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What effects must be avoided, remediated or mitigated to maintain indigenous biodiversity?

Susan Walker[1]*, Peter J. Bellingham[2,3], Geoff Kaine[4], Sarah Richardson[2], Suzie Greenhalgh[5], Robyn Simcock[5], Marie A. Brown[6], Theo Stephens[7] and William G. Lee[1]

[1]Manaaki Whenua – Landcare Research, Private Bag 1930, Dunedin, 9054
[2]Manaaki Whenua – Landcare Research, PO Box 69040, Lincoln 7640
[3]School of Biological Sciences, University of Auckland, Private Bag 92019, Auckland 1142
[4]Manaaki Whenua – Landcare Research, Private Bag 3127, Hamilton 3240
[5]Manaaki Whenua – Landcare Research, Private Bag 92170, Auckland 1142
[6]Catalyst Group, PO Box 1048, Wellington 6140
[7]PO Box 107, Haast 7844
*Author for correspondence (Email: walkers@landcareresearch.co.nz)

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Abstract: New Zealand's Resource Management Act requires avoiding, remedying or mitigating effects of human activities on the environment, including taking action to maintain terrestrial indigenous biodiversity. Here, we suggest that maintaining biodiversity requires halting its current decline, and to achieve that, New Zealand must move away from deeming only significant ecosystems and biota worthy of protection. We identify effects that must be avoided in order to maintain biodiversity, and those to be avoided unless they can be fully and promptly remediated. Effects should be avoided that reduce the extent and quality of most ecosystems and the habitats of indigenous species, including many highly modified ecosystems and habitats. Effects can be remediated only for a few, usually low-diversity and recently-established indigenous ecosystems and habitats, and we suggest a human generation (25 years) should be the maximum time to full remediation. Effects on individuals from some species' populations (but not populations at range or environmental limits, or outliers) may be remediated through replacement in certain circumstances. The clearance and modification of young (< 25 years), non-indigenous, non-riparian ecosystems that are neither important for connectivity and buffering nor habitat for threatened or at-risk indigenous species, may have a limited adverse effect on maintaining biodiversity, but could compromise ecosystem services and remove opportunities for future restoration. The approach to avoidance we suggest would help to slow the cumulative and ongoing loss of terrestrial biodiversity caused by multiple minor effects.

Keywords: impact assessment, protecting biodiversity, Resource Management Act

Introduction

The New Zealand Resource Management Act (1991) (RMA) regulates the effects of human activities on indigenous biodiversity (hereafter biodiversity), including indigenous species, habitats and ecosystems found on private land. However, implementation of the RMA is failing to halt the decline of indigenous species and their habitats (Ministry for the Environment (MFE) 2019; Monks et al. 2019). While some of the ongoing decline reflects the pervasive impacts of invasive non-indigenous species, the clearance and conversion of indigenous species' habitats (Weeks et al. 2013b; Belliss et al. 2017) promotes further loss of indigenous biodiversity (DOC & MFE 2000; Brown et al. 2015; DOC 2016).

The RMA devolves responsibility for maintaining biodiversity to New Zealand's regional councils and territorial authorities (MFE 2019). The resulting policies and planning instruments provide limited protection, and weak implementation has fostered ongoing loss (MFE 2019). However, a long-delayed National Policy Statement for indigenous biodiversity (NPS-IB) might soon provide binding central government direction to local government: a draft NPS-IB in November 2019 followed two years of consultation with a Biodiversity Collaborative Group (BCG) comprised of representatives from extractive and infrastructure industries, Māori, and environmental non-governmental organisations.

In late 2017 the BCG asked the authors: "In order to maintain biodiversity what effects on biodiversity must be avoided, and what effects could be remediated or mitigated, and why?"; reflecting the RMA's requirement (Section 5(2)(c)) to avoid, remedy or mitigate adverse effects on the environment. Here, we set out our response based on ecological considerations only, setting aside social, cultural, political, and economic impacts, and the practical and political feasibility

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of implementation, to add a purely ecological view and expert ecologists' perspective to the broader analyses and negotiations of the BCG. We recognise that Māori are the owners of natural resources under Te Tiriti o Waitangi, and that elements of biodiversity are tāonga. Te Ao Māori, including customary harvest and other uses of indigenous biota, must be part of any implementation.

In our response we make two propositions. First, biodiversity will decline if irreversible adverse effects on it continue. Second, present biodiversity loss and decline cannot be compensated by remediation of adverse effects in the future. Delaying remediation results in interim loss and interruption of ecological processes, which may have permanent effects; and longer interim losses make permanent and cumulative adverse effects more likely, and remediation less certain because future generations will have different priorities and legal or regulatory frameworks. We, therefore, define an adverse effect as irreversible if it cannot be fully remediated within a human generation (approximately 25 years).

Underlying principles

Our recommendations are based on the following set of principles, drawn from current understanding in conservation biology, and which cover ecological requirements for biodiversity maintenance, limits to and opportunities for remediation, and policy effectiveness.

