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Beyond carbon sequestration: Opportunities for multifunctionality of woody vegetation on New Zealand sheep and beef cattle farms

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Introduction

Two-thirds of Earth's global ice-free land surface, which amounts to approximately 196 million square kilometers has been converted to productive land uses, of which 45% is agricultural, leaving only 31% of the global ice-free land classified as natural ecosystems [1]. The conversion of natural ecosystems to agriculture and the continuous practice of intensive agriculture have many documented negative consequences, including the loss of biodiversity [2] and alterations to the ecosystem functions [3], such as the reduction of carbon sequestration from biomass and soils [4], increased soil erosion [5], and reduced habitat provision for native wildlife [6].

With the growing popularity of global programs to reduce the impact of climate change through tree establishment, including natural regeneration, people are beginning to look for more opportunities to incorporate trees into a wide variety of land uses, including integrating trees in agricultural ecosystems. Countries such as New Zealand, Australia, and the United Kingdom are aiming to plant more trees on agricultural land [7–9]. Forest Landscape Restoration is a global initiative to bring 150 million hectares of deforested and degraded land into restoration by 2020, and 350 million hectares by 2030, that emerged in response to the Bonn Challenge, includes planting trees on agricultural land as one of the strategies [10]. Private sector organisations, such as Nestle and Del Monte, have committed to support planting trees on and around farms as part of the One Trillion Trees initiative, the World Economic Forum's effort to accelerate Nature-based Solutions (NbS) [11].

The UNEA-5 resolution formally adopted the definition of NbS as 'actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits' [12]. The 'Resolution on Nature-based Solutions for Supporting Sustainable Development' also calls on UNEP to support the implementation of NbS, which safeguard the rights of communities and indigenous peoples [12]. Combining trees and agricultural systems on the same land area, could provide a valuable strategy to reconcile ecological and socio-economic objectives by treating agroecosystems as multifunctional landscapes [13]. In such systems, native forest remnants, naturally regenerated forests, agroforests, mixed species plantations, and commercial monoculture plantations all co-occur, providing a wide variety of ecosystem functions, including those that contribute to preventing native biodiversity loss, climate mitigation and climate adaptation [14,15]. Restoration of woody vegetation on agricultural lands could therefore provide valuable NbS for the enhanced provision of ecosystem functions while achieving multiple co-benefits [16].

Although some research has focused on the benefits of woody vegetation, including in agricultural landscapes, for mitigating and adapting to climate change (e.g., [17–19]), there are many knowledge gaps. Research has so far largely been limited to adding, converting, and optimizing only a few woody features, such as woodlots and shelterbelts, and a few ecosystem functions, such as increasing carbon stocks; this narrow focus limits the potential for recommendations that will increase the heterogeneity of these landscapes [2,20,21]. Research that measures the contributions of a diversity of existing vegetation is also lacking, potentially leading to the devaluing and conversion of certain plant community types, such as shrublands and native grasslands; such vegetation often supports unique and rare remaining native biodiversity [21]. Further, quantifying the ecosystem functions associated with increasing woody vegetation that have negative impacts on farm productivity or native biodiversity is also important for understanding the consequences of incentivising agroecosystem multifunctionality [22] and, thus, gaining balanced information for landscape planning and determining the necessary level of management intervention [20,21, 23].

Woody vegetation on sheep and beef cattle farms in New Zealand offers a case study example of how various ecosystem functions interact in these agricultural landscapes. Increases in the area and intensity of agricultural production pose a major threat to New Zealand's unique native biodiversity and ecosystem services in New Zealand [24],

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potentially contributing to the loss of natural habitat area, native species diversity, and a net release of carbon into the atmosphere [25]. Pastoral lands, including sheep and beef cattle farms, cover almost half of the country [26] and are predominantly located on the lowland areas where the majority of native vegetation cover has been converted to other land uses [27,28]. Pastoral lands, including sheep and beef cattle farms, cover almost half of the country [26] and are predominantly located in lowland areas where, nation-wide, the majority of native vegetation cover has been converted to other land uses [27,28]. Despite this, sheep and beef farms in New Zealand still contain a relatively high proportion of native woody vegetation at approximately 1,389,000 hectares, representing about 13.05% of the total sheep and beef farm area, or 17.1% of the total native woody vegetation cover in New Zealand, and about 4.62% of the total land area of the country [26]. This presents opportunities for farm managers to achieve high levels of agricultural production alongside native habitat conservation and other ecosystem services [29]. Many farmers in New Zealand are working to preserve and restore native woody vegetation as part of the agricultural landscape matrix [26], alongside woody features dominated by exotic species such as shelterbelts and timber woodlots [30]. These different vegetation types have both production and non-production benefits, and are becoming increasingly recommended as part of sheep and beef cattle farm planning [28,31].

Despite one of New Zealand's climate change mitigation strategies being to increase aboveground biomass, there are still gaps in the understanding of the contribution of woody vegetation in agricultural landscapes as an important part of this mitigation The total carbon stock held in woody vegetation on agricultural land is considered minor compared to the carbon stock per hectare (i.e., carbon stock density) of natural and exotic forest [32]. Considered to have a lower carbon value than other land cover types puts woody vegetation on agricultural land at risk of being transformed to a higher-carbon-value forest for the purpose of mitigating climate change [27]. Only a few estimates of carbon stock densities have been quantified for woody vegetation on New Zealand farms (e.g., [33,34]). Woody vegetation patches that are smaller than the threshold for the definition as 'forest' are not included in calculations for estimating New Zealand's carbon stocks [33]. The country's carbon credit or emissions trading scheme (ETS) also does not provide carbon credits for native remnants that do not meet the forest definition's eligibility criteria [27]. This scheme only provides carbon credits for replanted stands of exotic trees and excludes replanted native stands that were established in areas that were covered by native forest prior to 1990. Currently, there is no policy to encourage farmers to retain existing woody vegetation on agricultural land [35]. Furthermore, compared to exotic plantations, the carbon credits awarded for native trees are lower [27]. Despite incentivisation for planting native trees through New Zealand's national tree-planting program (One Billion Trees Programme, Ministry for Primary Industries), which targeted planting into less productive land, a lower carbon credit rate was assigned for native species. Although the incentivization in 1BT and ETS pay-outs was originally designed to encourage carbon capture as an ecosystem service, the implementation of both policies results in a lower economic return to landowners for planting native species compared to planting intensive exotic trees. Thus, in combination with the inclusion of existing planned exotic plantations into the scheme, a much higher number of exotic trees is being planted, despite the fact that the expansion of these plantations has been criticized for serving primarily socio-economic goals rather than biodiversity goals [36].

Without sufficient incentive for regenerating and conserving woody vegetation on farms, sheep and beef cattle farms with woody vegetation, especially with native woody vegetation, will be economically valued at lower levels than other land uses such as intensive dairy farming and exotic plantation forestry [37]. The combination of tree planting incentives and the emission trading scheme may further increase the competitive value of commercial exotic plantations, which will drive further clearance and conversion of native vegetation, including on sheep and beef cattle farms [27,38]. Hence, it is important to demonstrate the value of woody vegetation occurring on sheep and beef cattle farms and the multiple ecosystem functions it provides, such as carbon and native biodiversity, to decision-makers, such as landowners and land use planning authorities, so that management can be improved to optimize these functions alongside agricultural productivity.

Our study is the first to explore variation in carbon storage, species richness, and other ecosystem functions among different plant community types on three sheep and beef cattle farms. These case study farms were representative of this common New Zealand land use. We addressed the following research questions: (1) How does woody plant (including tree ferns) community structure and carbon stocks per hectare differ among different on-farm community types, and what plant community characteristics contribute to a higher total carbon stock? (2) How does multifunctionality differ, and what functions trade off, among different community types? To address these questions, we: (1) mapped woody plant species composition across the three farms using vegetation plots that were then classified into different plant community types; (2) compared the characteristics of each of the plant community type in terms of relative abundance, diversity, and stem size; (3) estimated the mean and variation of carbon stocks per hectare for each plant community type; and (4) quantified the relative potential multifunctionality by summing the estimated ecosystem functions associated with each woody plant species and then aggregating these values for each vegetation type. This research illustrates how the detailed assessment of the ecosystem functions associated with woody species can be used to estimate the relative benefits of different woody plant communities on farms for agroecosystem multifunctionality.

Methods

Study area

Our three case study sites were two farms in New Zealand's North Island (the Kaipara and Ruapehu farms), and a third farm in the South Island (the Hurunui farm) (Fig. 1). The three farms were sheep and beef cattle farms in the areas dominated by beef cattle farming, followed by dairy farming, sheep-beef cattle farming, sheep farming, forestry, and annual crop [39]. The vegetation of all three sheep and beef farms was typical of New Zealand farming landscapes in that it was highly fragmented and consisted of remnants or regenerating cut-over patches of native forest, as well as commercial exotic plantations. These three sheep and beef cattle farms were predominantly managed as sheep and beef farms, with some areas managed as exotic monoculture plantations of *Pinus* spp. (Manaaki [40]).

