



The significance of sheep and beef farms to conservation of native vegetation in New Zealand

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Abstract: Relying solely on public conservation lands for habitat provision will be inadequate for achieving national conservation goals. Production landscapes in New Zealand make up 60% of the land area and contain potential conservation habitat; however, the amount of native vegetation they contain is poorly known. While there have been previous assessments of native vegetation cover in New Zealand, no study has undertaken a national-scale assessment of multiple native vegetation cover types on different land uses. This absence limits the potential to manage production landscapes for conservation. Our study aimed to bridge this gap by using GIS and remote-sensing data to estimate the area of native vegetation, including forests, grasslands and wetlands, present on different land-use classes and in different environments. We found that while most of the country's remaining native vegetation was found on public conservation land, it was not evenly distributed across land environments and was biased towards high-elevation vegetation types. Yet private land, in particular sheep and beef farms, contained a quarter of the remaining native vegetation in the country, and 17% of remaining native forest. While this vegetation was often highly fragmented, it contained forest types that were otherwise under-represented on public conservation land. We conclude that sheep and beef farms in New Zealand have the potential to add to nationwide conservation efforts. However, realising this potential will involve improving the connectivity, area and quality of native vegetation.

Keywords: agriculture, biodiversity, conservation, forest, GIS, grazing, land use, pastoral, remote sensing, vegetation

Introduction

Land that has been appropriated for human use, food and fibre production, and urbanisation is estimated to cover 75% of the planet's ice-free surface (Ellis & Ramankutty 2008). As this process continues, pristine ecosystems that provide habitat for native and threatened species are shrinking. Those that remain are increasingly restricted to land that is less economically valuable or unsuitable for human use (Pressey & Tully 1994) such as uplands (Joppa & Pfaff 2009). These high-stress environments are usually lower in biodiversity (Scott et al. 2001), leaving substantial suites of species poorly represented by global conservation land and thus vulnerable to extinction. Conservation reserves are not just unrepresentative, but often lack connectivity for many species, leading to isolation, inbreeding and vulnerability (Jennings 2000; Minor & Lookingbill 2010). Given these difficulties, relying on reserves alone for biodiversity conservation is not viable.

Despite global destruction of natural habitats, considerable native biodiversity still survives in human-dominated landscapes, including in agroecosystems (Norton & Reid 2013), potentially providing habitat for native flora and fauna and increasing connectivity of reserves. While conservation

in agroecosystems cannot replicate conservation in natural habitats, many native species do persist in modified landscapes, performing important ecological functions (e.g. pollination, carbon sequestration) and retaining cultural and heritage values. These species may sometimes be the only remaining examples of the original ecosystems in those modified landscapes (Norton & Reid 2013). Sustaining biodiversity in agroecosystems also has social value: for example, greener landscapes may provide human health benefits (Cox et al. 2017), such as preventing so-called "nature deficit disorder" (Stanley et al. 2015).

Sustaining and enhancing native biodiversity in agroecosystems (Jackson et al. 2007; Norris 2008; Kovács-Hostyánszki et al. 2017), while balancing production with ecological benefits (Hunt 2015), is thus increasingly prominent in ecological discourse. Substantial discussion has centred on "land sparing" versus "land sharing" (Fischer et al. 2014), although an either/or dichotomy is likely to be counterproductive (Kremen 2015), since both approaches have merit depending on the local context and spatial scale (Fischer et al. 2008; Michael et al. 2016). There is also a growing interest in restoration plantings in agroecosystems, especially in degraded landscapes (Norton et al. 2018), as well as in creating multifunctional landscapes to enhance provision of

ecosystem services (Manning et al. 2018; McGranahan 2014). A major difficulty in designing multifunctional agricultural landscapes is that conservation action on private land is usually voluntary, and thus it may not occur in the places that public conservation managers might prefer (Kleijn & Sutherland 2003; Smith et al. 2012). We can design optimal landscape corridors, but in reality we are constrained by the existing layout of the landscape and the need to balance productivity and other factors (Smith et al. 2012; Duru et al. 2015). Knowing where biodiversity occurs in farming landscapes is therefore the first step to maintaining and improving it, and quantifying the amount, distribution, and condition of remaining native vegetation is critical for landscape-scale conservation planning. Such information may indicate where to focus on improving connectivity and condition of native vegetation for maximum benefit. However, our understanding of landscape-level biodiversity is often lacking for agroecosystems (Norton 2000; Bretagnolle et al. 2011), partly due to the difficulties in collecting data on private land. In New Zealand, previous assessments of native vegetation cover have been undertaken (such as the “land under indigenous cover” environmental indicator; Cieraad et al. 2015), but to date there has been no assessment of how multiple native vegetation cover types vary by land use and farm type.

We present a nationwide GIS assessment of the distribution of native vegetation on private land and conservation reserves in New Zealand, showcasing the value of farmland in designing landscape-level conservation plans. This study is, to our knowledge, the only national-scale assessment of native vegetation on farmland, although there are similar region-level assessments from Australia (Beeston et al. 1995; Smith 2008), the USA (Cunningham 2005; Rallings et al. 2019), South America (Etter & Alberto Villa 2000; Bergher et al. 2015.), and Africa (Chatelain et al. 1996). New Zealand makes for a useful case study as it is a microcosm of patterns that occur worldwide. For example, the same bias towards uplands in conservation land is present in New Zealand as globally (Awimbo et al. 1996), amplified by the small land area and steep terrain, and there is a need to balance conservation with primary production. However, New Zealand is unique in other ways: the country is characterised by a high proportion of conservation land and is dominated by a single type of extensive farmland (sheep and beef grazing), accounting for c. 40% of the land area. New Zealand landscapes have been modified for farming relatively recently (Ewers et al. 2006), so the native flora and fauna are still in a state of disequilibrium.