(1) Maintaining biodiversity entails representing "a full range" of life forms that can persist and continue to evolve. Natural areas in New Zealand mostly occur in environments unsuitable for development (Cieraad et al. 2015). A central challenge is to represent ecosystems, habitats, and species that occur only or mainly where human activities are concentrated, and where protection is least. Recognition of the importance of these often highly modified and exotic-dominated ecosystems for maintaining indigenous biodiversity remains low (e.g. non-forest vegetation in the eastern South Island).

(2) New Zealand's biodiversity has a unique combination of characteristics that need to be provided for. High levels of endemism, large size, considerable longevity, and low reproductive rates in many groups are distinctive features of New Zealand's biota (Gibbs 2016). For example, many distinctive species occur in wet forests growing on predominantly acidic, shallow, and infertile soils. Mosses, liverworts, and ferns have proliferated and an extraordinary forest litter fauna and soil mycorrhizal flora has formed. Habitats too cold, wet, salty or windy for trees have a biota rich in unusual species and tiny plants (Purcell et al. 2019). Naturally uncommon ecosystems can support unusually high numbers of endemic taxa (Williams et al. 2007), many of which are outcompeted by introduced species. Most indigenous species struggle in anthropogenic habitats such as pasture, crops, and exotic forestry plantations.

(3) Ecological (ecosystem and demographic) and evolutionary processes that sustain diversity need to be maintained. Policies must accommodate natural changes, via processes of evolution and succession, and provide the space needed for seasonal environmental change, breeding, and natural disturbance.

(4) Both evolutionary potential and ecological potential need to be provided for over relevant time scales. Sustaining evolutionary potential requires maintaining the adaptive variation within species to provide for selection and viability under changing climates. Species need to be protected from extreme events by retaining distinctive ecotypes, and populations at distributional limits and across their full environmental range.

(5) Interconnectedness and interdependence are vital. Species populations are dynamic networks (metapopulations), in which surpluses in one area (sources) can be essential for sustaining populations in adjoining areas under greater stress (sinks). And this is not just a species level issue: metacommunities and metaecosystems also need these connections to be maintained (Loreau et al. 2003). Effects that weaken or sever these connections and relationships may destroy the viability and functioning of populations and ecosystems.

(6) Currently unoccupied habitats for species are important. Species' occupancy of habitat may be transient or seasonal, because species metapopulations may colonise and go extinct locally in different patches at different times (Hanski 1998). Occupancy and abundance might fluctuate at climatic limits or range margins. Habitats of species sensitive to browsing or predation might be currently unoccupied, as are headwater streams where fish passage is physically or chemically restricted. Removal of currently unoccupied habitat reduces the likelihood that a species will persist.

(7) Regenerating indigenous ecosystems are needed to maintain biodiversity. Many indigenous ecosystems are recovering or successional following human or natural disturbance. These non-forest communities and shrublands are diverse in species, structure, and seral trajectories, often with novel combinations of biota and successions. Regenerating ecosystems support many indigenous species, provide nurse sites for late-successional species, often have high productivity or are critical for species that are early-successional obligates (Esler & Astridge 1974; Wardle 1991; Carswell et al. 2003; Whitehead et al. 2004;). Regenerating ecosystems may also be important for evolution and adaptation in new environments and disturbance regimes under climate change, and for ecosystem services (e.g. water purification, flood mitigation, or wild foods like honey; Ausseil et al. 2018).

(8) The anticipated effects of climate change need provisions, including maintaining species at their geographic and environmental limits; protecting multiple large populations to safeguard against more frequent fires; avoiding habitat fragmentation and reductions (Corlett & Westcott 2013); maintaining river and stream flows and flow variability; reducing riparian vegetation degradation and stream contaminants; and retaining and enhancing landscape-level habitat connectivity to accommodate biodiversity retreat from coastal areas, and from aggrading and more erosive rivers and flood plains.

(9) Incommensurate values require in-kind replacement and remediation. Incommensurable, non-interchangeable values have three dimensions (Salzman & Ruhl 2000; Walker et al. 2009a, b):

type: non-interchangeable elements or components of biodiversity are needed to maintain biodiversity. For example,

the value of a frog cannot be validly to compared to that of a tree,
space: the location of individuals, populations, and communities influences ecological interactions and biodiversity persistence, and the contribution of an individual location is strongly contextual and different from another,
time: temporary losses can permanently damage populations and result in cumulative effects (e.g. genetic bottlenecks; early and late seral stages of an ecosystem support different species).

Incommensurability means that damage to biodiversity can only be made good by "specific performance" (Bertram 2013). That is, replacement and remediation in-kind (type, space, and time), not by compensation in another form (a different type, place, or time).

(10) There are limits to remediation. The slow growth and low fecundity of much of the New Zealand terrestrial biota and altered ecological contexts impose practical limits to remediation. Occasionally the value of a resource has allowed intensive and expensive rehabilitation (e.g. mines, high-value residences) but many terrestrial ecosystems (e.g. many forests, communities of limestone pavement, tussock grasslands, and many types of wetland) cannot be restored within human-generation timeframes, or at all. Genuine and timely remediation is possible only for young ecosystems of highly mobile, common, generalist species and even their remediation can be protracted, leading to loss for many decades. For example, simplified wetlands need a century before woody components mature (Moreno-Mateos et al. 2012), and colonisation by many indigenous birds and insects depends on the slow development of complex vegetation.

