway et al. (2012) for naturally uncommon ecosystems; and on the New Zealand Threat Classification System (NZTCS) for plants and animals. Note that in the NZTCS, 'Threatened' species include species that are ranked as Nationally Vulnerable, Nationally Endangered and Nationally Critical.

Ecosystem: A set of organisms (community) living in an area, their physical environment, and the interactions between them.

Ecological integrity: The ability of the natural environment to support and maintain the full range of indigenous biodiversity and ecosystem functioning, both within and across ecosystems. It requires supporting and maintaining:

- Ecological representation: the occurrence and extent of ecosystems and indigenous species and their habitats across the full range of environments; and

- Composition: the natural diversity and abundance of indigenous species, habitats, and communities within and across ecosystems; and
- Structure: the biotic and abiotic physical features and characteristics of ecosystems; and
- Functions: the ecological and physical functions and processes of an ecosystem; and
- Resilience: any other properties that contribute to resilience of the indigenous components of ecosystems to the adverse impacts of natural or human disturbances.

Note:

- This definition is that provided to us by Patrick Kavanagh of MFE. It differs from the definition provided in the NBEA exposure draft, which was site-based and omitted representation. Representation is essential for maintaining indigenous biological diversity, and even more critical under a changing climate.
- We prefer the definition above to other definitions in use which are less specific or detailed. For example, the Environmental Reporting Act 2015 defines Ecological Integrity as 'the full potential of indigenous biotic and abiotic features and natural processes, functioning in sustainable communities, habitats, and landscapes'. Lee et al. (2005) (who introduced the concept of Ecological Integrity to Aotearoa-New Zealand) suggested three components of ecological integrity for the purpose of indicator development: (1) environmental representation; (2) species occupancy; and (3) indigenous dominance.

Effects Management Hierarchy: An approach to managing the Adverse Effects of subdivision, use and development that requires that:

- a Adverse Effects are avoided where possible;
- b Adverse Effects that cannot demonstrably be avoided are remedied where possible; and
- c Adverse Effects that demonstrably cannot be remedied are mitigated where possible.

Note:

- Under this Framework the Effects Management Hierarchy does not always apply. The avoidance of Primary Adverse Effects is required on all Off Limit Indigenous Biodiversity, and if that is not achievable the proposed activity cannot go ahead. Similarly, Primary Adverse Effects are to be avoided from all activities except for Nationally Significant Projects on High Value Indigenous Biodiversity.
- Under this Framework the definition of Effects Management Hierarchy does not include subsequent actions to address residual Adverse Effects. Instead, the Framework provides two alternatives depending on the Land Type which is being adversely affected. Biodiversity Compensation is applied to more than trivial residual Adverse Effects on Developing Indigenous Ecosystems. Biodiversity Offsets

are applied to more than trivial residual:

- Adverse Effects of all activities on High Value Indigenous Fauna Habitat on Converted Land
 - Adverse Effects of Nationally Significant Projects on High Value Indigenous Biodiversity
 - Secondary Adverse Effects from other activities on High Value Indigenous Biodiversity (noting avoidance of Primary Adverse Effects by these activities is required)
 - Secondary Adverse Effects from all activities on Off Limit Indigenous Biodiversity (noting avoidance of Primary Adverse Effects is required).
- We discuss implications of the terms 'possible' and 'minimise' in Section 8.4.

Endemic/endemism: A taxon is endemic if it is unique to a defined geographic location; for example, a New Zealand endemic is naturally found only in Aotearoa-New Zealand, whereas non-endemic indigenous and recently introduced taxa are also found elsewhere in the world. New Zealand endemics can also be 'regional endemics' when they are unique to a defined region, such as an ecological region. Endemism is the state of being endemic. The Aotearoa-New Zealand biota has exceptionally high levels of national and regional endemism, especially in some groups, which make our indigenous biodiversity an international priority for protection.

Note: The Aotearoa-New Zealand biota has exceptionally high levels of national and regional endemism, especially in some groups, which make our indigenous biodiversity an international priority for protection.

Enhancement: Improvement in the quality or condition of indigenous vegetation or an ecosystem, or an increase in the number of individuals in a species population.

Note: Enhancement, like degradation can occur without deliberate human agency, but often results from a wide variety of short term and long-term actions including pest mammal or weed control, noise walls (to reduce impacts of traffic noise), permanent removal of lighting (or replacement by alternative methods), removal of contaminants (e.g. in stormwater), replacing culverts with bridges to provide for connectivity or planting indigenous species within existing indigenous vegetation.

Environmental classification: A classification that uses environmental factors likely to influence the distribution of species to classify terrestrial, freshwater, coastal, marine domains or into groups with similar environmental conditions. The groups indicate sites that have similar potential ecosystem character – not necessarily the same in all respects but likely to naturally support similar groups of species and similar biological interactions and processes.

Note: For biodiversity offsetting and biodiversity compensation frameworks, an environmental classification ensures the potential character of a future offset or compensation site (where natural ecosystems have been cleared or modified by human activities or replaced by introduced plants and animals) will be similar to the present character of the impact site.

Exchange: The provision of recompense for more than trivial residual Adverse Effects on existing indigenous biodiversity.

Note: For example, in this Framework:

- the effect may be clearance of developing indigenous vegetation within a Developing Indigenous Ecosystem and the Biodiversity Compensation may be permanent protection of a new area of Converted Land for the purpose of restoration and regeneration of developing indigenous vegetation
- the effect may be a number of additional deaths of adult Pied Oystercatchers that collide with a new structure, and the Biodiversity Offset exchange is increased Pied Oystercatchers breeding and fledgling success to a level sufficient to replace the number of individuals lost and is as long-lasting as the new structure. This may be achieved by pest management in Pied Oystercatchers habitat elsewhere.

Exchange restrictions: Restrictions in a system of biodiversity exchange (e.g. in this case Biodiversity Offsets or Biodiversity Compensation) to limit out-of-kind exchanges. Exchange restrictions commonly cover four exchange dimensions (type, time, location, and risk). For example, exchanges may be limited to the same type of habitat, restoration may be required before impacts are allowed to proceed (addressing time and risk), geographic restrictions may be used to maintain connectivity and ensure impacted species populations are the same ones that benefit from the offset (location).

Habitat of indigenous species: Any area or space that is occupied by an indigenous species for all or part of its life cycle.

Note: Reduced habitat quality (habitat degradation) is a change in the resources and conditions of an area or spaces so that the probability of occupancy by a species is reduced. Habitat loss removes the resources and conditions that enable occupancy by that species.

High Value Indigenous Biodiversity: An area of land that is one or more of the below

- a indigenous vegetation that is 25 years old or older
- b supporting an ecologically important emergent forest tree

- c a naturally uncommon ecosystem that is classified as Endangered, Vulnerable, or Not Threatened
- d a sand dune
- e a habitat of a Threatened plant species that is ranked Nationally Vulnerable or Nationally Endangered
- f High Value Indigenous Fauna Habitat that is
 - i not on Converted Land, and
 - ii a habitat of an At Risk animal species, or a Threatened animal species ranked Nationally Vulnerable
- g a habitat of an indigenous plant or animal species at the geographic or environmental limit of its known natural range.

Note: Plant species and animal species are deliberately treated differently in clauses d and e (and in our other Land Type definitions). Animals are more vulnerable to rapid extinction than plants, which often have longer-lived and dormant life stages, and more options for reproduction such as vegetative propagation.

This definition depends on our definitions of habitat; of indigenous vegetation (including of ecologically important emergent trees); on the threat classification of Holdaway et al. (2012) for naturally uncommon ecosystems; and on the New Zealand Threat Classification System (NZTCS) for plants and animals. Note that in the NZTCS, 'Threatened' species include species that are ranked as Nationally Vulnerable, Nationally Endangered, and Nationally Critical.

High Value Indigenous Fauna Habitat: The areas or features used (at any part of their life cycle) by individuals or populations of indigenous fauna species that are classified as Threatened or At Risk in the New Zealand Threat Classification System. High Value indigenous Fauna Habitat may occur on any Land Type, including Converted Land; for example, large exotic trees with cavities may form habitat for Threatened indigenous bat species, and rock piles in pasture may be habitat for At-Risk lizard species.

Adverse Effects on High Value Indigenous Fauna Habitat include effects on individuals and populations not only the areas or features they use.

Indigenous biodiversity: the living organisms that are self-introduced to Aotearoa-New Zealand either before or after human settlement, and the ecological complexes of which they are part, including all forms of indigenous flora, fauna, and fungi, and their habitats.

Note: The term 'occur naturally' is used in the NPS-IB exposure draft. We substitute a precise definition to avoid potential debate on what 'occur naturally' means.

Indigenous species: living organisms that are self-introduced to Aotearoa-New Zealand either before or after human settlement, but not necessary endemic to New Zealand.

Indigenous dominance: The degree to which the structure, composition, and processes of an ecosystem are dominated by indigenous species (Lee et al. 2005).

Indigenous vegetation: A community of vascular plants, mosses and/or lichens that is the habitat of plant species native to the ecological district, OR an ecologically important emergent forest tree. The community may include or be dominated by exotic species.

Note: This definition aligns with the NPS-IB exposure draft with some slight differences which are appropriate because:

- 'a community' clarifies that it must be an association of plants, and not a single plant (unless an ecologically important emergent forest tree).
- 'vascular plants, mosses and/or lichens' ensures that the definition includes above-ground nonvascular plant species, which are key components of many indigenous plant communities, are important for indigenous biodiversity, and at some sites dominate the cover.
- 'native to the ecological district' means that some indigenous plant species must be native to the area, but communities composed entirely of species that are outside their natural range can be excluded. 'Ecological Districts' are already defined and mapped (McEwen et al. 1987) and species within the districts are well-known or lists of these species are easily found.
- the phrase 'that is the habitat of plant species...' clarifies that it is the functional role of indigenous vegetation in supporting and maintaining indigenous biodiversity that makes it important. Conversely, it is not important for the community to meet any other structural or compositional threshold in order to be 'indigenous vegetation'.
- the phrase 'may include or be dominated by exotic species' clarifies that communities where exotic species dominate is nevertheless classed as indigenous vegetation (because it is the habitat of indigenous plant species).

All these phrases are essential in the definition if the ecological integrity of indigenous biodiversity is to be maintained. In particular, areas of vegetation dominated by exotic species are now indispensable habitat for a high proportion of Aotearoa-New Zealand's indigenous species and maintaining modified habitats is especially critical for maintaining indigenous biodiversity in settled landscapes. Removal of today's exotic-dominated habitats for indigenous species would drive many to regional or global extinction, and catastrophically reduce the capability of many landscapes to support indigenous biodiversity.

There is no ecological basis for a 'dominance threshold'. Dominance tests such as in the natural wetland NPS-FW definition, and the word 'predominately' in the indigenous vegetation definition in the National Environmental Standard for Plantation Forestry (NES-PF) fail to recognise the importance of highly modified ecosystems for maintaining indigenous biodiversity, and so fail to provide for the persistence of indigenous biodiversity. For example, few, if any, of the plant communities now occupied by indigenous plant species in eastern South Island landscapes (e.g. the Mackenzie Basin, Central Otago, low and mid-elevation parts of the South Island high country) would

meet such dominance thresholds.

Emergent forest trees can play exceptionally important ecological roles in maintaining indigenous biodiversity within highly modified landscapes. We therefore suggest that ecologically emergent forest trees are treated as High Value Indigenous Biodiversity and are defined by:

- by height, age or both
- regionally, to reflect what is ecologically important in different ecological settings. For example, an individual kowhai or cabbage tree would not be significant on the west coast of the South Island but would be significant in the context of the Canterbury Plains.

In-kind/like-for-like exchange: A biodiversity exchange in which the biodiversity gained is the same as the biodiversity loss that occurred through the Adverse Effects of an activity.

Land Type: One of the following four categories

- a Converted Land
- b Developing Indigenous Ecosystem
- c High Value Indigenous Biodiversity
- d Off Limit Indigenous Biodiversity.

LENZ: Land Environments of New Zealand: An environmental classification developed by Manaaki Whenua – Landcare Research for MfE in 2003. LENZ uses climatic and landform factors likely to influence the distribution of species to classify the terrestrial landscape into groups with similar environmental conditions.

Levels I of the LENZ classification spatially defines 20 Levels nationally. LENZ Levels II, III and IV spatially define 100, 200 and 500 environments nationally, respectively.

Limit: A limit may be expressed, in relation to the natural environment or a specified part of that environment, as

- a the minimum biophysical state; or
- b the maximum amount of harm or stress that may be permitted.

An environmental limit may be

- a qualitative or quantitative;
- b set at different levels for different circumstances and locations;
- c set in a way that integrates more than 1 of the aspects of the natural environment.

Maintenance: For the purposes of maintaining the ecological integrity of indigenous biodiversity, maintenance means at least no reduction in ecological integrity.

Note: The 'no reduction in' definition aligns with the definition of maintenance in the NPS-IB Exposure Draft, in the context of maintaining indigenous biodiversity. The components of indigenous biodiversity in the NPS-IB Exposure Draft are framed differently to the components of ecological integrity (based on the definition provided to the us by MfE and defined above), but essentially covers the same things. They are, no reductions in:

- a the size of populations of indigenous species
- b indigenous species occupancy across their natural range
- c the properties and function of ecosystems and habitats
- d the full range and extent of ecosystems and habitats
- e connectivity between, and buffering around, ecosystems
- f the resilience and adaptability of ecosystems.

Maintenance of the ecological integrity of indigenous biodiversity in Aotearoa-New Zealand will require a combination of preventing further habitat loss (including preventing further loss of highly modified habitats and of the connectivity and buffering around remaining ecosystems) while simultaneously extending, reconnecting, and repairing those habitats and ecosystems that remain.

To be measurable, a date must be set from which no reduction of ecological integrity is allowed.

Māori land: means Māori customary land and Māori freehold land as defined in the Te Ture Whenua Māori Act 1993.

Multiplier/ratio: Multipliers or ratios (often used interchangeably) are applied to increase the likelihood of a successful biodiversity exchange.

Note: A 1:1 ratio is deficient in that it ignores the time lag before the full value of compensation areas is realised, as well as uncertainty in the extent to which the expected conservation value at the compensation areas will be realised (Hilderbrand et al. 2005). Heuristically, a 1:1 ratio is 'like making a zero-interest rate (biodiversity) loan to someone who is known to be unreliable and might pay back decades later' (Moilanen et al. 2009). Multipliers or ratios are to account for various factors including risk of failure, uncertainty in offset action, imperfect exchange currencies, time-lags, or biodiversity conservation objectives.

Nationally Significant Project: For Government to determine but should be explicit and limited. Examples might be some national linear infrastructure or certain mineral extraction.

Naturally uncommon ecosystem: Aotearoa-New Zealand ecosystems (also known as naturally rare, historically rare, or originally rare) listed in Williams et al. (2007) and Holdaway et al. (2012).

Note: Naturally uncommon ecosystems typically arise due to unusual environmental conditions, often independent of climate, are mostly small (<1–1,000 ha) and non-forested, and often support unique biodiversity. Most would have naturally occurred over relatively small areas in the absence of human activity.

Naturally uncommon ecosystems are typically not distinguished in national-scale land cover classifications. They contribute disproportionately to Aotearoa's indigenous biodiversity, and have often been poorly recognized, understood, and managed. Many are threatened, and the IUCN ecosystem red-list criteria have been used to derive a threat status for each naturally uncommon ecosystem (Holdaway et al. 2012).

Net gain of indigenous biodiversity: No net loss of indigenous biodiversity AND increases in:

- a the diversity of indigenous species or recognised taxonomic units; and/or
- b indigenous species' population sizes (taking into account natural fluctuations) and long-term viability; and/or
- c the natural range inhabited by indigenous species; and/or
- d the range and ecological health and functioning of assemblages of indigenous species, community types and ecosystems.

No net loss of indigenous biodiversity: No reduction in:

- a the diversity of indigenous species or recognised taxonomic units; and
- b indigenous species' population sizes (taking into account natural fluctuations) and long-term viability; and
- c the natural range inhabited by indigenous species; and
- d the range and ecological health and functioning of assemblages of indigenous species, community types and ecosystems.

Note: The NPS-IB Exposure draft does not provide a definition of no net loss or net gain. Our definitions are explicit and consistent with key aspects of ecological integrity (representation, composition, and function).

Our definition aligns with, but is also more explicit and comprehensive than the DOC best practice guidance (DOC 2014), which states that 'the goal of biodiversity offsetting is to achieve no net loss and, preferably, a net gain of biodiversity on the ground, with respect to:

- Species composition (e.g. individual species or species groups)
- Habitat structure (e.g. vegetation tiers)
- Ecosystem function (e.g. nutrient cycling rates)
- People's use of and cultural values associated with biodiversity'.

Off Limit Indigenous Biodiversity: An area of land that is one or more of the below

- a a naturally uncommon ecosystem classified as Critically Endangered
- b a habitat of a Threatened plant species ranked Nationally Critical
- c High Value Indigenous Fauna Habitat that is
 - i not on Converted Land, and
 - ii a habitat of a Threatened animal species ranked as Nationally Endangered or Nationally Critical.