In contrast with Europe, for example, which has a higher human population density, more intensive farming systems, and millennia of landscape modification, there is great opportunity to use the vegetation remaining in New Zealand farmland to reverse declines in endemic species. Other temperate countries with extensive farm systems (where extensive systems tend to have lower inputs of labour, fertiliser/pesticides, and lower stocking units per unit area), may present similar opportunities. Such countries include Australia, South America and many parts of the USA (Etter & Alberto Villa 2000, Michael et al. 2016, Norton & Reid 2013), as well as some subtropical and tropical areas where agricultural area is still expanding (Chatelain et al. 1996; Philpott & Armbrrecht 2006). In this study, we used nationally-available land cover and land-use datasets to address: (1) how much native vegetation remains in agroecosystems in New Zealand and (2) what contribution can native vegetation on farmlands, especially the native woody component, make to biodiversity conservation?

Methods

Study area

We confined our study to New Zealand’s North and South Islands, excluding Stewart Island and offshore islands. New Zealand has the third-largest proportion of public conservation land in the OECD, at almost one-third of its total land area (OECD 2017). Like many other countries (Joppa & Pfaff 2009), protected land in New Zealand is biased towards uplands and is therefore not representative of the full range of ecosystems that occurred before human settlement (Leathwick et al. 2003; Cieraad et al. 2015). Economically, New Zealand relies heavily on primary production (Ministry for Primary Industries 2018), and the dominant land-use is pastoral farming (sheep, beef and dairy; Stats NZ 2018). Partly due to low population density, New Zealand farms tend to be large; the mean area of a sheep and beef farm is 308 ha (ASUREQuality 2017). The land that is now used for farming has been cleared of much of its original pre-human forest, and though pastures are dominated by exotic grass and forb species (especially *Lolium* and *Trifolium* cultivars), sheep and beef farms in particular often contain patches of native vegetation. The steep topography of many sheep and beef farms protects some forest remnants, and coupled with lower livestock densities, this results in more native vegetation surviving than in more intensive farming, e.g. dairy (MacLeod & Moller 2006). There is substantial public pressure on New Zealand farmers to reduce their environmental footprint, and the primary sector increasingly acknowledges the potential economic, social and ecological benefits of on-farm conservation (Foote et al. 2015; Brown & Roper 2017; Norton et al. 2020).

Definition of vegetation classes

We quantified the distribution of native vegetation types on the North and South Islands of mainland New Zealand using the Land Cover Database (LCDB) version 4.1 (Landcare Research New Zealand 2015). The LCDB is a national-scale land cover dataset covering the full spatial extent of New Zealand, derived from multispectral satellite imagery and updated over the last decade with supplemental image and ground data (Dymond et al. 2017). This version of the database is based on 2012 satellite imagery. We aggregated the following ten LCDB classes, traditionally dominated by native species, into a “native vegetation” layer: alpine grass/herbfield; tall tussock grassland; depleted grassland; flaxland; fernland; mānuka and/or kānuka; broadleaved indigenous hardwoods; sub-alpine shrubland; matagouri or grey scrub; and indigenous forest. A second layer, “native forest”, comprised the LCDB classes: mānuka and/or kānuka; broadleaved indigenous hardwood; and indigenous forest. The third layer, “wetlands”, comprised the classes: herbaceous freshwater vegetation; herbaceous saline vegetation; lake or pond; and mangrove. Finally, the “grasslands” layer comprised alpine grass/herbfield; tall tussock grassland; and depleted grassland classes. Other studies have used similar methodologies to distinguish native vegetation cover in New Zealand (Walker et al. 2006; Weeks et al. 2012; Walker et al. 2015). We have used LCDB classes as a proxy for native vegetation as these have been used in national-level assessments (Cieraad et al. 2015). While LCDB classes do not directly measure all components of native biodiversity, especially animal biodiversity, they are an appropriate proxy as native vegetation cover is likely to be positively correlated with the presence of other native species (compared to non-native vegetation cover, such as pasture).

Native woody vegetation classes, such as those we used in our analyses, are especially likely to be positively correlated with other native species. However, we note that while these classes will be dominated by native plant species, they are likely to contain a mixture of native and non-native species.