Restoration attempts can fail because an ecosystem follows a different trajectory after removal of a pressure, or because recreating fundamental physical conditions (e.g. soil character) and processes (e.g. colonisation) is impossible or too expensive (Dickie et al. 2014; Standish et al. 2009). Changed biotic context also limits feasibility: sources for indigenous species are often missing, much reduced, or swamped by introduced species.

(11) Remediation is feasible in some situations. Young or disturbance-dependent ecosystems (e.g. saltmarshes, active coastal dunes, and young kānuka or matagouri shrublands) offer the best prospects for full remediation or mitigation, and short-lived, high-fecundity, rapidly-maturing species are most likely to be amenable. Actions to remediate or mitigate specific terrestrial impacts include removal of herbivores, weed control and predator control, and the reintroduction of competition- and predator-vulnerable species (such as mistletoes and birds in braided riverbeds; Caruso 2006; Seddon et al. 2007).

(12) Restoration can make a positive difference in highly modified landscapes. Restoration, not just protection of what is left, may be needed to maintain biodiversity in landscapes where little is left, and where there is extinction debt (Tilman et al. 1994). Opportunities exist to mitigate past and future loss and damage particularly in climate change-induced coastal and flood-zone retreats, and transition zones between land-uses. *De novo* restoration may be most successful adjacent to forest and shrubland ecosystems, which act as inoculants and buffers, especially for areas retaining some woody cover or debris. Early successional vegetation may be recreated along riparian areas and river valleys; and barriers to dispersal can be removed, such as fish passage blocks and chemical and temperature barriers.

(13) Ambiguity disadvantages biodiversity. Ambiguous rules and criteria yield policies and regulations that are difficult to implement, enforce, and monitor, and thus ineffective. Pardy (2005) suggested rules should be sufficiently abstract to be generally applicable and sufficiently precise to direct outcomes, unambiguously answering the question: "What are citizens allowed to do, and what are they not allowed to do?".

(14) National limits on activities with adverse effects are needed to avoid cumulative effects. Cumulative effects occur when multiple *ad hoc* decisions or omissions (e.g. permitted activities) enable minor or non-significant adverse effects (death by a thousand cuts) at local scales that collectively reduce populations, fragment species distributions and alter disturbance regimes (Deane & He 2018). Cumulative effects also result from loss of species or ecosystems that remain common in some districts or regions but have become rare in others.

(15) Ecological 'significance' may not be a reliable threshold. RMA Section 6(c) deems the protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna to be a matter of national importance. However, in the authors' experience, determinations of significance can change over time, with knowledge, and from one ecological consultant to another. Providing protection for only a narrowly selected set of significant or best examples can contribute disproportionately to species loss through systematic loss of smaller natural areas (Deane & He 2018).

What effects must be avoided or remediated, and why?

We developed two tables using these principles. Table 1 (Avoid) lists irreversible effects (i.e. loss is permanent, or feasibility of full replacement within 25 years is low) on components biodiversity that are now much reduced, threatened or at risk. Table 2 (Avoid if the effect cannot be fully remedied) lists potentially reversible effects where the biodiversity component is neither much-reduced nor at risk of extinction. Avoid would apply to features in Table 2 if remediation within 25 years is improbable.

We sought unambiguous criteria so that adverse effects could be readily and objectively identified, providing certainty for agencies and people. We do not distinguish between significant and other adverse effects, because opinions are likely to differ. We endeavoured to avoid terms and criteria that require conjecture, subjective judgement and opinion, or substantial effort in corroboration (but note that some attributes cannot be determined without more information than exists now). Where possible we refer to national schedules, documents, and spatial frameworks that exist and are available rather than regional schedules which vary in availability, quality, and comprehensiveness (but are important supplementary information).

We set out our reasoning for the contents of the two tables below:

Avoidance is fundamental

Habitat clearance and modification is a principal, ongoing cause of indigenous biodiversity decline in New Zealand and adds to both the spread and impacts of mammal predators and other invasive species. Therefore, limits on clearance and