Note: Plant species and animal species are deliberately treated differently. Animals are more vulnerable to rapid extinction than plants, which often have longer-lived and dormant life stages, and more options for reproduction such as vegetative propagation.

This definition depends on our definitions of habitat; of indigenous vegetation; on the threat classification of Holdaway et al. (2012) for naturally uncommon ecosystems; and on the New Zealand Threat Classification System (NZTCS) for plants and animals. Note that in the NZTCS, 'Threatened' species include species that are ranked as Nationally Vulnerable, Nationally Endangered and Nationally Critical.

Out of kind: The elements of biodiversity impacted by an activity are replaced by different biodiversity elements.

Note: In practice, as concluded by Overton & Stephens (2015), all exchanges (even in nominally like-for-like exchanges) are in fact out of kind to some degree over at least one of four dimensions (type, location, time, and risk). Out-of-kind exchanges are often 'concealed' (i.e. neither recognised nor explicitly accounted for in the exchange) and present significant risks to maintenance of indigenous biodiversity and ecological integrity.

Protected Land: Areas protected with the primary goal of natural heritage and/or indigenous biodiversity conservation.

Note: This will include most, but not all, categories of public conservation land and reserves managed by regional and local government, and some private land, such as QE2 Open Space covenants.

Public Land: Land owned by the Crown or central, local or regional government, whether used for conservation purposes or leased to a private interest or utility.

Note: This will include many riverbeds, Crown forest land (including land held in trust for Treaty Settlements), Crown pastoral land in the South Island high country, residential and commercial properties, closed schools, army land, courthouses and prisons, as well as public conservation land and local and regional government parks and reserves.

Recognisable Ecosystems, Fauna Habitat and Species: All Biodiversity Elements (see definition above) for which net gain is sought in a Biodiversity Offset. The disaggregated condition-area model developed for the NZ Department of Conservation (Maseyk et al. 2016 and associated online resources) provides a minimum standard.

Target: A level that is explicit and measurable (not aspirational) and reflects the desired future state (outcome) of biodiversity features (e.g. species population, ecosystem extent).

Threatened environment: A LENZ Level IV environment within Categories 1 to 5 of the Threatened environment classification (TEC). The TEC creates six categories of LENZ Level IV environments: Category 1: <10% indigenous cover remaining; Category 2: 10–20% indigenous cover remaining; Category 3: 20–30% indigenous cover remaining; Category 4: >30% indigenous cover remaining and <10% legally protected; Category 5: >30% indigenous cover remaining and 10–20% legally protected; Category 6: >30% indigenous cover remaining and >20% legally protected.

Trading up: Biodiversity elements that are thought to be less valuable for the maintenance of indigenous biodiversity are exchanged for biodiversity elements that are thought to be more valuable for maintenance of indigenous biodiversity.

Note: Whether an exchange is ‘trading up’ inevitably requires subjective judgement because biodiversity elements are non-fungible (different elements cannot be compared using a common currency), and it is not possible to determine objectively whether no net loss or net gain has increased or decreased overall when exchanges are out of kind. In practice, conservation status (e.g. NZTCS threat categories for species, IUCN categories for ecosystems) is often used as a surrogate for value, and elements that are already considered to be threatened, at risk or vulnerable are not available to be traded up.

5 Overview of types of land and development tracks

The Framework recognises four Land Types: Converted Land; Developing Indigenous Ecosystems; High Value Indigenous Biodiversity; and Off Limit Indigenous Biodiversity (Table 1). High Value Indigenous Fauna Habitat can occur on any of these four Land Types.

Preliminary estimates (Appendix 1) suggest that across Aotearoa-New Zealand:

- Converted Land covers 78–83% of all land that is not already Protected Land.
- Developing Indigenous Ecosystems are estimated to cover between 4 and 10% of land that is not already Protected Land. However, some of the area we have preliminarily estimated as a Developing Indigenous Ecosystems may be re-classified and mapped as another Land Type during the mapping process to implement this Framework.
- High Value Indigenous Biodiversity and Off Limit Indigenous Biodiversity together cover, at a minimum, 12% of land that is not Protected Land.

High Value Indigenous Fauna Habitat (see Section 4) that is not on Converted Land becomes either High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity, depending on the species’ threat status. Management of Adverse Effects on High Value Indigenous Fauna Habitat within land that is otherwise classified as Converted Land (e.g. bats or kiwi within plantation forestry, or lizards within urban brown fields areas and pasture) must follow Development Track 2 (Biodiversity Offsetting).

Table 1. Definitions of the four Land Types required for our Framework. Note that these definitions depend on our definitions of habitat; of indigenous vegetation; on the threat classification of Holdaway et al. (2012) for naturally uncommon ecosystems; and on the New Zealand Threat Classification System (NZTCS) for plants and animals. Note that in the NZTCS, ‘Threatened’ species include species that are ranked as Nationally Vulnerable, Nationally Endangered and Nationally Critical

Converted Land	Developing Indigenous Ecosystem	High Value Indigenous Biodiversity	Off Limit Indigenous Biodiversity
An area of land: a. where indigenous vegetation has been fully removed, or b. that is otherwise wholly exotic pasture, but where matagouri, mānuka, kānuka and/or tauhinu shrubs less than 25 years old and/or silver tussocks are present, or c. that is a plantation forest, or d. where wilding conifers or other exotic trees had achieved full canopy closure prior to the new NBEA being notified, or e. where vegetation has been planted as part of a domestic garden, for stormwater management, for production, or as a shelterbelt.	An area of land that is indigenous vegetation which is less than 25 years old, and is not one of the below: a. a naturally uncommon ecosystem b. supporting an ecologically important emergent forest tree c. a sand dune d. a habitat of a Threatened plant species e. High Value Fauna Habitat f. a habitat of an indigenous species at the geographic or environmental limit of its known natural range g. Converted Land	An area of land that is one or more of the below: a. indigenous vegetation that is 25 years old or older b. supporting an ecologically important emergent forest tree c. a naturally uncommon ecosystem that is classified as Endangered, Vulnerable, or Not Threatened d. a sand dune e. the habitat of a Threatened plant species ranked Nationally Vulnerable or Nationally Endangered f. High Value Indigenous Fauna Habitat that is (i) not on Converted Land, and (ii) a habitat of an At Risk animal species, or a Threatened animal species ranked Nationally Vulnerable g. a habitat of an indigenous plant or animal species at the geographic or environmental limit of its known natural range	An area of land that is one or more of the below: a. a naturally uncommon ecosystem classified as Critically Endangered b. a habitat of a Threatened plant species ranked Nationally Critical c. High Value Indigenous Fauna Habitat that is (i) not on Converted Land, and (ii) a habitat of a Threatened animal species ranked as Nationally Endangered or Nationally Critical

We propose a three-track approach (Development Tracks 1, 2, and 3) for managing all Adverse Effects of development within these different Land Types to meet Limits and Targets (Fig. 1).

Development track 1 – Developing Indigenous Ecosystems: This track applies to all activities in Developing Indigenous Ecosystems. The Effects Management Hierarchy applies to all Adverse Effects, followed only by Biodiversity Compensation for more than

trivial residual Adverse Effects. This Development Track is based on the generalised framework for a limit or target-based approach for ecological compensation as outlined in Simmonds et al. (2020). It provides a way to achieve Limits and Targets set under the NBEA. In this Development Track all Adverse Effects are managed in the same way to create a simple and tractable system to apply and administer.

Development track 2 – High Value Indigenous Biodiversity and High Value

Indigenous Fauna Habitat: For Nationally Significant Projects that impact on High Value Indigenous Biodiversity, the Effects Management Hierarchy applies to all Adverse Effects, followed only by Biodiversity Offsets to address more than trivial residual Adverse Effects. Nationally Significant Projects may include nationally significant infrastructure, nationally significant mineral extraction, and nationally significant aggregate extraction.

For other activities, avoidance of Primary Adverse Effects on High Value Indigenous Biodiversity is required, and if this is not possible the activity cannot proceed. For Secondary Adverse Effects, the Effects Management Hierarchy is applied followed only by Biodiversity Offsetting for all more than trivial residual Secondary Adverse Effects.

All activities with Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land apply the Effects Management Hierarchy, followed only by the Biodiversity Offsets Hierarchy. The more than trivial residual Adverse Effects both on species populations and on their habitats are offset.

Development track 3 – Off Limits Indigenous Biodiversity: All activities must avoid Primary Adverse Effects. If this is not possible then the activity cannot proceed. For more than trivial Secondary Adverse Effects, all activities must apply the Effects Management Hierarchy followed only by Biodiversity Offsetting.

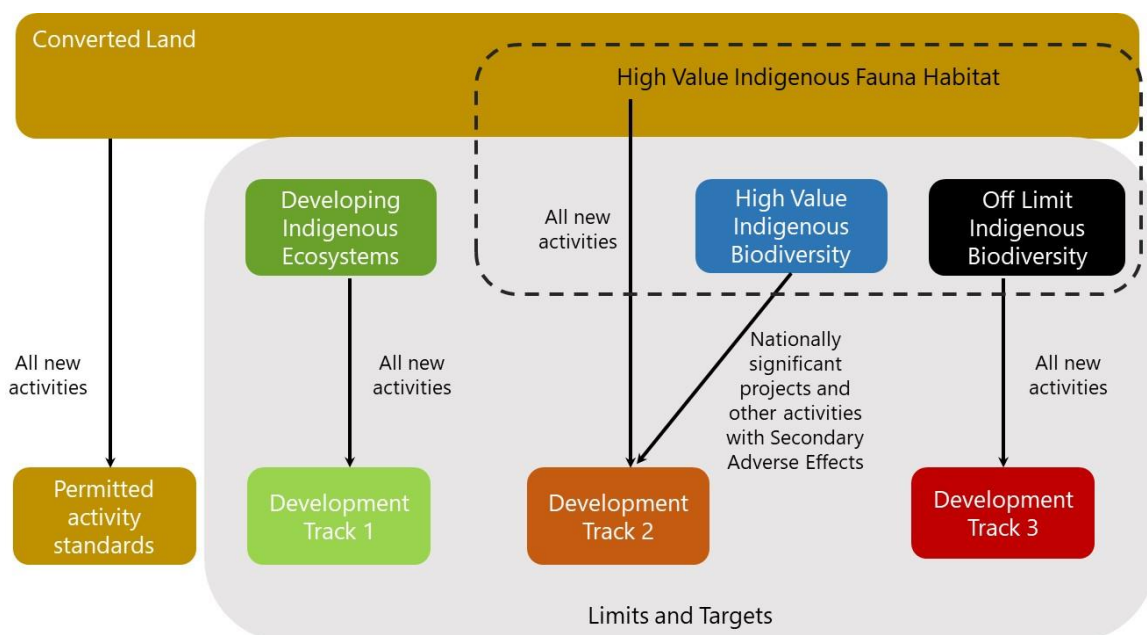


Figure 1. Land Types and tracks for development.

It is important to note:

- Use of the term 'compensation' in the Framework differs from the current system. Presently, and in the NPS-IB exposure draft, biodiversity offsetting and biodiversity compensation tend to be available sequentially (after avoidance, remediation, and mitigation) and for effects on all indigenous biodiversity.
- The Framework includes a requirement for all activities to avoid Primary Adverse Effects on Off Limit Indigenous Biodiversity and for most activities to avoid Primary Adverse Effects on High Value Indigenous Biodiversity. The list of Primary Adverse Effects adopted by the Framework is essentially the same as that proposed by the Biodiversity Collaborative Group and subsequently consulted on by MFE; advice to the Biodiversity Collaborative Group was unanimous that avoidance of the Primary Adverse Effects is required to maintain indigenous biodiversity and protect ecological integrity. High Value Indigenous Biodiversity and Off Limit Indigenous Biodiversity support the most threatened and critically endangered types of indigenous biodiversity in Aotearoa-New Zealand.
- The term 'more than trivial' is used in recent Government papers on the NBEA and differs from 'more than minor' in the RMA. Implications of this change are discussed in Section 8.1.
- The approach for Māori land (including what constitutes 'Māori land') is beyond the scope of this report and needs to be co-developed with Māori.
- The Development Tracks apply to activities in the same way, whether they are undertaken within or outside public and Protected Land.
- Nationally Significant Projects need to be defined by Government. The integrity of the Framework depends on Nationally Significant Projects being few and well defined; the greater the 'carve outs', the greater the potential loss of indigenous biodiversity.
- Effects of activities on Converted Land that have off-site impacts on indigenous biodiversity will also need to be managed to achieve Limits and Targets. However, requirements and guidance for those activities are beyond the scope of this report.

6 Proposed Framework

This section covers:

- Section 6.1. Principles to underpin decisions to manage the effects of activities on indigenous biodiversity generally. These principles will be particularly useful as a resource where decisions are not clear-cut. Note: the 'principles' typically used in the current system to describe what qualifies as a biodiversity offset or biodiversity compensation are framed in this report as requirements. These requirements have been specifically tailored for the purposes of the proposed Framework.
- Section 6.2. Limits and Targets to protect ecological integrity, their requirements, area of spatial application, and their implementation guidance and prerequisites.

- Section 6.3. Development Track 1: Biodiversity Compensation for Developing Indigenous Ecosystems.
- Section 6.4. Biobank establishment for Biodiversity Compensation under Development Track 1
- Section 6.5. Development Track 2: Biodiversity Offsets for High Value Indigenous Biodiversity and High Value Indigenous Fauna Habitats
- Section 6.6. Development Track 3: Off Limit Indigenous biodiversity
- Section 6.7. Multipliers

6.1 Guiding Principles to underpin decisions

The guiding principles outlined in this section are to be used for all decisions made while applying our Framework. They are different from the biodiversity offset principles typically used in the current system and in the NPS-IB exposure draft, which state the criteria that a proposed biodiversity offset (or compensation) should meet. Rather, the typical biodiversity offset principles have been adapted in our Framework and are framed as 'requirements' to be met, while the 'guiding principles' are to help navigate decision-taking in each Development Track. The guiding principles listed below should always be referred to, and will have greater utility where greater complexity and/or uncertainty exists.

The principles are:

1 Relevance

Use data, methods, criteria, and assumptions appropriate to the type of Adverse Effects and the indigenous biodiversity being impacted.

Ensure the biodiversity information assessed and development options considered fully account for the contextual situation (including stakeholder values, risks, and scale as well as any ecological limitations), the pertinent legislative frameworks (local, regional, and national), the scientific knowledge relating to that environment, and the inter-connectedness between resources being managed. All decisions should be founded on using the applicable Development Track, the appropriate science-based evidence when designing a Biodiversity Offset, and applying the correct multipliers to determine the size of a Biodiversity Offset or Biodiversity Compensation.

2. Completeness

Consider all information that may affect the assessment of the adverse effects of activities on indigenous biodiversity (ecosystems, species habitats and species), and cover all possibilities at each stage of the Effects Management Hierarchy.

All steps in the relevant Development Track should be followed and all relevant information is included when quantifying the size of the Biodiversity Compensation or Biodiversity Offset needed. Among other things this means applying each stage of the Effects Mitigation Hierarchy to reduce any more than trivial Adverse Effects as much as

possible before moving to the next step as well as applying the Biodiversity Offset Hierarchy to determine the type of Biodiversity Offset. It also applies to the disaggregation of Biodiversity Elements for a Biodiversity Offset and the actions required to offset any more than trivial Adverse Effects on these elements.

3. Transparency

Provide clear and sufficient information for assessors, stakeholders, and the public to understand the development impacts on indigenous biodiversity and to assess the credibility of the proposed Biodiversity Offset or Biodiversity Compensation.

Transparency is critical for determining the type and quantity of a Biodiversity Offset or Biodiversity Compensation. Information on the Adverse Effects on Biodiversity Elements should be compiled, analysed, and documented clearly and coherently so that assessors, stakeholders, and the public may evaluate its credibility, and judge the integrity of the subsequent Biodiversity Offset or Biodiversity Compensation. Outcomes from the application of the Effects Management Hierarchy should be documented and shared with assessors and stakeholders. Specific exclusions or inclusions should be clearly identified, multipliers stated and justified, assumptions should be explained, and appropriate references should be provided for both data and assumptions. The data and information from monitoring activities should be sufficient for assessors, stakeholders, and the public to determine the state and condition of the regenerating indigenous biodiversity (vegetation and/or species populations).

4. Accuracy

Reduce uncertainties as much as is practical.

The impact of Adverse Effects on indigenous biodiversity and the success of activities to regenerate indigenous biodiversity are inherently uncertain. Where possible the uncertainties related to the impact of Adverse Effects from activities on indigenous biodiversity are reduced as much as is practical, and all measurements and estimation methods used should avoid bias. All uncertainties related subsequent Biodiversity Offset or Biodiversity Compensation should be transparently documented. The impacts of Adverse Effects and state and condition of regenerating indigenous biodiversity should be monitored to reduce uncertainties on the correctness of any Biodiversity Offset or Biodiversity Compensation, and remedial actions taken, where needed, to adaptively manage the regenerating indigenous biodiversity. Where it is not possible to reduce uncertainties, the conservativeness principle should be applied.

5. Consistency

Use data, methods, criteria, and assumptions that allow meaningful and valid comparisons.

