

SHORT COMMUNICATION

An updated assessment of indigenous cover remaining and legal protection in New Zealand's land environments

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Abstract: It is important, yet hard, to assess how much of the full range of New Zealand's terrestrial natural ecosystems and biodiversity remains, and is protected from loss. Updated spatial datasets of land cover and protection allow a nation-wide consistent assessment of the loss and protection context of indigenous biodiversity components. A revision of the 'Threatened Environment Classification' is presented using a combination analysis of the national land cover database based on satellite imagery (2012), an updated national spatial database of protected areas (2012), and an abiotic classification of New Zealand's land environments. The data suggest there is more protection in environments with historically high levels of indigenous vegetation and protection, while a number of lowland and montane environments have less indigenous vegetation and protection than was previously estimated. In conjunction with field surveys, the threatened environment classification can help identify places that are priorities for formal protection against clearance and/or incompatible land uses, and for ecological restoration.

Keywords: land cover; land cover database; legal protection; loss of indigenous habitat; New Zealand; threatened environment classification

Introduction

A goal of the New Zealand Biodiversity Strategy is to 'halt the decline in New Zealand's indigenous biodiversity, and to maintain and restore a full range of remaining natural habitats and ecosystems to a healthy functioning state' (DOC & MfE 2000). Meeting this goal requires knowledge of the full range of natural ecosystems and their biodiversity components, but conducting a national assessment is notoriously hard (Lee et al. 2005) and hampered by data availability and access, and inter-agency agreement and cooperation. Indicators such as loss of extent and the protection from further loss can be more readily assessed by combining spatial data delineating land cover types, legal protection for terrestrial biodiversity and New Zealand's land environments. This combination analysis was first summarised by Walker et al. (2006) in a six-category 'Threatened Environment Classification' (TEC).

The threatened environment classification is most appropriately used to provide information on the context of loss and protection of indigenous biodiversity components identified on the ground. In conjunction with site surveys, it enables resource managers to identify places that are priorities for formal protection against clearance and/or incompatible land uses, and for ecological restoration to restore linkages, buffers and lost species. The classification also provides a standardised national framework for assessment of biodiversity representativeness and protection. Remaining indigenous vegetation in the first two categories of the classification (land environments with less than 20% indigenous cover remaining; Table 1) has been identified in national conservation policy as a national priority for biodiversity protection on private

land (MfE 2007). These national priorities have been adopted into environmental plans and policy documents and are being implemented by a variety of organisations.

A revision of the threatened environment classification has been made possible by release of the updated national land cover database, 'LCDB4' (Pairman 2014). This database includes revised classifications of satellite imagery from 1996/97, 2001/02 and 2008/09, and a new classification derived from 2011/12 imagery (hereafter '1997', '2002', '2009' and '2012', respectively). An updated national spatial database of protected areas in 2012 was assembled (Cieraad et al. 2014, adapted from Rutledge 2013, unpubl.) concurrent with the most recent satellite imagery. Here, we combine these databases with New Zealand's land environments, and we present and discuss the updated threatened environment classification ('TEC 2012').

Methods

Our analyses follow Walker et al. (2006) and combine national spatial datasets of land environments, land cover and natural heritage protection. We used Land Environments of New Zealand (LENZ) level IV as a surrogate for the potential full range of terrestrial ecosystems and biodiversity. LENZ classifies New Zealand's terrestrial environments on the basis of abiotic variables (climate, soil and landform; Leathwick et al. 2003a,b) that are major drivers of spatial patterns in most living organisms. We assume that different environments potentially supported an assemblage of ecosystems, habitats and species in the past that differed in some respects from those in other environments. The abiotic variables in LENZ

are also good predictors of the patterns of human land use (Leathwick et al. 2003b), and therefore the risk to indigenous biodiversity from that use.

The threatened environment classification uses the area of indigenous vegetation cover within a land environment as a surrogate for the area on which components of New Zealand's indigenous biodiversity still remain. These biodiversity components include indigenous ecosystems, habitats, and communities, and the indigenous species, subspecies, varieties and genetic diversity that they support. We assigned the 33 cover classes of LCDB4 to either an indigenous (20) or exotic (13) category (online Appendix S1; Walker et al. 2006), acknowledging that a binary split is an oversimplification (e.g. see Brockerhoff et al. 2008; Cieraad 2008; Walker et al. 2008), but recognising that data are not yet available to more accurately quantify indigenous flora (or other components of biodiversity) remaining in land cover classes across the country. Areas classified as the indigenous cover classes River and Lakeshore Gravel and Rock, Landslide, Alpine Gravel and Rock, Lake and Pond, River, or Estuarine Open Water but classified in an exotic cover class in a former LCDB version were not considered to be 'indigenous cover', because it is uncertain whether these disturbed or inundated cover types will succeed to indigenous vegetation over time (no instance of such succession was observed between the different time steps available in LCDB4).

