NEW ZEALAND JOURNAL OF ECOLOGY

RESEARCH

Establishing an evidence-based framework for the systematic conservation of New Zealand's terrestrial ecosystems

John R. Leathwick[1]*, Amy L. Whitehead[2], Nicholas J.D. Singers[3] and Elizabeth Daly[4]

[1]Heathcote Valley, Christchurch, New Zealand
[2]Manaaki Whenua Landcare Research, 74 Gerald Street, Lincoln 7608, New Zealand
[3]Turangi, New Zealand
[4]Horizons Regional Council, Private Bag 11025, Manawatū Mail Centre, Palmerston North 4442, New Zealand
*Author for correspondence (Email: john.leathwick@gmail.com)

Published online: 8 December 2023

Abstract: Although New Zealand's 2020 biodiversity strategy, Te Mana o Te Taiao, places a high priority on protecting indigenous ecosystems, it provides minimal detail on how this will be accomplished. Using spatial data and a conservation prioritisation tool we demonstrate the implementation of a comprehensive framework for the systematic conservation of New Zealand's terrestrial ecosystems, as proposed in a pioneering paper by Kelly (1980). Working within the Horizons Region (Manawatū-Whanganui, lower North Island), we analyse the extent of losses of 65 terrestrial ecosystems since human settlement by combining maps of their potential distribution and current land cover. Two-thirds of the original indigenous cover has been lost, with lowland ecosystems suffering greatest losses; much surviving cover is substantially modified. Our prioritisation analyses identify various options for siting conservation management to maintain the integrity of a full range of indigenous ecosystems in a highly modified landscape, given varying degrees of constraint on the availability of land for conservation. Restricting management to DOC-administered land would severely constrain ecosystem representation, but dramatic improvements in ecosystem representation would result from protecting and managing a relatively small number of sites on land of other tenures, mostly at lower elevations. Results such as these could play a crucial role in supporting achievement of New Zealand's high-level goals for ecosystem conservation and meeting international conservation obligations. They could be used to (1) assess the conservation status of individual terrestrial ecosystems, (2) develop national and regional policies specifically targeting protection of at-risk ecosystems, (3) design and implement strategies that explicitly target management across a full range of ecosystems, (4) support processes designed to coordinate management among different conservation actors, and (5) inform individual landowners of the conservation value of indigenous ecosystems on their land. Obstacles to implementing such an approach include a range of technical, institutional, and social factors.

Keywords: biodiversity goals, ecosystem loss, land tenure, New Zealand, spatial prioritisation, systematic conservation, terrestrial, zonation

Introduction

Recognition of the need to protect Earth's ecosystems (United Nations 1992; Christenson et al. 1996; Noss 1996; IPBES 2019; Convention on Biological Diversity 2022) has prompted the development of several international initiatives for their systematic conservation. For example, Keith et al. (2013; 2015) developed criteria for the establishment of a red list of threatened ecosystems that parallels the International Union for Conservation of Nature's (IUCN) red list for threatened species (Bland et al. 2017). A subsequent evaluation of the utility of this framework in countries where it had been adopted indicated its effectiveness in informing legislation, land-use planning, protected area management, monitoring and reporting, and ecosystem management (Bland et al. 2019).

More recently, Nicholson et al. (2021) proposed a set of goals, milestones, and indicators for ecosystem conservation in the post-2020 global biodiversity framework. They identified three core components: assessment of change in ecosystem extent, loss of integrity and risk of collapse. They also presented a comprehensive framework for ecosystem management based on systematically addressing the drivers of loss, along with criteria for the selection of indicators of progress towards ecosystem conservation goals. Further support for a globally consistent approach to ecosystem conservation is provided by a recently proposed, functionally based typology for Earth's ecosystems (Keith et al. 2022). Last, the importance of systematic approaches to ecosystem conservation is explicitly reinforced in recent decisions released by the Convention on Biological Diversity (CBD; Convention on Biological Diversity 2022). The first of 21 urgent targets to be achieved by 2030 explicitly identifies the need for the use of "biodiversity

DOI: https://doi.org/10.20417/nzjecol.47.3557

inclusive spatial planning" to support ecosystem and species conservation, while the third target highlights the need for the establishment of "ecologically representative, well-connected and equitably governed systems of protected areas".

Ecosystem conservation in New Zealand

In New Zealand, the primary importance of ecosystem conservation is explicitly recognised in the Reserves Act 1977, whose purposes include both the protection of a full range of native species and "the preservation of representative samples of all classes of natural ecosystems and landscape which in the aggregate originally gave New Zealand its own recognisable character" (S31b). This defines a crucial temporal reference point, i.e. representation of New Zealand's original ecosystem pattern, not just those ecosystems that have survived human settlement. This legislative definition was influenced strongly by the pioneering thinking of Kelly (1980), who subsequently (1) highlighted the unbalanced representation of ecosystems in New Zealand's protected areas, and (2) proposed a comprehensive strategy to address these discrepancies. This included development of a national vegetation classification, national mapping of vegetation cover, a national biological survey, assessment of the adequacy of representation for vegetation types in protected areas, and centralised storage of data describing the distributions of species and habitats—a visionary approach that prefigured more recent international approaches to ecosystem conservation. Although some elements of Kelly's (1980) approach were implemented through surveys of individual ecological districts (McEwen 1987) under the protected natural areas programme (PNAP) (Myers et al. 1987), vegetation units were described on an ad hoc, district-by-district basis (Ravine 1995). As a consequence, while some individual elements of Kelly's (1980) vision have since been implemented (Wiser 2011; Singers & Rogers 2014), his call for a systematic national assessment of ecosystem patterns, representation and status remains substantially unfulfilled.

Two decades later, Park (2000) further promoted the need for systematic management of New Zealand's ecosystems, based on their prominent position in the Reserves Act 1977 and Resource Management Act 1991. Park argued for the active management of ecosystems, reiterating Kelly's (1980) call for a national ecosystem classification based on recurring combinations of vegetation type and landform, the explicit mapping of New Zealand's ecosystems, the identification of at-risk ecosystems and the prioritisation of those in need of restoration.

Ecosystems occupy a prominent position in New Zealand's latest biodiversity strategy, Te Mana o Te Taiao (Department of Conservation 2020), which was updated to meet our obligations as signatories to the 1992 Convention on Biological Diversity. Its high-level conservation goals are intended to set "the overall strategic direction for biodiversity in Aotearoa New Zealand for the next 30 years". The first of these focuses on ecosystem conservation, identifying our need to protect and secure "a full range of indigenous ecosystems". However, although the Department of Conservation (DOC) has a well-developed framework for assessing and reviewing the conservation status of individual species (Townsend et al. 2008), it lacks a formal framework for assessing the conservation status of ecosystems, including changes in their extent, integrity, or risk of collapse. A subsequent action plan (Department of Conservation 2022) released in support of the strategy identified the need to prioritise conservation work, i.e. by 2025 "A framework for 'identifying and prioritising high biodiversity value areas has been developed and agreed on". This reflects a broader consensus that achievement of New Zealand's high-level conservation goals will require much greater coordination of management actions by different conservation actors than occurs at present (Parkes et al. 2017; Willis 2017; Department of Conservation 2020; Leathwick & Byrom 2023).

Such prioritisation is likely to be challenging, given the marked increase over the last two decades in the number of agencies, organisations, and individuals actively engaged in or seeking to influence conservation management (Willis 2017; Innes et al. 2019; Towns et al. 2019; Department of Conservation 2020; Leathwick & Byrom 2023). First and foremost, much greater recognition is now accorded to the Treaty Partnership between Māori and the Crown in conservation, including in both Te Mana o Te Taiao (Department of Conservation 2020) and the newly released National Policy Statement on Indigenous Biodiversity (NPSIB) (Ministry for the Environment 2023). Practical expressions of this recognition include the return of some large areas of formerly Crown-managed lands to Iwi (e.g. Te Urewera Act 2014), the development of formal co-governance arrangements for sites retained by the Crown (e.g. Taranaki Maunga – Te Ao Māori News 2021), and the development of significant Iwi-led conservation management initiatives both on Crown land (e.g. Raukūmara Pae Maunga 2023) and their own land (Nga Whenua Rahui – Department of Conservation 2023). In addition, a number of other actors now undertake significant conservation management activities, including regional councils, community groups, commercial businesses, philanthropists, and private landowners (Willis 2017; Innes et al. 2019; Towns et al. 2019; Department of Conservation 2020; Leathwick & Byrom 2023). Current management often strongly emphasises the management of a relatively small number of predation-vulnerable species, often with minimal consideration of the ecosystems on which they depend (Leathwick & Byrom 2023). At the same time, some hunter groups have attempted to minimise the active management of the introduced ungulates that they value for hunting, despite their well-documented negative impacts on most indigenous ecosystems (Leathwick & Byrom 2023). Finally, a number of rural communities strongly criticised the draft NPSIB for its requirement for regional councils to identify significant natural areas on private land and place restrictions on their management (Stuff 2021).

Approaches used to prioritise conservation management actions in this complex, multi-player setting must be capable of identifying the relative contributions of candidate projects to high level conservation goals, while also taking account of the wide variation in the resources, aspirations, world views, and particular interests held by various parties. Here, we demonstrate the use of quantitative analyses designed to support and contribute to this process. We first demonstrate the use of standard geographic information system (GIS) analyses of spatial data from the Horizons (Manawatū-Whanganui) Region (Fig. 1) to assess the current conservation status of 65 indigenous ecosystems as indicated by losses of their likely historic extent. We then provide a proof-of-concept analysis using Zonation (Moilanen et al. 2005; Moilanen et al. 2022), a tool developed within the discipline of systematic conservation planning (Margules & Pressy 2000) that calculates continuous rankings for a landscape, enabling the flexible selection of varying-sized subsets of the landscape that maximise the representation of a full range of biodiversity features.