Each person has innate biases that will inadvertently affect a decision. While this is natural, efforts should be made to collect, analyse, and evaluate all information and options in a similar manner, including using the same criteria and assumptions. This applies to all decisions within the Framework including, among others, the classification of indigenous biodiversity into land types, the application of multipliers, the dis-aggregation of

indigenous biodiversity into Recognisable Ecosystems, Fauna Habitats, and Species in Development Track 2 and the measures and metrics used to assess the elements of indigenous biodiversity (Biodiversity Elements) at both the impact and offset site.

6. Conservativeness

Use conservative assumptions, values, and approaches when uncertainty around the Adverse Effects of activities, type of land being impacted, and/or ability to regenerate indigenous biodiversity is high.

Do not overestimate the rate or ability of an indigenous ecosystem, species habitat or species population to establish and regenerate on Converted Land. If regeneration success is more uncertain then increase the area of the Biodiversity Offset or Biodiversity Compensation. Uncertainty is likely greater the longer the time needed to replace an indigenous ecosystem, the higher the threat status of the impacted Biodiversity Element and where the ability of an ecosystem, habitat or population to establish is unknown. The more modified Converted Land is the greater the uncertainty around the ability of indigenous biodiversity to regenerate and/or time taken to do that. When the Land Type where an activity is being proposed is not clear, then a Land Type with more restrictions on development should be assumed. Multipliers should be applied conservatively to account for any inequality in exchange dimensions (type, time, location, and risk). Requirements for Biobanks, Developer Provided Compensation and Biodiversity Offsets to be established in advance of Adverse Effect(s) from activities helps operationalize the conservativeness principle, reduce uncertainties and improve the efficacy of any exchange.

6.2 Limits and Targets

Biodiversity offsetting and biodiversity compensation are being considered as methods to address the Adverse Effects of development on indigenous biodiversity to meet Limits and Target within a Biodiversity Management Unit under the NBEA. Biodiversity Management Units, Limits, Targets, and methods must work together to achieve protection of 'ecological integrity' of the natural environment, including, specifically, protection of ecological integrity of indigenous biodiversity.

How Biodiversity Management Units, Limits, and Targets are defined determines how, when, and where biodiversity offsetting and biodiversity compensation are provided for. Our understanding is that Limits and Targets are being proposed by MfE as follows:

- Limit – Limits are intended to delimit or demark the current state of the natural environment, in this case indigenous biodiversity, within a Biodiversity Management Unit. The intention is that this current state is maintained.
- Target – Targets are intended to delimit or demark a desired future state of the natural environment, in this case indigenous biodiversity, within a Biodiversity Management Unit, to ensure ecological integrity is protected. It is intended that the meeting of Targets is mandatory, and that once a Target is reached it is maintained.
- Each specified Biodiversity Management Unit would have a Limit(s) and Target(s).

- The overall goal of Limits and Targets is to ‘maintain ecological integrity’ of indigenous biodiversity. We note that:
 - to maintain (allow no reduction in) indigenous biodiversity and ecological integrity, the area (extent) of indigenous biodiversity must at least be retained (kept at the same level); and in many environments, maintenance will require an increase in extent. An increase in extent will not automatically mean an outcome over and above maintenance is achieved.
 - where there is a risk of effects before a Limit or Control comes into force, the Courts’ have ordered that the relevant rules/provisions have immediate legal effect on notification.² In the context of new law, this issue can be overcome by stating that the relevant requirement applies from a date prior to commencement.

6.2.1 Requirements: Limits and Targets

Limits and Targets set in the NPF or regional plans shall:

- be applied within defined Biodiversity Management Units that represent the full range of environments and biophysical potential across Aotearoa-New Zealand (such as LENZ). This is required to maintain the occurrence and extent of ecosystems and indigenous species and their habitats across the full range of environments (being ‘environmental representation’, which is a component of ecological integrity).
- be set based on a year prior to the new NBEA being operative to avoid the clearing of indigenous vegetation or removal of species habitat to reduce any potential restrictions on activities on land prior to legislation coming into force.
- be science-based.
 - Where they are used to set a minimum biophysical state (in this context the current state of indigenous biodiversity), limits must be quantitative so that losses and gains against that minimum state can be measured. Examples are the extent of an area or ecosystem, a number of species, or some other measurable quantum of ecological integrity. In this context, the Limit/Target effectively defines the currency in which performance is audited, and the exchange currency used, in Biodiversity Offsets and Biodiversity Compensation.
 - Where Limits are used to express a “maximum amount of harm or stress that may be permitted”, they may be qualitative. An example is a requirement to avoid Adverse Effects or specified Adverse Effects, on an area or value (e.g. Policy 11 NZCPS).
 - Both types of Limits are used in this Framework:
 - i A minimum biophysical state for indigenous biodiversity for maintaining the extent of indigenous biodiversity.
 - ii A maximum level of harm by stating how Adverse Effects on indigenous biodiversity are to be managed, including residual Adverse Effects.

² For example see: *Re Mackenzie District Council* [2017] NZEnvC 202.

- provide protection for the most threatened and at-risk ecosystems and species, with only narrow exceptions.
- be focused on (at a minimum), and so require quantification of
 - Developing Indigenous Ecosystem
 - Potential and Identified High Value Indigenous Fauna Habitat
 - High Value Indigenous Biodiversity
 - Off Limit Indigenous Biodiversity
- require rules controlling the activities necessary to be met. For example, we anticipate rules controlling or even prohibiting activities that transform indigenous habitats locally or at large scales such as oversowing and topdressing or irrigation in dry grassland environments, clearance and subdivision in low land coastal environments, exotic afforestation, and drainage.
- be the responsibility of Government to maintain.
- be monitored by Government to track changes with respect to Limits and Targets.

6.2.2 Implementation guidance: Limits and Targets

The following are recommendations for the implementation of the requirements for Limits and Targets outlined above:

- **Biodiversity Management Units:** We recommend that the Land Environments of New Zealand (LENZ) be used as the basis for defining terrestrial Biodiversity Management Units.

The LENZ classification (Leathwick et al. 2003a,b; commissioned and coauthored by MfE, and maintained by Manaaki Whenua) is an appropriate framework because it classifies biophysical potential, not ecosystem current state. In doing so, it provides for indigenous biodiversity adaptation to future climate change across the full spectrum of soils, geology, and topography. Biodiversity Management Units with similar biological potential are needed so that Biodiversity Offsetting or Biodiversity Compensation actions do not degrade the environmental representation component of ecological integrity (for example, by replacing rare alluvial terrace ecosystems with more common hillslope ecosystems).

LENZ exists, has consistent national coverage, and is widely available and used. While it is possible to use LENZ for this purpose now, at some point it may need to be updated as climate and soil data improve. Any update may alter the spatial boundaries of Biodiversity Management Units, but the transition need not be problematic (e.g. an earlier LENZ classification version used at the time of a Biobank's establishment could still be considered valid in the future if necessary).

Levels II, III, and IV of the LENZ classification spatially define 100, 200, and 500 environments nationally, respectively. LENZ Level III environments within regions is recommended as the appropriate level to define Biodiversity Management Units. Level III environments within regions will:

- constrain exchanges to areas of similar biophysical potential and therefore prevent depletion of the 'full range' of indigenous biodiversity, while

- providing an adequately ‘thick’ exchange market within a Biodiversity Management Unit to work in practice.

Level III environments may cross regional and local authority jurisdictional boundaries (Appendix 2), as is currently the case with some SNAs under the RMA system. This situation need not be problematic but will require additional guidance. For simplicity a region is likely to want to constrain Biodiversity Compensation and Biodiversity Offsets to their regions, but in some instances cross-jurisdictional exchanges may be preferable (e.g. where only a small area of LENZ Level III environment falls within a jurisdictional boundary).

LENZ has the advantage that it could also be used to define Biodiversity Management Units at a scale other than regions (for example, the four jurisdictional areas proposed as part of Three Waters Reform). However, larger scales have important drawbacks, e.g. in New South Wales, exchanges are not required to be local and can be 100s of km apart. This has led to severely depleted biodiversity in areas with high land values, and adverse effects in areas with cheaper land where establishing offsets has led to removal of grazing across whole properties.

- **Base year:** The base year should be set before the new NBEA is operative and should align with an existing underpinning land cover assessment such as a Land Cover Database (LCDB) assessment. Note that LCDB is necessary, but not sufficient, to define the Land Types within a Biodiversity Management Unit at the appropriate scale for managing indigenous biodiversity.
- **Mapping Land Types:** The way to approach the mapping is to initially map Converted Land, Developing Indigenous Biodiversity, and areas of potential High Value Indigenous Fauna Habitat on Converted Land. The remaining land will be either High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity; these categories will be resolved where and when sufficient information exists (e.g. where there is information from SNA surveys or naturally uncommon ecosystems maps) and, when necessary, on a case-by-case basis (e.g. where and when a resource consent application is made for a Nationally Significant Project). The mapping of Land Types should be regularly updated (e.g. as part of a monitoring cycle).
- **Mapping High Value Indigenous Fauna Habitat:** This mapping will need to be more bespoke than Land Type mapping. A two-stage process will usually be needed, with areas of potential High Value Indigenous Fauna Habitat mapped promptly where site-level data are currently sparse. On-site assessment and verification would then be undertaken by a Council over a longer time period, including on a case-by-case basis where a resource consent application is made for an activity affecting potential High Value Indigenous Fauna Habitat (see Section 9 Examples).
- **Limits:** Limits specifying current biophysical state are based, at a minimum, on the extent of Land Types in the base year. There is insufficient information currently available to quantify or monitor a quality Limit for Land Types over large scale areas. Quality will, however, be relevant to determining Adverse Effects. In addition, where Biodiversity Offsets or Biodiversity Compensation is required, there will be requirements that quantity and quality of indigenous vegetation, species habitat and/or species are assessed pre- and post- development. Knowledge of quality should, however, improve with time.

- **Targets:** Targets should be science-based and measurable. Like Limits, they should be quantitative where this is possible and be based on extent at a minimum. Science-based targets should relate to Biodiversity Management Units (such as LENZ Level III environments).
- **Protection of indigenous species:** In this Framework, both the habitats and individuals of the most Threatened and At Risk flora and fauna are High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity, and Primary Adverse effects on these must be avoided to maintain Limits. We have allowed exceptions for Nationally Significant Projects in Development Track 2, which provides for Biodiversity Offsetting of Primary Adverse Effects on ecosystems, faunal habitat, and individuals from species populations in areas of High Value Indigenous Biodiversity. However, at a minimum, the replacement of any areas of species' habitat lost is required in Biodiversity Offsetting, to maintain an extent-based Limit. Replacement of the number of impacted individuals in affected populations is also required in Biodiversity Offsetting.
- **Rules to achieve Limits and Targets:** Rules in the NPF or regional plans should be designed to achieve each Limit and Target and should limit harm from human activities. These may include, for example, rules controlling drainage, fertiliser application, and pest plant invasion for each Biodiversity Management Unit. These controls may be achieved through conditions on a resource consent or through standards that an activity must meet to be a Permitted Activity.

6.2.3 Implementation prerequisites: Limits and Targets

More detailed implementation guidance related to setting and administering Limits and Targets requires further development beyond the scope of this report. This includes:

- Setting limits. Limits should be set at current state of indigenous biodiversity (to maintain ecological integrity) for each Biodiversity Management Unit. If current state is below what is needed to maintain ecological integrity of indigenous biodiversity within that Biodiversity Management Unit, then a Target which represents maintenance of ecological integrity will need to be set and achieved over time. Targets may also be set for other reasons, e.g. cultural aspirations; amenity; human health. Spatially identifying current state will be essential if meaningful Limits and Targets are going to be developed and adhered to. If LENZ Level III is used for terrestrial Biodiversity Management Units, as we recommend, the spatial definition of those Units already exists. If LENZ is not used, definition of Biodiversity Management Units to achieve maintenance of ecological integrity (of indigenous biodiversity) will require significant implementation support.
- Mapping the four different Land Types (Converted Land, Developing Indigenous Ecosystems and High Value Indigenous Biodiversity, and Off Limit Indigenous Biodiversity), including:
 - Regional-level mapping of all four Land Types, both for defining the current state, management of effects, and for future monitoring and reporting against Limits and Targets. This mapping will be within the capability already existing in most regional councils, many of which have previously developed similar spatial databases for their region. However, for consistency this Land Type mapping will

require national guidance to be developed for all regional authorities on how to spatially define the Land Types. It is important to note that the national landcover database (LCDB) is a key preliminary input to this spatial definition, but insufficient on its own. The Land Type mapping exercise would be mainly desk based (using remote sensing data) supplemented by field checks and ground truthing.

- Identification of any parts of Converted Land and Developing Indigenous Ecosystems that are High Value Indigenous Fauna Habitat will be needed. This will need national guidance to ensure an ecologically correct and consistent approach. An increase in ecological capability will be required in many regional councils (although some already have in-house capability for vertebrate groups).
- Higher-resolution mapping of Land Types may be needed for urban areas due to smaller and more fragmented areas of indigenous biodiversity and the high irreversibility of the Adverse Effects of development.
- Preliminary conversations with regional council ecologists have confirmed that identification of the four Land Types underpinning this Framework approach will be possible, practicable, efficient, and is likely to be considerably less demanding than mapping SNAs/SEAs.
- New mapping of certain harmful activities for the control of those activities across Land Types and so that Limits can be monitored (e.g. mapping of, and controls on, oversowing and topdressing, woody weed spread, irrigation, exotic plantation forestry, and/or drains within Biodiversity Management Units). We are aware of spatial methods that are developed (or now being developed, e.g. Burge et al. in preparation for drainage) for identifying such land use practices and weed spread. These methodologies would need to be assembled, tested, and promulgated.

6.3 Development Track 1: Biodiversity compensation for Developing Indigenous Ecosystems

Development Track 1 is for Adverse Effects of all activities on terrestrial Developing Indigenous Ecosystems (<25 years old). Developing Indigenous Ecosystems comprising or including common and not-threatened indigenous species are the only ecosystems that can be readily replaced with reasonable certainty in Aotearoa-New Zealand.

The currency we propose for the indigenous biodiversity exchanges is simple: hectares of affected land, with simple exchange restrictions on location (e.g. exchanges constrained to be within the same Land Environment with simple multipliers applied). Depending on the nature of the Developing Indigenous Ecosystem impacted and the Biodiversity Compensation area, there may be no requirement for active planting, with natural regeneration instead being able to be relied on.

Our assumption is that the types of indigenous biodiversity lost through Adverse Effects in Developing Indigenous Ecosystems are mostly common and/or readily regenerating components of indigenous biodiversity that will be able to be replaced through Biobanks or Developer-provided Compensation, within the same Biodiversity Management Unit.

A simple currency and use of natural regeneration helps minimise transaction costs. The detailed assessment and consequent high upfront cost (\$20,000–\$25,000 per property) to determine the biodiversity units (i.e. currency) for a Biobank has been detrimental to the establishment of Biobanks in the NSW scheme. A simple area currency that is generated from fully converted land also enables efficient monitoring for shrubland, wetland or forest areas using aerial images (enabling targeting of ground assessment).

Also, for simplicity and tractability, all Adverse Effects are treated similarly and aggregated into a total area of impact that would need to be compensated.

Although it is necessary that Biodiversity Compensation is established in advance of an impact occurring, there is often still an interim loss, leading to an interim drawdown of indigenous biodiversity (i.e. interim net loss), albeit of mostly common and readily regenerating components. Interim loss brings risk of permanent loss, and exchange restrictions and multipliers are needed to partly address these risks. In the requirements in Section 6.31 below we propose some simple restrictions and multipliers based on both risk to indigenous biodiversity and risk of non-delivery.

6.3.1 Requirements: Development Track 1

Biodiversity Compensation shall:

- comply with all other legislation, standards and rules that may apply to the development site.
- not be required for Adverse Effects on Converted Land; however, standards and rules from other policies will apply to this Land Type, e.g. National Policy Statement for Freshwater Management.
- not be used to exchange the more than trivial residual Adverse Effects on High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity.
- be required to exchange any more than trivial residual Adverse Effects of any permitted, controlled, or discretionary activities on Developing Indigenous Ecosystems, including off-site Adverse Effects.
- be used only after exhausting all efforts to apply the Effects Management Hierarchy to any more than trivial Adverse Effects of controlled or discretionary activities on Developing Indigenous Ecosystems. This means that within Developing Indigenous Ecosystems the complete management hierarchy is:
 - Adverse Effects are avoided where possible;
 - Adverse Effects that cannot demonstrably be avoided are remedied where possible;
 - Adverse Effects that demonstrably cannot be remedied are mitigated where possible
 - Any more than trivial residual Adverse Effects are subject to Biodiversity Compensation.
- ensure at least, no net loss of **area** of indigenous vegetation or species habitat against a Limit in a Biodiversity Management Unit with a margin for uncertainty, and

- be new **areas** of indigenous vegetation created on Converted Land that is then permanently legally protected, and managed, e.g. permanent covenants or reserves and actively controlled for weeds and pests.
- be established and then managed in a way that is consistent with allowing and supporting regeneration of indigenous vegetation, e.g. fencing, restricted use of fertilisers, no drainage, removal of non-native canopy (e.g. plantation), or planting of indigenous species where necessary, although planting may not always be required.
- not be created from Developing Indigenous Ecosystems, High Value Indigenous Biodiversity, or Off Limit Indigenous Biodiversity.
- include a buffer area around the core area used for Biodiversity Compensation unless adjacent to existing Protected Land. For accounting purposes, only the core area is counted.
- be additional to requirements under other environmental policies.
- be subject to at least the following exchange restrictions on **location** of the new **area** of indigenous vegetation. Biodiversity Compensation is to be within the:
 - same Biodiversity Management Unit (e.g. under our recommendations, the same LENZ Level III environment); and
 - same or higher category of threat to indigenous biodiversity within a Biodiversity Management Unit, if applicable (e.g. if LENZ Level III is used as the Biodiversity Management Unit, within the same or higher threat category of the Threatened Environment Classification); and
 - same or comparable land tenure (see Section 7.1 for discussion on the use of Protected Land).
- use multipliers to determine the amount of Biodiversity Compensation (or the Biodiversity Compensation ratio) required for any impact.