In the threatened environment classification, the percentage of each land environment covered by legal protection for the purpose of natural heritage protection is used as a surrogate for the relative vulnerability of the remaining indigenous biota to pressures such as land clearance or incompatible land uses. Our dataset of areas legally protected for natural heritage in 2012 included land managed or administered by the Department of Conservation (DOC), and covenants administered by DOC, Ngā Whenua Rāhui and the Queen Elizabeth II National Trust. In addition, we compiled data from a number of regional and district councils. To the best of our

ability, we identified and included only those areas protected and managed with the primary goal of natural heritage and/or indigenous biodiversity conservation. Limitations and methods relating to the compilation and sorting of protected area data are described by Rutledge et al. (2004; see also Appendix S2).

We converted the spatial datasets described above to 25-m GIS raster files and re-projected these to the New Zealand map grid (NZMG). Reasons for and effects of rasterising and re-projection are discussed in Appendix S3. Datasets were combined in GIS using the KEAline program (Robbie Price, Landcare Research, unpubl.) and output tables were exported into R (Version 3.0; R Core Team 2014) for further analyses. We mapped the net changes in percent of land under indigenous cover between 2002 and 2012 (as depicted in LCDB4) and in legal protection between 2004 and 2012 (as recorded in our protected area databases) by land environment. We then used estimated percentages of land under indigenous cover and legal protection in 2012 to group the 500 Level IV land environments into six categories, following Walker et al. (2006) (Table 1).

Differences between our updated classification (TEC 2012) and that described by Walker et al. (2006) reflect (1) corrections (provided in LCDB4; Pairman 2014) to the 2002 land cover data published by Terralink (2004); (2) changes in land cover between 2002 and 2012 as identified in LCDB4; (3) changes in our protected area database between 2004 and 2012; and (4) error in all three. We tabulated and mapped two types of transitions between TEC categories: those arising from correcting the Terralink (2004) land cover alone, and those arising from land cover changes depicted in LCDB4 and in protected land represented in our two protected area databases. We note that changes between TEC categories can result from small changes in indigenous cover or protection if the environment is already close to a classification threshold, while substantial real changes in indigenous cover or protection extent may not change a category when an environment is originally far from a threshold.

Table 1. The six categories (Cat.) of the threatened environment classification in 2012, showing the number of environments and areas of all land, indigenous cover, protected land, and indigenous cover that is not protected (rounded to the nearest 10 ha) in each. Parentheses enclose estimates reported by Walker et al. (2006), and we note that differences reflect changes in the membership of the categories as well as changes in indigenous cover and/or protection and/or the availability of better quality data. Land areas are summed across all 25-m terrestrial pixels of the Land Environments of New Zealand (LENZ) classification, excluding 'Null' environments.

Cat.	Criteria	Number of environments	Total land area (ha)	Indigenous cover remaining (ha)	Area of protected land (ha)	Indigenous cover not protected (ha)
1	<10% indigenous cover left	158 (158)	5,882,040 (5,888,290)	215,680 (220,860)	53,800 (60,750)	186,220 (184,920)
2	10–20% indigenous cover left	72 (74)	2,650,460 (2,323,070)	402,680 (344,890)	126,110 (72,390)	297,200 (289,100)
3	20–30% indigenous cover left	54 (52)	2,474,140 (2,788,940)	606,940 (674,220)	230,040 (249,430)	418,250 (468,250)
4	>30% left and <10% protected	28 (33)	1,527,990 (1,771,690)	587,120 (754,430)	93,020 (97,160)	509,000 (673,180)
5	>30% left and 10–20% protected	21 (23)	1,252,640 (1,511,700)	502,360 (809,690)	193,860 (256,520)	323,570 (571,600)
6	>30% left and >20% protected	167 (160)	12,218,510 (11,716,990)	10,243,140 (9,828,130)	7,809,870 (7,362,320)	2,576,970 (2,608,530)