Table 1. Effects to avoid

Level of diversity	Effect	Why?	Examples
AVOID			
1.1 Indigenous ecosystems and the habitats of indigenous species	Temporary or permanent fragmentation, reduction in size, or degradation of the ecological integrity[1] of: 1.1a. habitats used by Threatened, At Risk and Data Deficient species at any stage of their life cycle[2] 1.1b. habitats of indigenous species at the geographic or environmental limit of the species' known natural range[3], or outlier[4] populations.	Most ecosystems and habitats of species cannot be restored or remediated in a timely manner, if at all. Their loss reduces populations and compromises species' persistence. Habitat fragmentation often involves both habitat destruction and subdivision of contiguous habitat. Subdivision disconnects ecosystems and alters physical and biological properties and processes.	Fragmentation, or size reduction. Shrubland sprayed with herbicide or burnt Vegetation irrigated, flooded, or drained Trees felled. Indigenous grassland cultivated or planted. Streams or rivers diverted or obstructed. Low-stature breeding habitat for banded dotterel or lizards irrigated and converted to exotic pasture.
	1.1c. indigenous vegetation[5] in land environments[6] with less than 20% indigenous cover remaining[7]	Patches of vegetation supporting indigenous species in extensively cleared land environments are modified but represent the last examples of habitat types, communities, and species indigenous to flat, low, dry environments. Populations of common species may represent genetically distinct geographic varieties or races adapted to specific environmental conditions (ecotypes). Species populations in these environments may be important because they may have adaptations to the drier and more-variable climatic conditions expected in many areas under climate change.	Degradation of ecological integrity A forest is selectively logged, or buffers removed, increasing edge effects. Grazing and browsing pressure change vegetation composition or structure. Stock trampling reduces litter in forests, and survival and regeneration of species in the ground tier. Low-nutrient ecosystems receive nutrient-rich runoff, or are planted in or invaded by nitrogen-fixing species (e.g. lupins, *Lotus* spp.).
	1.1d. a naturally uncommon (also known as originally rare[8], or historically rare) terrestrial ecosystem that is categorised as Critically Endangered, Endangered, or Vulnerable using IUCN criteria[9]	Terrestrial ecosystems classified as naturally uncommon (originally rare, or historically rare) have distinctive physical environments that are difficult to restore. Those assessed as Critically Endangered, Endangered, or Vulnerable are at higher risk of elimination due to the degree to which they are geographically restricted, face serious ongoing threats, and have undergone declines in geographic extent, ecological function, and ecosystem processes.	
	1.1e. indigenous forest[10] and indigenous shrubland[11] below regional treelines[12]	Where indigenous forests, shrublands, wetlands and tussock grasslands and cushion and mat vegetation remain, they are ecologically significant.	

[1]The indigenous dominance and species occupancy components of ecological integrity (Lee et al. 2005) are degraded by changes to the structure of the vegetation and the abundances of species within it (e.g. logging of trees, consumption of palatable species by herbivores, burning of flammable components, trampling of groundcover species). These effects are distinguished from those under **1.2 Ecological processes and connectivity** because they involve direct impacts on indigenous species. The distinction is blurred in practice because indirect effects on ecological processes and connectivity are also likely to result.
[2] In the New Zealand Threat Classification System (Townsend et al. 2008). An exemption for habitats that are plantations or orchards established for commercial or aesthetic purposes could be provided. However, fragmentation, reduction in size, or degradation of these habitats adversely affect indigenous species.
[3]Determining a range will require database records and expert knowledge.
[4]An outlier is a population that lies an abnormal distance outside the core range of a species.
[5]There are two approaches to defining 'indigenous' vegetation or an 'indigenous' ecosystem. 'Indigenous' can be defined qualitatively (e.g. for vegetation, a plant community or ecosystem containing naturally occurring indigenous species) or quantitatively (e.g. 'a plant community or ecosystem in which indigenous vascular and non-vascular plant species comprise more than 20% of the number of vascular and non-vascular plant species present'). Quantitative cut-offs will exclude vegetation that is dominated by non-indigenous plant species but essential for maintaining indigenous species.
Some definitions specify that indigenous vegetation include vegetation regenerated with human help. An exemption for plantations or orchards established for commercial or aesthetic purposes is sometimes provided, even though fragmentation, reduction in size, or degradation of these may adversely affect indigenous species. These exemptions reflect the argument (which we accept) that avoidance and remediation requirements would not normally apply to biodiversity components that are restored with private resources and on private land for the purpose of commercial use or harvest. The purpose of this exemption would be to not discourage actions not required by regulation and that restore indigenous species and their habitats.
[6]Leathwick et al. (2003)
[7]Cieraad et al (2015), accessed at https://www.landcareresearch.co.nz/resources/maps-satellites/threatened-environment-classification.
[8]Williams et al. 2007.
[9]Holdaway et al. (2012) provide lists of naturally uncommon terrestrial ecosystems (from Williams et al. 2007) categorised as Critically Endangered, Endangered, or Vulnerable.
[10]For these purposes we define a forest as a community with indigenous tree species in the canopy. We include secondary forests and forests that have been logged within this definition, as well as low forest communities that are yet to attain full stature or are limited by extreme environments. Trees are defined and 215 indigenous tree species listed by McGlone et al. (2010) (https://doi.org/10.7931/76j1-8c38).
[11]For these purposes we define a shrubland as a community in which indigenous woody species that attain heights ≤6 m tall (including lianes) are in the canopy.
[12]In the absence of remaining forest, the mean warmest month temperature (MWMT) isotherm of 11° C provides a reasonable approximation of the upper limits of trees (McCracken 1980; Wardle 1985, 1991) and can be derived as a spatial line file from published climate surfaces. Elevation is unsuitable because treeline elevation lowers considerably from north to south across New Zealand. Cieraad & McGlone (2014) provide a recent analysis of New Zealand treelines.