An overview of the Biodiversity Compensation process is outlined in Fig. 2.

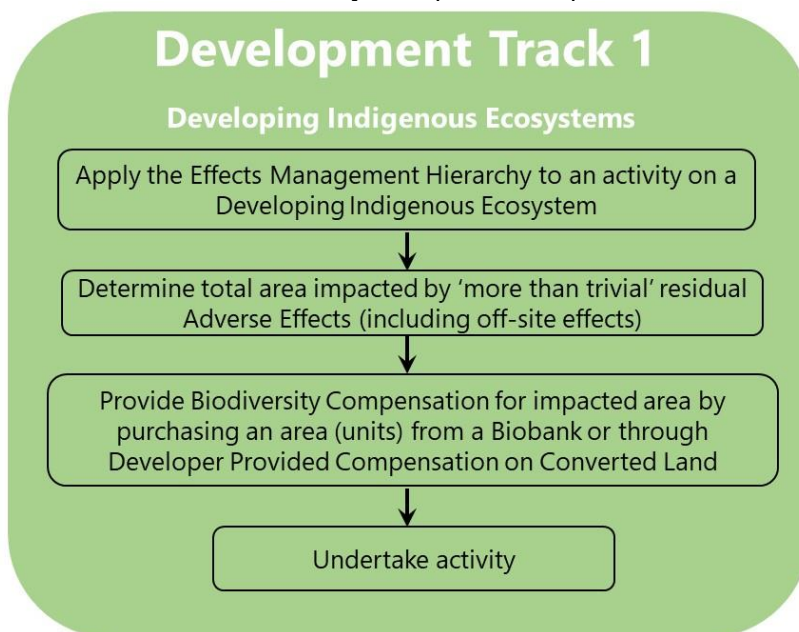


Figure 2. Biodiversity Compensation process for Developing Indigenous Ecosystems.

6.3.2 Implementation guidance: Development Track 1

The following are recommendations for the implementation of Development Track 1:

- **Sourcing Biodiversity Compensation:** Biodiversity Compensation should be sought from a registered Biobank or be Developer Provided Compensation that fulfills the requirements of Biodiversity Compensation prior to any impacts occurring. If no applicable registered Biobank exists and the developer cannot provide the required Biodiversity Compensation themselves, then the residual Adverse Effect(s) should not be allowed, and the activity should not go ahead. This emphasises the importance of Government supporting the establishment of Biobanks and a supporting registry as soon as possible. It will avoid the situation in NSW where payments to the Biodiversity Conservation Fund have allowed clearance before the biodiversity gains have been made. There is a shortfall in biobank units in NSW where state government reported 'the current calculator relies on relatively limited trading data and may deviate from the actual cost of supplying credits' (NSW 2022).
- **Estimating Adverse Effects:** In Development Track 1, our requirement is that all Adverse Effects, whether they involve indigenous vegetation clearance or not, are treated the same: the total area to be compensated is calculated as any area experiencing an Adverse Effect(s). For some activities, such estimates may be simple (e.g. the demarcated area of a residential section or logging skid site). For others, such as edge effects or effects on fauna species, presence related to effects other than physical habitat loss (e.g. noise), these may be less readily estimated and will vary with ecological context (e.g. edge effects may extend longer distances in grasslands and wetlands than in forests). In our experience, edge effects are often overlooked or underestimated for some development activities (e.g. farming). We recommend that standards and guidance are developed for regional rules that specify setback distances for edge effects of different activities in different Land Types. For example, a regional rule would specify a mandatory setback distance for aerial herbicide spraying, to ensure that spray drift did not have Adverse Effects on Developing Indigenous Ecosystems, High Value Indigenous Biodiversity, and Off Limit Indigenous Biodiversity.
- **Nationally significant projects:** Agencies undertaking similar Nationally Significant Projects could collaborate to provide adequate areas of Biodiversity Compensation for their needs.
- **Permitted activities:** If Limits focused on maintaining current state are to be met, Biodiversity Compensation will need to be required for more than trivial Adverse Effects from Permitted Activities on Developing Indigenous Ecosystems. This would be done by including Biodiversity Compensation as a standard that an activity must comply with to qualify as a Permitted Activity. All land use activities should be treated the same to minimize perverse outcomes, e.g. in NSW some permitted clearance was allowed on farmland but not adjacent urban land. This led to pre-emptive clearance on land-banks/peri-urban areas in advance of consent for intensification to reduce any offset requirements. One advantage of a Biobank is it simplifies the Biodiversity Compensation process for a Permitted Activity. The entity(ies) undertaking the Permitted Activity would purchase the required number of units from the Biobank to compensate for any more than trivial Adverse Effects the activity causes in a Developing Indigenous Ecosystem. We see regional councils having an important role

in either establishing, or supporting the establishment of, Biobanks to provide units for Permitted Activity exchanges.

A notification process would need to be developed at the local level for a Permitted Activity to notify the local authority the activity is being undertaken and where the Biodiversity Compensation is located.

For this system to work, councils would need to be able to undertake relatively comprehensive Permitted Activity monitoring, and charge for that monitoring.

- **Exchange restrictions on location:** If Biodiversity Management Units are LENZ Level III environments, as we recommend, the Threatened Environment Classification ('TEC'; Walker et al. 2006; Cieraad et al. 2012) will be appropriate for restricting the location of compensation. TEC creates six categories (Category 1: <10% indigenous cover remaining; Category 2: 10–20% indigenous cover remaining; Category 3: 20–30% indigenous cover remaining; Category 4: >30% indigenous cover remaining and <10% legally protected; Category 5: >30% indigenous cover remaining and 10–20% legally protected; Category 6: >30% indigenous cover remaining and >20% legally protected).

In specific places where there is high risk or high consequences of 'hollowing out' are identified (such as in cities, peri-urban and coastal areas), smaller Biodiversity Management Units than LENZ Level III environments may be deemed necessary. This will further restrict the location of Biodiversity Compensation to ensure that indigenous biodiversity is maintained. There may still be some instances where indigenous biodiversity on high-value (monetary) land (e.g. coastal and peri-urban land) is exchanged for lower-value land (e.g. remote from urban areas) in similar land environments, as reported in NSW. Similarly, an ACT review found offset sites were disproportionately located in landscapes not immediately threatened by development (Connors 2020). Regional Spatial Strategies can be used for further alleviate this risk.

6.4 Biobank establishment for Development Track 1

In this section we outline requirements and guidance for permanent terrestrial Biobanks to be established and maintained. Biobanks are new to Aotearoa-New Zealand (Brown 2017c). Their implementation is critical to the success of our Framework; however, Aotearoa-New Zealand's experience with them is limited. As a result, detailed requirements and guidance will need to be developed for their successful establishment.

A key assumption of a Biobank in our Framework is that the Developing Indigenous Ecosystems being replaced by a Biobank are simple ecosystems and made up of mostly common indigenous vegetation and mobile fauna species. The success of a Biobank relies on the 'Field of Dreams' hypothesis of restoration ecology (i.e. 'if we build it, they will come'; Hilderbrand et al. 2005). We advise that in many instances, setting aside an area of Converted Land and then protecting and managing that land to support indigenous vegetation regeneration will be sufficient, rather than needing to undertake plantings, because:

- Developing Indigenous Ecosystems (by definition) have been able to establish themselves without (or with limited) human help on Converted Land in the last 25 years, and
- Biobanks will need to meet standards for management that facilitate the regeneration of indigenous ecosystems.

High Value Indigenous Fauna Habitat (i.e. habitat for Threatened and At Risk species) cannot be assumed to be replaced in a Biobank. Additional actions are required to effectively replace and sustain that habitat. Therefore, High Value Indigenous Fauna Habitat is grouped within our High Value Indigenous Biodiversity Land Type when it is located on Developing Indigenous Ecosystems.

6.4.1 Requirements: establishment of biobanks

A terrestrial Biobank shall:

- be established
 - and used for an exchange for more than trivial residual Adverse Effects on Developing Indigenous Biodiversity from permitted, controlled, or discretionary activities in a Biodiversity Management Unit, and
 - to replace or expand Developing Indigenous Ecosystems to achieve Limits or Targets.
- comply with all requirements for Biodiversity Compensation outlined in Section 6.3.1.
- be created and managed by a third party, such as a regional council, an NGO, or a Māori Trust.
- comply with any existing and future national legislation and regional policies, including standards for management that facilitates the regeneration of indigenous ecosystems.
- be publicly registered and assessed to ensure it is on Converted Land and so is a new area of indigenous vegetation (i.e. additional) prior to registration.
- record all exchanges (sales) from the Biobank in the centrally managed public registry.
- be centrally managed for all monitoring, auditing and enforcement actions.
- sell any unit from a Biobank only once.

6.4.2 Implementation guidance: Biobanks

The following points are recommendations for the implementation of Biobanks:

Biobank establishment should:

- **Be undertaken and then managed by a Third party.** Biobanks provide entities with access to a simple exchange mechanism for any more than trivial residual Adverse Effects of an activity on Developing Indigenous Biodiversity. The cost of purchasing area units from a Biobank will provide the revenue stream for the management

activities required in the Biobank to successfully recreate Developing Indigenous Biodiversity. The other form of Biodiversity Compensation, Developer-provided Compensation, does not allow a transfer/sale of units.

- **Be planned, located, and sized appropriately** to anticipate and respond to expected Adverse Effects on Developing Indigenous Biodiversity within Biodiversity Management Units, including Adverse Effects from permitted, controlled and discretionary activities. Regional Spatial Strategies are likely to be a key tool for helping to identify where future activities are most likely to locate and so which LENZ Level III environments Biobanks are most likely to be needed, as well as for identifying the location of established Biobanks. An example of a spatial restoration is the Dunedin Halo project and site prioritisation tool (<https://www.haloproject.org.nz/source-to-sea>)
- **Incentivise landowners** to establish Biobanks on their land. The primary incentive is that the owners of land on which a Biobank is located will receive an on-going revenue stream for setting aside their land for indigenous biodiversity. The revenue stream is anticipated to come from the purchase of units from a Biobank by those entities undertaking permitted, controlled or discretionary activities on Developing Indigenous Biodiversity. The NSW biobank experience suggests additional incentives may be required, particularly to reduce 'up front' costs by coordinating assessments of private lands in strategic restoration areas (such as under Regional Spatial plans), e.g. 'Environment Zones' in Cumberland Plain Conservation Plan, Western Sydney.

Buffers around a biobank: The need for a buffer around a Biobank could be reduced or negated where it adjoins other existing areas of indigenous biodiversity, including other Biobanks and Protected Land.

Biobank register: We recommend there is a single Biobank Register for all Biobanks established around the country. This will provide transparency around where Biobanks exist, the sale of units from those Biobanks and to facilitate the regular monitoring of Biobanks. The Register could be dual purpose in that it is the register for both Biobanks (and their exchanges) as well as for Developer Provided Compensation and Biodiversity Offsets. This would provide a complete and transparent picture of what is being established and where. The New Zealand Emissions Trading Scheme contains a registry that could be used as a guide for a Biobank Register (or potentially expanded to include the Biobank registry – this would need further exploration to determine feasibility). The transparency provided by an open list of exchanges and areas has been identified as providing community confidence in such Schemes.

Separate standards and guidance for establishing Biobanks should be written: If Biobanks are to be provided for, then detailed standards and guidance will be needed for their establishment and use, and this will be beyond what is contained in NBEA or NPF. It may, for example, require its own set of regulations. There will need to be some regional differentiation, especially as there is variation in how readily indigenous vegetation will establish on Converted Land across the country. The details of these standards are beyond the scope of this report; however, ideally these standards would be developed before the NBEA is operational.

Regional Spatial Strategies: Regional councils should be required to delineate zones for Biobanks within their spatial strategy.

Centralised auditing, monitoring, enforcement: Regular monitoring will need to be undertaken by entities managing a Biobank to ensure they are meeting all Biobank requirements. The entity managing the Biobank Register will also need to audit the Biobank monitoring reports for compliance purposes and undertake any necessary enforcement actions. This will ensure consistency in audits and remove any issues arising from local entities doing audits (Brown et al., 2013; Brown 2017a,b; Report of the Biodiversity Collaborative Group 2018). The central Biobank Register could be overseen by a newly established enforcement entity (as others have recommended be established) or within an existing entity like the EPA, which has been allocated enforcement powers under the RMA as part of recent legislative amendments. To increase the effectiveness of the auditing and enforcement, training should be provided (Brown et al. 2013; Brown 2017a,b). This approach was adopted in Victoria and appears to have been successful in supporting more consistent, stronger enforcement.

Permitted activity impacts: It may be beneficial for regional councils to establish their own Biobanks to ensure that the Adverse Effects of permitted activities can be adequately and simply compensated for within their region.

6.4.3 Implementation prerequisites: Biobanks

Processes and roles for Biobank establishment, registration, and monitoring: We anticipate that considerable work will be needed to guide the establishment of robust Biobanks. This is beyond the scope of this report, but some areas may include, but are not limited to:

- Process to establish and register a Biobank.
- Monitoring requirements for a Biobank.
- Standards for management within Biobanks to ensure the successful regeneration of indigenous ecosystems.
- Role and powers of the central Biobank Register, e.g. auditing, compliance, unit exchange process.

Accelerating Biobank establishment: To be successful, Biobank establishment needs to begin immediately. Regional councils should be an integral player in the establishment of Biobanks, especially those used to provide exchanges for more than trivial Adverse Effects of Permitted Activities. As noted, the regional spatial planning process provides opportunity for strategic identification of both specific Developing Indigenous Ecosystems considered most likely to be affected by development, and areas of Converted Land within the same Biodiversity Management Unit that are best suited for Developer Provided Compensation and Biobanks. The areas where Biobanks may be challenging to establish are on high-value economic land and it will require intentional decisions to establish Biobanks on this land. Accelerating establishment of Biobanks will require the process and standards for Biobank establishment to be prioritised for development.

We recognize there have been challenges in other jurisdictions (e.g. Queensland and New South Wales) to attract sufficient sites for their advanced offsets (similar to the Biobank concept in this Framework). The mapping of Converted Land, the identification of Biobanks (and potentially other areas important for strategic planning of Biodiversity Compensation as described above) in Regional Spatial Strategies and the involvement of regional councils in Biobank development are seen as key factors for driving Biobank establishment within this Framework. This Framework also does not allow an option where an entity can compensate for their Adverse Effects through a financial payment (as in Queensland). Rather, units must be purchased from an established Biobank prior to the Adverse Effect occurring. This also provides an incentive to establish Biobanks or Developer-provided Compensation.

In some areas, the availability of land for Biobanks is going to be constrained, e.g. in urban areas. A mixed approach involving onsite and offsite compensation could help address this challenge. Smaller areas of Developer Provided Compensation within development sites (as they do in the UK; zu Ermgassen et al. 2021) as well as Biobank exchanges could be used to compensate for Adverse Effects of urban development. zu Ermgassen et al. (2021) recommends that a minimum portion of any compensation should meet regional indigenous biodiversity priorities, not just rely on small onsite actions. This will require Biobanks to be available for areas of high demand and hence the need to accelerate their establishment.

6.5 Development Track 2: Biodiversity Offsets for Adverse Effects on High Value Indigenous Biodiversity and High Value Indigenous Fauna Habitat on Converted Land

6.5.1 Overview

Development Track 2 provides for Biodiversity Offsetting to address more than trivial residual (Fig. 3):

- Primary and Secondary Adverse Effects of Nationally Significant Projects on High Value Indigenous Biodiversity.
- Secondary Adverse Effects of all other activities on High Value Indigenous Biodiversity after application of the Effects Management Hierarchy (Primary Adverse Effects must be avoided).
- Primary and Secondary Adverse Effects of all activities on High Value Indigenous Fauna Habitat on Converted Land.