The Kaipara Farm (152 ha; Fig. 1 B) is located in the Kaipara region, close to Kaipara Harbor in the North Auckland Peninsula. The farm spans across several elevations, ranging from approximately 50 meters to 100 meters above sea level. The average daily temperature ranges from 7-8°C in the winter to 22–24°C in the summer [41]. The farm experiences a mean annual rainfall of 1454 mm [42]. The region is known for its strong and gusty winds, with a high frequency of gusts exceeding 63 km/hr and 96 km/hr each year. The farm is mostly composed of high-productivity grassland, along with a small amount of shelterbelt, two small remaining native forest patches, and exotic woodland. However, the northern area of the farm is vulnerable to soil slip, while the southern area consists of gullies and is vulnerable to earthflow erosion. The Ruapehu farm (2,167 ha; Fig. 1 C) is situated in the Manawatu-Wanganui region. The farm spans across several elevations, ranging from approximately 200 meters to 400 meters above sea level. The average annual rainfall for the area is 1522 mm, while the median winter average daily minimum temperature can range from 2–14°C and the median summer average daily maximum temperature is 10–24°C [43]. The Ruapehu farm mostly comprised of high-productivity grassland and a sizable area of exotic woodland that was close to some small patches of remaining old forest. The Canterbury farm (770 ha; Fig. 1 D)

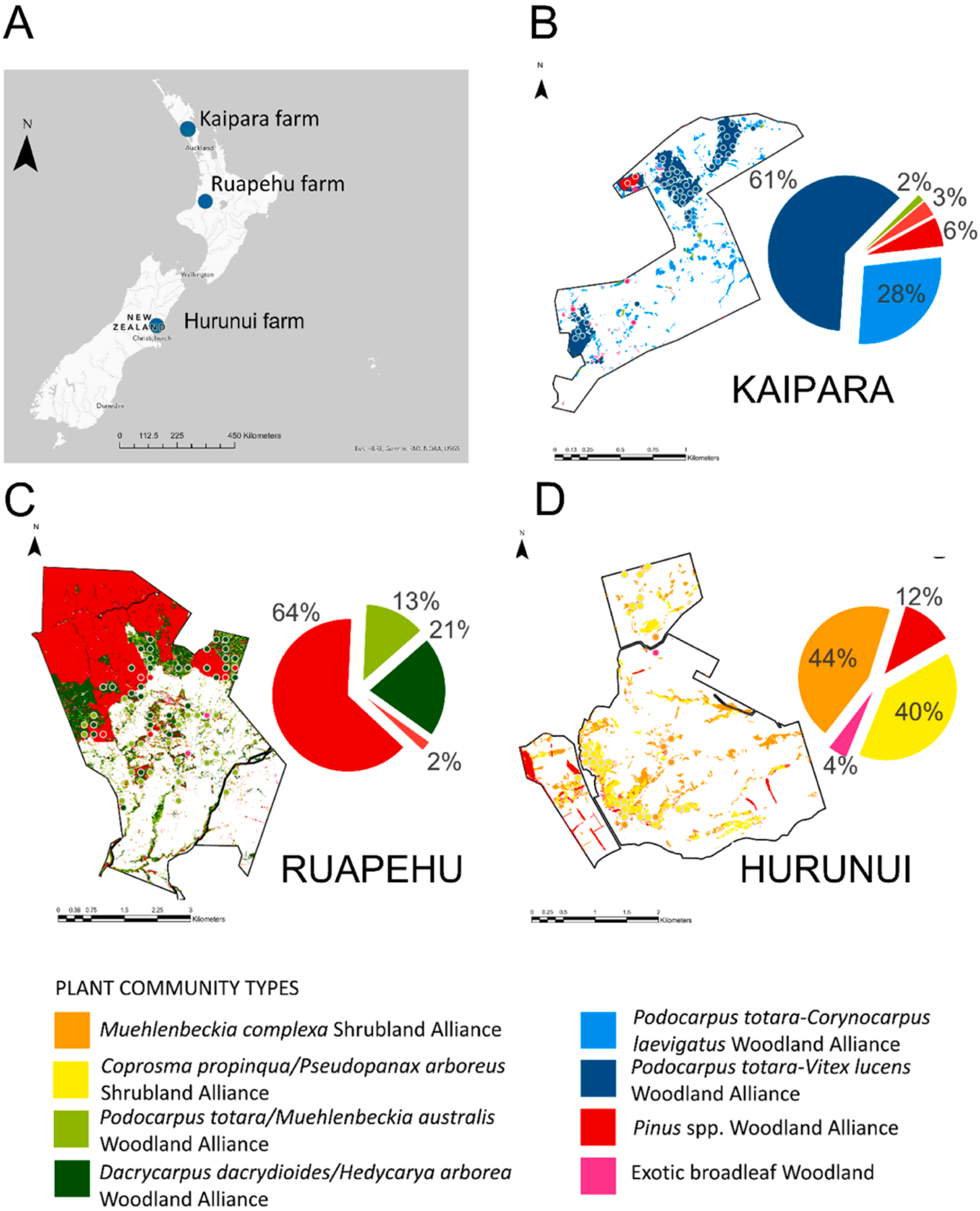

Fig. 1. A) Inset map shows the locations of three sheep and beef research farms in New Zealand: Kaipara, Ruapehu, and Hurunui; and the three other maps show the distribution of plant communities across three farms on B) Kaipara, C) Ruapehu, and D) Hurunui. The colours of polygons and pie charts represent eight plant communities: two shrubland alliances (Muehlenbeckia complexa and Coprosma propinqua/Pseudopanax arboreus shrubland alliances), four native-dominated woodland alliances (Podocarpus totara/Muehlenbeckia australis, Dacrycarpus dacrydioides/Hedycarya arborea, Podocarpus totara-Corynocarpus laevigatus, and Podocarpus totara-Vitex lucens woodland alliances), and two exotic-dominated woodland alliances (Pinus spp. and Exotic broadleaf woodland alliances). Pie charts illustrate the proportions of plant community area relative to the total area of all plant communities in each farm.

is situated in the Canterbury region and consists primarily of high-productivity grassland, at an elevation of around 100 m above sea level, with a few tiny patches of shrubs and exotic shelterbelts. The region receives 618 mm of rain on average per year, and the median winter average daily minimum temperature can range from -2 to 11°C and the median summer average daily maximum temperature can range from 4 to 22°C [44].

Data collection

Ground truthing of aerial photographs was initially used to classify the woody vegetation occurring across each farm into five broad vegetation types, based on differences in species composition and structure: exotic pine forests, exotic shelterbelts, remnant native forests, regenerated native forest, and shrublands. This classification was used as a basis for a stratified random sampling scheme to quantify the aboveground and belowground carbon stock densities of the different tree and shrub communities present within woody vegetation patches on each farm. Within this study, tree ferns were also included due to their large size and functional role as sub-canopy trees within woody vegetation patches. Sampling plots were randomly positioned within each farm. At each sample location, woody vegetation was inventoried within square, 0.01-ha (10 × 10 m) survey plots (10 × 10 m), following a standard reconnaissance plot sampling method [45,46]; 145 plots in total were sampled across the three farms (Fig. 1). We recorded the percent cover of trees and shrubs, including tree ferns (see Appendix 2 for complete name of species) on a six-point scale: <1%, 1-5%, 6-10%, 11-25%, 26-50%, 51-75%. For each plot, we collected the following data: (1) identification and measurement of the diameter and estimated height of trees and shrubs, identified to the lowest taxonomic level possible, for all stems with a diameter of at least 2.5 cm at 1.3 m height (DBH) and for discrete shrubs (multiple stems at 1.3 m height), (2) the number of individuals, (3) the length and width of coarse woody debris (CWD, i.e., the remnants of dead trees with a diameter and length greater than 10 cm), and (4) the width and height of discrete shrubs, which was subsequently used to calculate cuboid volume. Heights were estimated visually for all stems that belonged to the same species in a sample plot's four quadrants. Plant nomenclature followed the New Zealand Plant Names Database [47]. To measure soil carbon in the upper mineral soil, we collected an approximately 15 × 15 cm by 15 cm deep soil sample from each of the four quadrants of the plot.

Woody plant community classification

To classify plots by their species composition, we used the canopy cover data. We first categorised the plots manually into three, very different compositional types: (1) native-dominated plots that were classified within remnant or regenerating native forests or shrub patches ($n = 131$); (2) *Pinus* spp.-dominated plots that occurred in monocultural plots (within pine plantation areas) ($n = 8$); and (3) exotic broadleaf plots that either in the form of dispersed single trees or group of trees that were planted as monoculture stands of exotic species (*Erythrina* × *sykesii* Barneby & Krukoff ($n = 1$) and *Salix* L. ($n = 5$).