Definition of land use classes

We used public and commercial land use spatial layers to classify land use across the whole of New Zealand as one of eight general land use categories: arable, conservation, dairy, forestry, horticulture, sheep and beef, urban and “other”. Because we used multiple independent layers in our analysis, there were some areas of spatial overlap between layers and disagreement in land-use classification. To rectify these disagreements, we used a number of rules to assign a final land use class in such cases (see Appendix S1 in Supplementary Materials). The Agribase™ farm land use dataset (ASUREQuality 2017) was used as the primary source of land-use class data, supplemented with layers of New Zealand pastoral leases and public conservation land. Pastoral lease property data were obtained from Land Information New Zealand (LINZ 2015). Pastoral leases are public lands leased to farmers for grazing purposes and we classified them as sheep and beef farms in our analysis. Public conservation land was classified using Department of Conservation and LINZ crown property data (Department of Conservation 2017, Land Information New Zealand 2016). In areas where farmland and public conservation land overlapped, the area was classified as farmland; conversely, overlaps between public conservation land and Agribase classes “native” or “other miscellaneous” were classified as public conservation land. Approximately 92% of our study extent was assigned a land-use type using this process. To classify land-use for the remaining 8% of the country, we used primary cadastral parcel (Land Information New Zealand 2011) and the Land-use and Carbon Analysis System (LUCAS; Ministry for the Environment 2014) datasets (Appendix S1). Areas classified as rivers, roads, offshore features, and open water were excluded from our analysis.

Potential Forest Types

Since most sheep and beef farms were forested prior to human settlement of New Zealand (Ewers et al. 2006; Wilmshurst et al. 2008), we ran further analyses on the distribution of native forest types on land use classes. We intersected the native forest layer described previously with the Land Environments of New Zealand (LENZ; Leathwick et al. 2002) classification, as a proxy for broad potential forest types and their distribution (Leathwick et al. 2003). The LENZ classification uses climatic and physical land characteristics to group areas with broadly similar environmental conditions relevant to forest species distributions. Hence, we would expect areas within a given LENZ class to contain similar native forest types. These classes are arranged into four hierarchical levels, level I being the coarsest classification (20 classes). At a national scale, we determined the area of each level I environment covered by native forest (each being a forest ‘type’), and the proportion of that native forest type occurring on sheep and beef farms versus public conservation land (the two dominant national land use classes by area).

Analysis

All data preparation and analyses were carried out in ArcMap version 10.1 (Esri 2016) in the New Zealand Transverse Mercator projection (NZTM2000), using polygon shapefiles

to calculate geodesic areas as accurately as possible. We performed intersections in GIS for all combinations of vegetation and land use layers, as well as forests, LENZ classes and land use, and calculated the geodesic areas of the resulting polygon features in hectares. We also calculated the observed mean distance between native forest patches occurring on public conservation land and sheep and beef farms (the two largest land use classes), and their mean geodesic areas. As a final step, we calculated the amount of native vegetation on sheep and beef farms formally protected under the voluntary QEII conservation covenant scheme. The QEII National Trust works with landowners to provide legal protection to remnants of native vegetation on their land and provides financial assistance with this. It is the major voluntary conservation scheme on private land in New Zealand. We intersected native vegetation on sheep and beef farms with QEII covenant locations (QEII National Trust 2017). For visualisation purposes, national-scale polygon maps were aggregated to 5 km grid cell rasters to produce Figs 1 and 2. Figures 3 and 4 were prepared in R version 3.5 (R Core Team 2017) using the packages ‘ggplot2’ (Wickham, 2009) and ‘tidyr’ (Wickham & Henry 2017).

Results

Native vegetation and land use

Sheep and beef farms, followed by public conservation land, were the two dominant land-use classes in the North and South Islands of New Zealand, comprising c. 40% and 31% of the 27 million ha total land area respectively (Table 1). Dairy, “other” (lifestyle blocks, other grazed livestock e.g. deer, privately owned reserves) and plantation forestry were also nationally significant land uses, all similar in size and accounting for a further c. 26% of the land area. The remaining land uses (horticulture, arable and urban) covered approximately 2% of the land area, with 1% outside of the classification scheme (e.g. roads, bodies of water).

The total area of remaining native vegetation and of native woody vegetation comprised 43% and 30%, respectively, of the New Zealand land area. The remaining 57% of the land area was dominated by non-native vegetation and consisted mainly of pasture and plantation forest. Public conservation land was where most of New Zealand’s remaining native vegetation (61.5%) and native woody vegetation (65%) occurred. However, sheep and beef farms contained nearly 25% of the remaining native vegetation, and 17% of the remaining native woody vegetation. In contrast, dairy pasture contained little native (1.4%) or native woody vegetation (1.9%). This absence is also true of plantation forestry (2.8% and 3.8%, respectively). In contrast, land use described as “other” contained a considerable amount of remaining native (10%) and native woody vegetation (11%).

Native grasslands (as opposed to pastures dominated by exotic species) were nearly equally distributed between public conservation lands (52.1% of the remaining area) and sheep and beef farms (44.7%), together comprising nearly all remaining native grasslands. Wetlands were a minor component in all non-public conservation land-use categories, both in terms of total area and percentage of remaining wetland. The majority of New Zealand’s remaining wetland vegetation was found on public conservation land (36.3%) or on land not classified by our analyses, which was predominantly riverbeds, estuaries, lakes and coastlines (54.3%); the percentage of total wetland area on sheep and beef farms was negligible (0.6%).

Table 1. Amount of total native vegetation, native woody vegetation and native wetland on each land use in New Zealand, as a percentage of total vegetation and in ha. Unclassified land use refers to land that falls outside of the classification scheme, e.g. roads, rivers, and estuaries.