Results

Indigenous cover, protection and threatened environments in 2012

Estimates of the total area of indigenous cover remaining across New Zealand have decreased in successive land cover databases (Fig. 1a). LCDB4 data indicate that less than half (48.3% or 12,558,900 ha) of New Zealand’s land area (as defined by LENZ pixels) remained under some form of indigenous cover in 2012; 24,370 ha and 60,560 ha less than in 2008 and 2002, respectively. In the North Island, less indigenous cover is recorded in environments in western inland Taranaki and the Waikato, Northland, and Hawke’s Bay and more in East Cape, Bay of Plenty, and Wellington regions than in 2002 (Fig. 1a). In the South Island, less indigenous cover is recorded in low- to mid-elevation environments in Nelson and North Westland, and in inland Canterbury, Otago and Southland. In contrast, estimates of indigenous cover for some environments on Banks Peninsula, in inland Marlborough, coastal north-west Nelson, and south Canterbury have been revised upwards.

Our 2012 protected area database suggests just over one-third (8.5 million ha, or 35.3%) of New Zealand’s land is legally protected for natural heritage purposes. This is 4.2% more than the 31.1% of terrestrial New Zealand included in the database of protected areas reflecting the 2004 status (Walker et al. 2006). More protection is now recorded in high-elevation environments of the main South Island high country mountain ranges and foothills (east of the main divide of the Southern

Alps), and in some environments in north-west Nelson, the central North Island axial ranges, the Wairarapa, inland Taranaki, Coromandel Peninsula, and Northland (Fig. 1b). However, less protection is now recorded in environments in east and central parts of the North Island and on the South Island west coast, mainly at lower elevations (Fig. 1b).

The updated threatened environment classification (TEC 2012) is mapped in Fig. 2a. Figure 2b and c compare the updated classification with the version published in Walker et al. (2006). Figure 2b shows transitions to categories of the updated classification derived from land cover changes between 2002 and 2012 depicted in LCDB4 and in protected land represented in our two protected area databases (2004 and 2012). Four environments crossed the threshold from Category 2 to Category 1, two environments crossed the threshold from Category 4 to Category 3, and two crossed from Category 2 to Category 3 due to changes recorded in indigenous cover in LCDB4. Category transitions among Categories 4, 5 and 6 reflect either an increase in the estimated areas of protected land within environments (13 transitions) or a decrease (4 transitions).

Additional transitions arising from corrections to the interpretation of 2002 land cover (released as part of LCDB4) are mapped and tabulated in Fig. 2c. As a result of these corrections, one environment crossed the threshold from Category 2 to Category 1 (<10% cover remaining), two crossed the threshold from Category 3 to Category 2 (<20% cover remaining), and nine environments crossed thresholds to less threatened categories.