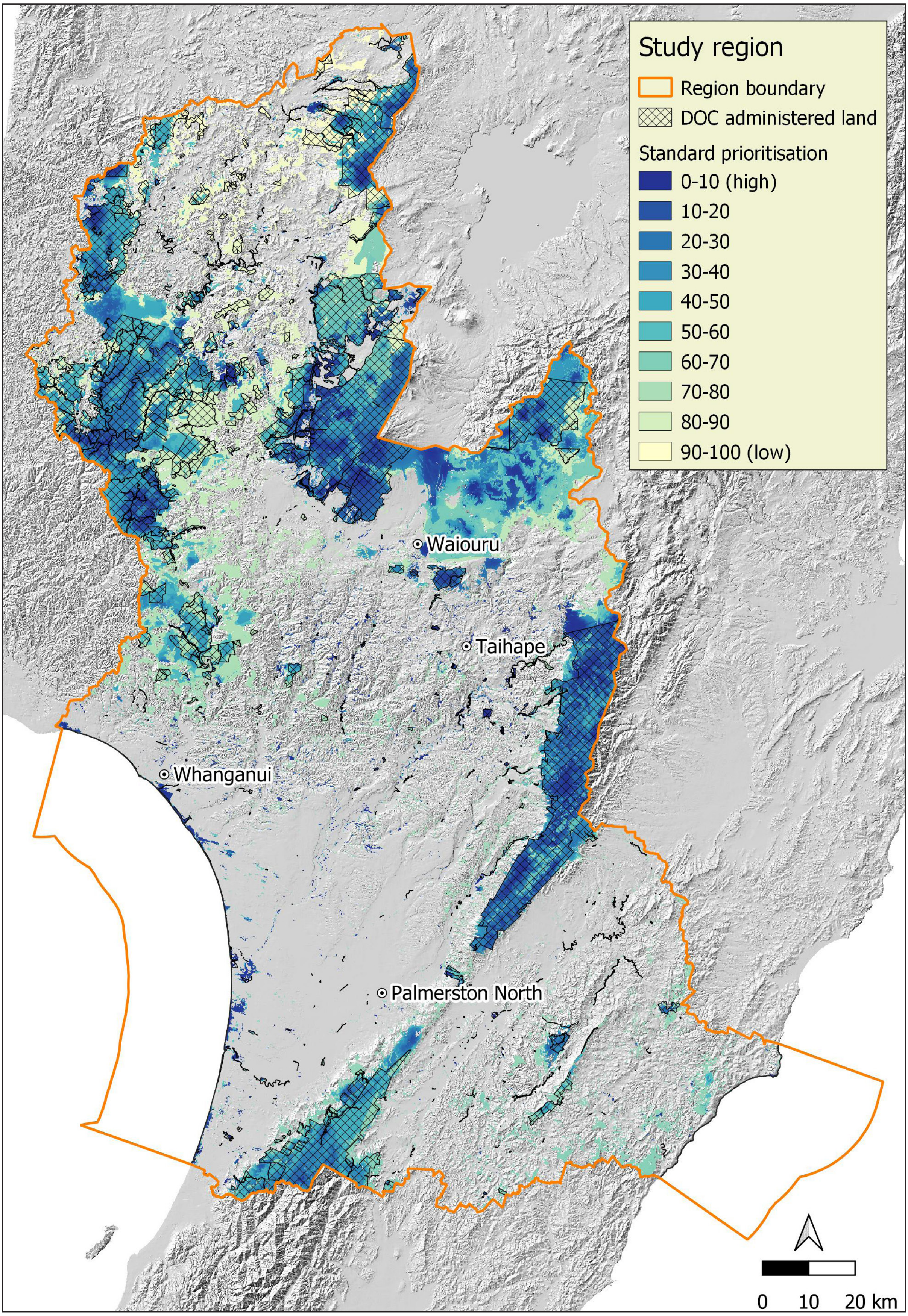

Figure 1. Geographic extent of the Horizons Region in the lower North Island, New Zealand, showing the extent of land currently administered by the Department of Conservation (DOC) and the extent of surviving indigenous terrestrial cover. The latter is symbolised to show rankings from our standard prioritisation—the highest ranked 10% of the landscape is indicated by the darkest blue colours, the top 20% by the two darkest blue colours, etc.

Published examples of previous uses of Zonation include: evaluation of the conservation benefits of fishing industry-proposed Benthic Protection Areas in New Zealand's Exclusive Economic Zone (Leathwick et al. 2008), optimisation of biodiversity offsetting of mining impacts in the Hunter Valley, Australia (Kujala et al. 2015), identification of candidate sites for the expansion of Japan's protected area network (Lehtomäki et al. 2019), and a global analysis to identify terrestrial and marine areas at greatest risk of biodiversity loss from over-harvesting (Di Minin et al. 2019).

Methods

Input data

Spatial data used in our analysis were drawn from three main sources (upper left of Fig. 2): digital mapping of the potential terrestrial ecosystem cover for the Horizons Region (Singers & Lawrence 2018), national satellite-based mapping of contemporary land cover (LCDB4.1) (Landcare Research 2015; Dymond et al. 2016), and a layer delineating land administered by the Department of Conservation as at January 2017 (Koordinates 2023).

The potential ecosystem layer mapped the distributions across the Horizons Region of 65 indigenous ecosystems (Appendices S1, S2 in Supplementary Material) categorised according to the national ecosystem classification of Singers and Rogers (2014), which includes both widespread and naturally uncommon or rare ecosystems. It was compiled using both published and unpublished descriptions of New Zealand's terrestrial ecosystems, both historic and surviving, in conjunction with climate and soils data, to identify the most likely terrestrial ecosystem cover, including where the original indigenous ecosystem cover has been removed (Singers & Lawrence 2018). Although this can generally be interpreted as indicating the historic cover at the time of human arrival, our ability to predict historic cover is complicated by the important role played across many New Zealand landscapes by natural disturbance events such as volcanism, tectonics, drought, and natural fire (Wyse et al. 2018). Such events would likely have resulted in at least some extensive areas of secondary cover in the Horizons Region at the time of human arrival.

The contemporary land cover layer (LCDB4.1) was derived from national mapping based on satellite imagery collected during the summer of 2012/13. This used a generalised classification of 33 classes to map the vegetation cover across all of New Zealand. Eighteen of these classes describe indigenous-dominated terrestrial cover types (Cieraad et al. 2015), of which twelve occur within the Horizons Region (Appendix S3). A further three classes that describe the distribution of

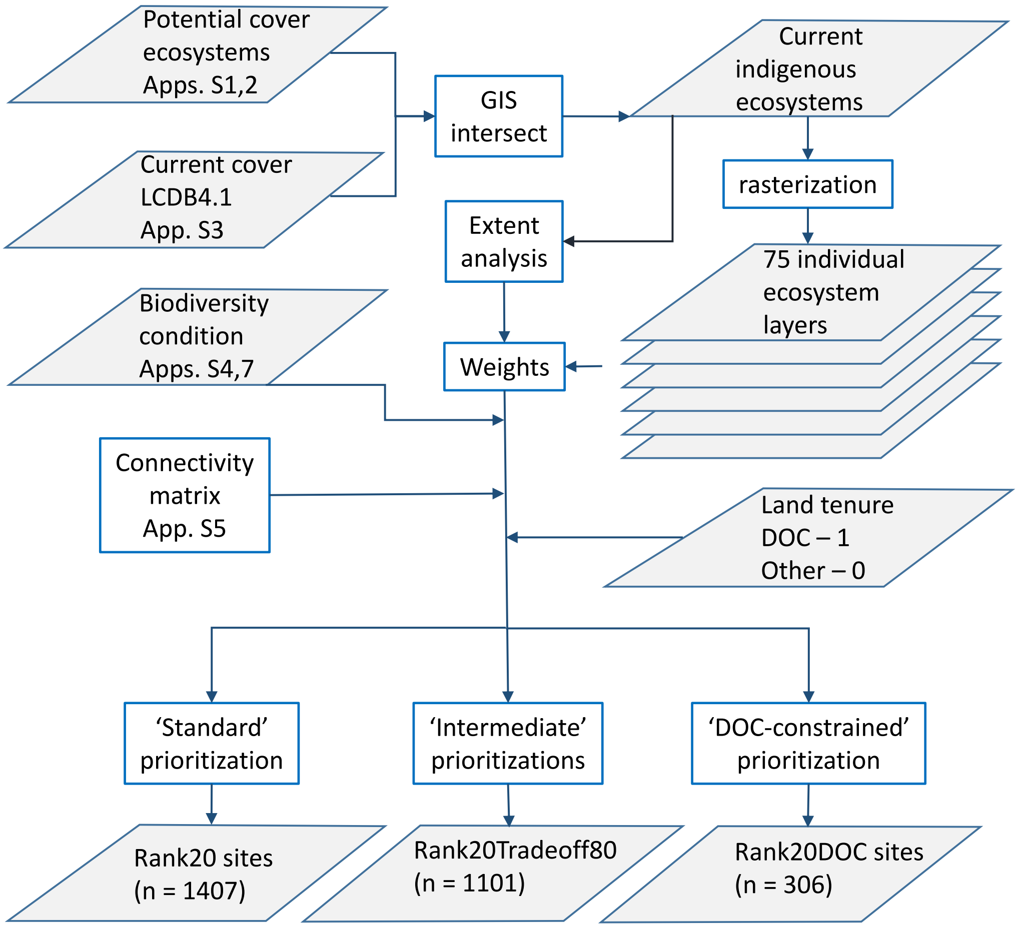

Figure 2. Analysis schematic. Spatial data layers are represented by grey-filled parallelograms, and analysis steps by un-filled rectangles. The 75 ecosystem layers comprise 65 ecosystems from the potential ecosystems mapping, eight predominantly secondary LCDB4.1 classes, and two LCDB4.1 wetland classes. OL-App I = Appendix S2, etc.

bare ground were also included, along with occurrences of one class that is nominally dominated by exotic species ("low producing grassland"), which was used extensively to map vegetation still retaining strong indigenous elements on dunes along the Manawatū coast.