Table 1. Continued

Level of diversity	Effect	Why?	Examples
AVOID			
		Indigenous forest has been reduced from about 80% of land at human settlement to 24% today, and natural shrublands in habitats below regional treelines that do not naturally support forest have been similarly reduced.	
	1.1f. indigenous wetlands[13]	Wetlands have been reduced to 10% of their former area nationally (Clarkson et al. 2013).	
	1.1g. tall and short tussock grassland[14], and other derived indigenous cushion and mat vegetation below regional treelines	Tussock grasslands have a distinctive biota. At lower elevations they are being reduced and fragmented by clearance and modified by pastoral intensification and wilding conifer invasion[15].	
	1.1h. indigenous ecosystems, vegetation, and habitats of species in New Zealand drylands[16]	Dryland ecosystems have been disproportionally reduced in area and modified. They are poorly protected and sustain large numbers of threatened species.[17]	
	1.1i. developing indigenous ecosystems ≥ 25 years old[18]	Developing ecosystems contribute to indigenous biodiversity in multiple ways, including as safe sites and nurse communities for late-successional species, providing high-productivity habitats, and critical habitat for early-successional obligates.	
	1.1j. indigenous freshwater ecosystems	New Zealand's freshwater ecosystems are degrading[19] and many indigenous fishes are threatened[20]. Freshwater systems, and hence effects, have high connectivity (e.g. action that reduces pollutants in streams will reduce the degradation of lakes and estuaries through these inputs). Effects on low-order streams require stringent avoidance because these affect all downstream reaches.	
	1.1k. riparian vegetation[21]	Many riparian habitats in production and urban landscapes have been modified. Loss of overhanging vegetation[22] from streams changes temperature and light regimes, leading to stress and algal mat proliferation. It also reduces the supply of organic debris (logs, branches, litter), which provides habitat and food resources for indigenous aquatic and terrestrial species.	
	1.1l. areas that have been given formal protection under the Reserves Act or Conservation Act (including Stewardship Land), or that have been identified as ecologically significant for the purpose of Section 6(c) of the RMA	This category includes features beyond those listed as 1a to 1k, with recognised natural heritage value that require long-term security.	

[13]Wetland types are defined by Johnson and Gerbeaux (2004).
[14]A grassland community including tussocks of *Chionochloa, Festuca, Poa* and other indigenous grass genera.
[15]Weeks et al. (2013a,b).
[16]Drylands are spatially defined Level IV land environments (in LENZ; Leathwick et al. 2003) east of the main axial ranges with long-term average Penman annual water deficits of more than 270 mm (Rogers et al. 2005).
[17]de Lange et al. (2018). Walker et al. (2008) stated that >70% of indigenous habitat has been lost, and only 1.9% of the zone was then legally protected.
[18]These ecosystems include a wide range of non-forest communities that are either mature or are developing through a variety of successional pathways and are diverse in species, processes, and structure.
[19]As summarised by Leathwick et al. (2009), they have been affected by removal or modification of riparian vegetation, point source and diffuse inputs of sediment and nutrients (Wilcock et al. 1999, 2006), with consequent reductions in biological values (e.g., Quinn 2000; Niyogi et al. 2007). Other impacts include the 'straightening' and constraining of rivers for flood control, the abstraction of water for irrigation, and the diversion or alteration of their flow for power generation (Ministry for the Environment 2007). New Zealand's lowland waterways are generally the most affected by human activity (e.g., Harding et al. 1999; Larned et al. 2004).
[20]Ministry for the Environment & Statistics NZ 2017. New Zealand's Environmental Reporting Series: Our fresh water 2017. Retrieved from www.mfe.govt.nz and www.stats.govt.nz.
[21]As defined in the River Environments Classification (https://www.niwa.co.nz/freshwater-and-estuaries/management-tools/river-environment-classification-0) (see Appendix 1).
[22]For stream biodiversity, it makes little difference whether the riparian vegetation is indigenous or not. However, there may be some types of non-indigenous cover that are more useful or more weedy than others, and adverse effects of weed spread may need to be considered.