For the native-dominated plots, an Importance Value Index (IVI) for each species was calculated by summing its cover-score midpoint recorded in each plot, multiplied by the depth of the height tier (the difference between the minimum and maximum values) [48]. We then generated a dendrogram for the native-dominated plots based on the importance values for each species plant species composition using the Two-Way Indicator Species Analysis (TWINSPAN; [49]) implemented in the community analysis software package PC-ORD [50]. TWINSPAN is a hierarchical, divisive method of classifying plots based on their species composition [49]. The default settings [50] were used for the maximum number of indicator species per division (five), the minimum group size (five plots), and for the maximum number of species in the output table (total number of species occurring in the plots). The pseudospecies cut levels [50] were set to 0, 0.15, 1.65, 31, and 194, based on the importance values for species in each community type.

Groups of compositionally similar plots resulting from the TWINSPAN were then assigned a name following the International Vegetation Classification (IVC) method [51]. These names were given as an "alliance", or a physiognomically uniform group of plant associations, sharing one or more dominant or diagnostic species, that occurred in the uppermost stratum of the vegetation [51]. Alliance names were a combination of the floristic name and the name of the structural community type. We determined the dominant species for inclusion in the floristic name by ranking the species in the alliances according to their relative cover and/or relative constancy. The slash symbol in the floristic name '/' is used to distinguish that the two dominant species occurred in different tiers, and the hyphen symbol '-' indicates where the two dominant species occurred in the same tier. The species that occurred in the uppermost stratum are listed first. We categorised alliances based on the dominant growth form; the term "woodland alliance" was used to describe the plant communities where trees were dominant over shrubs, and the term "shrubland alliance" was used to describe the plant communities that were dominated by shrubs [51]. Plots dominated by the exotic-*Pinus radiata* were classified as one alliance: *Pinus* spp woodland alliance; the rest of exotic-dominated plots were assigned to one group: exotic broadleaf woodland.

A Principal Coordinates Analysis (PCoA) was performed on the plot-level dataset to visualize the dissimilarities in species composition among plant community types, based on an Ochiai dissimilarity matrix computed using abundance data [52]. We then generated a spatial map to visualize the distribution of plant community types in each of the farms, where all woody vegetation patches were assigned plant community types based on the similarity of the sample plots.

Tree and shrub abundance and species richness estimation

The abundance of each tree and shrub species was estimated from the number of stems on each plot. Woody species diversity was calculated as relative species richness (number of species in each sample plot) using all woody and tree fern taxa that occurred within the 0.01-ha survey plot (10 × 10 m) [53].

Carbon estimation

We calculated the total carbon stored in two carbon pools: aboveground and in the soil; and then estimated the carbon stored belowground from the calculated aboveground carbon stock. To quantify aboveground carbon stock, we estimated carbon stored in live stems, shrubs, and coarse woody debris using known allometric equations and other published information (Appendix 1). We estimated the live stem biomass for individual trees within each community type on each farm by using the collected tree stem diameter and height data. First, for the New Zealand native species and *Pinus* spp., we estimated tree heights for individuals that had been assigned an average height (i.e., where multiple individuals of the species were in the plot) using species-specific diameter-height equations. For species for which only one individual occurred in a subplot and species for which species-specific diameter-height equations were not available, the field estimated height was used. Second, we used the estimated stem heights, the stem diameter data from plots, to estimate the biomass of individual live stems a within plots. We used species-specific equation when available, and when the species-specific allometry was not available, we applied country-specific equations. Different equations and methodologies were used for estimating biomass from live stems (for native tree species, selected exotic tree species, native tree ferns) (Appendix 1, See equation 1-6). Wood-specific density to calculate live stem biomass was obtained from two Y databases: 1) New Zealand species wood specific density and 2) global wood specific density dataset [54,55]. For species without species-specific wood specific density values ($n = 48$), we used the corresponding genus-level mean; when a genus-level mean was not available, a growth-form mean was used [54].

After estimating carbon stored in live stems, we estimate carbon stored in shrubs, using the measured volume of discrete shrubs (Appendix 1 equation 7). Discrete shrub density was obtained from Coomes et al. [56] and when the shrub density of specific species was not available, we used the mean shrub density of all species.

To calculate biomass content from coarse woody debris, we applied two different equations for coarse woody debris from 1) trees and shrubs, and 2) tree ferns and palms (Appendix 1, see equation 8-11). For coarse woody debris of trees and shrubs, we first estimated the volume from standing and fallen logs. that was then calculated to estimate the biomass content of coarse woody debris. We calculated the biomass of coarse woody debris differently for logs classified into four decay classes: 1, 2, 3, and 4 [56]. A decay-stage modifier (DSM) was obtained from Holdaway et al. [54]. Fresh-wood specific density of fallen and standing logs was obtained from Coomes et al. [56], and when the species-specific fresh-wood specific density was not available in Coomes et al. [56], we applied wood specific density from Holdaway et al. (2017) [57]. The carbon fraction of live stems, discrete shrubs, and coarse woody debris was then estimated as 0.5 of biomass [54]. Total carbon stored in live stems, discrete shrubs, and coarse woody debris were summarised as carbon from the aboveground biomass (AGB) pool. Then, we made the sum and estimation for each plot.

To estimate soil organic carbon (SOC), first we estimate the amount of total organic carbon (TOC) in the soil samples. Mineral soil samples taken from each plot subplot were aggregated and a 10 grams subsample of soil was combusted at 450°C in a muffle oven for eight hours following the loss-on-ignition (LOI) method [58]. The total organic carbon content (TOC as a percent measure) quantified for each of these samples represented the percentage weight loss of the sample due to combustion (Equation 12; Appendix 1). The %TOC converted to a soil organic carbon (SOC) per hectare quantity, assuming that carbon concentrations were representative of the top 30 cm of mineral soil at each plot (Equation 13; Appendix 1); carbon estimates were made relative to a 30 cm depth in order to align with other soil carbon studies in New Zealand. Soil bulk density was obtained from Sparling et al. [59], from two representative classes in sheep and beef cattle farms; native forests (0.84 Mg m^{-3}) and *Pinus radiata* plantation (0.81 Mg m^{-3}). The conversion to soil carbon per-hectare densities required the incorporation of estimates of bulk density at the plot locations; for this purpose, the mean bulk density of native forests was used for the native-dominated woodland and shrubland plots and the mean bulk density of *P. radiata* plantation was applied to the exotic-dominated woodland plots [59]. When soil samples were not available for some plots ($n = 12$), a mean soil carbon stock per hectare of plots of similar plant communities in the nearby habitat was applied.

We then estimated belowground biomass carbon (BGB), comprising biomass of live roots, as 25% of aboveground carbon [60] in each plot. Finally, we summed the carbon densities calculated for the three carbon pools: aboveground carbon, soil carbon, and belowground carbon, as total carbon stock density (t C ha^{-1}) for each plant community on each farm.

Quantification of potential ecosystem function

In addition to carbon, we estimated a range of metrics for nine ecosystem functions using data from each plot. The nine selected metrics indicate functions that support or represent both economic farm productivity and native biodiversity on sheep and beef cattle farms [61]. These metrics were estimated as the number of individuals of specific woody species in each plot that are recognised in the published literature for: (a) timber provision, (b) stabilizing gullies, (c) stabilizing soil from erosion, (d) reducing soil surface erosion by wind (soil erosion caused by strong wind), (e) providing livestock shelter, (f) providing food for birds, and (g) enhancing native plant biodiversity. In addition, two indicators of ecosystem 'disservice' (i.e., that have a detrimental effect on farm production) were selected: (h) the number of individuals of introduced woody plant species that have become invasive weeds, and (i) a community weighted measure of mean flammability across all species in a plot.

Data on the characteristics of each species contributing to the above indicators were acquired from secondary databases [62–67], except for community weighted flammability. Plant relative flammability data that were acquired from shoot-level flammability measurements, using a standard methodology applied to samples collected on the three farms for this study and existing datasets [68–70]. Community weighted flammability was estimated from individual relative flammability weighted using IVI following Cubino et al. (2018) [68]. For classifying number of introduced woody plant species that have become invasive weeds, we excluded species that are not perceived as weeds by farmers, e.g., willow (*Salix* spp.). All species-level data are given in Appendix 2. We then calculated average total carbon stock per hectare and the average scores for ecosystem functions for each plant community. The average scores was then normalized as *Z*-score.