Changes in extent

Changes in the extents of the 65 ecosystems mapped across the Horizons Region were calculated by intersecting the potential ecosystems and current land cover layers to create a set of c. 91 000 polygons delineating all land still supporting indigenous cover or bare ground (shown in Fig. 1). Each polygon encompassed a discrete area containing a particular combination of potential ecosystem and current indigenous land cover. This layer was extensively edited to reconcile incompatible combinations of potential ecosystem and current land cover that resulted largely from the contrasting spatial scales at which these two layers were compiled (detailed in Appendix S4).

The edited intersection layer was then used to compare the current and historic extents of individual ecosystems. To allow discrimination between relatively un-modified areas and those likely to have been subject to major disturbance, particularly for forests, current extent statistics were also calculated within five groups based on combinations of their potential and current cover (assignments of LCDB4.1 classes to these groups are detailed in Appendix S3). A 'primary' group included all subalpine ecosystems, along with all areas mapped as forest in the potential ecosystems layer and as 'Indigenous forest' in the current cover layer. A 'secondary' group included all potentially forested areas now supporting secondary and non-forest LCDB4.1 classes, while the 'wetland' group included all areas mapped as wetland in the current cover layer and/or potential ecosystem layers. A 'non-forest' group included all areas mapped as a cliff (CL), duneland (DN) or temperature inversion (TI) ecosystems by the potential ecosystem mapping and by secondary or low-stature classes in the LCDB4.1 layer. Areas mapped by the LCDB4.1 bare ground classes were assigned either to the 'non-forest' group (potential cover of BR, CL or DN) or to a 'bare ground' group (all other potential ecosystem classes).

Calculating conservation priorities

We then used the spatial prioritisation software, Zonation (Moilanen et al. 2005; Moilanen et al. 2022), to calculate ten conservation prioritisations covering all surviving indigenous cover within the Horizons Region. All candidate sites were ranked for their ability to contribute to the representation of a full range of ecosystems, given varying degrees of constraint on the selection of land beyond that currently held by the Crown for conservation purposes. Primary input to these analyses consisted of 75 gridded, 30 m resolution spatial layers describing the distributions of each of the 65 ecosystems mapped in the potential ecosystem layer, and the ten secondary, general wetland, and bare ground cover classes from the LCDB4.1 layer (Appendix S4). A land tenure layer that distinguished DOC-administered land from land of other tenures was used to influence outcomes in some prioritisations.

Weights were used to control the relative influence of the different input layers, with ecosystem layers assigned a weight of one by default. However, weights of two or even three were used to increase the influence of ecosystems most reduced in spatial extent since human settlement (Appendices S5, S6). Conversely, secondary ecosystems were given lower weights to reflect their generally lower contribution to ecosystem representation, relative to primary ecosystems. Negative weights of varying magnitude were assigned to the tenure layer in some analyses (see below) to discourage the allocation of high priorities to non-DOC land.

All prioritisations used a layer describing the estimated biodiversity condition (Appendices S4, S7) constructed from separate estimates of the impacts of fragmentation, risks of weed invasion, logging modification of forest ecosystems and introduced browsers, with the combined impacts adjusted to account for recent conservation management. This layer was used in the prioritisation analyses to encourage the allocation of higher priorities to better condition examples of each ecosystem, all other things being equal. Finally, all prioritisations used settings to account for the importance of landscape connectivity when identifying conservation priorities, i.e. larger areas that contain sequences of related ecosystems offer better prospects for long term conservation than when an equivalent area is fragmented and scattered across a number of locations (e.g. Christensen et al. 1996). These settings allowed for varying degrees of interaction between different ecosystems occurring adjacent to each other (Lehtomäki et al. 2009) at distances of up to 1 km (Appendices S5, S6).

An initial 'standard' prioritisation identified conservation priorities regardless of land tenure (lower Fig. 2), indicating the maximum ecosystem representation achievable within the surviving indigenous cover of the Horizons Region when there are no constraints on the selection of land for conservation management. We next calculated a 'DOC-constrained' prioritisation, in which the land tenure layer was used as a mask, forcing all DOC-administered land to have higher priorities than all other land. This allowed assessment of (1) the ecosystem representation delivered by DOC-administered land alone, and (2) the additional ecosystem representation provided by land of other tenures. A further eight prioritisations were then calculated that were intermediate between our standard and DOC-constrained prioritisations. These used a negatively weighted land tenure layer, with the magnitude of this weight progressively raised to apply increasing penalties to the allocation of high priorities to non-DOC land. This allowed us to explore how varying the restriction of high priorities to DOC-administered land would reduce the achievement of ecosystem conservation goals, while also identifying those non-DOC sites with the highest potential contributions to conservation outcomes, given varying degrees of constraint on their selection. A final 'random' prioritisation indicates the expected ecosystem representation that would be achieved if sites were chosen for management at random. Copies of command and setup files for all prioritisations are provided in Appendix S6.

To simplify the presentation of spatial results, the highest-ranked 20% of the landscape identified from each prioritisation was delineated by polygons. High-priority grid cells located within 250 m of each other were aggregated to form 'sites', with statistics calculated for each site describing their extent, their mean priority, and their mean elevation, with the latter determined by overlay onto a digital elevation layer with a grid resolution of 8 m (Land Information New Zealand 2012). Sites of less than 1 ha were removed given their likely lower viability for conservation management.

Results

Changes in ecosystem extent

Combining the current land cover layer with the potential ecosystems layer allowed flexible analysis of the loss and modification of indigenous ecosystems, which we demonstrate here at three contrasting levels of detail: overall loss of indigenous ecosystems by structural class, loss and modification of forest cover by bioclimatic zone, and loss and modification of individual forest ecosystems of warm climates.

Since human settlement, the indigenous ecosystem cover of the Horizons Region has been reduced to just over one-third of its original extent (Table 1, Fig. 1, cross-hatched in Appendix S1). Forests, which once made up nearly 97% of the regional ecosystem cover, have been reduced to 33% of their estimated historic extent, while coastal ecosystems have been reduced to 53% of their original extent, non-forest ecosystems to 86%, and wetlands to 37%. This latter figure is likely to considerably under-estimate actual wetland losses, reflecting the identification of numerous small wetlands in the LCDB4.1 layer that were not differentiated in the potential ecosystem mapping because of the broader scale at which it was compiled.

Considering forest cover in more detail, primary forests make up around two-thirds of the potentially forested area that still supports indigenous cover (Table 2, Appendix S8); the balance of the cover in these areas is mostly secondary woody cover or induced tussock grasslands. However, primary forest survival varies strongly by climatic zone (defined in Appendix S2). In cold, cool, and mild climates, primary forests still occupy more than half of the potentially forested area that still supports indigenous cover (Table 2). By contrast, warm climates have suffered not only the greatest overall loss of indigenous cover but also the greatest loss of primary forest, with the latter now making up less than one quarter of the area that still supports indigenous cover.

The individual warm forest ecosystems also show strong variation both in their degree of loss and modification (Table 3, Appendix S8). Tawa, tītoki, podocarp forest (WF3 of Singers & Rogers 2014) was once the most extensive of these, occupying more than 200 000 ha of well drained soils. Since human settlement it has been reduced to 7% of its former extent, of which just under 30% or 4225 ha is primary forest, the balance mostly comprising secondary forest and scrub. Kahikatea, pukatea forest (WF8), which once occupied c. 112 000 ha of poorly drained alluvium, has suffered even greater loss. This has been reduced to just 2% of its former extent, of which only 37% or 970 ha is primary forest; the balance supports a mix of secondary woody cover and wetland. Primary remnants of the remaining five warm climate forest ecosystems, which were of limited extent even before human arrival, now together total less than 20 ha.

Table 1. Current and potential extent of broad indigenous ecosystem groups in the Horizons Region. Ecosystem codes in the left-most column correspond to the ecosystem groupings of Singers and Rogers (2014) as described in Appendix S2. %P = percentage of potential extent.