Table 1. Continued

Level of diversity	Effect	Why?	Examples
AVOID			
1.2 Ecological processes and connectivity	Loss of, or damage to: 1.2a. biological or physical networks and connections between indigenous ecosystems, including between terrestrial, freshwater or marine ecosystems 1.2b. part of a connected sequence of indigenous vegetation across different ecosystems or landforms, including ecotones	The viability and functioning of populations and ecosystems is damaged or destroyed when ecological networks and connections are weakened or severed. Fragmentation and truncation of connected ecosystems or sequences of indigenous vegetation remove the connectivity which allows for species and populations to move and migrate in responses to seasonal, interannual, and longer-term variation.	Patches of indigenous woody vegetation in pasture are cleared. Vegetation at one end of a continuous area across a sequence of elevation or environmental characteristics is cleared. Clearance divides a continuous indigenous vegetation sequence. A dam, weir or culvert blocks upstream fish passage. Impervious urban surfaces with piped connections to streams increase the risk of acute contaminant spills. Connectivity of freshwater with adjacent flood zones is severed. Freshwater passage for species is lost through artificial fish barriers (pump stations, flood gates, dams, culverts, crossings). Light pollution affects the movement of crepuscular and nocturnal species, the efficacy of their foraging, or avoidance of predators.
	1.2c. habitat and resources for migratory and mobile animal species	Species may need resources or conditions available in different places at different times, and on connections between them.	Removal of any species' seasonal breeding habitat, feeding habitat, seasonal food source, or roosting habitat (e.g. through harbour reclamation) reduces migratory bird-feeding habitat.
	Alteration or degradation of: 1.2d. ecological properties (including processes)[23] of the ecosystems, habitats of indigenous species, and vegetation in 1.1	Species characteristic of an ecosystem are often lost or displaced when ecosystem condition or processes are altered. Alteration of ecosystem properties is often practically irreversible (e.g. alteration of the chemical fertility of soils). Organic matter and litter layers develop over decades while peat formation and development of podzols may take hundreds to thousands of years.	Pastoral intensification or agricultural conversion[24] of grasslands and cushion and mat vegetation. Runoff or overspray of irrigation water, effluent or waste water leads to the invasion of rare plant habitat by introduced grasses. Hydrology of indigenous wetlands or naturally dry areas is altered (e.g. peripheral drainage around kahikatea swamp). Naturally unstable ecosystems or habitats are stabilised (e.g. by sowing or planting on active dunes, screes or floodplains). Livestock (especially but not only cattle and deer) access forests,[25] and other indigenous habitats altering soils and litter communities.
	1.2e. nutrient, sediment and contaminant[26] status of freshwaters (including chronic effects, and acute effects such as spills)[27]	Eutrophication of rivers, lakes, wetlands and other oligotrophic or naturally low-nutrient freshwater communities is often only slowly reversible. Removal of contaminants can be difficult, and rehabilitation slow.	A lake is polluted by runoff from a new subdivision or pastoral intensification of the catchment through increases in stocking or fertiliser. Sedimentation after logging or fire in a catchment changes river or lake bed structure reducing food for aquatic invertebrates.
	Modification of flow regimes of streams and rivers that: 1.2f. reduces mean annual low flow 1.2g. involves takes that are large relative to annual mean flows, such that they reduce natural sediment transport by reducing freshes or freshettes	Abstraction from streams and rivers in ways that do not avoid these effects will remove, reduce or degrade habitats of species.	Abstraction reduces mean annual low flows, leading to loss of habitat and connectivity. Abstraction is high relative to annual mean flow, and transport of sediment inputs impaired. Gaps between stream-bed cobbles become filled and habitat is changed from three-dimensional to two-

[23]Ecosystem properties are the abiotic (physical) and biotic (biological) components, structures, and processes of ecosystems and their variability in space and time. Ecosystem *properties* therefore include *processes*, as well as physical and biological components and structures.
[24]Agricultural conversion means direct drilling or soil cultivation (by ploughing, disking or otherwise) or irrigation. Pastoral intensification includes oversowing, topdressing, subdivision fencing and change to heavier stock type (e.g. sheep to deer, deer to cattle).
[25]Wardle et al. (2001) describe "far-ranging effects of introduced browsing mammals in New Zealand at both the community and ecosystem levels of resolution, with particularly adverse effects for indigenous plant communities and populations of most groups of litter-dwelling mesofauna and macrofauna". Denmead et al. (2015) show that even minor livestock trampling has severe effects on land snail communities in forest remnants.
[26]The range of contaminants is wide and growing, and includes chemicals such as ammonium, heavy metals, pharmaceuticals and pathogens.
[27]Note that although 1.2e to 1.2h are part of 1.2d, we single out effects specific to freshwaters (rather than terrestrial ecosystems) here. We expect that a similar specification should be developed for marine ecosystems, but that is beyond the expertise of this team.

Table 1. Continued

Level of diversity	Effect	Why?	Examples
AVOID			
	1.2h. compromises species migration (except where migration of introduced fish will negatively affect indigenous fish species[28])		dimensional (i.e. bed armouring). A poorly screened intake causes indigenous fish mortality. A plantation in a catchment reduces flows.
1.3 Species	1.3a Temporary or permanent reduction in the size of a population of indigenous species at the geographic or environmental limit of the species' known natural range, or outlier populations	To maintain genetically based phenotypic variation for future selection and viability under changing climates and extreme events.	Individuals of a plant species are removed from a population at its southern geographic limit, or at the driest site in its range. A lizard population is transferred from near the dry limit to a wetter site. Raising lake levels reduces the number of southern rātā trees in an outlier population at the margins of an intermontane basin.
1.4 Biosecurity	1.4a Regional introductions and local actions that will increase the distributional range or propagule pressure from known invasive weeds, invertebrate pests, pathogens of indigenous plants and animals, and vertebrate pests[29].	With a few exceptions (e.g. giant white butterfly, Asian gypsy moth), New Zealand has not been able to eradicate invasive species of plants[30], aquatic pests (e.g. fish and algae), invertebrate pests, and pathogens. Devastating and transformational impacts on indigenous ecosystems and species are accumulating, along with minor or subtle and indirect impacts. Control of introductions and other local actions that increase propagule pressure of invasive species, will be necessary to maintain biodiversity.	Coastal and inland endemic cress (*Lepidium*) species are susceptible to invertebrate pests and pathogens of related species grown as crops and crop weeds. There is a new introduction of brassica crops into areas adjacent to indigenous brassicas. Conifers are planted in sites where they have the potential to spread. Bird-dispersed crops (e.g. blueberries, olives, kiwifruit, loquats, ginseng, cherries) are established in places where they are likely invade indigenous ecosystems A new coastal resort plants nitrogen-fixing, or drought-tolerant non-indigenous species adjacent to invasible indigenous vegetation. Non-indigenous slugs and other invertebrates are spread via potting mix used in tree planting. Russell lupins are sown on roadsides or in pasture and invade braided riverbeds, smothering nesting sites of birds, invertebrates and plant species. New drought-tolerant grasses are introduced to dryland areas, where indigenous dryland New Zealand plant species are already threatened by introduced pasture grasses. Non-indigenous ungulates are introduced beyond their feral ranges. Roadside maintenance or enhancement facilitates the spread of pest plants, including herbicide-resistant weeds (*Agapanthus*, Spanish heath).