Land Use	Area (ha*1000)	% of total native vegetation in land use category (ha*1000)	% of total native woody vegetation in land use category (ha*1000)	% of total native grassland in land use category (ha*1000)	% of total native wetland in land use category (ha*1000)
New Zealand	26,732	43.0 (11,490)	30.3 (8106)	10.2 (2737)	2.1 (556)
Sheep and beef	10,625	24.5 (2813)	17.1 (1389)	44.7 (1223)	0.6 (3)
Public conservation land	8283	61.5 (7069)	65.0 (5265)	52.1 (1425)	36.3 (202)
Dairy	2711	1.4 (165)	1.9 (156)	0.2 (4)	2.4 (13)
Other	2359	9.6 (1104)	11.3 (914)	1.5 (42)	4.8 (27)
Forestry	1891	2.8 (317)	3.8 (305)	0.2 (5)	1.6 (9)
Arable	230	<0.1 (3)	<0.1 (2)	<0.1 (0.5)	<0.1 (0.03)
Horticulture	116	<0.1 (5)	<0.1 (4)	<0.1 (0.8)	0.1 (0.05)
Urban	152	<0.1 (0.06)	<0.1 (0.06)	<0.1 (0.001)	<0.1 (0.09)
Unclassified	365	0.1 (14)	0.9 (70)	1.3 (37)	54.3 (302)

The distribution and density of native vegetation was different between public conservation land and sheep and beef farms (Figs 1a, b). Native vegetation on public conservation land covered on average 35 ± 37 (\pm SD)% of each 5 km grid cell, whereas on sheep and beef farms it covered 15 ± 20 %; thus, it was more fragmented on sheep and beef farms. By mapping only the native woody vegetation component (Figs 2a, b), these patterns became more pronounced, also highlighting

the fact that sheep and beef farms contained native vegetation in areas with little public conservation land. Woody vegetation comprised a mean of 28 ± 33 % of each 5-km cell area on public conservation land, and 8 ± 12 % on sheep and beef farms. These patterns were also demonstrated by the nearest neighbour distances and mean forest patch areas: on sheep and beef farms, native forest patches were separated by a mean distance of 5.3 km, with a mean patch area of $2058 \pm$

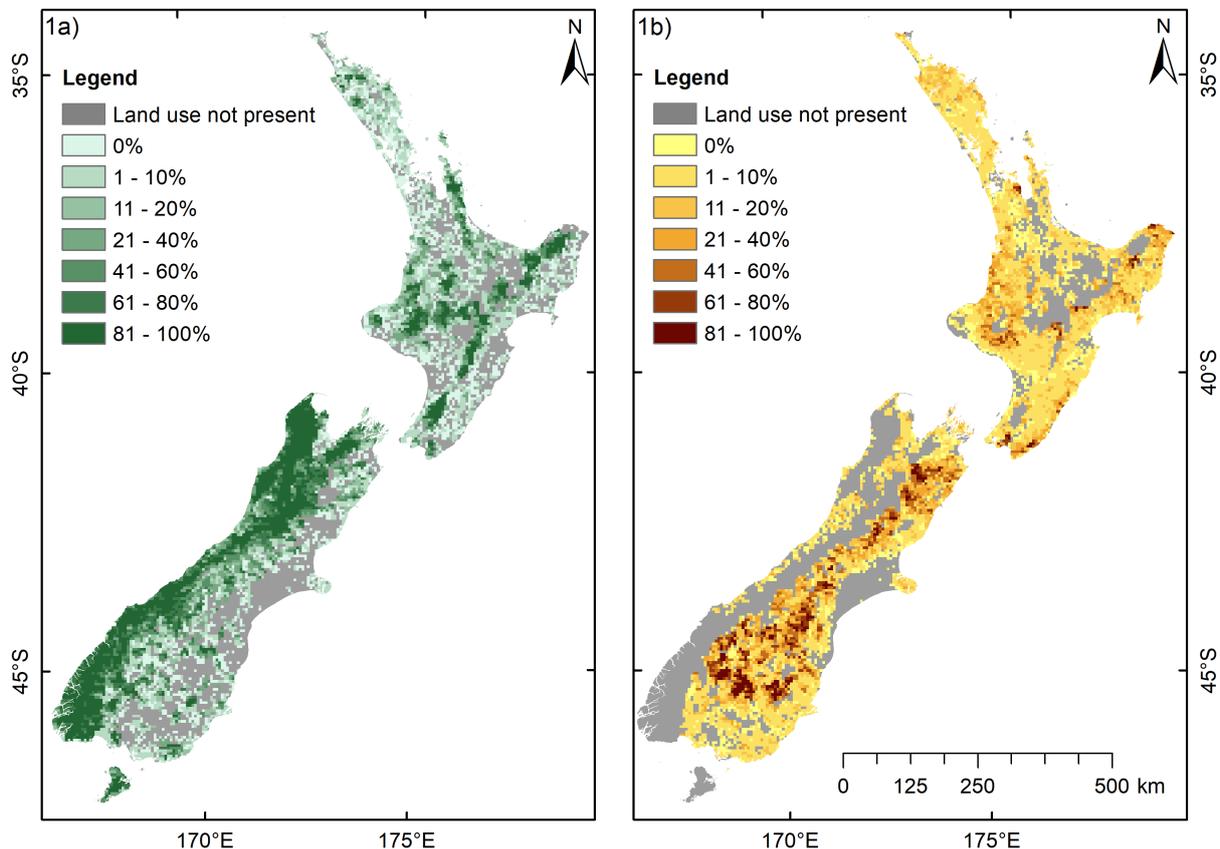


Figure 1. Extent of native vegetation cover on (a) public conservation land and (b) sheep and beef farms in New Zealand, shown as percentage cover per 5-km grid cell.