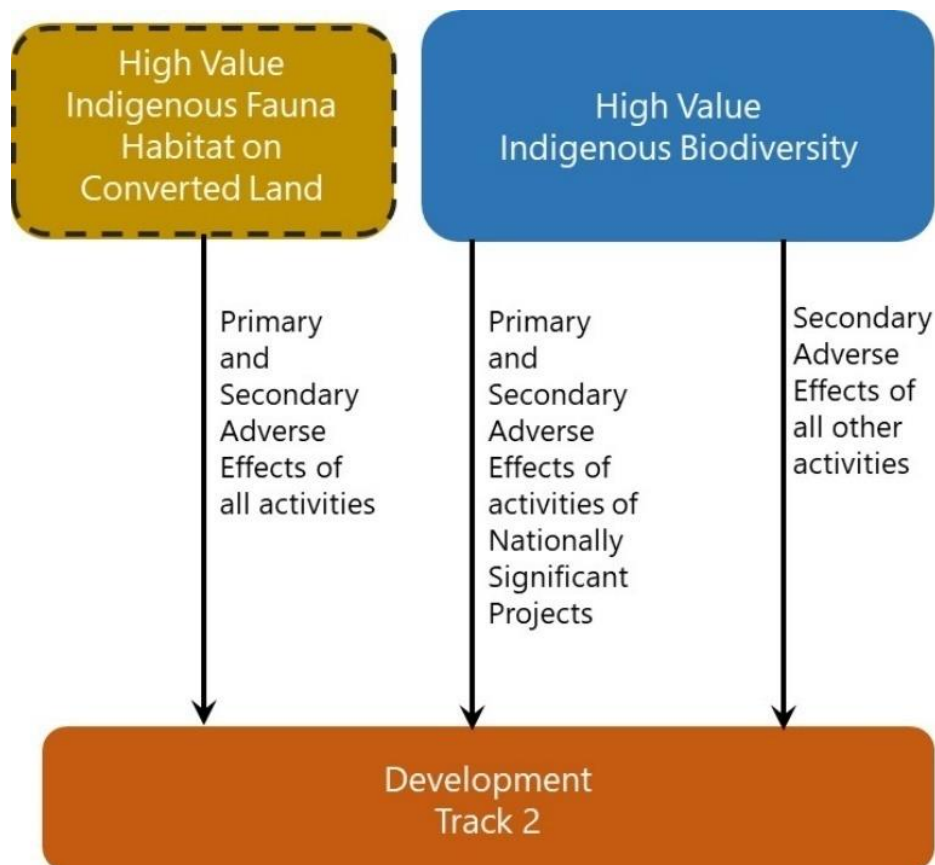


Figure 3. Overview of Treatment of Adverse Effects in Development Track 2.

Three types of Biodiversity Offsets are provided for. These three types of Biodiversity Offsets themselves are intended to form a hierarchy (the 'Biodiversity Offset Hierarchy'). Thus, the Effects Management Hierarchy – in the situations where it applies – is as follows:

- More than trivial Adverse Effects (or Secondary Adverse Effects) must be avoided where possible
- Any more than trivial Adverse Effects (or Secondary Adverse Effects) that cannot demonstrably be avoided must be remedied where possible
- Any remaining more than trivial Adverse Effects (or Secondary Adverse Effects) that cannot demonstrably be avoided or remedied must be mitigated where possible
- Any remaining more than trivial residual Adverse Effects (or Secondary Adverse Effects) must be subject to a Biodiversity Offset, applying the Biodiversity Offset Hierarchy below:

1. **Offset in-kind close to the impact site.** This is a measure to offset any more than trivial residual Adverse Effects that cannot be avoided, remedied and/or mitigated, to achieve a net gain of indigenous biodiversity. The offset replaces indigenous Biodiversity Elements impacted by a development with the same indigenous Biodiversity Elements, close to the impact site.

2a. If it is possible to provide an **Offset in-kind** but not possible to provide it close to the impact, then an **Offset in-kind distant from the impact site** can be provided. This option is limited to exchanges for any more than trivial residual

Adverse Effects on individuals of a mobile species population that cannot be avoided, remedied, mitigated or addressed through an in-kind offset close to the impact site. This option is intended only to apply in specific situations where measurable gains in the species impacted can be made at a distance because of its habits and lifecycle. An example is predator management in a breeding habitat of a mobile bird species distant from the impact site in exchange for individuals of that species displaced from or killed at the impact site (e.g. by a windfarm).

2b. If it is not possible to provide either type of **Offset in-kind** then an **Offset out-of-kind close to the impact site** can be provided. This option is a measure of last resort and strict tests apply:

- First, it must be not *possible* (i.e. the lesser test of *not practicable* is inappropriate) to replace the Biodiversity Element that is impacted with the same Biodiversity Element.
- Second, for individuals and populations of species, the impacted species must be Not Threatened, and any out-of-kind exchange must 'trade up' to a Threatened or At Risk species. This equates to avoiding Adverse Effects on species that are 'irreplaceable' or 'vulnerable' as in the NPS-IB exposure draft offset and compensation principles. Larger multipliers are applied to more taxonomically dissimilar exchanges and ecological dissimilar species' habitat.
- Third, if it is not possible to replace Biodiversity Elements that are habitats, ecosystems or communities, then replacements of the most similar Biodiversity Elements possible must be created with larger multipliers applied for rarity and dissimilarity to the displaced Biodiversity Element.

3. If it is not possible to provide **Offset in-kind** or **Offset out-of-kind close to the impact site**, then the activity cannot proceed.

Like Biodiversity Compensation, under this Framework Biodiversity Offsets do not allow for the use of 'averted loss' Biodiversity Offsets. This is achieved through the requirement, at a minimum, to provide new areas of indigenous vegetation or species habitat in any Biodiversity Offset.

The Offset out-of-kind close to the impact site option within the Biodiversity Offset Hierarchy is the highest risk option in the Framework. It provides an opportunity to exchange biodiversity that does not appear to be provided for in the NPS-IB Exposure Draft. We recognise that some projects that are not 'offsettable' like-for-like are likely to go ahead if they are Nationally Significant. This option will result in the permanent and irreversible loss of ecosystems, species, and species habitats that are most challenging to rehabilitate and of highest value ecologically to New Zealand, and globally. This will be a permanent and irreversible loss of ecological integrity.

Nationally Significant Projects on High Value Indigenous Biodiversity

For all more than trivial Adverse Effects Nationally Significant Projects must apply the Effects Management Hierarchy followed by the Biodiversity Offsets Hierarchy.

Under this Framework, if a Biodiversity Offset cannot be provided in any instance where it is required, then the activity cannot proceed.

All other development activities with Adverse Effects on High Value Indigenous Biodiversity

All activities other than Nationally Significant Projects must

- avoid Primary Adverse Effects on High Value Indigenous Biodiversity; and
- apply the Effects Management Hierarchy followed by the Offsetting Hierarchy for all Secondary Adverse Effects.

Under this Framework, if a Biodiversity Offset cannot be provided in any instance where it is required, then the activity cannot proceed.

All activities with Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land

All entities undertaking activities with more than trivial Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land must apply the Effects Management Hierarchy followed by the Biodiversity Offsets Hierarchy. The more than trivial residual Adverse Effects both on species populations and on their habitats must be offset.

Under this Framework, if a Biodiversity Offset cannot be provided in any instance where it is required, then the activity cannot proceed.

6.5.2 Rationale for Development Track 2

As noted in Section 2.1, many regulatory biodiversity offset programmes are failing biodiversity internationally, and no remedies have proven effective. In this Framework, indigenous biodiversity is High Value Indigenous Biodiversity when there is little, or no, credible ability to replace the actual ecosystems or species being impacted. As described in Section 2.2, these ecosystems and species are rare, and/or old and/or difficult or not possible to restore within 25 years. Thus, Nationally Significant Projects following Development Track 2 will always result in a drawdown (i.e. loss) of indigenous biodiversity and are therefore incompatible with maintaining ecological integrity (of indigenous biodiversity); and with achieving a Limit defined as the current state or a Target set to improve ecological integrity. Therefore, any use of Development Track 2 must be both restricted and held to the highest international standards. The larger the 'carve outs' and exceptions, the larger the permanent loss of indigenous biodiversity.

The intent of Development Track 2 is to strike the right balance between making Biodiversity Offsets costly enough to provide a strong incentive for Nationally Significant Projects or developers in High Value Indigenous Fauna Habitat (see also Section 7.4) to either locate their activity away from High Value Indigenous Biodiversity or High Value Indigenous Fauna Habitat, or to manage Adverse Effects in accordance with the Effects Management Hierarchy, while at the same time providing for a genuine biodiversity offsetting opportunity.

Development Track 2 requires developers of Nationally Significant Projects with Adverse Effects on High Value Indigenous Biodiversity, and all those undertaking activities with Adverse Effects on High Value Indigenous Fauna Habitat to undertake bespoke restoration and management to offset those Adverse Effects. Development Track 2 also requires all those undertaking activities with Secondary Adverse Effects on High Value Indigenous Biodiversity (but not Primary Adverse Effects which must be avoided) to apply the Effects Management Hierarchy, and then apply the Biodiversity Offset Hierarchy to any more than trivial residual effects.

Recourse to a third-party Biobank or developer-provided Biodiversity Compensation is not available in Development Track 2. Bespoke restoration and management are required because replacement of High Value Indigenous Biodiversity and High Value Indigenous Fauna Habitat is typically more complex and demanding than for Developing Indigenous Biodiversity. The consequences of the Adverse Effects are more uncertain, making detailed assessment necessary before applying the Effects Management Hierarchy and potentially the Biodiversity Offset Hierarchy.

Ideally Biodiversity Offsets would be provided well in advance of a project's impacts to minimise interim loss to the maximum extent possible. General Adverse Effects of large projects often will be known in advance of consenting, with the specific Adverse Effects known once the detailed assessments are completed during consenting. In some situations, an offset established close to the impact site before the activity is established could be adversely affected by the construction of the activity itself. Some local authorities have been hesitant to support preparation of Biodiversity Offsets substantially in advance of a project because of a concern it may be seen as pre-determining decision-making on the resource consent application. A new resource management system, and Regional Spatial Strategies, may present an opportunity to support early investment in Biodiversity Offsets.

6.5.3 Requirements: Development Track 2

The developer of a Nationally Significant Project shall:

- follow the principles (in Section 6.1).
- comply with all other legislation, standards and rules that may apply to the development site.
- only consider a Biodiversity Offset for any more than trivial residual Adverse Effects on High Value Indigenous Biodiversity, after all the steps in the Effects Management Hierarchy have been sequentially exhausted. Adverse Effects on Developing Indigenous Ecosystems follow Development Track 1.
- follow the Biodiversity Offset Hierarchy for any more than trivial residual Adverse Effects on High Value Indigenous Biodiversity.
- meet all Biodiversity Offset requirements set out below.
- be responsible for the establishment, monitoring, and registration of any resulting Biodiversity Offset, including paying for any required audit monitoring.

An entity undertaking activities with Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land shall:

- follow the guiding principles (in Section 6.1).
- comply with all other legislation that may apply to the development site.
- only consider a Biodiversity Offset for any more than trivial residual Adverse Effects on High Value Indigenous Fauna Habitat, after all the steps in the Effects Management Hierarchy have been sequentially exhausted.
- follow the Biodiversity Offset Hierarchy for any more than trivial residual Adverse Effects on High Value Indigenous Fauna Habitat, including the individuals and populations of the fauna species.
- meet all Biodiversity Offset requirements set out below.
- be responsible for the establishment, management, monitoring, and registration of any resulting Biodiversity Offset, including paying for any required audit monitoring.

An entity undertaking an activity with only Secondary Adverse Effects on High Value Indigenous Biodiversity shall:

- follow the principles (in Section 6.1).
- comply with all other legislation that may apply to the development site.
- not undertake the activity if there are any Primary Adverse Effects associated with the proposed activity.
- only consider a Biodiversity Offset for any more than trivial residual Secondary Adverse Effects on High Value Indigenous Biodiversity, after all the steps in the Effects Management Hierarchy have been sequentially exhausted.
- follow the Biodiversity Offset Hierarchy for any more than trivial residual Secondary Adverse Effects on High Value Indigenous Biodiversity.
- meet all Biodiversity Offset requirements set out below.
- be responsible for the establishment, management, monitoring, and registration of any resulting Biodiversity Offset including paying for any required audit monitoring.

Biodiversity Offsets shall:

- be applied only after the steps in the Effects Management Hierarchy have been exhausted for any Adverse Effects.
- be derived by applying the Biodiversity Offset Hierarchy to determine the type of offset to be used.
- dis-aggregate the adversely affected indigenous biodiversity into Recognisable Ecosystems, Fauna Habitats, and Species. The same measures and metrics must then be used for the same elements of indigenous biodiversity (Biodiversity Elements) at both the impact and offset site.
- achieve a net gain in all Recognisable Ecosystems, Fauna Habitats and Species. Net gain is measured by type, amount and condition at the impact and offset site and requires an explicit loss and gain calculation. The net gains at the offset sites

are the same across types, amounts and quality (e.g. condition) of indigenous biodiversity, as those lost at the impact site and are achieved in the minimum possible time.

- establish new areas that replace all adversely affected Recognisable Ecosystems and Fauna Habitats and manage those areas. These areas must be:
 - initiated before any impact occurring on the development site
 - have multipliers applied to determine the size and condition of the new Biodiversity Offset area
 - close to the impact location, e.g. at the minimum in the same ecological district and land environment
 - additional (e.g. they must not displace any areas of Developing Indigenous Ecosystems)
 - permanently protected against future loss and not used to offset any future Adverse Effects
 - include buffer areas around the core area of the Biodiversity Offset
 - managed for on-going pressures such as weeds, pests, and diseases
 - on land of the same or comparable land tenure as the impact site unless the Biodiversity Management Unit (e.g. LENZ Level III environment) does not occur on land of the same tenure.
- establish or create new individuals for all impacted species populations and manage those individuals and their habitats for on-going pressures such as weeds, pests and diseases so long as the impacts last. These activities are:
 - initiated before any impact occurring on the development site
 - wherever possible, undertaken close to the impact location
 - have multipliers applied to determine the numbers of individuals and populations to be created by the new Biodiversity Offset
 - additional (e.g. they must not displace ongoing or potential future predator management activities or initiatives by other parties) and are not used to offset any future Adverse Effects
 - undertaken on land of the same or comparable land tenure as the impact site unless suitable habitat does not occur on land of the same tenure within the Biodiversity Management Unit.
- be established to minimise the delay between loss of indigenous biodiversity at the impact site and gain or maturity of indigenous biodiversity at the offset site.
- use and apply a robust quantitative method to calculate multipliers for time lags.
- in addition to establishing new areas or new individuals, address temporal gaps so that interim loss of Biodiversity Elements is avoided. For example, enhancement activities on existing habitats must replace lost Biodiversity Elements before impacts and maintain those Biodiversity Elements until such time as any new replacement ecosystems, habitats or populations mature.
- be managed to secure outcomes of the activity that last as least as long as the impacts, and preferably in perpetuity.
- provide for long-term persistence of Recognisable Ecosystems, Fauna Habitats and Species, including through ensuring connectivity and considering the impact

of activities in the wider landscapes on the Biodiversity Offset. For example, the Biodiversity Offset would need to overcome impediments to landward mitigation of coastal ecosystems and altered flood regimes in creating new offset areas.

- if Adverse Effects are on Public and Protected Land, offset those Adverse Effects on Public and Protected Land of similar status.
- achieve gains in indigenous biodiversity above and beyond gains that would have occurred in the absence of the Biodiversity Offset, including gains additional to any remediation and mitigation undertaken in relation to the adverse effects of the activity.
- be registered as a Biodiversity Offset in a centrally managed public Offset Registry. The biodiversity Offset Registry will record the aggregated offset as well as all dis-aggregated indigenous Biodiversity Elements.
- have a comprehensive biodiversity offset management plan for all impact and offset sites, including processes for adaptive management to achieve indigenous biodiversity outcomes.
- be covered by bonds or other security arrangements adequate to achieve indigenous biodiversity outcomes should the developer fail to carry out agreed actions or achieve the offset outcomes. The full bond must be provided before the activity starts.
- be verified at multiple time points. At a minimum, the adverse effects are assessed at the consenting stage, at the establishment of the offset, after the initial impact has occurred and then at specified time periods. Specified time periods are determined by the ecological characteristics of the Biodiversity Offset.
- be audited by a centralised (i.e. national) body for compliance with consent conditions and the Biodiversity Offset's management plan. Regional and local authorities should not be tasked with the auditing, compliance, and enforcement of Biodiversity Offsets, in particular for Adverse Effects of Nationally Significant Projects.

An overview of the Biodiversity Offset process is outlined in Fig. 4.