[28]Barriers to connectivity for aquatic predators (especially protected brown and rainbow trout) can be important for maintaining populations of threatened indigenous species.
[29]Some of these will be listed in relevant national and regional pest schedules, although these will be incomplete and outdated in many cases and supplementary information may be needed for credible assessment.
[30]For example, in 111 Department of Conservation weed eradication programs, only 4 met with success, 21 were discontinued, and the rest remain "an ongoing challenge" (Howell 2012).

Table 2. Effects to avoid if the effect cannot be fully remediated within 25 years[31]

Level of diversity	Effect	Why?	Examples
AVOID IF THE EFFECT CANNOT BE FULLY REMEDIATED WITHIN 25 YEARS			
2.1 Indigenous ecosystems and the habitats of indigenous species	Fragmentation, reduction in size, degradation of ecological integrity, or cumulative drawdown[32] of: 2.1a. indigenous terrestrial, freshwater or marine ecosystems, habitats of indigenous species, or indigenous vegetation not specified in Table 1, including 2.1b developing indigenous ecosystems less than 25 years' old	As noted in our **Principles**, only a few, young, low-diversity ecosystem types comprising highly mobile, common, generalist species can be replaced; replacement will often lag, leading to interim biodiversity loss; and recovery from degradation of ecological integrity is often slow. The timeframe for full remediation should therefore be no greater than 25 years. That is, it will be necessary to avoid effects on indigenous ecosystems and habitats of indigenous species that can't be remediated within 25 years, and effects on younger (< 25 year old) developing ecosystems that cannot be replaced.	Early seral stage kānuka habitat on a peri-urban section is removed and replaced nearby.
2.2 Ecological processes and connectivity	2.2a Loss of, or damage to ecological corridors and areas important for linking or buffering terrestrial, freshwater or marine ecosystems, and habitats of indigenous species in 2.1 above 2.2b Alteration or degradation of ecological properties (including processes) of the terrestrial, freshwater or marine ecosystems, habitats of indigenous species, and vegetation in 2.1	As in 2.1, the timeframe for full remediation should be no greater than 25 years.	See examples for Effects 1.2a and 1.2b in Table 1.
2.3 Species	2.3a Reduction in the size of a population of any Threatened, At Risk or Data Deficient[33] indigenous species	Reducing population size temporarily or permanently increases the risk of extinction, even if loss of habitat (Table 1) is avoided. However, there are cases where take of individuals of species can be remediated with simultaneous actions. Remediation of species populations would need to be undertaken prior to or simultaneously with the effect, and not later. Feasibility will depend on factors particular to the species, including: rarity (e.g. is the population already small); life history (long lived or low fecundity species will be slower to replace); life stage of take (e.g. juvenile or adult); and whether there is technical restoration and husbandry experience.	A windfarm kills 15 adult South Island pied oystercatchers per annum. Potential remediation might be a simultaneous predator and habitat management programme increases chick survival in their South Island breeding habitats. Survival estimates show that this more than replaces the adults killed. There is cultural harvest of a fruiting plan in forest. The effect might potentially be remediated if simultaneously, herbivores or predators are controlled and field monitoring confirms an increase in the plant population and fruit abundance.
2.4 Coastal and river ecosystem movement	2.4a Impediments to landward migration of coastal ecosystems or the natural migration of aggrading rivers with the sea-level rise and altered flow regimes expected with climate warming[34]	As the climate warms, coastal and freshwater ecosystems will be lost if their natural migration is constrained by developments, and their ecological processes and connectivity altered (2.2).	Roads or residential subdivisions are developed behind coastal dunes or on the margins of estuaries. Fill raises the elevation of paddocks on the margins of an estuary. Groynes or stop banks restrain a river's natural movement. In some cases these effects may be remediated, especially by disestablishing similar developments existing elsewhere to enable natural migration and re-establish connectivity. Replacement of plantation forests and other stabilising non-indigenous species of coastal sands may allow re-establishment of natural dune processes and ecosystems.

[31]We assume that there would be expert case-by-case assessment of features in this table, because there are no simple criteria that would determine whether remediation within 25 years is or isn't feasible in the case of ecosystems, or whether simultaneous remediation of takes from populations was feasible in the case of species. If prompt remediation is found not to be possible then Avoid applies. This is likely to be the case in many instances, including with some 'young' emerging ecosystems.
[32]Cumulatively, actions could still draw down and degrade the 'stock' of youthful ecosystems and species habitats in the interim, even if a limit on the regeneration timeframe is observed. In this case, biodiversity will not be maintained, and it would become necessary to avoid these effects until such time as remediation 'catches up'.
[33]Townsend et al. (2008).
[34]Wright (2015). New Zealand is already committed to significant sea-level rises.

other activities that alter ecological properties and processes are central to the approach we set out.