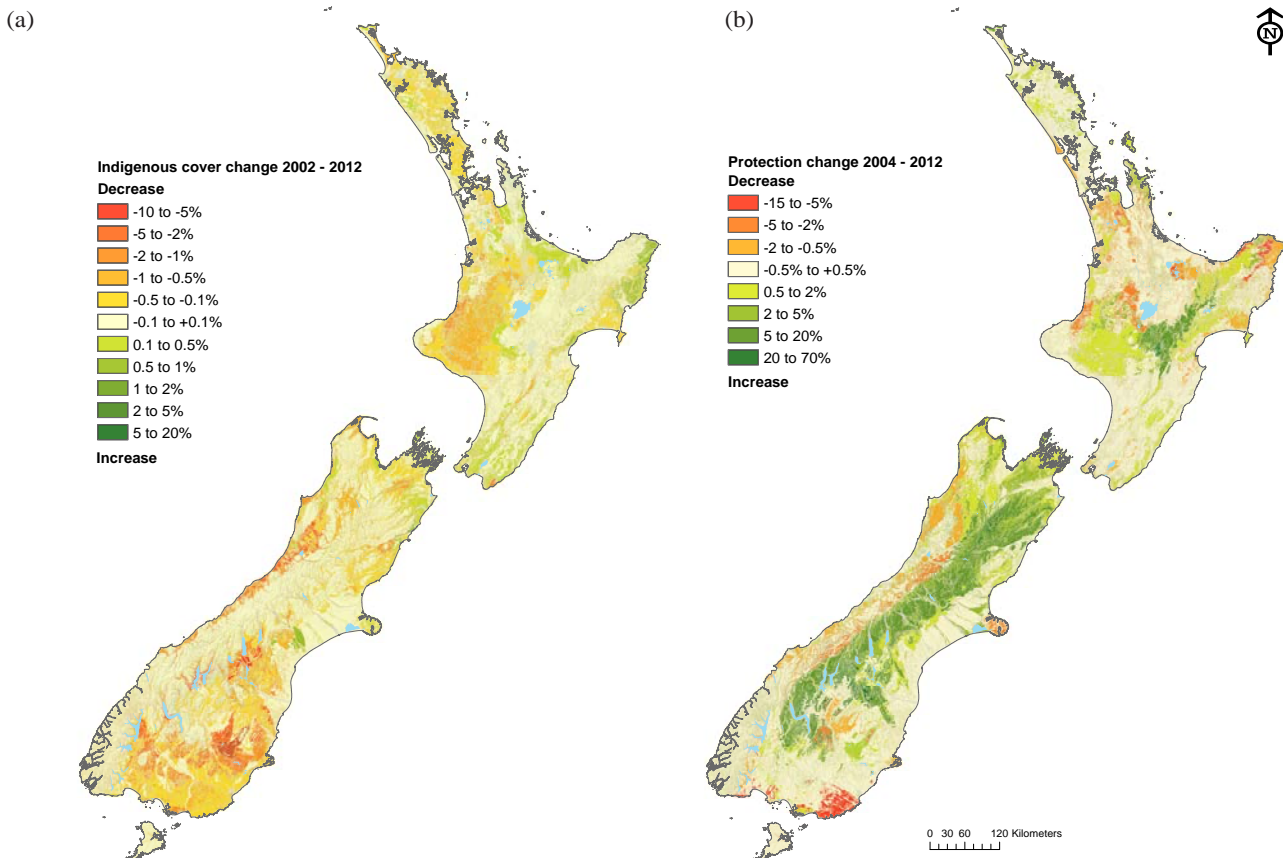
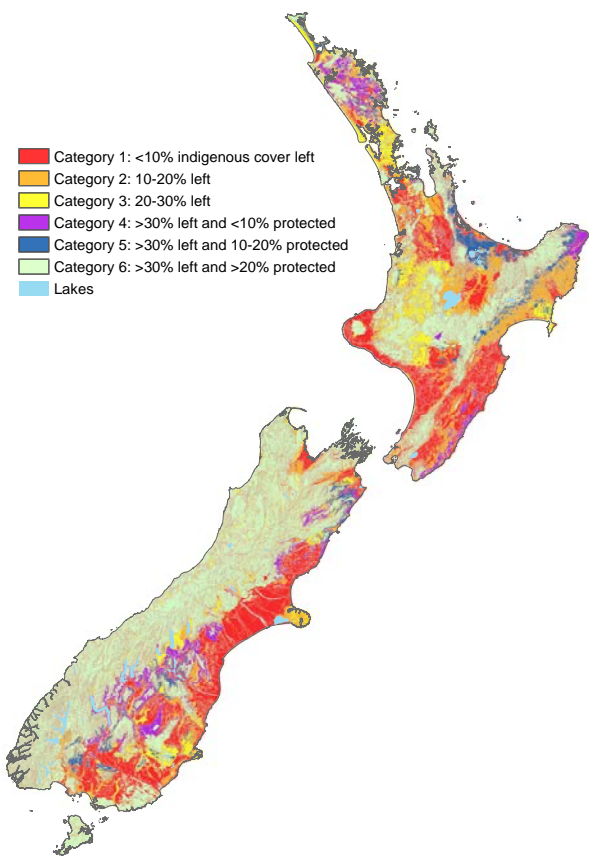
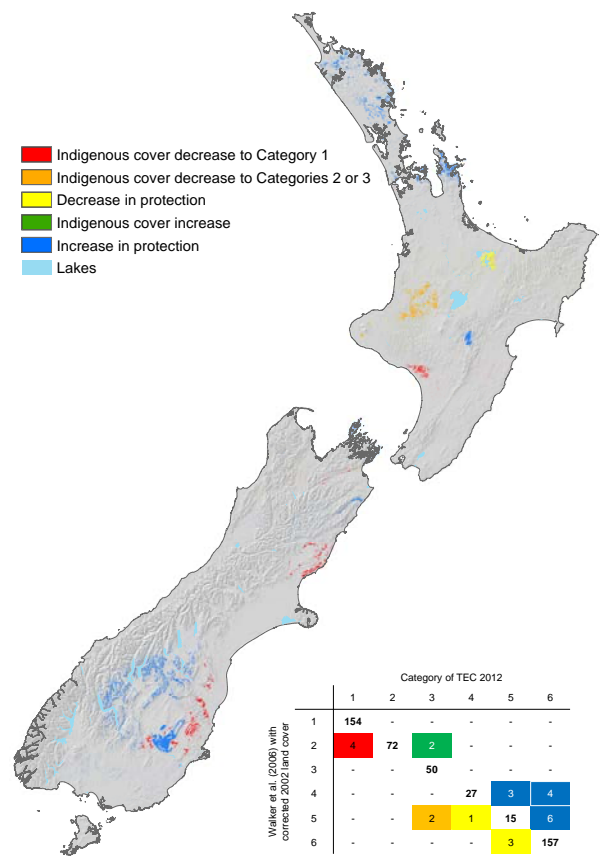