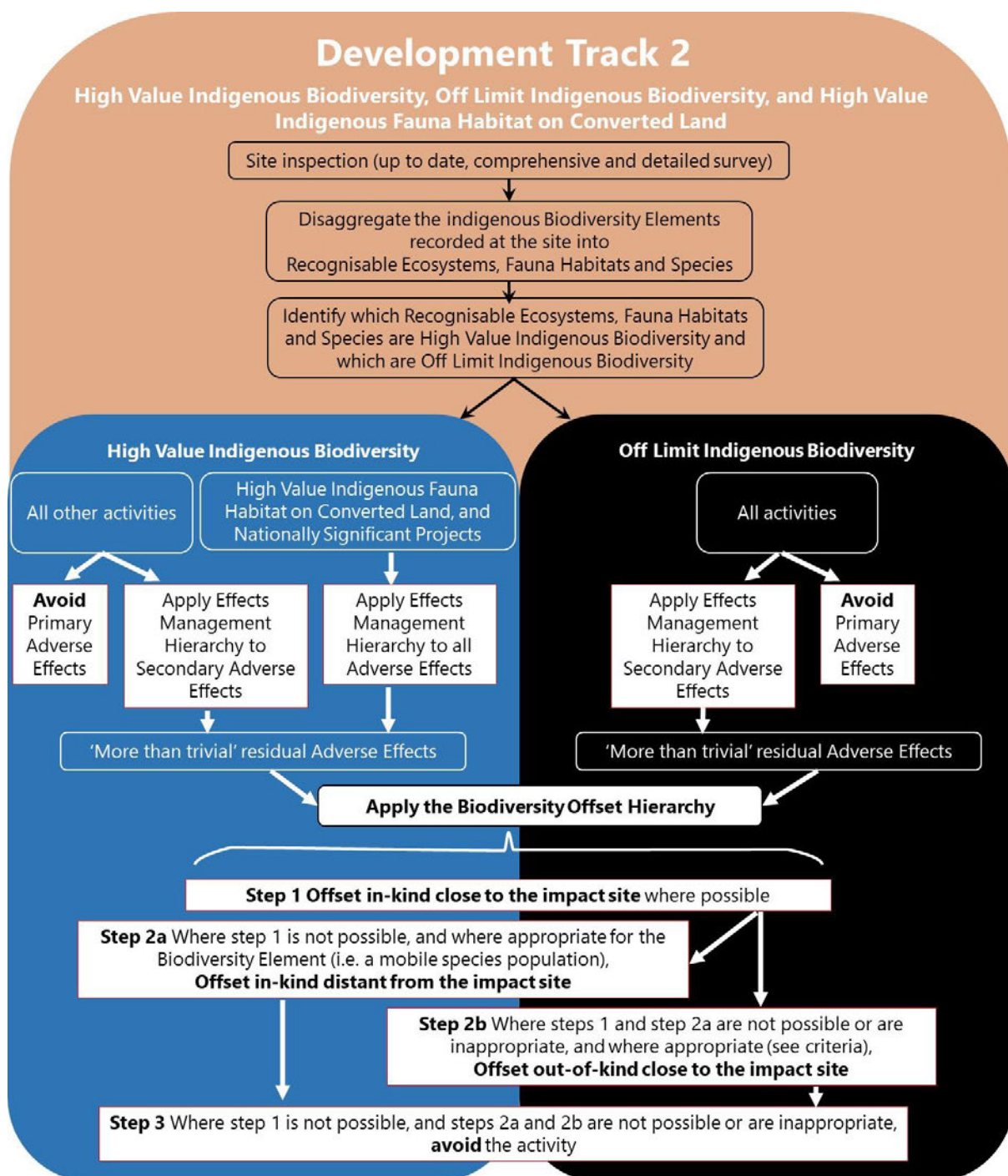


Figure 4. Biodiversity Offset process for High Value Indigenous Biodiversity, Off Limit Indigenous Biodiversity and High Value Indigenous Fauna Habitat on Converted Land.

6.5.5 Implementation guidance: Development Track 2

The following points are recommendations for the implementation of Development Track 2:

- **In-kind exchanges are preferred** to:
 - 1 ensure that indigenous biodiversity gains are comparable to the losses that occur through an activity, hence minimising the loss of difficult-to- conserve indigenous biodiversity; and
 - 2 better demonstrate net gain of indigenous biodiversity because equivalence can be assessed. There is no method for comparing and exchanging different components of indigenous biodiversity.
- **Disaggregation into Recognisable Ecosystems, Fauna Habitats and Species:** Any element of indigenous biodiversity not explicitly accounted for in a Biodiversity Offset is either lost in the trade or exchanged by default. More aggregate currencies increase the number of these 'concealed trades'. We recommend the disaggregated condition-area model developed for the Department of Conservation (Maseyk et al. 2016 and associated online resources) as a minimum standard for disaggregated offsetting. Further development based on more recent experience may be warranted (Dr Fleur Maseyk, pers. Comm.).
- **Assessing the Recognisable Ecosystems, Fauna Habitats and Species:** The initial assessment of the Biodiversity Elements should be based on current information with the Biodiversity Elements clearly mapped, described, and tabulated/recorded. Without reliable information it is not possible to assess the ecological value, address what the Biodiversity Offset would include and determine how the Biodiversity Offset would be undertaken.
- **Biodiversity Offsets of impacted ecosystems and species habitats require the establishment of new replacement areas**, and not only the protection and enhancement of already pre-existing areas of indigenous ecosystems and species habitats to address any interim loss. Likewise, Biodiversity Offsets of impacts on indigenous species populations requires the creation of new individuals and not simply greater protection for pre-existing individuals in another population. This approach is:
 - required to better maintain the current state, although there will inevitably be some drawdown (i.e. loss) of indigenous biodiversity involved in a Development Track 2 Biodiversity Offset.
 - likely to increase the cost of using the offset mechanism, and therefore incentivise developers to more adequately avoid, minimise and remedy any impacts at the development site.
- **Biodiversity Offset for indigenous fauna species:** A Biodiversity Offset to achieve a net gain in individuals of an indigenous fauna species can use that species' present habitat.
- **Biodiversity Offset design:** The design and implementation of a Biodiversity Offset should be a documented process informed by science, including an appropriate consideration of mātauranga Māori.

- **Biodiversity Offset registry:** A single registry for Aotearoa-New Zealand is recommended to provide transparency on the Biodiversity Offsets around the country, promote consistency in offset documentation and to facilitate the monitoring and auditing of Biodiversity Offsets over time. The registry could be stand alone or dual purpose where it contains Biodiversity Compensation details – Biobanks (and their exchanges) and Developer Provided Compensation – as well the details on Biodiversity Offsets. There are Biodiversity Offset registries in other jurisdictions that could be compared and assessed for their appropriateness for the Aotearoa-New Zealand context and for what to include in a registry. For example, the Queensland Government offsets register provides information on the location of impacted areas requiring an offset, impacted environmental values, payments made to the Queensland Government for offsetting impacted areas, offsets that are being delivered, areas suitable for delivering future offsets (this is similar to the Biobank concept outlined in this Framework) and approved activities for delivering offset projects (Queensland Government 2022). We are not suggesting that the Queensland offset register is the model registry, rather it is an example of how one jurisdiction has designed a registry.
- **Management plan(s) and consent conditions:** Information required for Biodiversity Offsets will often be too complex or lengthy for consent conditions. All Biodiversity Offsets must therefore have a comprehensive Biodiversity Offset management plan, and consent conditions must refer to this plan. Consent conditions for Biodiversity Offsets should contain key milestones to be achieved and their timeframes, that those in the management plan should align with.
- **Bonds and other security arrangements:** Secure, in-advance financial bonding is needed to ensure that the developer carries out required actions; or that in the event they do not, another party has the means to do so. Consent conditions should clearly state what these financial arrangements are.
- **Stakeholder involvement:** Relevant stakeholder and Māori representation should be involved during development of any Biodiversity Offset.
- **Leakage:** Many biodiversity offset programmes require avoiding displacing activities harmful to indigenous biodiversity to other locations. This Framework is developed to cover all Land Types in New Zealand, so the risk of leakage is low. However, there may be some cases where leakage may occur and if that case is identified then leakage should be included in the Biodiversity Offset requirements.

6.5.6 Implementation prerequisites: Development Track 2

The points below outline areas we believe guidance should be developed to assist with the robust implementation of Development Track 2:

- **Verification process at impact site and offset**
- **Determining multipliers**
- **Disaggregation of impacts**
- **Renewal of consents where Biodiversity Offsets are involved:** Future assessments of Adverse Effects should be based on the original indigenous biodiversity condition at the point that the original consent was granted. That is, the pre-development

baseline must be retained, and there should be no resetting of the 'existing environment' to a post-development baseline.

- **A centralised body is established for registering and auditing the Biodiversity Offsets** to ensure there is a both a credible and consistent approach and regular verification of biodiversity offset projects across New Zealand. These functions could be performed by an existing organisation/agency (e.g. the EPA) or by new organisation. Regardless of who performs the function, developers should pay a levy to fund this body. This levy would cover the costs of audit monitoring a Biodiversity Offset. Other funding would likely be required for the operation of this entity.

6.6 Development Track 3: Off Limit Indigenous Biodiversity

All Primary Adverse Effects of any activity on Off Limit Indigenous Biodiversity are avoided, because this category represents Aotearoa-New Zealand's most threatened and critically endangered types of indigenous biodiversity. An activity that cannot avoid Primary Effects cannot proceed.

Secondary Adverse Effects must be managed by applying the Effects Management Hierarchy, followed by the Biodiversity Offset Hierarchy (Section 6.5.1). An activity that cannot address all more than trivial residual Secondary Adverse Effects using one of these options cannot proceed. Any Biodiversity Offset must meet the same requirements set out in Section 6.5.3.

6.7 Multipliers

Multipliers define how much indigenous biodiversity needs to be restored to:

- fully recompense the Adverse Effects caused by development
- achieve additional or complementary goals, such as (in the NBEA context) maintaining Limits and reaching Targets.

Multipliers in Biodiversity Offset or Biodiversity Compensation

- minimise the risk that promised gains are not or cannot be fully delivered
- provide incentive for the Effect Management Hierarchy to be applied fully
- provides disincentive for undertaking development where the risk to indigenous biodiversity is higher, in indigenous ecosystems that will take longer to re-establish, and further from the impact site.

Multipliers are typically expressed as a ratio:

Amount or size of Adverse Effect: Amount or size of Biodiversity Offset or Compensation

The multiplier applies to the Biodiversity Offset or Biodiversity Compensation side of the above equation. A 1:1 ratio (a multiplier of 1) will not achieve no net loss or a net gain of indigenous biodiversity (and therefore will not maintain ecological integrity) because it assumes full, immediate, and certain realisation of the gains sought to be achieved by the

Biodiversity Offset or Biodiversity Compensation. This is not realistic because there are inevitably inequalities in exchange dimensions (type, time, location, and risk). For example:

- there will usually be differences between the habitat impacted and restored (type inequality)
- full restoration may occur sometime after impacts and there is interim loss (time inequality)
- a new geographic location may not deliver connectivity, leading to poorer species population outcomes (location inequality)
- development leads to certain loss, whereas reviews of practice (e.g. zu Ermgassen et al. 2019) show that a Biodiversity Offset rarely produces its promised outcomes for biodiversity (risk inequality).

We recommend that the multiplier used in a given situation be calculated with reference to persistence probability (Overton & Stephens 2015), including by considering:

- the **threat status** of the impacted Biodiversity Element. A given Adverse Effect will have a larger impact on the persistence probability of a more threatened ecosystem, habitat, or species population. Therefore, the more threatened the Biodiversity Element, the larger the Biodiversity Offset or Biodiversity Compensation will need to be.
- the **length of time for delivery** of the Biodiversity Offset or Biodiversity Compensation. Persistence probability at all levels of biological organisation (from genes to ecosystems) is sensitive to time lags between loss and restoration. Also, the longer the time lag, the greater the risk that a Biodiversity Offset will not actually be delivered in full. Therefore, the longer the time lag, the larger the Biodiversity Offset or Biodiversity Compensation will need to be to maintain pre-impact persistence probability. The longer the Biodiversity Offset has been established likely the smaller the multiplier.
- **the distance of the Biodiversity Offset or Biodiversity Compensation from the impact.** Replacement more distant from impact sites is more likely to disrupt spatial ecological processes, and result in greater dissimilarity between impacted and replacement indigenous biodiversity. The further from the impact site, the larger the Biodiversity Offset or Biodiversity Compensation will need to be.
- **the certainty of mitigation success.** This is linked to species response to habitat creation and removal of threats (e.g. pest control), and the potential for biodiversity gains to be increased in the event that expected outcomes are less than expected (e.g., through adaptive management). Certainty may be influenced by the potential of the new geographic location to deliver connectivity, species richness and other outcomes linked to landscape pattern and location.

The risk to biodiversity persistence posed by time lags can be addressed by estimating the size of a robustly fair exchange using the approach of Moilanen et al. (2009) and the method of Pouzols and Moilanen (2013). Another rigorous approach is that of Bruggeman and colleagues (Bruggeman et al. 2005, 2009; Bruggeman & Jones 2008), which explicitly accounts for spatial and temporal effects on species' rates of survival, recruitment, and migration. These approaches use a form of multiplier (known as a discount rate) to

compensate for some of the undesirable consequences of time-lags, and increase the size of the offset required to achieve equivalence with specified certainty. Evans et al. (2013) demonstrate an approach to estimating an appropriate discount rate informed by species or ecosystem threat status, which can be quantified as an annual probability of extinction.

The development of appropriate multipliers will need the careful consideration of the uncertainties listed above. The use of multipliers highly sensitive to one factor are more vulnerable to 'gaming' (zu Ermgassen et al 2021). This risk, and the risk of 'under-offsetting' or 'under-compensation' through ecologically unrealistic gains may be minimised by the rigorous assessment of proposals by biodiversity-trained regulators. The multiplier approach should be developed prior to the NBEA becoming operational to provide greater certainty to developers and those looking to establish Biobanks around the size of Biodiversity Offset or Biodiversity Compensation required. Several jurisdictions (e.g. Queensland; Queensland Government 2020) provide multiplier calculators that could be assessed and compared to determine the suitability of such approaches to the Aotearoa-New Zealand context and achieving a net gain in indigenous biodiversity.

7 Issues for further consideration

7.1 Public and Protected Land

The authors agreed that Biodiversity Offsets and Biodiversity Compensation in exchange for Adverse Effects on Public and Protected Land should also be located on Public and Protected Land (this approach is also used in Tasmania). However, the authors were not able to agree on whether Adverse Effects on Private Land should be able to be exchanged for Biodiversity Offsets or Biodiversity Compensation located on Public and Protected Land, as has sometimes occurred under the RMA. We set out some relevant considerations below on whether that practice should be allowed.

Public and Protected Land is mainly found on land with lower value for development and primary production, while in most lowland and coastal landscapes, Public and Protected Land areas are typically few, small, and insufficient on their own to maintain indigenous biodiversity. Under the NBEA, targets for increases in the area of indigenous vegetation and species habitats are most justified in landscapes where the least indigenous biodiversity remains.

Allowing Biodiversity Compensation and Biodiversity Offsets in Public and Protected Land in exchange for losses on Private Land risks further concentrating indigenous biodiversity into places where representation is already higher. This at the same time enables further habitat loss from development in areas where indigenous biodiversity is already more reduced. This process of 'hollowing out' reduces ecological integrity, because biodiversity loss is not a linear process: loss of species and of ecological function accelerates as the amount of habitat in a landscape is reduced (Andren 1994; Banks-Leite et al. 2020). Further habitat loss in a 'hollowed out' part of any landscape has a larger adverse impact on indigenous species and their long-term viability than a loss of similar magnitude in a place where representation remains higher (e.g. Connors 2020). Conversely, marginal gains from restoration where representation is already higher will usually be smaller than gains from

equivalent restoration in 'hollowed out' places. Cunningham et al. (2014) and Ruffell & Didham (2017) provide examples using indigenous birds in Australia and Aotearoa-New Zealand.

Hollowing out

- has been observed to be encouraged by offsetting policies elsewhere (e.g. in New South Wales; Gibbons et al. 2018)
- is also an important consideration for Regional Spatial Strategies because regional and local authorities may be tempted to prioritise biodiversity actions on more remote, cheaper, and less-contested land, where there will be the least benefit for ecological integrity.

In our Framework, Biodiversity Compensation can occur only on Converted Land, which accounts for a small fraction of Public and Protected Land, and we recommend spatial exchange restrictions based on LENZ Land Environments. This may limit the magnitude of the risk of hollowing out through our Development Track 1, but that risk may nevertheless be ecologically important.

Some Converted Land on Public and Protected Land will already be naturally regenerating. However, it is not a given, nor a legal requirement, that all will regenerate or be restored to indigenous cover, nor be enhanced where degraded; and from a legal point of view Protected Land covers a range of different conservation and recreation (e.g. regional parks) purposes. It may be difficult to predict which areas of Converted Land within Public and Protected Lands would or would not have naturally regenerated (because ecological contexts will be variable and predicting both future states and future management is challenging). It would therefore be difficult to ensure that additionality is achieved through our Development Tracks if exchanges between Public Land and private land were allowed.

There is also a risk that central or local government owners of a Biobank or Offset site on Public and Protected Land could substitute their funding for biodiversity maintenance and enhancement activities with funds obtained from development actions. Development-driven restoration has the potential to displace future actions by public agencies or voluntary community efforts. Such substitutions would be very difficult to identify. Whether or not substitution occurs, any public agency staffing and conservation actions funded through exchanges for development activities may result in conservation becoming reliant on development-sourced funding ('development-led'; Carver 2021).