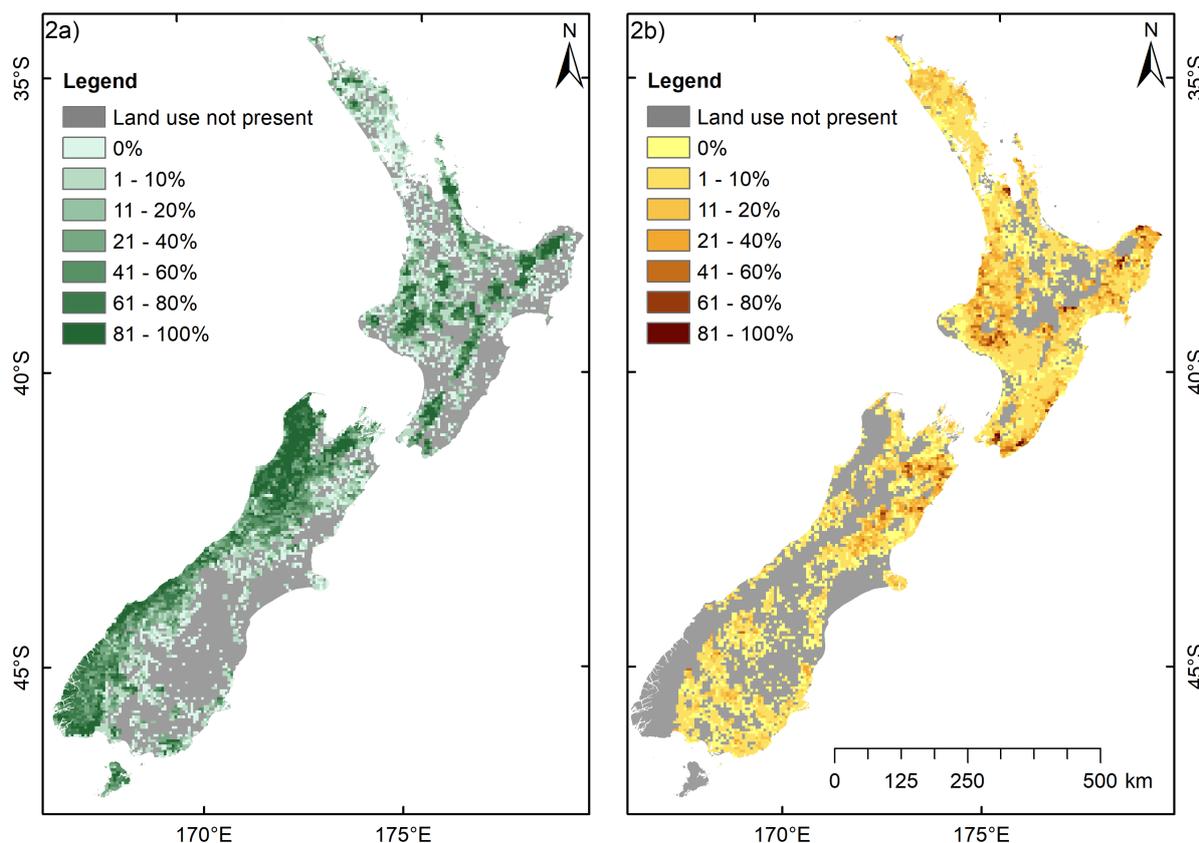


Figure 2. Extent of native woody vegetation cover on (a) public conservation land and sheep and (b) beef farms in New Zealand, shown as percentage cover per 5-km grid cell.

9621 ha. Meanwhile, on public conservation land, the mean patch area is $2\,007\,014 \pm 403\,546$ ha, separated by a mean distance of 104.7 km.

Potential forest types on sheep and beef farms vs public conservation land

Native woody vegetation on sheep and beef farms tended to represent different land environment classes (inferred forest types) to native woody vegetation on public conservation land (Appendix S2). Generally, land environments at lower

elevations tended to have less native woody vegetation remaining than those at higher elevations (Figs 3a, b), and furthermore, at lower elevations little forest occurs on public conservation land (Fig. 3a). Instead, at low elevations, a large proportion of the native forest present occurs on sheep and beef farms (Fig. 3b). Similarly, in land environments that are cooler and wetter, most of the forest remaining tends to occur on public conservation land (Fig. 4a), while in warmer, drier classes most remaining forest occurs on sheep and beef farms (Fig. 4b).