Figure 1. Change in the percent of LENZ Level IV environments (a) in indigenous cover between 2002 and 2012 (LCDB4) and (b) under legal protection between 2004 (Walker et al. 2006) and 2012 (this paper).

(a) The updated threatened environment classification ('TEC 2012')



(b) 2002–2012 category changes, from a baseline of corrected 2002 land cover



(c) Category changes arising from corrections to 2002 land cover

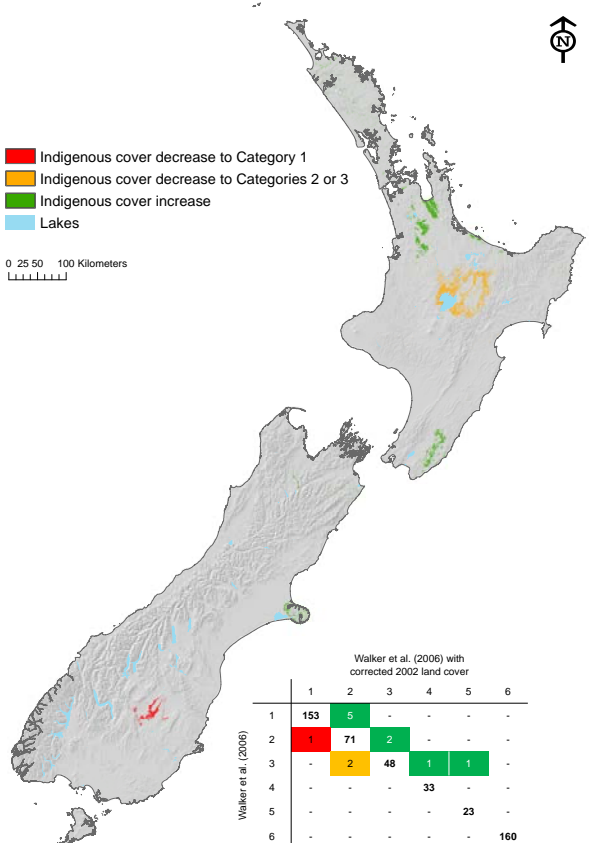


Figure 2. (a) The new threatened environment classification ('TEC 2012'), using 2012 land cover from LCDB4, and protected areas in 2012; (b) category changes from a baseline of corrected 2002 land cover (published with the release of LCDB4) and 2004 protection data to the status in 2012; (c) changes from the original classification (Walker et al. 2006) arising from the corrections to 2002 land cover published with release of LCDB4. In the two-way tables shown on (b) and (c), numbers in the top-left to lower-right diagonal cells (in bold) represent environments that remained in the same threat category. Numbers below that diagonal represent environments that changed to a more threatened category, those above the diagonal represent environments that changed to a less threatened category, and colours indicate types of changes shown in the map legends.

According to our databases, in 2012, 158 Level IV environments retained less than 10% of their indigenous cover, and 72 retained between 10% and 20% indigenous cover (Table 1). Together these 230 ‘National Priority 1’ environments (Categories 1 and 2 of the TEC) represent 32.5% New Zealand’s land area, and support 4.9% of New Zealand’s remaining indigenous cover, 11.2% of remaining indigenous cover that is not legally protected, and 2.0% of all protected land. Although there are two fewer National Priority environments than estimated by Walker et al. (2006), the areas of land, indigenous cover, protected land and unprotected indigenous cover estimated to remain in Categories 1 and 2 of the TEC are now greater. The chief reason for these increases is the reassignment of a particularly large land environment (the 335 000-ha F7.1b, north of Lake Taupo in the North Island) from Category 3 of the TEC to Category 2 following corrections to the 2002 land cover database (Fig. 2c).