Data Analysis

To address the first questions on how woody plant (including tree ferns) community structure and carbon stocks per hectare differ among community types, and what plant community characteristics contribute to a higher total carbon stock, we conducted a Principal Component Analysis (PCA) on the plot-level dataset to determine the relationships among the stem size, abundance, tree and shrub richness, and the aboveground carbon stock densities for the different plant communities. To address the second question on how multifunctionality differs and what functions trade off among different plant community types, we first calculated the relative values of each ecosystem function, abundance, and richness for each community type. We obtained these values by dividing the total value of each variable across all plots by the number of plots for each community type. To visualize these values, we created three bar plots: one for abundance, one for richness, and one for the score of multifunctionality. For the bar plots of abundance and richness, we used the actual values, while for the bar plot of multifunctionality, we plotted the sum of Z-scores, with a mean of zero and standard deviation of one. In addition, we created a radar plot to visualize the Z-scores, rescaled from 0 to 10, of each ecosystem function for each plant community type. This allowed us to compare the relative multifunctionality of each plant community type on each farm. For the last two ecosystem functions (number of introduced woody plant species that have become invasive weeds and community weighted flammability), the score was taken as the reverse so that higher values represented the more desirable situation for farm productivity. The sum of the Z-scores for each plant community was used as an estimate of the relative total multifunctionality of each plant community. All analyses, except TWINSPAN, were conducted in R 4.0.3 [71].

Results

Woody plant community types and stand structural characteristics

Native-dominated plots across the three farms were classified into six, distinct, plant community types. Together with the two exotic-dominated woodland community types, this resulted in eight different plant community types across the three farms (Fig. 2): two native-dominated shrubland alliances, four native-dominated woodland alliances, and two exotic-dominated woodland alliances (*Pinus* spp. woodland and Exotic broadleaf woodland). Across all farms, the native *Podocarpus totara-Vitex lucens* woodland alliance was the most common plant community in the plots sampled ($n = 35$; only present on the Kaipara farm), followed by the *Dacrycarpus dacrydioides/Hedycarya arborea* woodland alliance ($n = 32$; only present on the Ruapehu farm), and the *Coprosma propinqua-Pseudopanax arboreus* shrubland alliance ($n = 24$; only present on the Hurunui farm), respectively. The Kaipara farm had the greatest number of different plant community types.

The ordination diagrams (Fig. 2) showed a clear separation in species composition among the three farms, and a clear distinction between the two structural woody vegetation types: woodland alliances and shrubland alliances. Only 12 species occurred in more than 10 stems per plot (Fig. 2). The ordination also showed that most plots of exotic-dominated woodland alliances in Kaipara and Ruapehu farms had species composition similar to the native-dominated woodland alliances and only very few exotic-dominated plots that had distinctive species composition (Fig. 2).

Average woody species abundance and richness were highly variable among the eight plant communities (Table 1). The average number of species (± standard deviation) ranged from one (*Pinus* spp. woodland alliance) to 5.60 ± 2.52 (*Podocarpus totara-Vitex lucens* woodland), and the average number of individual stems ranged from 4.13 ± 2.03 (*Pinus*

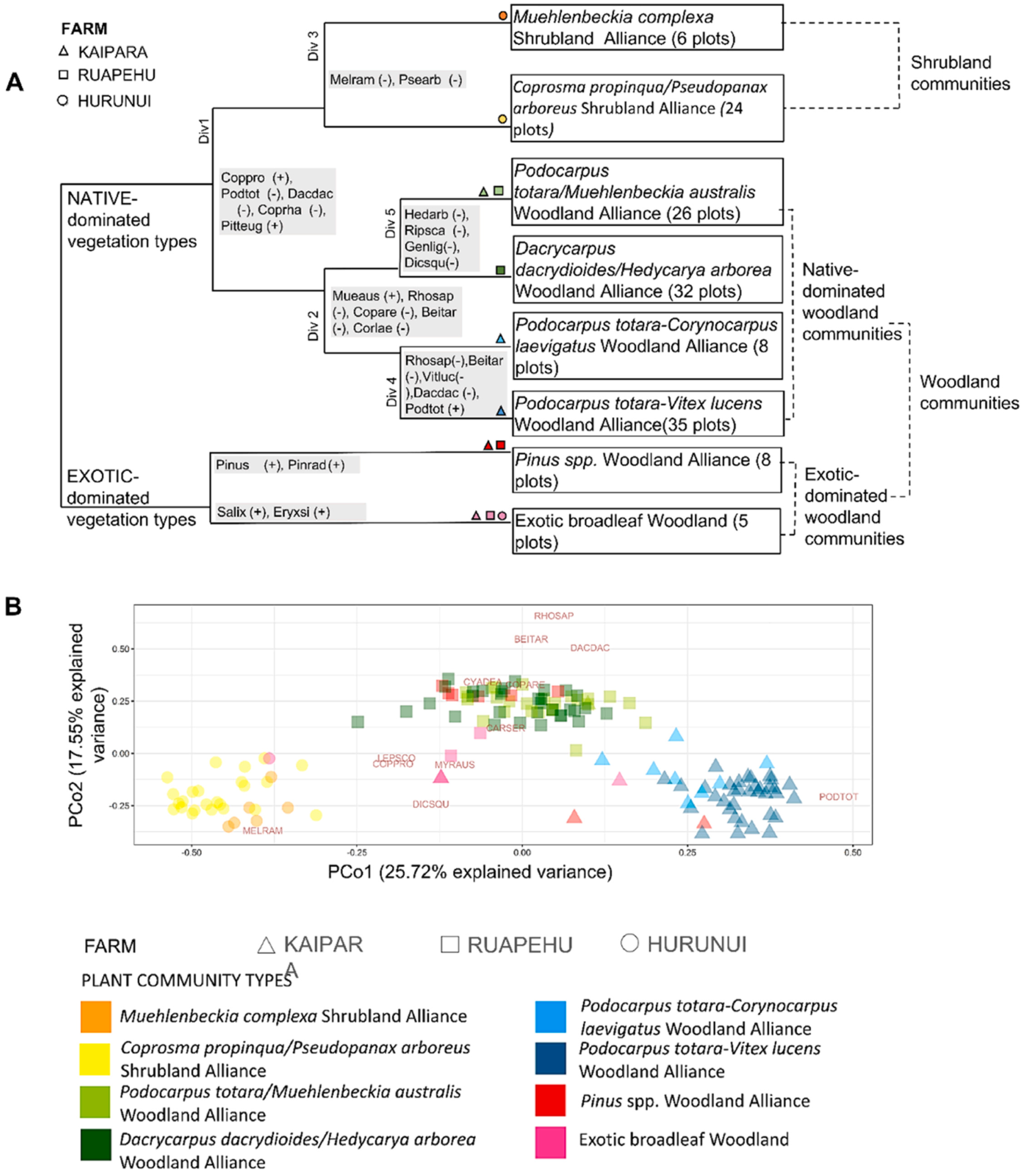

Fig. 2. **A**) A dendrogram of six native-dominated and two exotic-dominated plant communities and its two structural groups: shrubland alliances and woodland alliances; across the Kaipara, Ruapehu, and Hurunui farms. The floristic name of plant communities represented the two species with the highest mean IVI across all strata (≥10) and/or the highest species occurrence in each plot, combined with the structural community's name. Species codes (in grey boxes) are the first three letters of the generic and species name for each pseudospecies (see Appendix 2 for full species names and life-forms); positive (+) and negative (-) signs indicate the preferences. The symbols indicate the location of community occurrence; and B) A two-dimensional scatterplot from a Principal Coordinate Analysis of species composition of on the Kaipara, Ruapehu, and Hurunui farms. Colours represent plant community type, each point represents a plot, and the distance between plots indicates their relative similarity. Red species labels on each graph indicate taxa represented by more than ten stems on each plot and represents the first three letters of the genus name and specific epithet (see Appendix 2 for full names).

spp. woodland alliance) to 29.68 ± 9.14 (*Podocarpus totara-Vitex lucens* woodland) (*Muehlenbeckia complexa* shrubland).

Smaller diameter stems under 25 cm dominated the sample plots in all three farms, with only a few larger diameter stems exceeding 25 cm or 50 cm (Appendix 3). The diameter of the stems ranged from 2.67 ± 4.19 cm (*Muehlenbeckia complexa* shrubland) to 47.77 ± 11.41 cm (*Pinus* spp. woodland alliance), and the height of the stems varied from 1.62 ± 2.55 cm (*Muehlenbeckia complexa* shrubland Alliance) to 20.28 ± 1.38 cm (*Pinus* spp. woodland alliance) (Table 1). Woodland alliances had larger and higher stems compared to shrubland alliances (Table 1). Exotic-dominated woodland alliances had the most stems with diameters greater than 25 cm ($n = 36$), while native-dominated woodland communities had the fewest (Appendix 3). Similarly, trees taller than 10 cm were seen on woodland alliance plots, with exotic plots having a higher frequency (Appendix 3, Appendix 4). This general distribution was similar on the three farms, with only very few plots having stems with an average diameter larger than 50 cm and higher than 15 cm (Appendix 3, Appendix 4).