Broad structural	Indigenous cover group (000 ha)		
	Potential	Current	%P
Snow & ice	0.4	0.4	100.0
Subalpine (AL, AH)	35.3	35.1	99.3
Forest (CDF, CLF, MF, WF)	2146.1	701.2	32.7
Non-forest (CL, BR, SC, TI)	12.9	11.1	86.3
Wetland (WL)	14.9	5.6	37.3
Coastal (SA, DN)	4.5	2.4	53.4
Total	**2214.1**	**755.7**	**34.1**

Spatial prioritisation

High conservation priority areas identified by the first two spatial analyses differed markedly in the average ecosystem representation that they deliver. The standard prioritisation, which ranks sites regardless of their tenure, delivers a strongly curvilinear increase in ecosystem representation as an increasing proportion of the landscape is selected for management by progressively including sites of lower and lower priority (left to right on horizontal axis in Fig. 3). Selecting the 10% of the landscape with the highest conservation priority (darkest shading in Fig. 1) delivers average ecosystem representation of 65.8%, the highest priority 20% of the landscape delivers average representation of 78.9%, and the highest priority 30% delivers average representation of 86.2%.

While ecosystem representation initially also rises steeply in the DOC-constrained prioritisation, it then rapidly plateaus (dashed line in Fig. 3). This reflects the constraining of DOC-administered land to have higher priorities than all other land, with these sites being unable to provide representation for ecosystems that occur predominantly on (lower priority) lands of other tenure. As a consequence, the highest priority 20% of the landscape delivers average ecosystem representation of

Table 2. Potential and current extents of forest ecosystems aggregated by climatic zone, with current extents separated according to broad current land cover groups. %P = percentage of potential extent. Second = secondary; Non-for. = non-forest.

Climatic zone	Potential forest	Current indigenous-dominated cover (000 ha)									
		Total	%P	Primary	%P	Second.	%P	Wetland	%P	Non-for.	%P
Cold 10–12.5°C	188.3	151.0	80.2	81.5	43.3	66.8	35.5	1.3	0.7	1.4	0.7
Cool 12.5–15°C	151.0	61.1	40.5	45.6	30.2	14.4	9.5	0.7	0.5	0.4	0.3
Mild 15–17.5°C	1373.5	464.8	33.8	321.9	23.4	141.4	10.3	0.5	0.0	0.9	0.1
Warm 17.5–22.5°C	433.3	24.3	5.6	5.9	1.4	12.8	2.9	0.7	0.2	4.9	1.1
Total	**2146.1**	**701.2**	**32.7**	**454.9**	**21.2**	**235.3**	**11.0**	**3.3**	**0.2**	**7.7**	**0.4**

Table 3. Potential and current extents of warm climate forest ecosystems, with current extents separated according to broad current land cover groups. %P = percentage of potential extent. Prim = primary; Sec. = secondary; Wet. = wetland. Ecosystem descriptions are available in Appendix S2.

Forest ecosystems	Potential (ha)	Current indigenous-dominated cover (ha) Total	%P	Prim.	Sec.	Wet.	Other	Bare
WF1: Titoki, ngaio forest	1854	55.5	3.0	2.8	38.3	3.5	-	10.8
WF2: Totara, matai, ribbonwood forest	19 651	812	4.1	243	210	12.6	8.6	338
WF3: Tawa, titoki, podocarp forest	200 797	14 596	7.3	4225	10 071	67.3	1.7	231
WF3-2: Kahikatea, pukatea, tawa, titoki forest	45 070	1313	2.9	401	730	56.0	92.3	34.0
WF3-2/WF6 mosaic	20 708	1851	8.9	12.3	30.4	39.5	1,545	224
WF6: Totara, matai, broadleaved forest [Dune Forest]	30 488	2775	9.1	43.3	245	155	2,197	135
WF8: Kahikatea, pukatea forest	111 911	2612	2.3	970	1239	290	-	114
WF8: Kahikatea, pukatea forest and Swamp mosaic	2 849	321	11.3	3.4	198	113	-	6.2

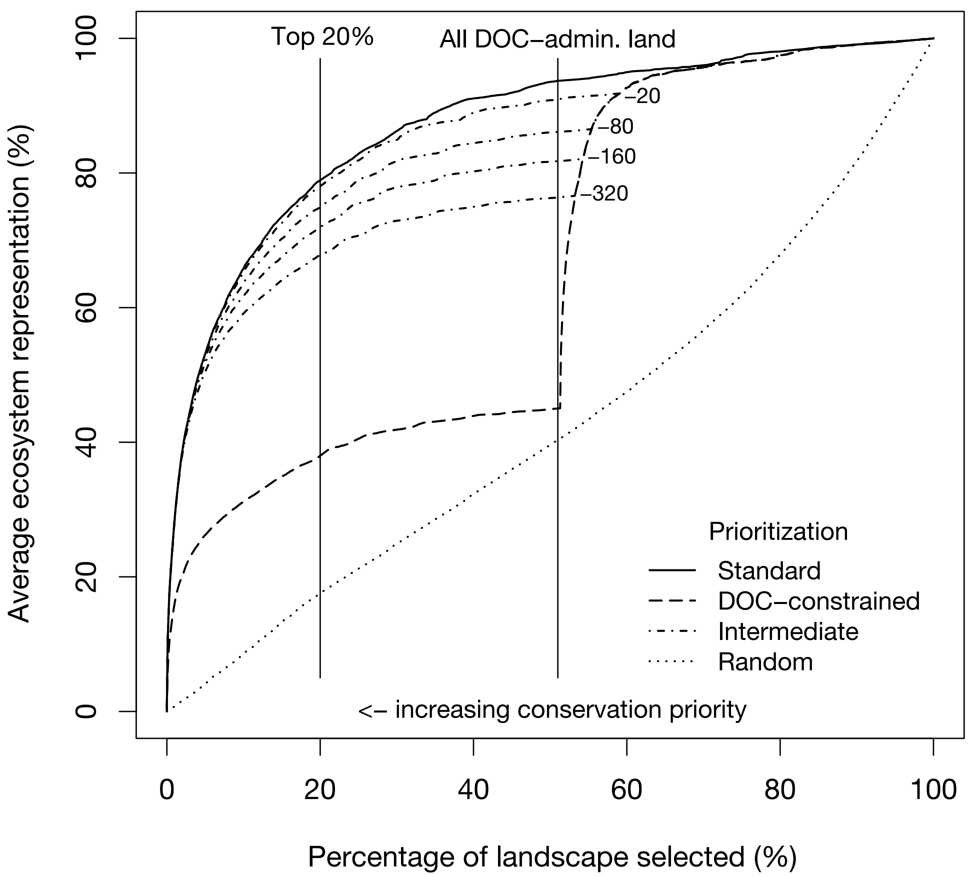

Figure 3. Relationships between the percentage of the indigenous-dominated landscape of the Horizons Region selected for management and the average representation of 65 terrestrial ecosystems and two LCDB4 wetland classes. Results are presented for six contrasting spatial prioritisations that varied in their ability to assign high priorities to non-DOC land. No constraint was applied in the standard prioritisation, while all non-DOC land was forced to have lower priorities than DOC administered land in the DOC-constrained prioritisation. Varying constraints were applied to the ranking of non-DOC land in the four intermediate prioritisations shown here, weights for which are shown on the figure; results for the lower weighted intermediate prioritisations are omitted for clarity. Results from a random landscape removal routine are included for comparison (Appendix S5). Vertical lines correspond to selection of the highest priority 20% of the landscape, and all DOC-administered land respectively.

just 38%, less than half that provided by the highest priority 20% of the landscape from the standard prioritisation (78.9%). Even when all DOC-administered land is selected (51.3% of the landscape), average ecosystem representation reaches just 45.0%, less than half that delivered by an equivalent area selected using the standard prioritisation (93.7%), and only marginally more than an equivalent area selected at random from the landscape (40.5%) (Fig. 3). However, ecosystem representation rises rapidly once the highest priority 10% of non-DOC land (ranks in the range 51.3–61.3%) is added to the DOC-administered land. These additional areas provide representation for ecosystems not found on DOC-administered land, resulting in the average ecosystem representation more than doubling from 45.0% to 93.5%.

A range of more nuanced outcomes are provided by the eight 'intermediate' prioritisations that used negative weights to impose varying degrees of penalty on the selection of non-DOC land. In particular, less substantial negative weights resulted in the extensive allocation of high priorities to non-DOC land, with the top-ranked 20% of the landscape delivering average ecosystem representation approaching that delivered by our initial unconstrained prioritisation (right of Fig. 4). Use of an intermediate level of constraint (weight of c. −80) reduced substantially the inclusion of non-DOC land in the top-ranked 20% of the landscape, but with only small reductions in average ecosystem representation. More substantial negative weights both reduced the prioritisation of non-DOC land and resulted in substantially lower ecosystem representation (left of Fig. 4).