In the updated threatened environment classification (2012), there are 167 Category 6 environments, which represent

47.0% New Zealand’s land area (Table 1). They are estimated to support 81.6% of New Zealand’s remaining indigenous cover, 59.8% of remaining indigenous cover that is not legally protected, and 91.8% of all protected land. These areas of land, indigenous cover and protected land are greater than estimated by Walker et al. (2006), and the area of unprotected indigenous cover is smaller. These changes principally reflect the transfer of Crown pastoral leasehold to public conservation land in less-reduced and better protected environments, especially in the South Island high country (Fig. 1b).

Table 2 summarises the area of indigenous cover types estimated to remain in each category of the updated threatened environment classification. Of the indigenous or mixed indigenous–exotic cover classes cover remaining in Category 1 and 2 environments, the most extensive is Low Producing Grassland (395,900 ha), followed by Mānuka and/or Kānuka (189,900 ha), Indigenous Forest (170,000 ha), and Broadleaved Indigenous Hardwoods (100,900 ha). In Category 6 environments, Indigenous Forest is the most extensive cover

Table 2. Area (ha, rounded to the nearest 10 ha) of remaining indigenous and mixed indigenous–exotic cover classes in the six categories of the threatened environment classification (‘TEC 2012’). Low Producing Grassland and Mixed Exotic Shrubland (lowest rows in the table) are treated as non-indigenous cover classes in our analyses. Values in parentheses show the percent of that remaining cover that is protected in each category (e.g. 24.7% of the remaining Indigenous Forest class in Category 1 environments is protected).

Area, ha (% protected)		Category of the threatened environment classification (‘TEC 2012’)					
		‘Threatened environments’ (Categories 1 to 5)					
		1. <10% indigenous cover left	2. 10–20% left	3. 20–30% left	4. >30% left and <10% protected	5. >30% left and 10–20% protected	6. >30% left and >20% protected
Indigenous Forest	6,368,140 (80.3)	56,800 (24.7)	113,210 (48.1)	259,190 (46.2)	111,530 (37.1)	223,580 (52.0)	5,603,830 (85.1)
Tall-Tussock Grassland	2,331,800 (52.4)	10,970 (15.8)	13,520 (10.1)	39,920 (19.4)	154,900 (7.4)	93,180 (21.1)	2,019,310 (58.4)
Mānuka and or Kānuka	1,169,320 (31.1)	50,260 (9.7)	139,610 (15.0)	150,800 (19.5)	142,100 (9.3)	95,470 (25.7)	591,070 (45.8)
Gravel and Rock	754,820 (71.4)	9,570 (4.4)	7,520 (6.0)	12,270 (18.3)	14,290 (8.9)	6,730 (21.7)	704,460 (75.7)
Broadleaved Indigenous Hardwoods	581,850 (35.4)	34,770 (7.9)	66,100 (72.1)	63,890 (18.5)	39,410 (11.5)	44,650 (25.4)	333,040 (49.5)
Sub Alpine Shrubland	423,800 (81.1)	50 (20)	290 (72.4)	330 (21.2)	5,320 (10.2)	1,600 (53.1)	416,220 (82.2)
Alpine Grass/ Herbfield	228,320 (82.8)	0 (0)	0 (0)	10 (0)	360 (25.0)	300 (40.0)	227,640 (83.0)
Depleted Grassland	171,980 (14.8)	3,910 (3.6)	12,340 (4.6)	21,030 (5.2)	64,550 (3.9)	14,230 (4.4)	55,920 (36.8)
Herbaceous Freshwater Vegetation	121,430 (50.4)	13,990 (23.4)	22,890 (58.2)	9,300 (38.8)	4,850 (9.5)	4,570 (28.9)	65,830 (59.6)
Matagouri or Grey Scrub	107,450 (11.5)	10,710 (1.8)	8,420 (3.2)	18,410 (9.4)	32,220 (5.0)	11,040 (13.9)	107,450 (26.4)
Other Indigenous	299,990 (56.9)	25,510 (8.0)	18,840 (17.1)	31,810 (35.2)	17,570 (6.5)	7,040 (14.3)	199,190 (76.3)
Total Indigenous	12,558,900 (65.7)	216,540 (13.6)	402,740 (26.2)	606,960 (31.1)	587,100 (13.3)	502,390 (35.6)	10,243,160 (74.8)
Low Producing Grassland	1,628,100 (8.6)	209,440 (2.8)	186,520 (2.4)	290,540 (8.3)	395,740 (2.5)	114,980 (6.8)	430,880 (20.3)
Mixed Exotic Shrubland	48,310 (12.2)	5,650 (5.5)	9,510 (6.6)	8,340 (9.0)	15,080 (8.2)	2,480 (8.5)	7,250 (38.1)