Table 1

Summary (mean ± standard deviation) of stand characteristics of eight plant community types, in terms of size measurements for: live stem mean height (m) and mean diameter at breast height (DBH - cm), continuous shrub mean height (cm) and mean volume (cm^3), coarse woody debris mean diameter (the vertical measurement of coarse woody debris; cm) and mean length (the horizontal measurement of coarse woody debris/ length; cm), and mean live stem species richness (per 0.01 ha) and abundance (per 0.01 ha)

Plant community types	Live stem size		Shrub size		Coarse woody debris size		Stem species richness	Stem Abundance
	Height (m)	DBH (cm)	Height (m)	Volume (cm^3)	Diameter (cm)	Length (cm)		
Muehlenbeckia complexa shrubland Alliance	1.62 ± 2.55	2.67 ± 4.19	0.9 ± 0.48	0.91 ± 0.72	N/A	0.02	2.67 ± 1.21	29.67 ± 9.14
Coprosma propinqua/Pseudopanax arboreus shrubland alliance	5.39 ± 1.48	9.2 ± 4.87	0.08 ± 0.38	0.14 ± 0.71	0.60 ± 0.26	10.92 ± 4.99	3.46 ± 1.72	17.33 ± 9.90
Podocarpus totara/Muehlenbeckia australis woodland alliance	10.9 ± 4.72	28.07 ± 23.65	N/A	N/A	0.39 ± 0.36	12.29 ± 12.92	2.58±1.65	6.00±4.71
Dacrycarpus dacrydioides/Hedycarya arborea woodland alliance	7.75 ± 2.24	19.04 ± 6.20	N/A	N/A	0.54 ± 0.28		4.75 ± 2.02	18.66 ± 11.83
Podocarpus totara-Corynocarpus laevigatus woodland alliance	8.48 ± 2.15	19.47 ± 8.07	N/A	N/A	0.1 ± 0.29	5.81 ± 16.44	2.25 ± 1.16	8.88±8.48
Podocarpus totara-Vitex lucens woodland alliance	10.06 ± 3.06	18.14 ± 11.67	N/A	N/A	0.47 ± 0.35	13.49 ± 13.77	5.60 ± 2.52	18.40 ± 9.84
Pinus spp. woodland alliance	20.28 ± 1.38	47.77 ± 11.41	N/A	N/A	0.67 ± 0.08	14.99 ± 2.83	1.00 ± 00	4.13 ± 2.03
Exotic broadleaf woodland	10.99 ± 7.22	40.65 ± 38.23	0.55 ± 1.34	4.39 ± 10.75	0.11 ± 0.27	1.71 ± 4.18	1.67 ± 1.03	5.50 ± 5.65

Carbon stock per hectare for each plant community type

Mean total carbon stock densities were highly variable across all eight plant community types; ranged from 19.83 ± 18.87t C ha^{-1} (*Muehlenbeckia complexa* shrubland alliance) to 318.62 ± 278.8 t C ha^{-1} (Exotic broadleaf woodland), with an average 175.58 + 99.93 t C ha^{-1} across all plant community types (Fig. 3 A; Appendix 5). Total carbon stock densities from the three measured carbon pools (aboveground, belowground, and soil) were greater in the woodland alliances than in the shrubland alliances; the two exotic-dominated woodland alliances, the *Pinus* spp. woodland alliance and the exotic broadleaf woodland, had the highest total carbon stock per hectare (Fig. 3; Appendix 5). Although a significant difference in carbon stock per hectare was observed between the two native shrubland alliances and the exotic-dominated woodland alliances, neither of these groups were significantly different from the native woodland alliances (Fig. 3A).

The greatest carbon pool was aboveground biomass (71.62%), followed by belowground biomass (17.90%) and soil carbon (10.47%) (Appendix 5). The greatest contribution to aboveground carbon stocks (measured from live trees, discrete shrubs, and deadwood) was from live trees (97.22%, representing 71.62% of the total; Appendix 5). Soil carbon stocks showed the lowest variation among all plant communities (Appendix 5) compared to the other two carbon pools.

Aboveground biomass carbon was shown to be more closely associated with stem size than species richness and abundance (Fig. 3B). In total, smaller diameter stems that appeared more frequently in the sample plots produced a lower total aboveground carbon stock than larger diameter stems that occurred less frequently (Fig. 3C).

The relative potential multifunctionality of plant community types

A relationship was observed between multifunctionality scores and plant diversity. Native-dominated plant communities showed higher multifunctionality and diversity scores compared to exotic-dominated plant communities (Fig. 4). *Muehlenbeckia complexa* shrubland alliance that had the highest abundance had the highest multifunctionality score, while *Pinus* spp. woodland that had the lowest richness and abundance had the lowest multifunctionality score (Fig. 4 A, B and C). In communities with low species diversity, the number of ecological functions inherent to each species had a greater influence on multifunctionality. For example, a low abundance, a low species richness and a low multifunctionality score were observed for *Pinus* spp. woodland, which mostly consisted of species with fewer ecosystem functions (*Pinus* spp. only had a function in timber provisioning; Appendix 2, Fig. 4).

The sum of Z-score (Fig. 4C) represents overall plant community multifunctionality scores, ranging from 20.78 (Pinus spp. woodland) to 54.95 (*Coprosma propinqua/Pseudopanax arboreus* woodland alliance). Plant communities with more individual stems and associated ecosystem functions generally scored higher on total multifunctionality. The multifunctionality scores of shrubland alliances and native-dominated woodland alliances were higher than exotic-dominated woodland alliances that were relatively lower in stem number (Fig. 4A and C). The exotic-dominated woodland alliances had a lower overall multifunctionality score compared to shrubland alliances and native-dominated woodland alliances due to a higher number of stems of introduced woody plant species that have become invasive weeds and a higher value of community flammability, which lowered the total area of multifunctionality. The mapped ecosystem functions varied between shrubland and woodland plant community types (Fig. 4D). For example, woodland alliances outperformed shrubland alliances in terms of carbon sequestration, shelter, and timber (Fig. 4 D). In contrast, shrubland alliances scored higher on their quantity of native species, soil stabilization, reduction of soil surface erosion by wind, and the presence of number of introduced woody plant species that have become invasive weeds and community flammability (Fig. 4.D).

Discussion

Our research on New Zealand sheep and beef cattle farms illustrates the necessity of incorporating native trees and shrub to achieve multifunctionality on farms that contain woody plant communities. In doing so, we have identified NbS actions that can help landowners enhance multifunctionality on their farms to deliver multiple co-benefits (as per [12,16]). We observed possible relationships among carbon stocks, woody plant species richness, and multiple ecosystem functions across three New Zealand sheep and beef cattle farms. Carbon stocks were strongly and consistently related to stem diameter and height, rather than abundance or woody plant richness; however, plant richness and the presence of key species were essential for high relative multifunctionality on farms. Combining multiple species with different ecosystem functions can result in a multifunctional land use that meets as many ecologically- and socially-beneficial outcomes as possible. This increased diversity and function is likely to increase farm resilience in the face of multiple land management challenges such as climate change. Thus, our findings have implications for achieving multiple benefits for the management of woody vegetation in these