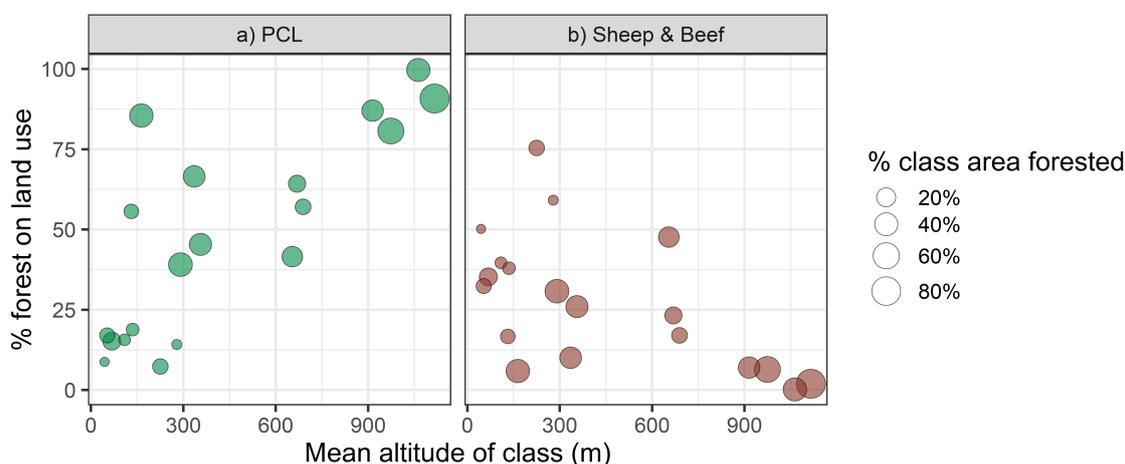


Figure 3. The percentage by area of native forest in each land environment New Zealand (LENZ) class that occurs on a) public conservation land (PCL) and b) sheep and beef farmland, against the mean altitude of the LENZ class in metres. Each point corresponds to a level I LENZ class, and circle size corresponds to the total percentage by area of the LENZ class that is covered by native forest (all land uses).

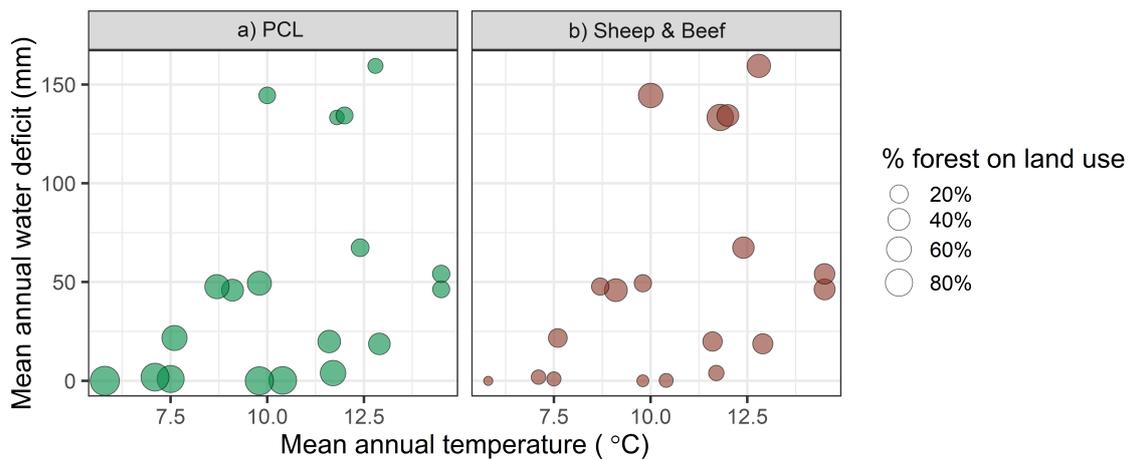


Figure 4. The mean annual water deficit (mm) of each level I land environment New Zealand (LENZ) class versus its mean annual temperature ($^{\circ}\text{C}$). Circle size corresponds to the percentage by area of native forest in each LENZ class that occurs on a) public conservation land and b) sheep and beef farmland.

Proportion of native vegetation protected by covenants

As of 30 June 2017, approximately 170 000 hectares of native vegetation in New Zealand was protected by QEII covenants. Of this area of covenanted vegetation, 53% was on sheep and beef farms. However, only c. 3% of all native vegetation present on sheep and beef farms had been covenanted (38 385 ha of forest, 48 833 ha of grassland, and 25 ha of wetland).

Discussion

We aimed to quantify the extent of indigenous vegetation cover remaining in New Zealand agroecosystems, and to assess the contribution that this vegetation could make to conservation. Of the c. 11 million ha of native vegetation remaining nationwide, we found that 25% occurred on sheep and beef farms. Not only do sheep and beef farms contain large amounts of native vegetation, both woody (forest and shrubland) and herbaceous (grassland and wetland), they tend to occur in environments that are climatically and environmentally distinct from public conservation land, e.g. warmer, low elevation areas, and in environments that have been otherwise heavily deforested. Thus, sheep and beef farms in New Zealand contain nationally significant amounts of native vegetation that is under-represented on existing public conservation land. However, that vegetation is more fragmented than that on public conservation land. Previous studies have shown that the amount of native vegetation in New Zealand has declined in recent years, both on farmland and overall (Walker et al. 2006, Weeks et al. 2012).