class (5,603,800 ha), followed by Tall Tussock Grassland (2,019,300 ha), Gravel and Rock (704,500 ha), and Mānuka and/or Kānuka (591,100 ha).

The updated threatened environment classification can be freely accessed for viewing and downloading on <http://www.ourenvironment.scinfo.org.nz>, and more information, including a user guide (Walker et al. 2015), is available from www.landcareresearch.co.nz/resources/maps-satellites/threatened-environment-classification.

Discussion

Overall our results describe a pattern of past loss and poor protection for indigenous cover across New Zealand similar to that described by Walker et al. (2006). New Zealand's lowest, flattest, warmest and driest environments have lost high proportions of their indigenous cover and what remains is poorly protected, while the highest, steepest, coolest, and wettest environments have been less reduced by human land use and are much better protected. However, our results suggest that the status of New Zealand's land environments in 2012 was more polarised than indicated by previous analyses (Walker et al. 2006). The data suggest that environments that were previously identified as having relatively high proportions of indigenous vegetation remaining and high protection levels are now better protected than a decade earlier. In contrast, a number of montane and lowland environments that previously had low amounts of indigenous vegetation and little legal protection had even less indigenous vegetation and legal protection for natural heritage in 2012.

Walker et al. (2006) suggested that date-stamped updates of national land cover and protection databases would be needed to allow the retention and legal protection of natural habitats across New Zealand's land environments to be tracked over time. There have been some steps towards this, but the data still fall short of providing reliable estimates of change on the ground. Differences between the previous and current updated threatened environment classification therefore reflect a combination of real 'on-the-ground changes' in indigenous cover and/or protection, and changes in the availability and quality of data and their interpretation, which cannot be readily distinguished. For this reason we caution against interpreting changes in indigenous cover between LCDB versions, changes in protection estimates, and category-transitions between revisions of the TEC, as a direct indication of changes that have recently occurred across New Zealand on the ground. Rather, the TEC and its underlying data should be regarded as a high-level, broad-scale overview of the context of loss and protection of habitats for components of indigenous biodiversity within land environments across New Zealand that is based on the best available, but imperfect, national datasets.

Ongoing improvements to the land cover database have been funded by government in recent years. Consequently, we were able to distinguish changes in the updated threatened environment classification that result from corrections to the earlier land cover database (LCDB2; Terralink 2004) from the land cover transitions that LCDB4 now records as having occurred on the ground between 2002 and 2012. However, accuracy assessments of LCDB4 are yet to be carried out (David Pairman, Landcare Research, pers. comm.), and these are needed before the error associated with land cover designations at any given time-stamp can be quantified (e.g. Dymond et al.

2012). Assessment of error in the detection of *change* requires an additional and separate accuracy assessment. Both accuracy assessments are planned (John Dymond, Landcare Research, pers. comm.) and will expose the degree of error in our estimates and support interpretation of the pattern of change. However, estimates of the extent of indigenous cover remaining in New Zealand will remain crude, as a consequence of the broad qualitative nature of LCDB cover classes, which rely on manual interpretation of spectral signatures for mapping, and the binary split of mapped cover classes into indigenous and exotic categories. A more quantitative approach to classifying land cover and ongoing collection of biodiversity data across land cover classes and environmental gradients will enable a more sophisticated apportioning of indigenous and exotic biodiversity in the future.

Protected area information remains inconsistently collected and managed across multiple agencies and sources in New Zealand. We know that our 2012 collation is incomplete and has limitations (further details are given in Appendix S2). Up-to-date data are not readily available, and details such as the purpose of protection (e.g. biodiversity, road reserve, marginal strip) or the date of effective protection are not always recorded. Consequently both databases of protected areas used here (2004 and 2012) have errors of omission and commission that we have been unable to quantify. We also note that our binary split into 'protected' and 'not-protected' land classes fails to reflect the wide variation in the type and strength of protection provided by legislation or covenant conditions, and their implementation across New Zealand. Together, these sources of error could either inflate or understate the amount of protection for natural heritage across land environments. Reporting protection data in consistent ways across organisations nationwide would ease the task of compiling the information and providing status-and-change reports. We recommend that a protocol for consistent national collation of these data be considered and implemented (e.g. Rutledge 2013, unpubl.). Such an undertaking may be overseen by Statistics New Zealand or the Ministry for the Environment.