We suggest that avoiding adverse effects is paramount, and remediation and mitigation of those effects a last resort. Restoration may assist maintenance of indigenous biodiversity, especially in regions where little now remains, but rarely compensates for habitat loss and degradation because it is seldom successful in re-establishing the complete range of biodiversity features (ecosystems, species, genes). Moreover, remediation actions required as conditions of consent are often not carried out in New Zealand because agencies frequently fail to ensure compliance (Brown et al. 2013; Brown 2017; Brower et al. 2018).

Modified and regenerating ecosystems

Our approach recognises that maintaining biodiversity requires avoiding adverse effects on highly modified (including exotic-dominated) ecosystems, as well as more pristine ecosystems. Settled and transformed regions and districts harbour the only remaining examples of many rare ecosystems and habitats for threatened and declining indigenous species (Holdaway et al. 2012).

Ecosystems that are regenerating after disturbance often take unpredictable successional pathways with novel biotic combinations (Standish et al. 2009) but are important for maintaining biodiversity. Many will also be valuable for mitigating impacts on humans of climate change, urbanisation and intensive land use as sea-level rises and droughts and storms become more frequent (Royal Society of New Zealand 2016). For example, productive lowland regenerating ecosystems can rapidly sequester carbon, and lowland riparian zones are more likely to contribute to flood regulation and maintaining freshwater quality by filtering nutrients, sediment, and bacteria.

Defining indigenous

The definition of indigenous (e.g. in indigenous vegetation or indigenous ecosystem in Tables 1, 2) will influence maintenance of biodiversity. We suggest that the presence of indigenous species should be the primary determinant. A quantitative definition with an arbitrary threshold (e.g. > 20% of species or plant cover) is problematic because it would exclude ecosystems and habitats important for indigenous biota. Many ecosystems and plant communities dominated by non-indigenous plant species are essential for maintaining indigenous species, for example dryland plants (Walker et al. 2016), wētā in gorse (Sherley & Hayes 1993), endangered black-billed gulls *Larus bulleri* in non-indigenous pasture (Mischler 2018), dotterels on motorway margins (Judd 2007), kiwi, bats, *Peripatus* and land-snail species in plantation forests, and geckos and skinks in urban areas.

What does not need to be avoided?

We do not identify non-indigenous, recently-regenerated (< 25 years) ecosystems and biological communities (e.g. gorse or broom shrublands) that occur outside riparian zones as essential to avoid or remediate unless they are habitat for threatened or at-risk indigenous species, or provide connectivity and buffering. Such recent communities may, however, provide ecosystem services in critical zones, and contribute towards biodiversity maintenance if they have potential for restoration.

Take of individuals

We suggest that the take (by deliberate harvest or accidental by-kill) of individuals from populations of some species (including threatened species) could be remediated through enhancement of populations in some circumstances. Experience shows replacement of individuals can be achieved in a few species of indigenous birds, lizards and snails, mostly through predator control and captive breeding. However, take of taxa with little-known responses to management or demanding reproductive or regenerative requirements should be avoided. Species' adaptive variation (e.g. traits of species in populations at their geographic or environmental limits) is unlikely to be replaceable except via prolonged evolution, and therefore take from populations at or near their limits and in outlier populations should also be avoided.

Regional contexts matter

National lists provide overviews, but species and ecosystems may also be regionally threatened and their ranges further reduced by loss in those regions. We suggest that regional status should predominate where supplementary information identifies species or ecosystems more threatened or at risk regionally than nationally.

Practical implications

Avoiding adverse effects on indigenous biodiversity across New Zealand would entail a shift from current practice, especially in districts where persistence of indigenous ecosystems and species' habitats still conflicts with other land uses and district plan rules are lax. However there are situations where avoiding effects would not differ substantially from current practice: for example in districts where habitats of indigenous species are already absent from land with potential for development, where landowners and communities are not contemplating clearance of areas that still support indigenous biodiversity, or where comparable criteria have already been used to identify significant indigenous vegetation and species habitats for protection under Section 6c of the RMA (1991). Here, changes would mainly involve greater protection of freshwater habitats, and a reinforcement of national freshwater, afforestation, and climate change-mitigation initiatives already underway.

Conclusion

We have proposed a rule-based approach to slow the ongoing loss of New Zealand's terrestrial biodiversity. The criteria we suggest are straightforward, based on current understanding in conservation biology, and would offer a prospect of maintaining biodiversity if put into practice. We also suggest that the nationally consistent approach set out here would offer *a priori* certainty and easier planning for those intending to change current land use and cover, and simplify the current practices for determining the significance, or otherwise, of adverse effects.

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Susan Walker: conceptualisation, writing – original draft, review and editing, Peter J. Bellingham, Geoff Kaine, Sarah Richardson, Suzie Greenhalgh, Robyn Simcock, Marie A. Brown, Theo Stephens, William G. Lee: conceptualisation, writing - review and editing.

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Supplementary material

Additional supporting information may be found in the supplementary material file for this article:

Appendix S1. Glossary of technical terms used.

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