The significance of sheep & beef farms to biodiversity conservation

Sheep and beef farms differ to other New Zealand farm systems (e.g. arable, dairy) in that they contain substantial amounts of native vegetation, both grassland and woody. As the dominant land-use in New Zealand, sheep and beef farming contributes substantially to New Zealand's exports (Ministry for Primary Industries 2018), despite contractions in the red meat sector in recent decades (MacLeod & Moller 2006; Fetzel et al. 2014). However, the sector is facing increasing pressures – for

example, wool prices have been relatively low in recent years (Beef & Lamb NZ 2017), alternative meat technologies are on the rise (Edelman et al. 2005; van Huis 2013; Bryant & Barnett 2018), consumer demand for sustainable products is growing (Tait et al. 2016) and the carbon footprint of meat production is under scrutiny (Hilborn et al. 2018; Poore & Nemecek 2018). In this context, sheep and beef farms will need to improve their environmental footprint to retain their social license and profitability (Norton et al. 2020). The significant amounts of native vegetation and forest on sheep and beef farms therefore present an opportunity to alleviate some of these issues while enhancing biodiversity, and potentially could provide economic returns to farmers if managed appropriately (Hawke & Dodd 2003; Pollard 2006; Young et al. 2014; Norton et al. 2020). Examples of such management could include retention and enhancing of connectivity of native forest patches, as well as exclusion of livestock and pests from forest (Dodd et al. 2011). However, we acknowledge that these actions are not always mutually beneficial for farm operations, and that trade-offs between conservation and productivity are likely to be necessary.

The continued existence of large amounts of native woody vegetation on sheep and beef farms is likely due to farm management practices, historical legacy and policy. As an extensively-managed farming system, sheep and beef farming is more conducive to the retention of woody vegetation than more intensive systems; these farms often deal with harsh climates and erosion issues (Hunt 2015), which creates incentives to retain trees for shelter and erosion control. In other cases, steep topography has rendered clearing difficult or left gullies inaccessible to stock or fire. Additionally, policy has alternately incentivised the clearance or retention of native forest. For example, the removal of government subsidies for land development in the 1980s meant that, for many farmers, clearing regenerating native forest on their land was no longer financially viable (MacLeod & Moller 2006; Haggerty et al. 2009). As a result, the woody vegetation remaining on farms differs in successional stage; some farms contain remnants of old growth forest, e.g. rimu (*Dacrydium cupressinum*) and tawa (*Beilschmiedia tawa*) while others are dominated by early successional species, e.g. tōtara (*Podocarpus totara*) and kānuka (*Kunzea* species). While some of the reasons that

vegetation has been retained are unique to New Zealand sheep and beef farms, large amounts of native vegetation persists in many extensive/low intensity farming systems worldwide (Etter & Alberto Villa 2000; Dietschi et al. 2007; Norton & Reid 2013; Evans et al. 2015).

In more intensive farming systems, it is considerably less practical to retain native woody vegetation. Arable, dairy and horticultural farms contained less native vegetation than sheep and beef farms; however, 173 000 hectares of native vegetation is still a substantial amount and dairy farms in fact contain more native wetland than sheep and beef farms (13 000 vs 600 ha respectively). Although there is less potential to conserve forest patches in high intensity systems, hedgerows and riparian strips can make large contributions to biodiversity conservation and connectivity in these systems (Welsch et al. 2014; Rallings et al. 2019).

The value of vegetation on sheep and beef farms for biodiversity

We focused mainly on the distribution of native woody vegetation because, in New Zealand, forest is the pre-human state of most ecosystems and is critical for a large number of threatened species (Leathwick et al. 2003). However, we identified large amounts of native grassland on sheep and beef farms, especially in the South Island. While many of these grasslands have been induced by fire from previous woody states (McGlone 2001), they are important for a number of native plants and animals, with some species dependent on them for survival (Rogers & Overton 2007).

Arguably more important than the amount of vegetation cover is its distribution and the land environments in which it occurs. The native forest found on sheep and beef farms was commonly representative of land environments that have otherwise been heavily deforested, and these forest types are therefore nationally under-represented in reserves. The forest types on sheep and beef farms tend to occur in lower elevation and drier parts of the country than the forest on public conservation land. For example, the eastern plains of the South Island (LENZ Level I environment N) is low-elevation dryland that has been extensively deforested (Ewers et al. 2006), and less than 1% of the area contains native woody vegetation. However, nearly 60% of the small amount of remaining native woody vegetation of the eastern plains occurs on sheep and beef farms. Similarly, in the central dry lowlands of the North Island (LENZ Level I environment B), over three-quarters of the less than 10% remaining native woody vegetation occurs on sheep and beef farms. Further analyses using more detailed land environment data show similar patterns to those described above across most regions in New Zealand (Norton & Pannell 2018). However, as shown by Awimbo et al. (1996), the historical context of a region also has an effect on the present-day distribution of remnant native forest. Regional variation aside, our general findings are in line with others from New Zealand (Walker et al. 2008) and overseas (Joppa & Pfaff 2009), where it has been shown that public conservation land is not representative of the potential range of forest types, and that private land contains forest types that are under-represented nationally.