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References

- Brockerhoff EG, Shaw WB, Hock B, Kimberley M, Paul T, Quinn J, Pawson S 2008. Re-examination of recent loss of indigenous cover in New Zealand and the relative contributions of different land uses. *New Zealand Journal of Ecology* 32: 115–126.
- Cieraad E 2008. How much indigenous biodiversity remains on land under indigenous vegetation? Final report on a pilot study based on existing data. Landcare Research Contract Report LC0708/145. Available from the Department of Conservation Information Services, PO Box 10420, Wellington 6143. 65 p.
- Cieraad E, Walker S, Barringer J, Price R 2014. Indigenous cover remaining and biodiversity protection in New Zealand's land environments: a status update using LCDB3.3 and recent information on protected areas. Landcare Research Contract Report LC1741. Available from the Department of Conservation Information Services, PO Box 10420, Wellington 6143. 51 p.
- DOC (Department of Conservation), MfE (Ministry for the Environment) 2000. The New Zealand biodiversity strategy: February 2000. Wellington, Department of Conservation and the Ministry for the Environment. 163 p.
- Dymond JR, Shepherd JD, Newsome PF, Gapare N, Burgess DW, Watt P 2012. Remote sensing of land-use change for Kyoto Protocol reporting: the New Zealand case. *Environmental Science & Policy* 16: 1–8.
- Leathwick JR, Wilson G, Rutledge D, Wardle P, Morgan F, Johnston K, McLeod M, Kirkpatrick R 2003a. Land environments of New Zealand. Auckland, David Bateman. 184 p.
- Leathwick JR, Morgan F, Wilson G, Rutledge D, McLeod M, Johnston K 2003b. Land environments of New Zealand: a technical guide. Wellington, Ministry for the Environment. 237 p.
- Lee W, McGlone M, Wright E 2005. Biodiversity inventory and monitoring: A review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. Landcare Research Contract Report LC0405/122, prepared for the Department of Conservation. Available online at: http://www.landcareresearch.co.nz/publications/researchpubs/biodiv_inventory_monitoring.pdf
- MfE (Ministry for the Environment) 2007. Protecting our places: introducing the national priorities for protecting rare and threatened native biodiversity on private land. Wellington, Ministry for the Environment. 7 p.
- Pairman D 2014. LCDB v4.0 – Landcover Database version 4.0. <https://iris.scinfo.org.nz/layer/412-lcdb-v40-landcover-database-version-40/>
- R Core Team 2014. R: a language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing. ISBN 3-900051-07-0; <http://www.R-project.org/>.
- Rutledge D, Price R, Heke H, Ausseil A-G 2004. National analysis of biodiversity protection status: methods and summary results. Landcare Research Contract Report LC0405/042, prepared for the Ministry for the Environment. Available online at: http://www.landcareresearch.co.nz/_data/assets/pdf_file/0015/21813/National_Analysis_Biodiversity_Status.pdf.
- Terralink 2004. New Zealand Land Cover Database (LCDB2). Wellington, Terralink International Limited. 14 p.
- Walker S, Price R, Rutledge D, Stephens RTT, Lee WG 2006. Recent loss of indigenous cover in New Zealand. *New Zealand Journal of Ecology* 30: 169–177.
- Walker S, Price R, Rutledge D, Stephens T, Lee WG 2008. Measuring accuracy of land cover data and content of cover classes: a reply to Brockerhoff et al. (2008). *New Zealand Journal of Ecology* 32: 127–129.
- Walker S, Cieraad E, Barringer J 2015. The Threatened Environment Classification for New Zealand: a guide for users. Landcare Research Contract Report LC2184. Available online at: <http://www.landcareresearch.co.nz/resources/maps-satellites/threatened-environment-classification>. 35 p.

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Supplementary Material

Additional supporting information may be found in the online version of this article.

Appendix S1. Assignment of LCDB4 land cover classes to 'indigenous' or 'exotic'.

Appendix S2. Protected area information.

Appendix S3. Rasterising and re-projecting of GIS layers.

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