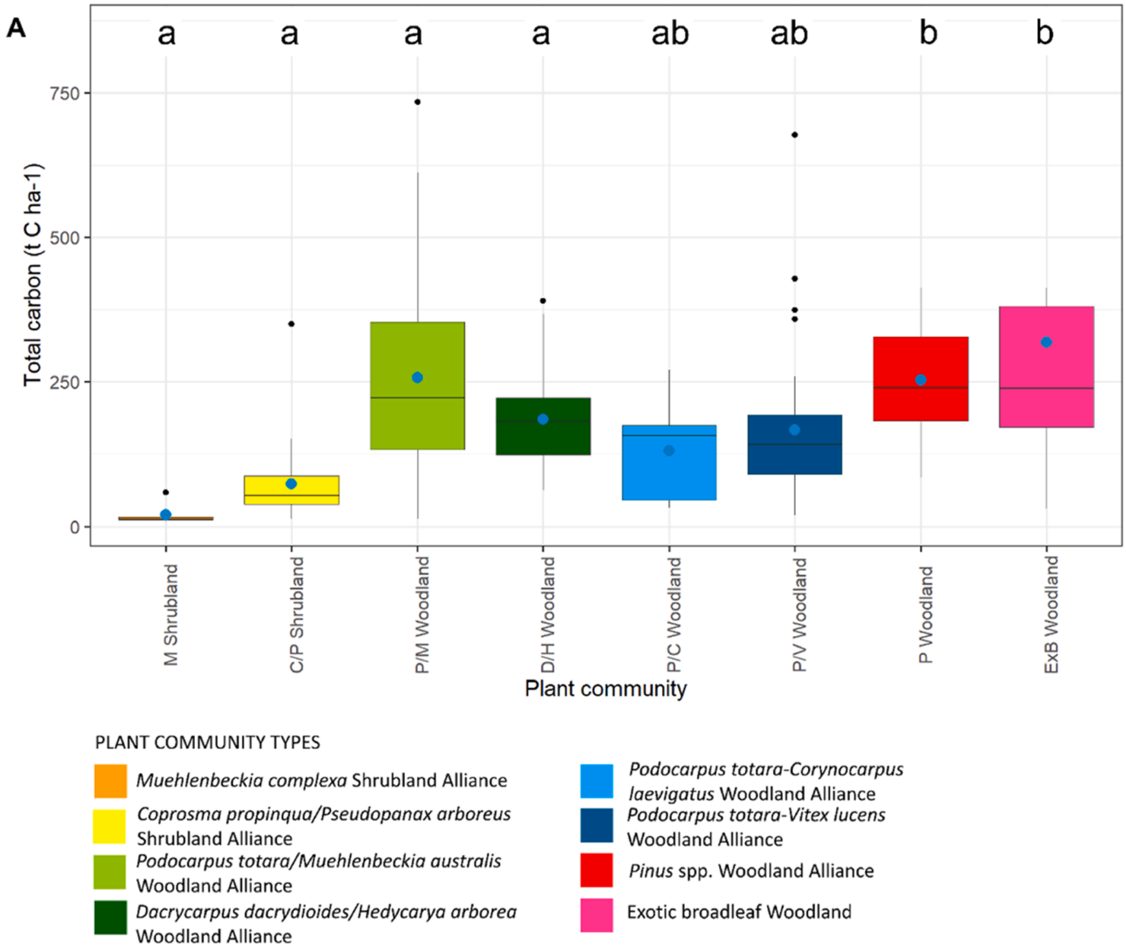

Fig. 3. The average total carbon stock per hectare for each plant community type, and the strong relationship between total carbon stock per hectare and stem size: **A**) Boxplots of total carbon stock per hectare (t C ha^{-1}). The numbers on A represent the mean value for each plot. The bottom and the top of each box represent the 25th and 75th percentiles, the thick band in the box represents the median, the whiskers represent 1.5 times the interquartile range, and the black dots represent outlier values that are bigger than the upper whisker and less than the lower whisker. The means sharing a letter are not significantly different (according to Tukey test); **B**) Principal Component Analysis (PCA) of the variables used to estimate the total carbon stock densities from all carbon pools on the Kaipara, Ruapehu, and Hurunui farms: stem diameter (cm), stem height (m), species richness, and abundance. Points on B show sample plots, variable loadings on the PC1 and PC2 are shown by blue and grey arrows: point shapes represent farms, and colour gradients represent mean aboveground carbon stock per hectare (t C ha^{-1}); and **C**) Proportion of total biomass carbon stock contributed by each DBH class: the bar plot shows the frequency of stems by DBH class, and the red dots shows the total carbon stock of all trees in all plots within each diameter class (1000 tonnes C).

agroecosystems. While this study provides insights into the potential ecosystem service provision of native species on farms, the assessment of ecosystem services was binary rather quantitative, which may not capture the quantity or quality of ecosystem service provisions or weigh some services more highly than others. However, it provides a relative comparison of the multiple ecosystem functions provided by the woody vegetation in productive landscapes.

Carbon estimates in farms and natural ecosystems

Our research showed comparable carbon stock values to those of other studies conducted in New Zealand. The average total carbon stock per hectare in our study was 293.48 ± 200.01 t C ha^{-1} for the exotic-dominated woodland alliances, 192.84 ± 132.86 t C ha^{-1} for the native-dominated woodland alliances, and 64.31 ± 66.96 t C ha^{-1} for the shrubland alliances (Appendix 7). The average aboveground biomass in native-dominated woodland alliances (145.20 ± 106.26 t C ha^{-1}) and in the exotic-dominated woodland alliances (202.87 ± 160.33 t C ha^{-1}) in our study (Appendix 7) were higher than the aboveground carbon stock per hectare in secondary forest (67.15 t C ha^{-1}; [57]), of the old growth forest (200.65 t C ha^{-1}; [57]), and native forest (169.1 ± 18.4 t C ha^{-1}; [56]). The average aboveground carbon stock per hectare of the shrubland alliances (44.61±53.02 t C ha^{-1}; Appendix 7) was comparable to the aboveground carbon stock in native shrubland community in the natural landscape (53.80 t C ha^{-1}; [56]). The average aboveground carbon stocks per hectare of native and exotic-dominated woodland alliances in our study farms were higher compared to the national estimate carbon stock per hectare of woody vegetations on farms, that was between 13.05 - 60.57 t C ha^{-1} for grassland with woody biomass [32].

Soil carbon contributed only a small percentage of the total carbon stock on these sheep and beef farms (14.99 ± 5.44 t SOC ha-1 under shrubland alliances and 19.19 ± 5.69 t SOC ha-1 under exotic-dominated woodland alliances and 20.39 ± 6.96 t SOC ha-1 under native-dominated woodland alliances). This result is consistent with the range of values presented in another study on soil carbon stocks under shelterbelts in agricultural landscapes in New Zealand (20.00 ± 12.1 t SOC ha^{-1}; [34]). Grazing that commonly occurs within woody plant communities on sheep and beef cattle farms likely has an effect on soil carbon sequestration by increasing disturbance, which may result in

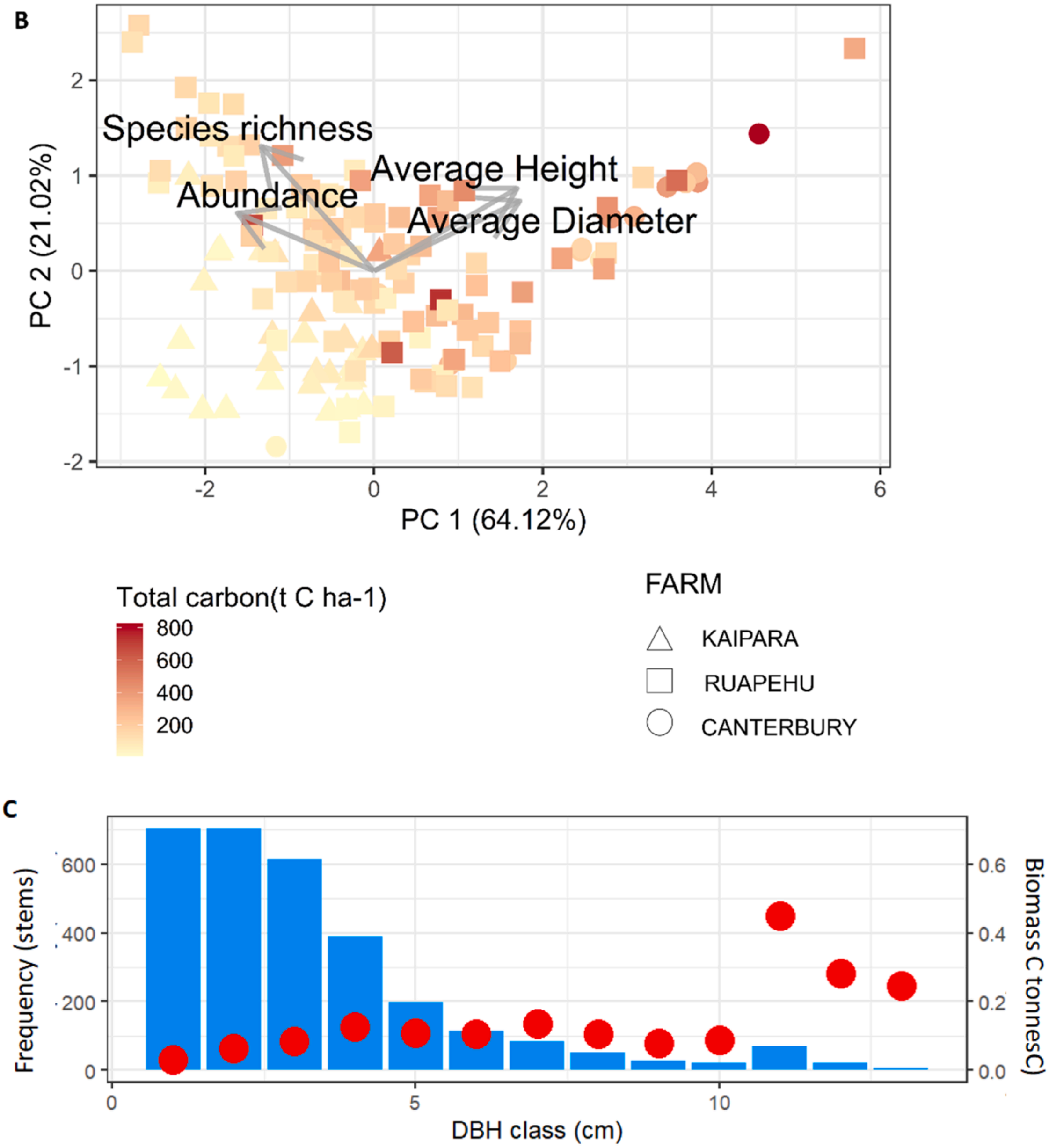

Fig. 3. (*continued*).