Characteristics of top ranked sites

Standard prioritisation

The highest priority 20% of the landscape identified by the standard prioritisation (Rank20 – Appendix S9) totals 151 687 ha in extent, or 6.9% of the original pre-human indigenous cover (Appendix S8). This comprises 1407 individual sites (Appendix S9) that vary in extent from 1–28 255 ha, with a mean of 107.5 ha. Their average elevation is 354 m above sea level. Although these sites deliver average ecosystem representation of 78.9%, there is strong variation in the representation of individual ecosystems (Appendix S8, Fig. 5a). In general, representation is negatively related to ecosystem extent, i.e. ecosystems with a current extent of less than 100 ha have on average 96.3% of their extent contained within the Rank20 sites, while those with a current extent greater than 1000 ha have average representation of 64.9%. In addition, ecosystems allocated higher weights to compensate for their greater reductions in extent since human settlement generally have higher representation than ecosystems less reduced by human activity. This includes many of the warm forest, non-forest, and wetland ecosystems (Appendix S8). By

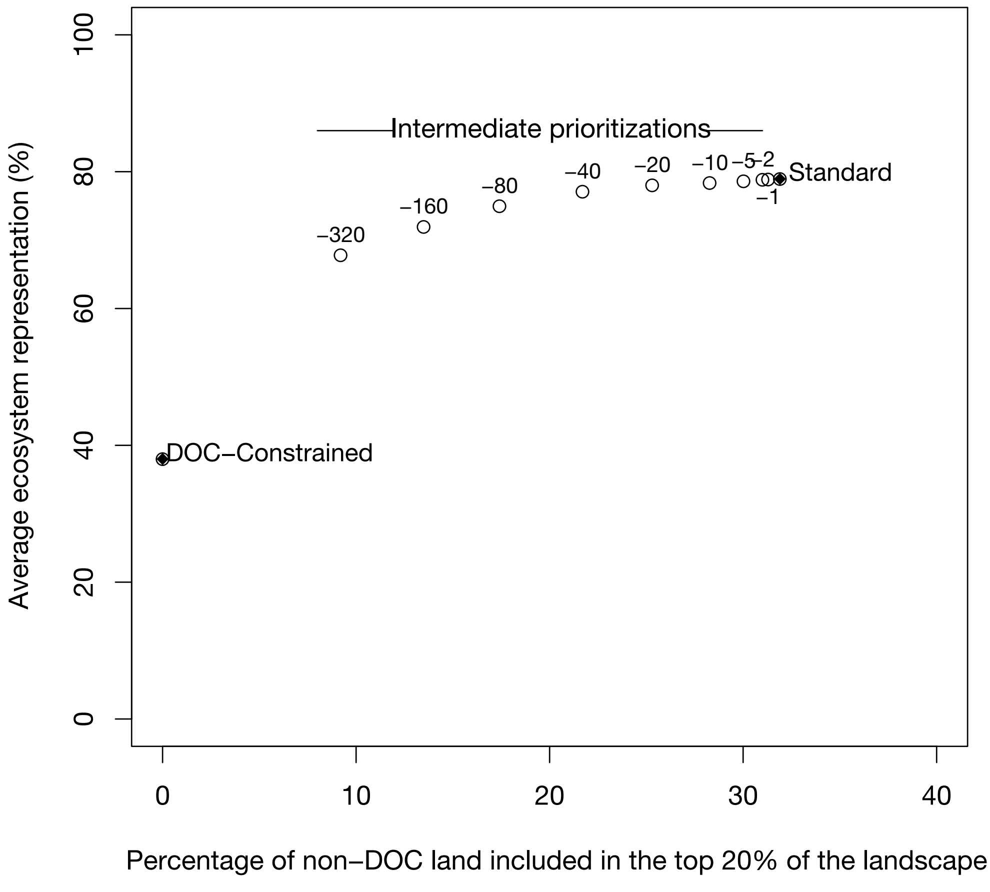

Figure 4. Relationships between the inclusion of non-DOC land in the top-ranked 20% of the indigenous-dominated landscape of the Horizons Region and the average representation of 65 terrestrial ecosystems and two LCDB4 wetland classes from ten prioritisations that varied in their ability to assign high priorities to non-DOC land. No constraint was applied in the standard prioritisation, while all non-DOC land was forced to have lower priorities than DOC administered land in the DOC-constrained prioritisation. Intermediate constraints were applied to the ranking of non-DOC land in the eight intermediate prioritisations, using negative weights as shown on the figure.

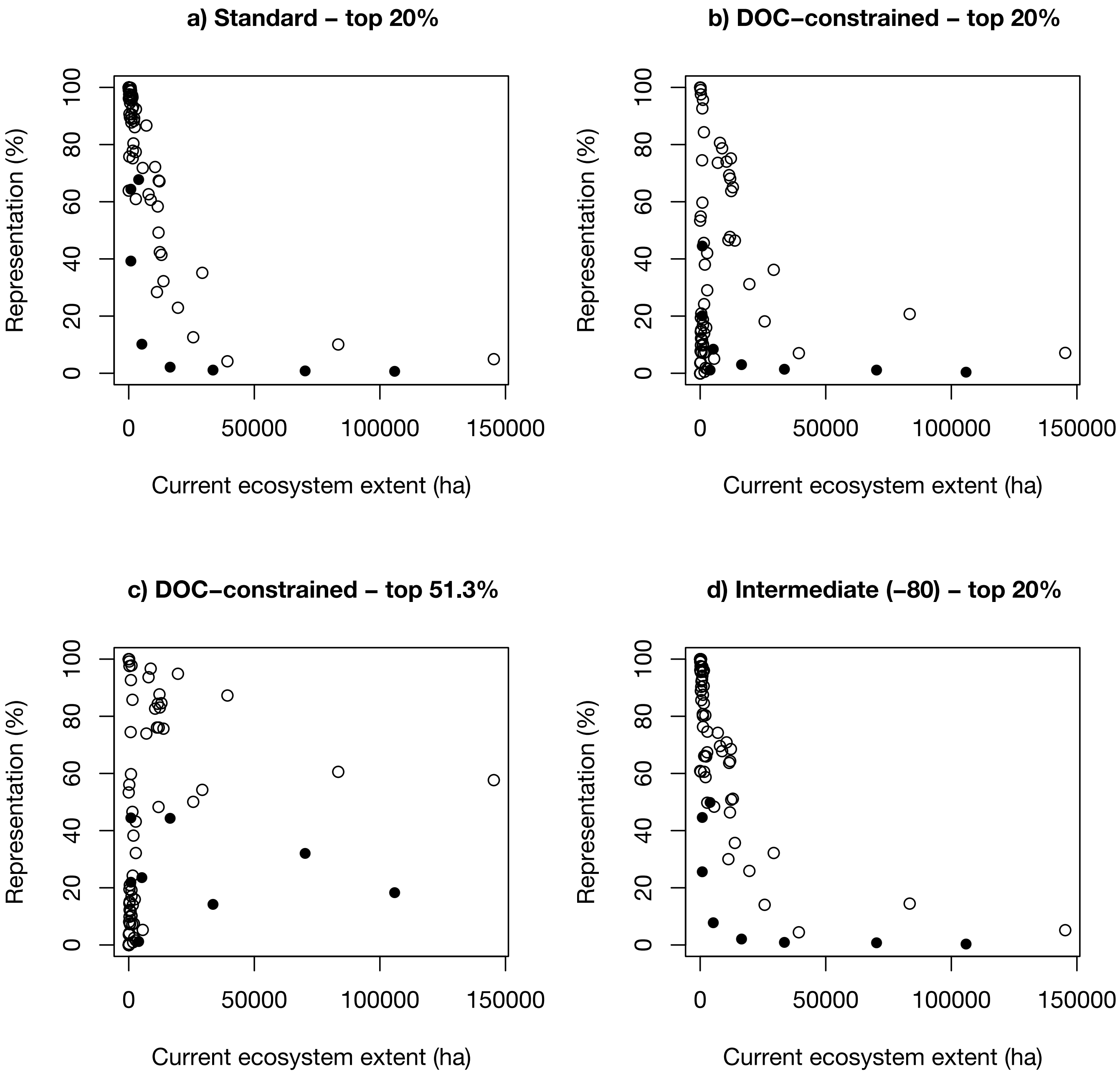

Figure 5. Relationships between current extent of individual ecosystems and their representation in high conservation priority sites selected from land with indigenous-dominated cover in the Horizons Region. Open circles are used to indicate the representation of the ecosystems of Singers & Rogers (2014), and solid circles are used to indicate the representation of predominantly secondary classes from the LCDB4.1 layer. The percentage of the indigenous-dominated landscape selected is shown in the title of each graph.

contrast, secondary ecosystems, which were assigned lower weights to reflect their lower conservation value relative to surviving primary ecosystems, generally have lower average representation (23.4%) (solid circles in Fig. 5a). Areas of secondary ecosystems that are included within the Rank20 sites occur mostly in close proximity to primary ecosystems, reflecting the influence of connectivity settings used in the prioritisation analysis.

DOC-constrained prioritisation

The top-ranked 20% of the indigenous-dominated landscape identified by the DOC-constrained prioritisation (Rank20DOC – Appendix S10) is composed of a much smaller number of individual sites (306), and these have both a greater average extent (494.8 ha, max = 45 504 ha; F-value = 18.02, p = 2.29e-05) and higher average elevation (453 m above sea level; F-value = 7.14, p = 0.0075) than the Rank20 sites. These differences reflect the restriction of these sites to DOC-administered land, which is located predominantly at higher elevations and generally supports less fragmented indigenous cover than non-DOC land.

Ecosystem representation provided by the Rank20DOC sites is both much lower on average (38.7%), and much more variable than that provided by the Rank20 sites (Fig. 5b). On one hand, the Rank20DOC sites provide representation of 20% or more for all four subalpine ecosystems, and the majority of the cold and cool climate forest ecosystems (Appendix S8), these being widespread on DOC-administered land. By contrast, these sites provide inadequate representation for most other ecosystems as indicated by the cluster of points to the lower left of Fig. 5b. These include lowland forests (WF), wetland (WL) and coastal ecosystems (DN and SA), and a number of azonal ecosystems, i.e. ecosystems occurring on gravel- and stone-fields (BR), cliffs (CL), and in temperature inversion basins (TI), their representation averaging just 26.1%—much less than the 96% representation provided for them by the Rank20 sites. This highly skewed representation of ecosystems persists even when all DOC-administered land (51.3% of the landscape) is selected for management (Appendix S8, Fig. 5c).