An argument used in favour of using Public and Protected Land for Biodiversity Offsets or Biodiversity Compensation is that restoration projects provide benefits for indigenous biodiversity that would not otherwise be realised. For example, a similar opportunity may not exist on other land (e.g. seed sources or species populations are absent). However, providing opportunities on Public and Protected Land will disincentivise avoidance of effects on private land and weaken policy intent (zu Ermgassen et al. 2020). Enabling use of Public and Protected Land could remove the need to seek alternative and potentially more costly options on Private Land, reduce the incentive to locate developments where Adverse Effects on indigenous biodiversity are fewer, and provide a public subsidy to development. A public subsidy (e.g. requiring 'market value' payment to government as a

'concession fee') again risks public conservation reliance on development-sourced funding.

A view exists that as a nation we need to redefine and adopt a unique ethic and practice of conservation that is apt and effective for Aotearoa-New Zealand, in line with Te Tiriti and that tangata whenua, and their tikanga and mātauranga, have historically been overlooked in conservation management and decision making (Options Development Group 2022). A move towards a more bicultural approach to managing Protected Land may not be consistent with the approach to Biodiversity Offsetting and Biodiversity Compensation in this Framework. Other than acknowledging this consideration, the authors do not have the expertise to reach any firm recommendations in respect of this matter.

Policy decisions on the appropriateness of use of Public and Protected Land could also consider:

- the wider legal question about whether matters of tenure should be taken into account under in the NBEA or determined by the land status legislation itself (e.g. the Conservation Act)
- legal issues around a government agency committing the agency to a particular land use (e.g. for Biodiversity Compensation or Offsetting) in perpetuity.

If Adverse Effects on private land are allowed to be compensated for or offset on Public and Protected Land, then this requires amending of clauses that constrain exchanges of land to the same land tenure in sections 6.3.1 and 6.5.3, and this amendment would not affect other aspects of the Framework.

7.2 Treatment of new activities versus existing activities within the Framework

This report refers to activities generally; it does not distinguish between those activities which are new and those that are 'existing'. However, it was written with a focus on controlling the Adverse Effects of new activities and changes to existing activities that increase their character, intensity, and scale. This aligns with the approach in the NPS-IB exposure draft, which also acknowledges the importance of existing activities to communities.

Some existing activities may stay the same (in character, intensity and scale) but nevertheless have increasing effects on the ecological integrity of indigenous biodiversity. For example, roads may have increasingly severe and cumulative effects as traffic increases and/or fauna in adjacent land become rarer. Where effects are increasing, those activities will need to be revisited if ecological integrity is to be protected and Limits are to be met.

Under the current RMA system

- revisiting is possible for activities authorised by a regional plan and by a regional authority. Those activities do not have long term protection and will, after a grace

period, have to apply for resource consent to continue under any newly introduced rules (s 20A RMA), and

- it is not possible to revisit activities authorised through a district plan or by a territorial authority unless the activity has stopped for a period of 12 months or more (s10 RMA). Those activities receive long term protection and can continue 'as is' when new plan rules are introduced.

7.3 High Value Indigenous Fauna Habitat on Converted Land

Some of Aotearoa-New Zealand's indigenous fauna species have adapted to habitats outside of indigenous ecosystems and on Converted Land. When these habitats are not located on Converted Land, many would be High Value Indigenous Biodiversity or Off Limits Indigenous Biodiversity given the vulnerability of the fauna species they support. Examples of High Value Fauna Habitat on Converted Land can include kiwi and bats in plantation forests, and lizards in rock or wood piles in pasture, roadsides or urban areas.

Requiring avoidance of Primary Adverse Effects from all or most activities on High Value Fauna Habitat on Converted Land can be challenging because they often occur in areas long used for human activities or zoned for new development.

We recommend that Adverse Effects on High Value Indigenous Fauna Habitat on Converted Land are managed by applying the Effects Management Hierarchy, followed by the Biodiversity Offset Hierarchy. This approach will provide some flexibility for addressing more than trivial residual Adverse Effects (e.g. a plantation forestry operation could use a combination of rotational harvest and predator management, to address Adverse Effects of logging on kiwi populations). However, our approach would require a change from current salvage-and-relocation practices for fauna under the RMA. Specifically, management would be better aligned with best practice requirements for fauna translocations, and entail creation of new habitat, enhancement activities, and responsibility for outcomes as long as the impacts last.

8 Comparison to approaches under the RMA

8.1 Managing 'more than trivial' Adverse Effects

This Framework focuses on managing 'more than trivial' Adverse Effects. This terminology has been used by MfE in internal documents, so we expect it will be used in the NBEA.

'More than trivial' is a change from the 'more than minor' term used under the RMA. 'More than minor' is specifically referred to as one of the 'gateway' tests for non-complying activity effects in RMA s104D. The term 'minor' is not defined by the RMA, and the Courts have found there is 'no absolute yardstick for what might constitute a minor effect', and that minor suggests adverse effects that are less than major and can include effects that are more than simply minute or slight.

The meaning of 'trivial' would probably come before the Courts relatively promptly, even if the NBEA provides some form of definition, because it will be assumed that a different word has been used deliberately.

8.2 Enhancement of existing indigenous ecosystems

Enhancement of existing indigenous ecosystems is a subset of ecological restoration.

Enhancement can be achieved by (1) extending or (2) repairing ecosystems. Extending ecosystems can be achieved by removing barriers to movement, e.g. fish barriers or gaps between suitable habitat (e.g. patches <150 m apart for poorly flighted forest species such as tomtits). Ecosystems can also be extended by creating suitable conditions under which target species are competitive, e.g. by flooding drained land, restoring severed connections between floodplains and rivers (removing stop-banks or daylighting streams), or restoring flood- flows that remove river-bed vegetation.

Enhancement is also used to improve the quality or condition of an ecosystem, or to increase the number of individuals in a species population (Bans-Leite et al. 2020). Common enhancement actions include fencing to eliminate ungulate browsing and allow decompaction of soil surface (leading to greater seedling survival and build-up of leaf litter), and pest mammal, wasp or weed control which can all lead to beneficial trophic cascades (e.g. McGruddy et al. 2020). In Auckland, the Stream Ecological Valuation tool (Neale et al 2011) is used to assess actions to enhance stream conditions (e.g. riparian planting and in-stream habitat). Stream condition may also be improved by stormwater detention and treatment to remove contaminants and reduce erosive flows.

Enhancement actions that reduce edge effects are particularly effective to enhance forest fragments with large edge:core ratios, typical of many lowland landscapes, and along linear infrastructure. Mitigation for edge effects include noise walls (to reduce impacts of traffic noise), alteration or removal of lighting, and establishment of dense edge vegetation by setting fence lines beyond the edge of tree canopy (drip line). The resilience of enhancement actions is critical – as Bans-Leite et al. (2020) note, decades of good governance can be undone by just months of environmental attacks (e.g. browse) or extreme climatic events such as drought-induced fire.

Enhancement is an important aspect of maintaining and improving the ecological integrity of indigenous biodiversity in Aotearoa-New Zealand, has often been used in biodiversity offsetting in Aotearoa-New Zealand and overseas, and is also important in this Framework. However, offsets or compensation that involve an exchange of *condition* (improved through enhancement) for loss of *area* is an 'averted loss' offset that inevitably leads to drawdown (net loss) of indigenous ecosystems and species habitats, 'locking in loss'. In order to maintain Limits and the current state of indigenous biodiversity, condition is not allowed to be exchanged for area in this Framework, and any new ecosystems must be created on Converted Land.

We acknowledge that creating new, young ecosystems on Converted Land can be more difficult than repairing existing ecosystems (e.g. in Aotearoa-New Zealand's drier environments). However, in some situations, creating new, young ecosystems is achievable

by supporting natural regeneration on Converted Land with no, or minimal, active planting (e.g. reflooding drained wetlands or estuaries, and returning flows to riverbeds). Also, many areas of Converted Land (as defined here) will already have some indigenous components that provide starting points for natural regeneration (e.g. understoreys of plantations and wilding conifers (Forbes & Norton 2021); areas of recently established matagouri or kānuka within pasture).

Enhancement activities (and their benefits) cover various timeframes and their effectiveness can be difficult to assess. Actions are more easily measured than biodiversity benefits and outcomes, and enhancement activities themselves can have adverse effects. For example, trapping stoats can increase numbers of rodents (Whitau et al. in press) with adverse effects on smaller indigenous fauna; plantings can introduce pathogens and pest animals (e.g. plague skinks, molluscs, Argentine ants, earthworms) and increase disturbance and weediness. Enhancement activities also vary greatly in their difficulty to specify (such as in consent conditions), to maintain long term, and to monitor and enforce. Therefore, in this Framework:

- Only relatively simple enhancement activities are required in the ongoing management of a Biobank or Developer Provided Compensation in Development Track 1 (and these activities cannot be exchanged for area impacted). Any Biobank will need basic ungulate and weed control to provide the appropriate conditions for regeneration of indigenous vegetation.
- More complex improvements in habitat condition through enhancement activities are required only for Biodiversity Offsets in Development Track 2. Again, those enhancements are required in addition to the creation of new areas of indigenous ecosystems, species habitats and/or new species populations, to replace those subject to Adverse Effects. We expect that most Biodiversity Offsets required under Development Track 2 will involve a combination of establishing new areas on Converted Land and enhancements within existing ecosystems. They will resemble some current practice under the RMA, but with full replacement of habitat areas and species individuals as bottom lines.

We note that several other avenues are available to enhance existing indigenous vegetation in Aotearoa-New Zealand at large scales, including:

- Payments for ecosystem services. For example, private interests in Aotearoa-New Zealand and overseas are already seeking opportunities to invest in such activities (e.g. Toha Foundry) and government initiatives already exist (e.g. regional council restoration funds or the New Zealand Emissions Trading Scheme).
- Having enhancement requirements on activities on Converted Land to help achieve Targets for Ecological Integrity. However, consideration for how enhancement activities may be applied to Converted Land is beyond the scope of this project.
- Using development rules that allow more intensive development when an area of existing indigenous vegetation is enhanced (e.g. additional building floors if a greater area is subject to pest and weed management than the requirements already in place for these activities).
- Forest Stewardship Council compliance for plantation forests entering certification.

8.3 Overlap with s 6(c) RMA areas of significant indigenous vegetation and significant habitats of indigenous fauna

Under s 6(c) of the RMA all persons exercising functions and powers must recognise and provide for the protection of significant indigenous vegetation and significant habitats of indigenous fauna as a matter of national importance. Identifying these Significant Natural Areas (SNA) or Significant Ecological Areas (SEA) requires an ecological determination, usually through application of 'ecological significance criteria' included in the relevant regional policy statement, or plan.

Currently, SNAs/SEAs are either spatially mapped in planning documents, or identified on a case-by-case basis when a resource consent is applied for, or spatially mapped as a desktop exercise using criteria in a relevant plan and then confirmed (or not) in site-based assessments. Regional and district plans then usually contain a suite of policies and rules controlling activities such as indigenous vegetation clearance, structures, drainage and earthworks, which are generally more stringent within SNAs/SEAs than outside them. Existing rules have varying coverage and stringency across the country and monitoring is generally poor. Most plans rely heavily on permitted activity standards (i.e. most vegetation clearance is permitted unless a standard is breached).

Identification of SNAs/SEAs has been inconsistent across the country, reflecting lack of nationally applicable criteria and Councils' capacity and willingness, and SNAs/SEAs on Private Land are politically controversial in some but not all areas. The NPS-IB exposure draft seeks to address these problems by providing nationally applicable SNA/SEA criteria, direction to councils, and effects management policies.

This Framework does not use SNAs/SEAs, which were deleted as an NBEA outcome in the Select Committee's review. Nevertheless, much work has gone into identifying SNAs/SEAs around the country, the exercise is already complete in several districts, and they are central to the recently released NPS-IB exposure draft. We advise that our Framework would work alongside SNAs. Specifically,

- Mapping of Land Types would complement and support identification of SNAs.
- Clauses added to Converted Land and Developing Indigenous Ecosystems definitions to exclude identified SNAs would be warranted. Implementing this through mapping would be simple as SNAs are mapped. Identified SNAs would be High Value Indigenous Biodiversity, Off Limit Indigenous Biodiversity, or identified High Value Fauna Habitat on Converted Land.
- Mapping of Land Types as set out in this Framework will usually provide more rapid, consistent, and comprehensive depiction of the areas important to maintain indigenous biodiversity than mapping SNAs and require less effort and cost. The Framework aligns with the NPS-IB exposure draft requirement to manage effects on indigenous biodiversity outside SNAs.

We have engaged with Regional Council ecologists to discuss the advice above, and have received positive confirmation and feedback.

8.4 Effects Management Hierarchy

The Effects Management Hierarchy in this Framework requires each step in the hierarchy is undertaken where 'possible', before moving to the next step in the hierarchy. The reason 'possible' (and not 'practicable') is used in this Framework is that it is legally stronger (see *Tauranga Environmental Protection Society Inc v Tauranga City Council* [2021] NZHC 1201) and more consistent with achieving Limits and meeting Targets to protect and maintain the ecological integrity of indigenous biodiversity. Specifically:

- 'Possible' places an obligation on those proposing to undertake an activity with Adverse Effects to demonstrate that they are unable to meet each step in the Effects Management Hierarchy before moving to the next. Determining whether managing effects is 'possible' does not involve an assessment of costs.
- In contrast, determining whether management is 'practicable' introduces a broader assessment incorporating financial viability, and debate about what cost is too high. 'Practicable' means 'possible to be accomplished with known means or resources' and is synonymous with 'feasible' which introduces matters of practical convenience (as well as cost).

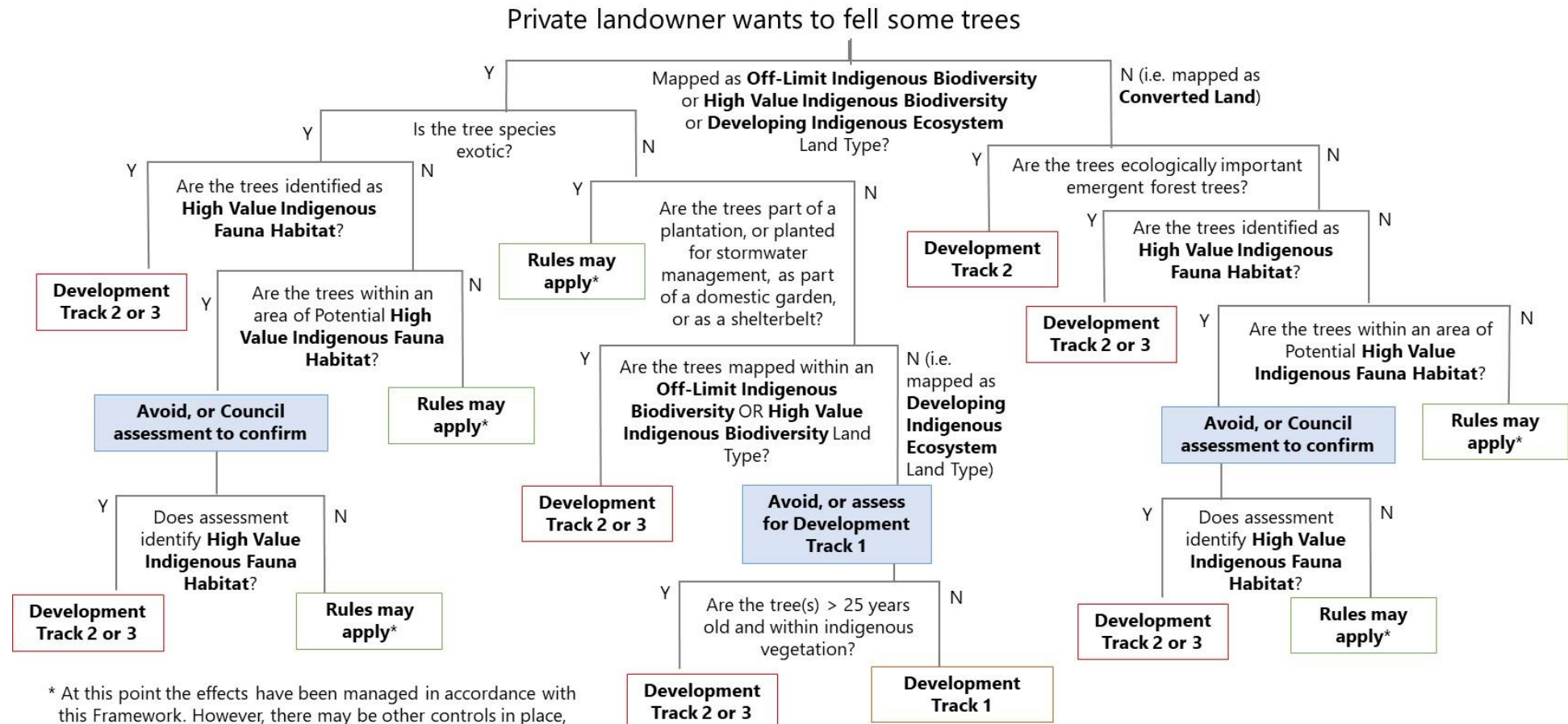
Regardless of the term used, it will be important to specify the standard for determining whether an option is 'not possible' or 'not practicable'.