Fig. 4. Bar plots and a radar graph present results for eight different plant communities: A) A bar plot illustrates the abundance stems per plot of eight plant communities; B) A bar plot shows the species richness stems per plot of eight plant communities; C) A bar plot displays the sum of *Z*-scores for nine ecosystem functions in eight plant communities; and D) Radar graphs depict the sum of *Z*-scores for 10 ecosystem functions of eight plant communities. The *Z*-scores of all ecosystem functions are plotted on the radar graphs, from center top to right top for eight plant community types, of TC (carbon sequestration), TI (timber provision), GS (gully stabilization), EC (soil erosion control), WE (wind erosion/soil surface erosion control), SH (shelter), BF (bird food), NS (enhancing native species), I_WD (fewer weeds), and I_FL (lower community flammability). All values on the radar graphs are relative, calculated as *Z*-scores with a mean of zero and a standard deviation of one, and rescaled from zero to 10. The color of the bar plots and the radar graph depict the plant community. The complete dataset can be found in Appendices 8 and 9.

lower sequestered soil carbon. Further comparative investigations on soil carbon stock in sheep and cattle farms are needed to understand the observed variation in soil carbon.

The link between aboveground carbon stocks and tree size has been well established [72]. In our study, as expected, plots in the woodland alliances contained trees of the larger sizes, compared to plots in the shrubland alliances (Table 1); therefore, woodlands consistently contained more carbon per ha than shrublands (Fig. 3). Among the woodland alliances, exotic trees were, on average, larger than native trees (Appendix 3). Our analysis showed that, for explaining variation in carbon stocks, tree size and abundance were more important than richness (Fig. 3. D). These findings are similar to the results of a previous study [73] showing that tree diameter is an important predictor of aboveground biomass carbon stock in Tanzania. Similarly, Chave et al. [74], estimated the carbon stock of the aboveground biomass on three continents (America, Asia and Oceania) and showed that trunk diameter and height to be important predictors of aboveground biomass.

Retaining large trees is crucial when tree size is the most important indicator of carbon storage, which is consistent with conclusions from prior research [75]. In this study, however, the majority of remaining native trees were small-sized trees, whereas the majority of the large-sized trees were exotic tree species that were purposefully planted. Thus, it is important for policy and land managers to prioritise the retention of existing trees, especially large and tall trees and species that have the potential to reach large diameters. When implementing restoration, managers also should prioritise the establishment of these type of species, especially native species that can grow larger than exotic [76], for example *Agathis australis, Podocarpus totara*, or *Dacrydium cupressinum* [77].

Managers should also aim to reduce the effects of disturbances, such as wind exposure, grazing, and drought, which can slow growth and therefore reduce the rate of carbon sequestration [78]. The retention and restoration of native species, given the multifunctionality they bring, is a long-term land and biodiversity management strategy that should be promoted to farmers. For example, although the exotic trees on our study farms were very fast-growing species, e.g., *P. radiata*, growth rates can be nearly matched by some native species, e.g., *P. totara*, and maximum potential size and life span is by far exceeded by other native species, e.g., *D. dacrydioides*, when properly managed [77, 79].

Co-benefits of carbon and biodiversity: The win-win outcome of managing for multifunctionality

Our study shows that native-dominated woodlands and shrublands provide greater multifunctionality than exotic-dominated woodlands (Fig. 4; see Appendix 2 for ecosystem functions of each species). This is likely because some species contribute to multiple ecosystem functions simultaniously. For example, *Muehlenbeckia complexa* shrubland alliance had low woody species richness but had a relatively greater multifunctionality due to the presence of *Muehlenbeckia complexa* that has multiple functions: soil erosion and wind erosion reduction. In contrast, the exotic *Pinus* spp. plantations have low diversity and low multifunctionality because of the limited functions inherent to this species, i.e., timber provision (Fig. 4). Interestingly, some native species on the three farms have potential ecosystem functions that are similar to exotic species. For example, the native *Podocarpus totara* that has multiple functions, including use as a source of timber, could be a better alternative to exotic *Pinus radiata*, which is considered invasive [80]; or the native *Kunzea* spp that benefits birds and bees, as an alternative to the exotic *Populus* spp for shelterbelt plantings [81]. Conserving and restoring native species that provide multiple ecosystem functions increases both native biodiversity and the multifunctionality of the landscape. Therefore, policy incentives that preserve and restore multifunctionality, rather than only provision of carbon stocks are desirable in New Zealand agroecosystems to realise their potential for enhancing native biodiversity and its funtioning. This would disincentivise the conversion of native ecosystems to intensive monocultures (e.g., *Pinus* spp. plantations), which have multiple social and ecological negative consequences (e.g. invasive species, myrtle rust) [60,82,83], including the post-harvest impacts such as soil disturbance and reduction of soil carbon and nitrogen stocks [84,85]. Land managers should carefully evaluate the tradeoffs between these two aspects—carbon stock and multifunctionality—to achieve win-win solutions for the economy and biodiversity. Careful and informed species selection, for both retaining and planting, will be vital to maximise the benefits of multifunctionality. Moreover, it is important for policymakers, in addition to farmers, to evaluate the trade-offs that their policies may incentivize.

Our multifunctionality scores were designed to illustrate the set of functions that will help land managers in assessing the multifunctionality of different plant community types. Some plant communities received high scores on several ecological functions, whereas others received only minimal or medium scores. This knowledge will assist land managers in determining which plant communities are most suited for specific purpose. For example, managing *Pinus* spp. and exotic broadleaf woodland plots will increase the farm's carbon stock, while shrubland management will benefit biodiversity. However, it is necessary to find a balance between multiple ecosystem services to preserve the farm's long-term sustainability [86]; in other words, multifunctionality and sustainability should receive priority above maximal production. For example, although the *Pinus* spp. woodland alliance stored more carbon, it did so at the expense of other ecosystem services (gully stabilization, erosion management, and higher flammability) (Fig. 4H), making the plant community more vulnerable to recurring extreme weather and less beneficial to biodiversity. On the other hand, having a larger shrubland community on the farm may reduce the farm's economic value, despite the benefits to birds and soil health. Enhancing multifunctionality in the production landscape to a more sustainable system may reduce average yields. Therefore, land managers need to consider plant communities that can be multifunctional and more adaptable to change while still supporting the farm's primary outputs, as exemplified by the *Podocarpus totara-Vitex lucens* woodland alliance that provides timber as well as other ecosystem functions. Considering multifunctionality is therefore important for identifying the NbS actions that can deliver carbon benefits, while simultaneously enhancing ecological services and conserving the structure, function, and composition of ecosystems [16].

When deciding what type of plant community to prioritize on land, our research shows that land managers should consider trade-offs. Our study should therefore be useful to land managers when choosing what type of combination is needed [27]. If increasing carbon stocks on farms is the only management goal, then the land managers could retain or plant exotic-dominated plant community. However, if the land manager wants to achieve multiple objectives that can lead to a more sustainable farm system, then the land manager may seek a strategy of combining multiple plant community types depending on the functions needed. Alternatively, the land manager could prioritize plant communities that can achieve multiple objectives simultaneously. More importantly, although pasture can have a significant soil carbon stock of up to 110.4 tonnes of carbon per hectare [87], it is important to consider that converting patches of woody vegetation to a land cover without biomass cover, such as pasture, will result in the loss of the biomass carbon that is shown to be significant in our study. Therefore, such actions should be avoided, as these areas of woody vegetation retain significant carbon stocks per hectare not only from soil, but also biomass carbon. Farmers need greater support for the retention or enhancement of woody vegetation that provide a pathway for carbon benefits and biodiversity conservation at a lower cost than new planting [27,88]. Land managers frequently search for possibilities to conserve and/or restore existing woody vegetation in their farm planning. This involves selecting the appropriate plant community for the appropriate functions to be conserved. The common practice of preserving woody vegetation on steep slopes or along stream corridors [89], to minimize erosion on farms, thereby protecting soil resources and ensuring water quality as well as increasing carbon storage, is an example of a policy that should be encouraged.

However, continuous grazing, which is typical in pastoral landscapes [26], has likely affected the quality and quantity of native woody biomass in agricultural land [27]. Fragmentation might also reduce the ability of remnants of native woody vegetation to maintain structure and species within the woodland vegetation patches (Norton & Miller, 2000). The common practice of selective logging would also threaten the sustainability of the structure because it has removed larger trees from the native-dominated woodland on agricultural landscapes. This is similar to other studies in other countries, for example in Brazil [90] and in Colombia [88] where plant composition and structure of woodlands in agriculture landscape was lower compared to the natural ecosystems, resulted on a lower aboveground biomass. Tree species present in pastoral systems in Central America, without proper conservation, will continuously be degraded [91]. Although this has been observed in many countries, this is also likely to happen in New Zealand [29]. Therefore, conserving the remaining trees and shrubs is an important action to retain multifunctionality.