Despite the apparent potential of this woody vegetation to contribute to biodiversity, the forest patches on farmland are often highly fragmented in a landscape context. If patches are suitably large and connected, they may be used as stepping stones or permanent habitat; but this will vary by species. For example, North Island brown kiwi (*Apteryx mantelli*)

can travel over 300 m between forest patches (Potter 1990), while North Island robins (*Petroica longipes*) are reluctant to travel more than 80 m between remnants (Wittern & Berggren 2007). Depending on the species of interest and the surrounding matrix, patch size and connectivity are key to improving biodiversity (Prevedello & Vieira 2010). In addition to the spatial characteristics of forest patches, to improve their biodiversity value it will be vital to improve their quality as in agroecosystems they may be severely degraded due to the presence of livestock and pests. Stock trampling reduces understorey plant and invertebrate diversity (Dodd et al. 2011), and in New Zealand, predator control is vital for any conservation effort. However, fragment quality can sometimes be restored with adequate fencing, predator control and replanting (Burns et al. 2011; Norton et al. 2018), although recovery may be slower in drier or cooler regions (Walker et al. 2009).

Accuracy of results and sources of uncertainty

The accuracy of our results depends on the level of uncertainty in the spatial data, some of which is quantifiable. The user accuracy of LCDB (i.e. the probability that the class represented on the map matches the land use on the ground) has been estimated at over 93% (Dunningham et al. unpublished report for Ministry of Environment), while the LUCAS layer user accuracy is over 95% (Newsome et al. 2018). Cadastral data are accurate to within 100 m (Land Information New Zealand 2011) and Agribase and QEII data are sourced from landowners and updated regularly. The overall user accuracy for our results, then, we estimate at c. 88% (LCDB user accuracy × LUCAS user accuracy). We expect that area calculations of vegetation classes are accurate to within 5% of true areas (Dymond et al. 2017). However, LCDB does not classify small (< 1 ha) patches of vegetation due to the resolution of the underlying satellite data. The accuracy of the LENZ data is harder to quantify as it is derived from numerous climatic and environmental data, including modelled and interpolated data. The main source of error in LENZ is likely to be the underlying soil data, the accuracy of which varies by region according to the coverage of soil surveys. In general, lowland areas surrounding large settlements are the most extensively surveyed. As a result, our LENZ analyses of native woody vegetation should be used as an indicator of general patterns rather than accurate predictions of site conditions.

This study did not assess either the quality or spatial arrangement of native vegetation. It is likely that much of the native woody vegetation on farmland is either modified old growth forest (e.g. after early timber extraction) or successional forest (e.g. dominated by relatively fast-growing short-lived angiosperm and coniferous trees). However, with appropriate management, especially exclusion of farmed and feral grazing animals, these areas can regenerate towards mature native forest (Dodd et al. 2011; Norton et al. 2018).

While our analysis was relatively fine-grained, it will not capture small features such as hedgerows or scattered individual native trees. However, even small features can have measurable biodiversity benefits, such as scattered trees in Australia (Manning et al. 2006; Crane et al. 2014), and hedgerows in Europe and the USA (Paoletti et al. 1997; Pywell et al. 2005; Morandin et al. 2014). Small fragments can be critical stepping stones for mobile species such as birds and therefore, play a key role in landscape-level networks (Isaac et al. 2018; Norton et al. 2018).

Implications for landscape-level management and policy

The substantial proportions of native woody vegetation cover found on sheep and beef farms are vital sources of propagules for the future, and in some cases farm remnants may contain the only remaining populations of species in such landscapes (Norton & Reid 2013). Retaining and growing these biodiversity resources will require a combination of approaches operating at different scales. There are numerous initiatives aiming to increase forest cover and biodiversity nationally (e.g. the New Zealand government's One Billion Trees initiative), and at a landscape level (e.g. community initiatives such as the Forest Bridge Trust and Te Ara Kākāriki, and covenanting schemes such as Ngā Whenua Rāhui and QEII Trust). Opt-in schemes such as QEII covenanting are widely viewed as successful in New Zealand, but as our analyses highlight, only a small percentage of landowners are likely to take part (Ward and Siddique 2015). In Europe, despite major investment, voluntary Agri-Environment Schemes have largely failed to show measurable biodiversity benefits (Whittingham 2011), and research has shown that the success of such schemes is highly context dependent, calling for more targeted approaches designed with better understanding of social factors surrounding landowner decision making (Batáry et al. 2015). In reality, achieving national and global biodiversity goals will require a multi-scale combination of top-down and bottom-up approaches, but in all cases working with landowners to design practical solutions, developed with consideration to the broader landscape context, is paramount.

Conclusions

Our results highlight the potential for sheep and beef farms to contribute substantially to biodiversity conservation in New Zealand, both in terms of overall area of native vegetation and because the vegetation on sheep and beef farms occurs in environments that have otherwise been heavily cleared. We provide the first national-scale assessment of native woody vegetation cover in agroecosystems in New Zealand, identifying land uses and regions with remnant native vegetation that could provide a template for landscape-level biodiversity conservation planning. Because sheep and beef farms contain c. 25% of the remaining native vegetation nationally and comprise 40% of the land area, they are uniquely poised to complement public conservation land by increasing the area and especially the landscape connectivity of native habitat. However, we recognise that the key to securing long-term sustainability in farm landscapes is working closely with land-owners, as well as having systems in place to support conservation actions on farm (Norton et al. 2020). We hope that our results will inform conversations with land managers about biodiversity in New Zealand and overseas, and help guide protection strategies and restoration programmes.

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Supplementary material

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

Appendix S1. Flowchart of layers and attributes used to classify land use into the 8 distinct classes used for analyses.

Appendix S2. Distribution of native woody vegetation by land environment across New Zealand.

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