Using the intermediate prioritisations

Although high average ecosystem representation could be delivered by managing a combination of all DOC-administered land along with the top-ranked 10% of sites from non-DOC land (e.g. priorities in the range 51.3–61.3% from the DOC-constrained prioritisation) (Fig. 5c), this would total nearly 397 000 ha in extent, or 61.3% of all surviving indigenous dominated ecosystems, making it very costly to manage. A much more efficient alternative would be to use one of the intermediate prioritisations, in which penalties of varying degree were applied to the allocation of high priorities to non-DOC land.

For example, the top 20% of the landscape identified by the prioritisation using a tenure layer weight of −80 (Rank20Intermediate80; Appendix S11) comprises a set of 1101 sites with an average extent of 137.4 ha and an average elevation of 353 m. These are distributed across a wide elevation range and provide average ecosystem representation of 75.0% (Fig. 5d), i.e. only a little less than that delivered by the unconstrained Rank20 sites (78.9%). However, in contrast to the Rank20 sites, the Rank20Intermediate80 sites include a much smaller area of non-DOC land (17.4%) than the Rank20 sites (31.9%), these comprising those non-DOC areas that are most critically required to deliver adequate representation for a full range of ecosystems.

Discussion

This study demonstrates how relevant spatial data could be analysed with landscape prioritisation software to develop a systematic, evidence-based approach to achieving a key goal of Outcome 1 of Te Mana o Te Taiao, i.e. “A full range of indigenous ecosystems are protected and secured for future generations” (Department of Conservation 2020). In particular, our coupling of potential and contemporary land cover data with land tenure data allows a robust, quantitative assessment of the conservation status of individual ecosystems in a manner that parallels the threat assessments currently used to advance the conservation of New Zealand’s threatened species (Townsend et al. 2008). In addition, our prioritisations provide a nuanced view of where to best undertake management actions aimed at maintaining the integrity of a full range of indigenous ecosystems in a highly modified landscape, given varying degrees of constraint on the availability of land other than that currently held by the Crown for conservation. This question of “Where to manage?” is critically important, given that New Zealand’s financial and/or human resources for conservation management are insufficient to systematically manage a full range of biodiversity pressures across all surviving terrestrial ecosystems. Addressing this question has the potential to deliver considerably stronger biodiversity outcomes than when management is deployed in an uncoordinated or ad hoc manner, as often occurs at present (Parkes et al. 2017; Willis 2017; Department of Conservation 2020).

Extending our analysis to a national scale would be technically straight forward, once the potential ecosystem mapping, already completed for 14 of New Zealand’s 16 regional councils and unitary authorities, is extended across the Canterbury and West Coast Regions. This would provide a powerful tool for the high-level analysis of national-scale changes in the extent of terrestrial ecosystems and informing the robust identification of priority sites for ecosystem conservation as required to meet New Zealand’s obligations under the CBD. In addition, when coupled with monitoring data, it would facilitate both robust ecosystem-specific assessment of integrity and risk of collapse as proposed for the post-2020 global biodiversity framework (Nicholson et al. 2021), and outcome-based assessment of New Zealand’s progress towards achievement of its high-level ecosystem goals.

At an operational level, such an analysis would allow DOC to develop strongly evidence-based national management strategies explicitly designed to plan and deliver interventions across the full range of ecosystems represented on the lands it administers, while also coordinating actions with those undertaking significant conservation projects on lands of other tenure. Similarly, it would substantially assist regional councils to meet their requirement under the recently announced NPSIB (Ministry for the Environment 2023, App. 5) to develop within ten years “regional biodiversity strategies to promote the landscape-scale restoration of the region’s indigenous biodiversity”. Specific components could include plans for the targeted protection of at-risk ecosystems, guiding the allocation of limited funds to projects protecting high value sites, targeting pest control, informing consenting, directing biodiversity offsetting or compensation, or identifying sites that should not be available for trading (Moilanen et al. 2011a). For some of these applications, sites of < 1 ha could also be included, given that some of these may support ecosystems now surviving only as very small fragments (Wintle et al. 2019). Some of these components were already being explored by the Horizons Region prior to the release of the NPSIB using an earlier version of these analyses (Horizons Regional Council, unpubl. report).

Analysis results could also be used to foster the integration of biodiversity management across administrative boundaries as required to meet Policy 5 of the NPSIB (Ministry for the Environment 2023). For example, results could inform deliberations by regional forums designed to coordinate conservation management among groups including DOC, regional councils, iwi, community organisations and/or individual landowners (e.g. Nelson City Council 2013). While our prioritisations may be challenging for a lay audience, they together provide a nuanced identification of those sites contributing most strongly to the achievement of ecosystem conservation goals in highly modified landscapes. Finally, analysis results could be used to help individual landowners understand the particular contribution that indigenous cover on their land makes to regional biodiversity conservation, or to guide the identification and protection of the highest value remnants by conservation organisations such as the Queen Elizabeth II National Trust.

Given the strategic value of both national and regional-scale analyses for planning and reporting, priority needs to be given to providing appropriate institutional support for the ecosystem mapping layers, including a robust process for peer-review and refinement of the classification, and review and update of its mapped expression (Kelly 1980).

Technical considerations

In technical terms, key elements of our analysis are consistent with (1) the ecosystem-centred approach proposed for New Zealand by Kelly (1980), (2) concepts embodied in the international framework currently used for ecosystem conservation by the IUCN (Keith et al. 2013; Bland et al. 2017), and (3) the ecosystem management framework proposed for use by the CBD (Nicholson et al. 2021) and which is likely to become binding in some manner on New Zealand. The terrestrial ecosystem classification that we used synthesises published descriptions of vegetation organised within a hierarchical environmental framework that combines spatially explicit layers describing temperature, moisture status, landform, and soil gradients (Singers & Rogers 2014) in a manner consistent with the global approach proposed by Keith et al. (2022). While we considered using an alternative, numerically based but currently unmapped classification of New Zealand vegetation types (Wiser et al. 2011; Wiser et al. 2016), the combination of environmental and biotic factors that underpin the classification of Singers and Rogers (2014) conforms more closely to the concepts and typology developed for use by the CBD (Keith et al. 2022). In addition, it can be applied to ecosystems for which no quantitative data are available and was already available for the Horizons Region in an explicitly mapped form.

Ideally our prioritisations would have used a layer identifying the locations of all land currently protected for conservation, including all land administered by DOC or local government agencies, and land protected under covenants administered by the QEII National Trust and/or Ngā Whenua Rāhui. Although Manaaki Whenua - Landcare Research has compiled a layer delineating all such land (Manaaki Whenua Landcare Research 2023), it is not currently available for use because of privacy-related restrictions. Meanwhile, the DOC-administered land layer contains a sufficient proportion of protected land to provide a meaningful demonstration of prioritisations that contrast the ecosystem representation of protected versus non-protected land.

The prioritisation software that we used (Zonation) is readily available and is based on well-established concepts and analytics (Moilanen et al. 2009b; Moilanen et al. 2022). Importantly, Zonation uses a complementarity-based scoring algorithm (Margules et al. 1988; Vane-Wright et al. 1991; Moilanen et al. 2009a) designed to assess the ability of groups of sites to collectively contribute to the representation of a full range of biodiversity features; this includes identification of sites that are irreplaceable because they support features occurring at few or no other sites. Its comparative, landscape-scale rankings considerably extend the information provided by the site-by-site scoring-based procedure (Myers et al. 1987; Walker et al. 2008) used to identify significant natural areas under the NPSIB (Ministry for the Environment 2023, Appendix I). The latter provides only limited information about the relative contribution of individual sites to the representation of a full range of biodiversity on a landscape, risking the loss of those ecosystems whose surviving examples are all in very poor condition (Kirkpatrick 1983). Other Zonation options include: sensitivity analyses to identify sites most critical for achieving full representation of biodiversity features (Moilanen et al. 2022); consideration of the cost of land acquisition or management (Arponen et al. 2010); allowing for predicted changes in the ecological integrity of a site if new management is implemented or existing management halted (Moilanen et al. 2011b); accommodating changes predicted to occur as a result of climate change (Kujala et al. 2013); and including geographic subdivisions within a region to encourage the more even spread of highly ranked sites among different communities of interest (Moilanen & Arponen 2011).

Improving both the range and quality of data used in the analysis would further strengthen its realism and utility. Adding distributional data for threatened species would arguably provide the greatest gains, enabling the identification of sites delivering benefits for both ecosystems and species. However, distribution data for threatened species in New Zealand is relatively disorganised, despite widespread recognition of the need for a comprehensive national storage and retrieval system (Kelly 1980; Department of Conservation 2020) such as Australia's Atlas of Living Australia (Belbin 2021). Weighting more heavily ecosystems known to support large numbers of threatened species would partially address this gap. Improving the identification of small wetlands in the potential ecosystems layer, and replacing our generic ecological condition layer with an expanded set of condition layers describing the specific threats faced by particular groups of ecosystems, e.g. subalpine, forest, wetland and coastal ecosystems, would also deliver further gains. Finally, layers could be used to identify areas having additional values for other purposes, allowing rankings to be elevated for areas valued for uses compatible with conservation such as passive recreation, or reduced to manage conflicts with incompatible uses such as recreational hunting (Moilanen et al. 2011a; Whitehead et al. 2014).