We use the terms 'avoid', 'remedy', and 'mitigate', which are the management steps currently referred to by the NBEA and used under the RMA. Continued use of these terms will preserve case law and knowledge as to their meaning (i.e. put simply, 'avoid' means do not allow; 'remedy' means fix, and 'mitigate' means reduce).

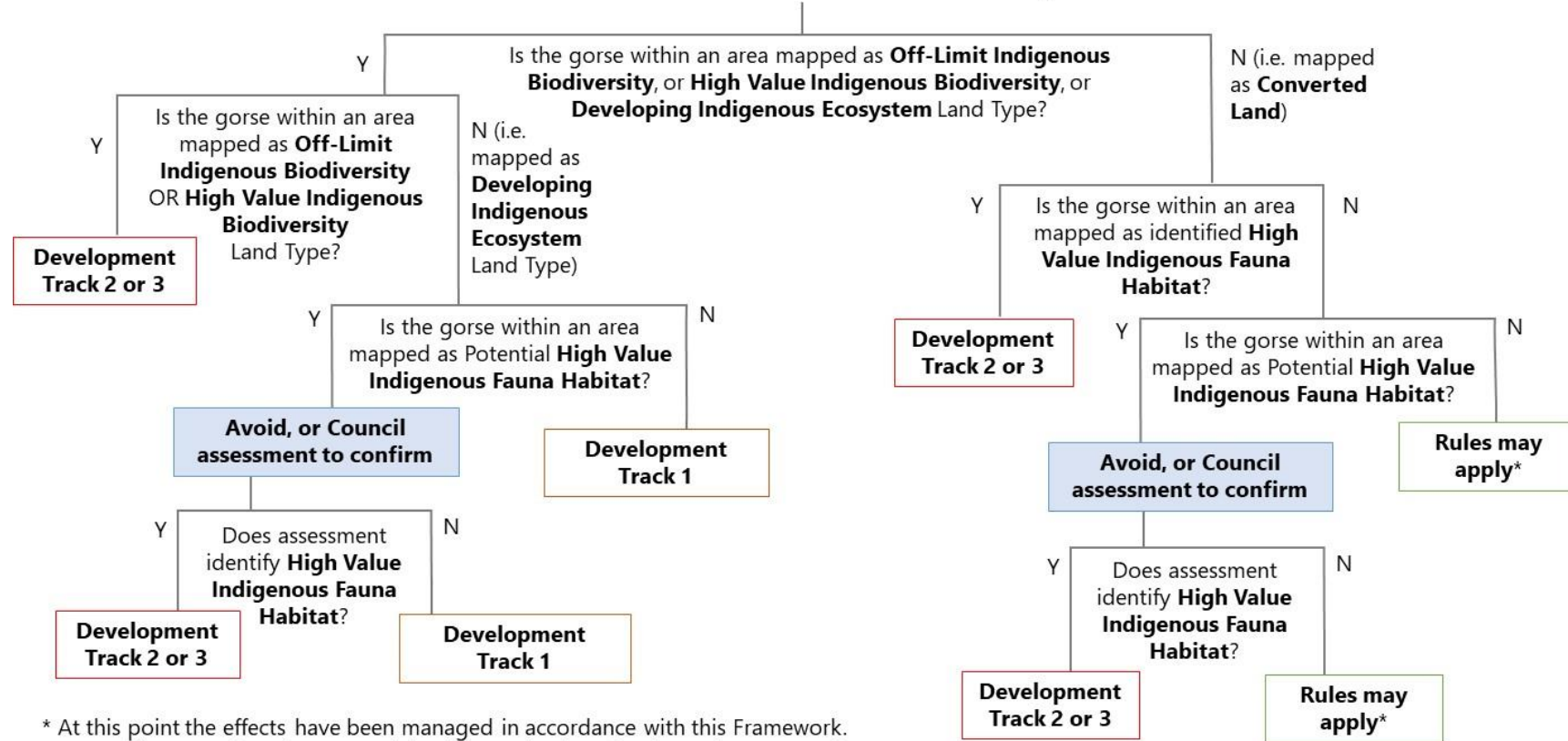
We regard 'minimisation' of effects as what effects management should achieve. If 'minimise' is adopted in place of remediation or mitigation – or both – we suggest defining the term to reduce risk of immediate litigation to determine its meaning on commencement of the NBEA.

9 Examples

The flow diagrams below show examples showing how the Framework would apply in different contexts.

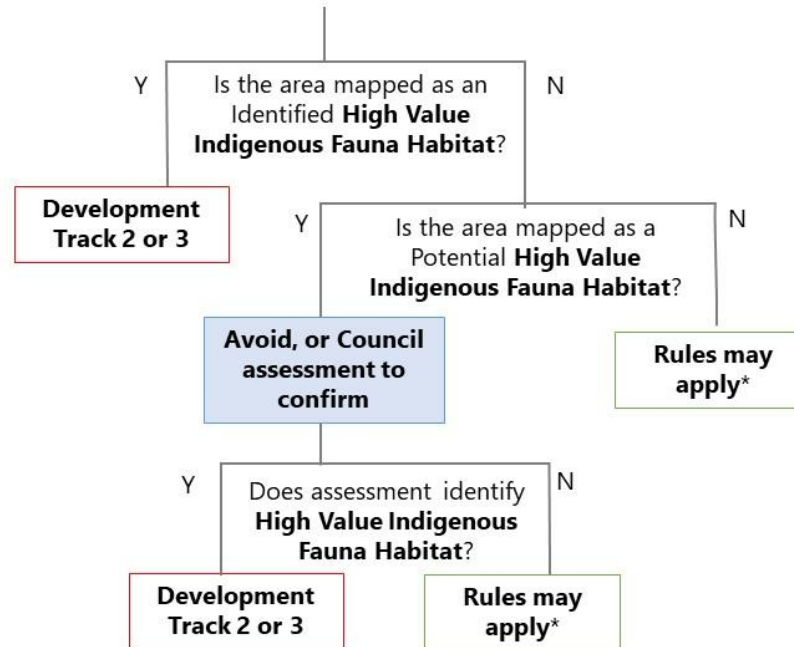


Private landowner wants to clear some gorse



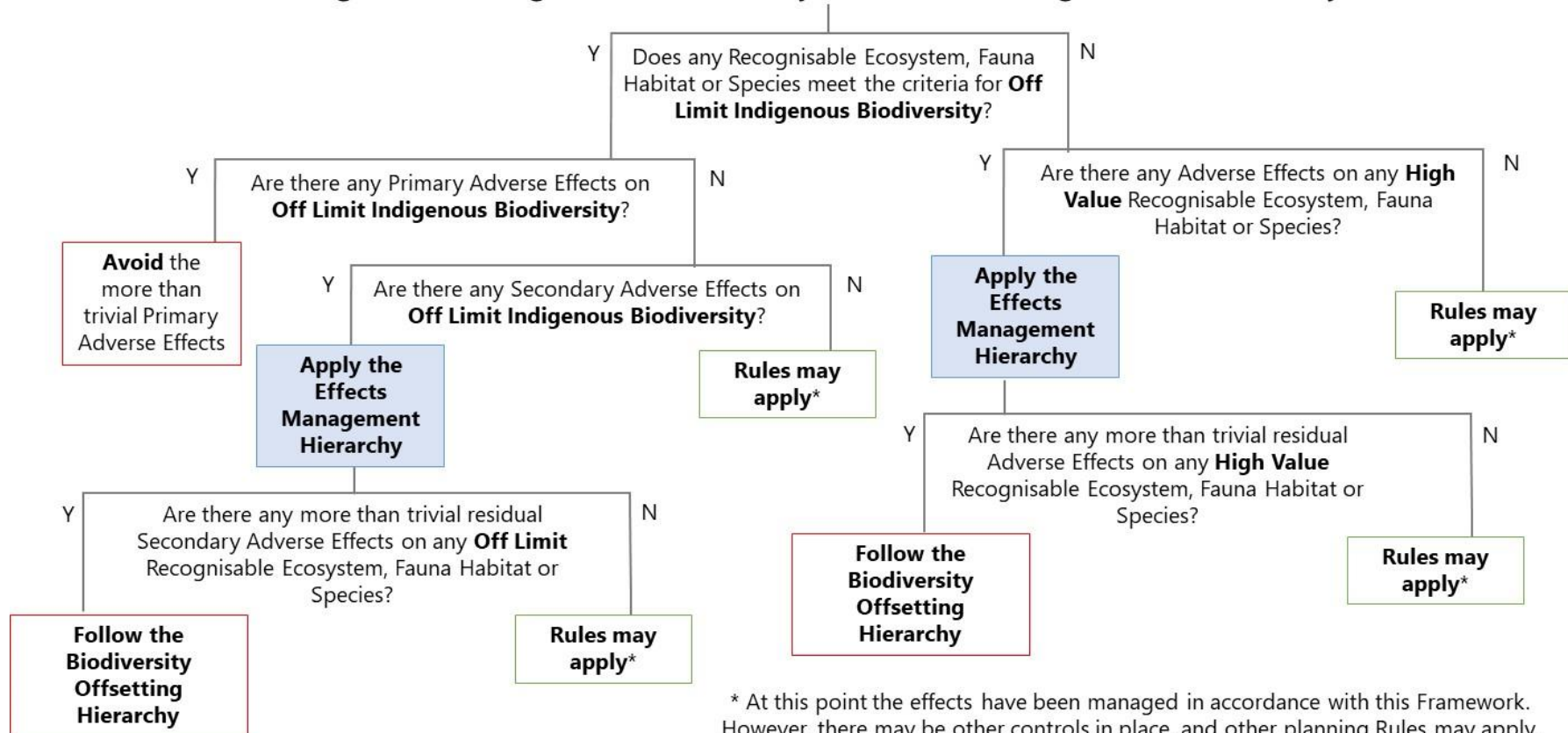
* At this point the effects have been managed in accordance with this Framework. However, there may be other controls in place, and other planning Rules may apply.

Private landowner wants to intensify
land use on converted land



* At this point the effects have been managed in accordance with this Framework. However, there may be other controls in place, and other planning Rules may apply.

A Nationally Significant Project is planned on High Value Indigenous Biodiversity or Off Limit Indigenous Biodiversity



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Appendix 1 – Extent of Land Types

In Table A1 we show how areas of land that are not currently protected for conservation in New Zealand are divided among our three categories (Converted Land, Developing Indigenous Ecosystem, and High Value Indigenous Biodiversity/Off Limit Indigenous Biodiversity). The numbers are approximate because our analysis is based on Aotearoa-New Zealand's Land Cover Database (LCBD) classes, which were not developed explicitly for this purpose, and therefore makes several assumptions.

Table A1. Approximate areas (in hectares) of land not protected for conservation purposes that are Converted Land, (potentially) Developing Indigenous Ecosystems, and High Value Indigenous Biodiversity/Off Limit Indigenous Biodiversity, based on categorization of LCDB classes and the protected area data included in TEC 2.0 (Cieraad et al. 2015)

	Converted Land, excluding Gorse and/or Broom (ha)	Maximum area of Developing Indigenous Ecosystems including Gorse and/or Broom (ha)	Minimum area of High Value Indigenous Biodiversity/Off Limit Indigenous Biodiversity (ha)
Auckland	401,400 – 400,400	21,200 – 22,200	29,700
Bay of Plenty	1,265,900 – 1,262,100	16,800 – 20,500	100,100
Canterbury	1,863,500 – 1,520,500	168,400 – 511,400	546,500
Gisborne	964,600 – 918,700	49,400 – 95,300	73,900
Hawke's Bay	1,116,900 – 1,105,500	50,700 – 62,100	77,700
Manawatu-Wanganui	1,428,100 – 1,393,300	64,600 – 99,500	159,200
Marlborough	541,300 – 464,900	53,300 – 129,700	170,500
Nelson	46,900 – 46,700	2,400 – 2,600	2,400
Northland	1,111,800 – 1,100,900	60,400 – 71,300	108,500
Otago	1,590,900 – 1,273,700	110,500 – 427,800	454,700
Southland	999,900 – 938,100	34,200 – 95,900	151,300
Taranaki	382,600 – 368,200	22,400 – 36,700	72,900
Tasman	500,200 – 492,900	23,600 – 31,000	38,900
Waikato	2,105,600 – 2,096,900	54,900 – 63,600	139,700
Wellington	575,100 – 566,300	52,300 – 61,000	63,000
West Coast	269,000 – 262,900	17,900 – 24,000	90,000
Total land not protected	15,163,700 – 14,212,000	802,900 – 1,754,600	2,278,700
Percent of all land not protected	83 to 78%	4 to 10%	12%

We assume that mixed seral (successional) LCDB classes (including 'Gorse and or Broom') are potentially Developing Indigenous Ecosystem. In reality, some older seral communities will be >25 years old and therefore added to High Value Indigenous Biodiversity/Off Limit Indigenous Biodiversity, while some Gorse and or Broom, especially in drier regions, will be fully Converted Land, and available for creating a Biobank.

Ranges in our estimates of areas of Converted Land and Developing Indigenous Ecosystems depend on how the LCDB class 'Low producing grassland' is coded.

We note that in Canterbury and Otago (and to a lesser extent Southland and Marlborough), the majority of Developing Indigenous Ecosystems and High Value Indigenous Biodiversity/Off Limit Indigenous Biodiversity is on Crown-owned pastoral leases in the high country. In several North Island regions, a high proportion of Developing Indigenous Ecosystems and High Value Indigenous Biodiversity/Off Limit Biodiversity may be on Māori-owned land. As noted in this report, an agreed approach on Māori land is beyond the scope of this report and needs to be co-developed with Māori.

Appendix 2 – Comparisons of LENZ Levels II and III

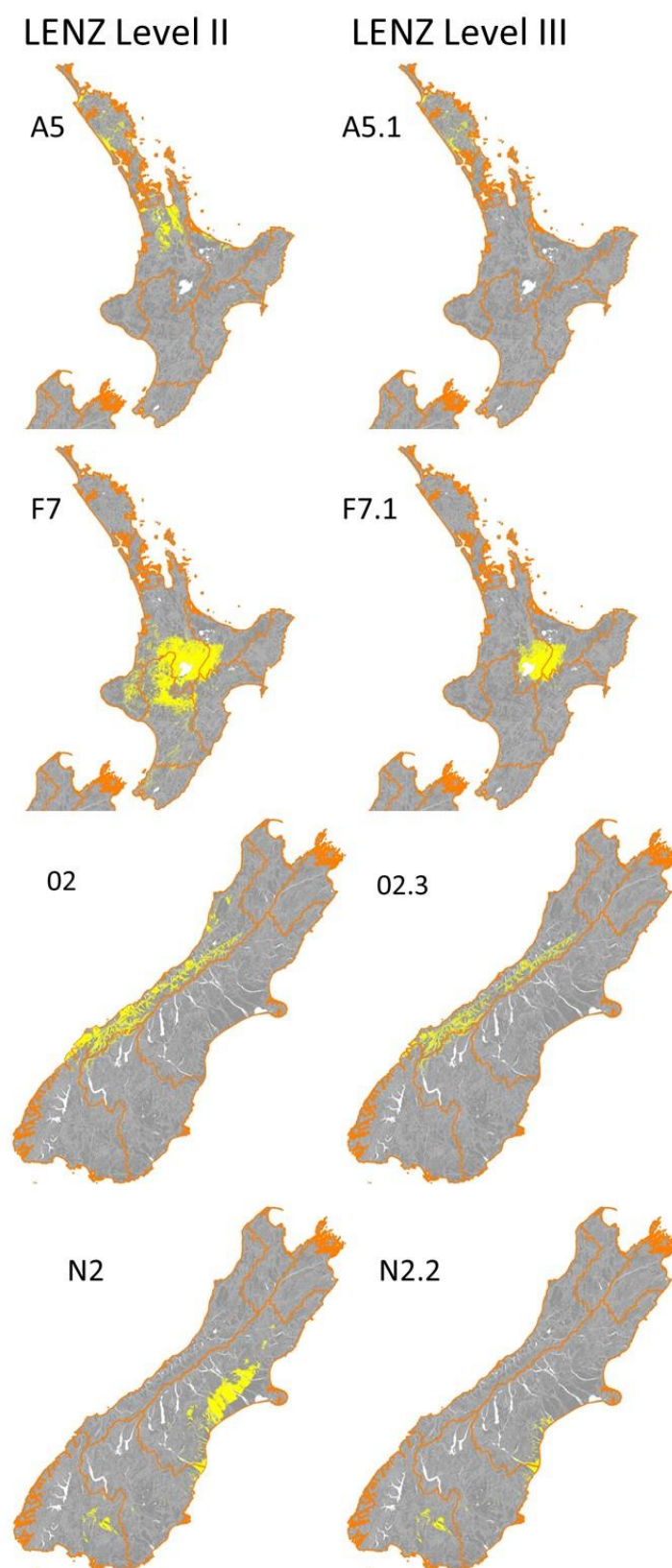


Figure A1. Randomly selected examples of the spatial extent of LENZ Level II land environments (left column), and a Level III land environment within each. Regional boundaries are shown as orange lines. LENZ Level III land environments cross fewer regional boundaries and more often occur mainly or only within a single Region.