In many respects, the greatest challenges in implementing a more systematic, evidence-based approach to the conservation of New Zealand's indigenous ecosystems as demonstrated here are not so much technical as social and institutional. On a positive note, there is now wide acknowledgement of the need to better coordinate actions amongst New Zealand's multiplicity of conservation actors (Parkes et al. 2017; Willis 2017; Department of Conservation 2020; Leathwick & Byrom 2023; Ministry for the Environment 2023). In addition, increasing recognition is being given to the current bias of much of our conservation management towards protection of a limited set of predator-vulnerable species while introduced ungulate browsers cause ongoing declines in the integrity of our indigenous ecosystems (Leathwick & Byrom 2023). However, we should not underestimate the institutional and social challenges that must be overcome if New Zealand's conservation system is to effectively align its management around both the high-level ecosystem and species goals set out in Te Mana o te Taiao and the objectives and policies set out in the NPSIB. Key aspects include the development of governance structures that bring together a full range of conservation players, the development of more collaborative management among different conservation actors and across land of different tenures, and substantial strengthening of the science capacity needed to support a more systematic approach to the securing and protection of New Zealand's ecosystems. Our hope is that implementing such changes will result in the status of New Zealand's indigenous ecosystems being improved much more substantially in the next four decades than in the four decades that have elapsed since the Kelly (1980) published his visionary work.

Acknowledgements

We gratefully acknowledge comments from Anne-Gaelle Ausseil, Brad Case, Spencer Clubb, Maya Hunt, Fleur Maseyk, Lorraine Cook, John Parkes, and an anonymous reviewer that substantially improved the manuscript. Heini Kujala critically reviewed our analytical approach and suggested several valuable refinements. Comments from the editor provided significant additional insights.

Additional information and declarations

Author contributions: JL performed the analyses and wrote the manuscript draft, both of which were subsequently refined jointly with ALW. NS contributed to editing and refinement of the manuscript, in particular, the sections dealing with the mapping of potential ecosystem cover, and ED contributed to the interpretation and communication of results from a regional council perspective.

Funding: No funding was received in support of this work.

Data and code availability: The potential ecosystems layer for the Horizons Region is held by the Horizons Council, who made it available for this analysis. The contemporary land cover layer (LCDB4.1) was downloaded from https://lris.scinfo.org.nz/layer/48423-lcdb-v41-deprecated-land-cover-database-version-41-mainland-new-zealand/. It has now been superseded by v. 5.0. The distribution of land administered by New Zealand's Department of Conservation is available at https://koordinates.com/layer/754-doc-public-conservation-areas/, and the 8m resolution digital elevation model is available at https://koordinates.com/from/data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/. Version 5 of the Zonation software is available for download from https://zonationteam.github.io/Zonation5/. Code for all prioritisation analyses is provided in Appendix S6. All GIS analyses were performed in QGis v. 3.16, available for download at https://qgis.org/en/site/.

Ethics: No animal ethics approval was required.

Conflicts of interest: The authors declare no conflicts of interest.

References

Arponen A, Cabeza M, Eklund J, Kujala H, Lehtomäki J 2010. Costs of integrating economics and conservation planning. Conservation Biology 24: 1198–1204.

Belbin L, Wallis E, Hobern D, Zerger A 2021. The atlas of living Australia: History, current state and future directions. Biodiversity Data Journal 2021 9:e65023.

Bland LM, Keith DA, Miller RM, Murray NJ, Rodriguez JP 2017. Guidelines for the application of IUCN Red List of Ecosystems categories and criteria. Version 1.1. Gland, International Union for Conservation of Nature. 99 p.

Bland LM, Nicholson E, Miller RM, Andrade A, Carre A, Etter A, Ferrer-Paris JR, Herrera B, Kontula T, Lindgaard A, Pliscof P, Skowno A, Valderrabano M, Zager I, Keith DA 2019. Impacts of the IUCN Red List of Ecosystems on Conservation Policy and Practice. Conservation Letters 12: e12666.

Christensen NL, Bartuska AM, Brown JH, Carpenter S, D'Antonio C, Francis R, Franklin JF, MacMahon JA, Noss RF, Parsons DJ, Peterson CH 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications 6: 665–691.

Cieraad E, Walker S, Price R, Barringer J 2015. An updated assessment of indigenous cover remaining and legal protection in New Zealand's land environments. New Zealand Journal of Ecology 39: 309–315.

Convention on Biological Diversity 2022. Decision adopted by the conference of the parties to the Convention on Biological Diversity. 15/4. Kunming-Montreal Global Biodiversity Framework. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf (Accessed 5 July 2023).

Department of Conservation 2020. Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy 2020. Wellington, Department of Conservation. 72 p.

Department of Conservation 2022. Te Mana o Te Taiao – Aotearoa New Zealand Biodiversity Strategy Implementation Plan. Wellington, Department of Conservation. 52 p.

Department of Conservation 2023. https://www.doc.govt.nz/get-involved/funding/nga-whenua-rahui/nga-whenua-rahui-fund/ (Accessed 28 June 2023).

Di Minin E, Brooks TM, Toivonen T, Butchart SHM, Heikinheimo V, Watson JEM, Burgess ND, Challender DWS, Goettsch B, Jenkins R, Moilanen A 2019. Identifying global centers of unsustainable commercial harvesting of species. Science Advances 5, eaau2879.

Dymond JR, Shepherd JD, Newsome PF, Belliss S 2016. Estimating changes in areas of indigenous vegetation cover in New Zealand from the New Zealand Land Cover Database (LCDB). New Zealand Journal of Ecology 41: 56–64.

Innes J, Fitzgerald N, Binny R, Byrom A, Pech R, Watts C, Gillies C, Maitland M, Campbell-Hunt C, Burns B 2019. New Zealand ecosanctuaries: types, attributes and outcomes. Journal of the Royal Society of New Zealand 49: 370–393.

IPBES 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Díaz S, Settele J, Brondízio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Roy Chowdhury R, Shin YJ, Visseren-Hamakers IJ, Willis KJ, Zayas CN eds. Bonn, IPBES Secretariat. 56 p.

Keith DA, Rodríguez JP, Rodríguez-Clark KM, Nicholson E, Aapala K, Alonso A, Asmussen M, Bachman S, Basset A, Barrow EG, Benson JS, Bishop MJ, Bonifacio R, Brooks TM, Burgman MA, Comer P, Comin FA, Essl F, Faber-Langendoen D, Fairweather PG, Holdaway RJ, Jennings M, Kingsford RT, Lester RE, MacNally R, McCarthy MA, Moat J, Oliveira-Miranda MA, Pisanu P, Poulin B, Regan RJ, Riecken U, Spalding MD, Zambrano-Martínez S 2013. Scientific Foundations for an IUCN Red List of Ecosystems. PLoS ONE 8(5): e62111.

Keith DA, Rodríguez JP, Brooks TM, Burgman MA, Barrow EG, Bland L, Comer PJ, Franklin J, Link J, McCarthy

MA, Miller RM, Murray NJ, Nel J, Nicholson E, Oliveira-Miranda MA, Regan TJ, Rodríguez-Clark KM, Rouget M, Spalding MD 2015. The IUCN Red List of Ecosystems: Motivations, challenges, and applications. Conservation Letters 8: 214–226.
Keith DA, Ferrer-Paris JR, Nicholson E, Bishop MJ, Polidoro BA, Ramirez-Llodra E, Tozer MG, Nel JL, Mac Nally R, Gregr EJ, Watermeyer KE, Essl F, Faber-Langendoen D, Franklin J, Lehmann CER, Etter A, Roux DJ, Stark JS, Rowland JA, Brummitt NA, Fernandez-Arcaya UC, Suthers IM, Wiser SK, Donohue I, Jackson LJ, Pennington RT, Iliffe TM, Gerovasileiou V, Giller P, Robson BJ, Pettorelli N, Andrade A, Lindgaard A, Tahvanainen T, Terauds A, Chadwick MA, Murray NJ, Moat J, Pliscoff P, Zager I, Kingsford RT 2022. A function-based typology for Earth's ecosystems. Nature 610(7932): 513–518.
Kelly GC 1980. Landscape and nature conservation. In: Molloy LF ed. Land alone endures. Discussion Paper No. 3. Wellington, Department of Scientific and Industrial Research. Pp. 63–87.
Kirkpatrick JB 1983. An iterative method for establishing priorities for the selection of nature reserves: An example from Tasmania. Biological Conservation 25: 127–134.
Koordinates 2023. DOC public conservation areas. https://koordinates.com/layer/754-doc-public-conservation-areas/ (Accessed 29 June 2023).
Kujala H, Moilanen A, Araújo MB, Cabeza M 2013. Conservation planning with uncertain climate change projections. PloS ONE 8(2): e53315.
Kujala H, Whitehead AL, Morris WK, Wintle BA 2015. Towards strategic offsetting of biodiversity loss using spatial prioritization concepts and tools: A case study on mining impacts in Australia. Biological Conservation 192: 513–521.
Land Information New Zealand 2012. NZ 8m Digital Elevation Model (2012). Available for download at https://data.linz.govt.nz/layer/51768-nz-8m-digital-elevation-model-2012/ (Accessed 28 June 2023).
Landcare Research 2015. Land Cover Database v4.1 – Land Cover Database version 4.1, Mainland New Zealand. https://lris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/ (Accessed 28 June 2023).
Leathwick JR, Byrom AE 2023. The rise and rise of predator control: a panacea, or a distraction from conservation goals? New Zealand Journal of Ecology 47(1): 3515.
Leathwick JR, Moilanen A, Francis M, Elith J, Taylor P, Julian K, Hastie T, Duffy C 2008. Novel methods for the design and evaluation of marine protected areas in offshore waters. Conservation Letters 1: 91–102.
Lehtomäki J, Tomppo E, Kuokkanen P, Hanski I, Moilanen A 2009. Applying spatial conservation prioritization software and high-resolution GIS data to a national-scale study in forest conservation. Forest Ecology and Management 258: 2439–2449.
Lehtomäki J, Kusumoto B, Shiono T, Tanaka T, Kubota Y, Moilanen A 2019. Spatial conservation prioritization for the East Asian islands: a balanced representation of multi-taxon biogeography in a protected area network. Diversity and Distributions 25: 414–429.
Manaaki Whenua Landcare Research 2023. Protected areas network - New Zealand (PAN-NZ) https://oldwww.landcareresearch.co.nz/resources/maps-satellites/pannz (Accessed 25 February 2023).
Margules CR, Pressey RL 2000. Systematic conservation planning. Nature 405: 243–253.
Margules CR, Nicholls AO, Pressey RL 1988. Selecting networks of reserves to maximise biological diversity. Biological Conservation 43: 63–76.
Ministry for the Environment 2023. National policy statement for indigenous biodiversity. Wellington, Ministry for the Environment. 48 p.
McEwen WM 1987. Ecological regions and districts of New Zealand. Third revised edition in four 1:500,000 maps. Publication No. 5, New Zealand Biological Resource Centre. Wellington, Department of Conservation. 139 p.
Moilanen A, Arponen A 2011. Administrative regions in conservation: Balancing local priorities with regional to global preferences in spatial planning. Biological Conservation 144: 1719–1725.
Moilanen A, Franco AMA, Regan IE, Fox R, Wintle B, Thomas CD 2005. Prioritising multiple-use landscapes for conservation: methods for large multi-species planning problems. Proceedings of the Royal Society London B 272: 1885–1891.
Moilanen A, Possingham HP, Polasky S 2009a. A mathematical classification of conservation prioritization problems. In: Moilanen A, Wilson KA, Possingham HP eds. Spatial conservation prioritization: Quantitative methods and computational tools. Oxford, Oxford University Press. Pp. 28–42.
Moilanen A, Wilson KA, Possingham HP eds. 2009b. Spatial conservation prioritization: Quantitative methods and computational tools. Oxford, Oxford University Press. 304 p.
Moilanen A, Anderson BJ, Eigenbrod F, Heinemeyer A, Roy DB, Gillings S, Armsworth PR, Gaston KJ, Thomas C 2011a. Balancing alternative land uses in conservation prioritization. Ecological Applications 21: 1419–1426.
Moilanen A, Leathwick JR, Quinn JM 2011b. Spatial prioritization of conservation management. Conservation Letters 4: 383–393.
Moilanen A, Kohonen I, Lehtinen P, Jalkanen J, Virtanen E, Kujala H 2022. Zonation 5 V 1.0 user manual. Available for download from https://zonationteam.github.io/Zonation5/ (Accessed 28 June 2023).
Myers SC, Park GN, Overmars FB compilers 1987. A guidebook for the rapid ecological survey of natural areas. New Zealand Biological Resources Centre Publication No. 6. Wellington, Department of Conservation. 113 p.
Nelson City Council 2013. Nelson biodiversity forum. http://www.nelson.govt.nz/environment/nelson-nature/community/partnerships/nelson-biodiversity-forum/ (Accessed 3 July 2023).
Nicholson E, Watermeyer K, Rowland J, Sato C, Stevenson S, Andrade A, Brooks TM, Burgess ND, Cheng S-T, Grantham HS, Hill SL, Keith DA, Maron M, Metzke D, Murray NJ, Nelson CR, Obura D, Plumptre A, Skowno AL, Watson JEM 2021. Scientific foundations for an ecosystem goal, milestones and indicators for the post-2020 global biodiversity framework. Nature Ecology & Evolution. 5. 1338–1349.
Noss RF 1996. Ecosystems as conservation targets. Trends in Ecology and Evolution 11: 351.
Park GN 2000. New Zealand as ecosystems: the ecosystem concept as a tool for environmental management and conservation. Wellington, Department of Conservation. 97 p.

Parkes JP, Nugent G, Forsyth DM, Byrom AE, Pech RP, Warburton B, Choquenot D 2017. Past, present and two potential futures for managing New Zealand's mammalian pests. New Zealand Journal of Ecology 41: 151–161.

Raukūmara Pae Maunga 2023. Raukūmara pae maunga https://www.raukumara.org.nz/ (Accessed 27 June 2023).

Ravine DA 1995. Manawatu Plains ecological district: survey report for the Protected Natural Areas Programme. Protected Natural Areas Programme Report No 33. Wanganui, Department of Conservation. 352 p.

Singers, NJD, Lawrence CCE 2018. A potential ecosystem map of the Manawatu Wanganui Region: Explanatory information to accompany the map (2018). NSES Report 34. Turangi, Nicholas Singers Ecological Solutions. 25 p.

Singers NJD, Rogers GM 2014. A classification of New Zealand's terrestrial ecosystems. Science for Conservation 325. Wellington, Department of Conservation. 87 p.

Stuff 2021. Significant Natural Areas (SNAs) in the Far North: What you need to know. https://www.stuff.co.nz/national/politics/local-democracy-reporting/300330331/significant-natural-areas-snas-in-the-far-north-what-you-need-to-know/ (Accessed 27 June 2023).

Te Ao Māori News 2021. Iwi gain co-governance of Taranaki maunga. https://www.teaomaori.news/iwi-gain-co-governance-taranaki-maunga/ (Accessed 27 June 2023).

Towns DR, Daugherty CH, Broome K, Timmins S, Clout M 2019. The thirty-year conservation revolution in New Zealand: an introduction. Journal of the Royal Society of New Zealand 49: 243–258.

Townsend AJ, de Lange PJ, Duffy CAJ, Miskelly CM, Molloy J, Norton DA 2008. New Zealand Threat Classification System manual. Wellington, Department of Conservation. 36 p.

United Nations 1992. Convention on Biological Diversity. https://www.cbd.int/convention/text/ (Accessed 5 June 2023).

Vane-Wright RI, Humphries CJ, Williams PH 1991. What to protect?—Systematics and the agony of choice. Biological Conservation 55: 235–254.

Walker S, Brower AL, Clarkson BD, Lee WG, Myers SC, Shaw WB, Stephens RTT 2008. Halting indigenous biodiversity decline: ambiguity, equity, and outcomes in RMA assessment of significance. New Zealand Journal of Ecology 32: 225–237.

Whitehead AL, Kujala H, Ives CD, Gordon A, Lentini PE, Nicholson E, Wintle B, Raymond CM 2014. Integrating biological and social values when prioritizing places for biodiversity conservation. Conservation Biology 28: 992–1003.

Willis G 2017. Addressing New Zealand's biodiversity challenge. A Regional Council thinkpiece on the future of biodiversity management in New Zealand. Pukekohe, Enfocus. 88 p.

Wintle BA, Kujala H, Whitehead AL, Cameron A, Veloz S, Kukkala A, Moilanen A, Gordon A, Lentini PE, Cadenhead NCR, Bekessy SA 2019. Global synthesis of conservation studies reveals the importance of small habitat patches for biodiversity. Proceedings of the National Academy of Sciences 116: 909–914.

Wiser SK, Hurst JM, Allen RB, Wright EF 2011. New Zealand's forest and shrubland communities: a classification based on a nationally representative plot network. Applied Vegetation Science 14: 506–523.

Wiser SK, Thomson FJ, De Cáceres M 2016. Expanding an existing classification of New Zealand vegetation to include non-forested vegetation. New Zealand Journal of Ecology 40: 160–178.

Wyse SV, Wilmshurt JM, Burns BR, Perry GLW 2018. New Zealand forest dynamics: a review of past and present vegetation responses to disturbance, and development of conceptual forest models. New Zealand Journal of Ecology 42: 87–106.

Received: 2 March 2023; accepted 26 October 2023
Editorial board member: Jason Tylianakis

Supplementary material

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

Appendix S1. Potential ecosystem cover for the Horizons Region, mapped using the ecosystem classification of Singers and Rogers (2014); the current (reduced) extent of indigenous-dominated cover is indicated by diagonally hatched polygons.

Appendix S2. Potential ecosystems for the Horizons Region.

Appendix S3. Land Cover Database classes used in the analysis.

Appendix S4. Input data for the prioritisation analyses.

Appendix S5. Command and setup files for the prioritisation analyses.

Appendix S6. Data files for the prioritisation analyses.

Appendix S7. Estimated condition of surviving indigenous-dominated terrestrial ecosystems for the Horizons Region.

Appendix S8. Potential and current geographic extents of terrestrial ecosystems of the Horizons Region and their representation in various subsets of the indigenous-dominated landscape selected using spatial prioritisation.

Appendix S9. Results from the 'Standard' prioritisation of surviving indigenous ecosystems of the Horizons Region.

Appendix S10. Results from the 'DOC-constrained' prioritisation of surviving indigenous ecosystems of the Horizons Region.

Appendix S11. Results from the 'Intermediate (-80)' prioritisation of surviving indigenous ecosystems of the Horizons Region.

The New Zealand Journal of Ecology provides supporting information supplied by the authors where this may assist readers. Such materials are peer-reviewed and copy-edited but any issues relating to this information (other than missing files) should be addressed to the authors.