Our analysis measured the standing stocks of woody vegetation on sheep and beef cattle farms, which could serve as a baseline for meeting national requirements for monitoring increases in carbon sequestration, while also providing opportunities for additional multifunctionality through the presence of native biodiversity. On the other hand, the sheep and beef cattle farms with existing woody vegetation are situated on lowland areas that are suitable for other land uses such as agriculture and monoculture plantation forestry [27]. It is important to note that regenerating native forests in rural New Zealand that often occurred on these sheep and beef cattle farms, are at risk of conversion to commercial exotic plantations due to the potential for generating greater carbon-credits through exotic forestry [27]. Land use with lower economic value, such as conventional sheep and cattle farms, may also be impacted by the need for land for carbon farming [92]. Some New Zealand farms have been purchased with the intention of converting them to carbon forestry, or where exotic radiata pine is planted for the purpose of obtaining carbon credit from the emissions trading scheme without the intention of harvesting the trees [93]. While the current policy does not specifically protect existing woody vegetation on farms, understanding of the importance of keeping and managing trees and shrubs in the agricultural environment, as well as preventing their conversion to reduced multifunctional land use, should be encouraged. For the maintenance or improvement of woody vegetation, farmers require greater assistance, which can take the shape of incentives or innovative best practices [36]. Developing an appropriate and acceptable policy, including incentives for farmers to diversify their farms for climate change adaptation and mitigation, is challenging and requires additional research and effort to tailor the policies to farmers' needs [94] (i.e., to incorporate quantification of ecosystem quantity and "value" beyond presence or absence, so that trade-offs can be more accurately characterized). Moreover, following the NbS guidelines, it is important that the likely effects of the trade-offs between ecosystem functions and objectives are accurately assessed, fully disclosed, and agreed upon by the landowners who will be most affected by them [16].

Conclusions

Overall, we have shown that the carbon stock per hectare currently held by woody vegetation patches on sheep and beef cattle farms is significant, and that the multifunctionality varies widely, depending on the species composition within patches. Management practices that conserve and restore native woody vegetation on farms can provide ecosystem benefits, potentially higher carbon stocks relative to exotic plantations, and the opportunity to increase the economic value of the land. Future research should aim to quantify the quantity and quality of ecosystem service provisions to provide a more comprehensive understanding of the trade-offs and co-benefits associated with conserving and restoring woody vegetation on farms. We further advise that, in order to better achieve win-win outcomes of carbon and biodiversity conservation for agricultural systems from the existing woody vegetation, a comprehensive understanding of trade-off dynamics and the integrated implementation of strategies needs to be used to choose the most feasible combination of co-benefits and trade-offs between ecosystem functions. Based on current findings, we recommend the following practices: 1) recommendations to landowners to retain the existing trees and shrubs species to conserve their multifunctionality and carbon stock, with additional management techniques to maintain the quality of the existing woody vegetation and large trees; and 2) when conserving existing woody vegetation and/or if the landowners want to plant more trees, careful species selection and species composition are necessary to enhance multifunctionality. In contrast to non-collaborative ecological restoration initiatives that may not explicitly target biological diversity, these recommendations can help support landowners to identify the NbS actions that explicitly include conserving and/or planting woody vegetation on farms to protect the long-term ecological integrity of the area while achieving multiple co-benefits [16]. If woody vegetation on farms is not valued, it risks being converted to more 'productive' land use (e.g., intensive dairy farming, residential areas, pasture for livestock, pine plantations) [95].

Declaration of Competing Interest

The authors have no conflicts of interest or competing interests to declare.

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Appendix 1 Equations used for estimating 1) live tree height, 2a.) volume of standing dead logs,2b.) volume of fallen dead logs; and biomass carbon stock densities for 3a.) native and exotic live stems, 3b.) exotic Pinus spp. live stems, 3c.) exotic Erythrina sykesii, 3.d.) exotic Salix spp., 3.e.) native tree ferns and palms, 4) discrete shrubs, 5a) biomass of dead tree, and 5b) biomass of dead tree ferns and palms. Where D was the diameter at breast height (cm), H was the height (m); A was the normalized elevation (elevation (m above sea level (a.s.l.)/100) of the plot scaled to be similar in range to the other predictors, a, b, c, and d were model parameters, ε_H was the coefficient of the height-diameter model, BLS was live stems biomass (kg), W was wood specific density, C_{Shrub} was the biomass carbon of discrete shrubs (kg), S was shrub density. Dm was the diameter of the dead log, L was the length of the log, r1 and r2 were two radii measures of the log, C_{CWD_T} was the biomass carbon of the coarse woody debris of trees (kg), $C_{CWD_{TFP}}$ was the biomass carbon of the coarse woody debris of tree ferns and palms (kg), V was the volume of the standing log (V_{SL}) or the fallen log (V_{FL}), FW was fresh-weight density, and DSM was the decay-stage modifier, DW_{oven} was the oven-dry weight (g) and IW_{400} was the weight after ignition (g), TOC was the total organic carbon concentration (%), BD was the soil bulk density (Mg m^{-3}), and h was the soil depth (h = 30 cm)

	Carbon pools	Components	Variable	Applied to	Equation	Citation
1	Aboveground biomass	Live stems	Height	Native species trees, and *Pinus radiata* D.Don	$Ln\ (H-1.35) = \ln(a)+\ln(1-bA)+\ln(1-\exp(CD^d))+\varepsilon_H$	[54]
2			Biomass	70 species of native trees and shrubs ($n = 2{,}443$) and exotic species that were not dominant ($n = 14$)	$B_{LS} = 0.905 \times W \times 0.000483(D^2H)^{0.978} + 0.00175\ D^{2.20} + 0.0171\ D^{1.75}$	[54]
3			Biomass	Biomass carbon of exotic *Pinus* spp. and *P. radiata* ($n = 40$)	$Ln(B_{LS}) = -9069 + 1.2273\ lnD + 0.1411\ (lnD)^2 - 0.0078\ lnh + 0.00840\ (lnH)^2$	[96]
4			Biomass	Biomass carbon of exotic *E.* × *sykesii* ($n = 68$)	$Ln\ B_{LS} = -1.4595 + 2.0618\ lnD$	[97]
5			Biomass	Biomass carbon of exotic *Salix* spp. ($n = 21$)	$B_{LS} = Exp(-2.2094 + 2.3867\ lnD)$	[98]
6			Biomass	Biomass carbon of native tree ferns ($n = 459$)	$C_{TFP} = 0.0027\ (D^2H)^{1.19}$	[99]
7		Shrubs	Biomass	Biomass carbon of discrete shrubs ($n = 189$)	$C_{Shrub} = 0.5 \times S \times cuboid\ volume$	[56]
8		Coarse woody debris	Volume	Volume of standing logs V_S ($n = 167$)	$V_{SL} = \pi \times \left(\frac{Dm}{2}\right)^2 \times L$	[54,99]
9			Volume	Volume of fallen logs V_F ($n = 279$)	$V_{FL} = \frac{\pi L}{3}[(r_1^2 + r_2^2) + (r_1 \times r_2)]$	[54]
10			Biomass	Biomass carbon of coarse woody debris of trees	$C_{CWD_T} = 0.5 \times \sum V \times FW \times DSM$	[54]
11			Biomass	Biomass carbon of coarse woody debris of tree ferns and palms	$C_{CWD_{TFP}} = 0.0027 \times DSM \times (D^2L)^{1.19}$	[54]
12	Soil carbon		Proportion of organic carbon	Total organic carbon	$TOC\ (\%) = \left[\frac{DW_{oven} - IW_{400C}}{DW_{oven}}\right] \times \frac{100}{7.2}$	[35]
13			Soil carbon	Soil organic carbon	$SOC = \%TOC \times BD \times h$	[35]

Appendix 2 Summary data of species and genus identified on the plant inventory on the three study farms and it's frequency of stem occurrence on the four quadrants within 10 × 10 m sample plots, shows species/taxa codes on inventory, local name, Maori name, suitability as timber source (TI), preference for soil erosion control (EC), preference for gully stabilization (GS), preference for soil surface erosion caused by wind (WE), preference as food source for birds (BF), preference as shelter for animals (SH), and the frequency of stems (Fr). "✓" symbol signifies the species that was planted to provide the certain ecosystem functions, and "*" symbol in the frequency column indicates that the species was present on the plot but the stem was too small (2.5 cm) to be counted on the stem inventory

	Code	**Preferred species name**	**Local name**	**Maori name**	**TI**	**EC**	**GS**	**WE**	**BF**	**SH**	**NS**	**WE**	**Fr**
1	AGAAUS	*Agathis australis* (D. Don) Lindl. ex Loudon (1829)	Cowrie kauri, kauri pine	Kaore (sapling), kauri, ware							✓	✓	4
2	ALEEXC	*Alectryon excelsus* Gaertn. (1788)	New Zealand ash, titoki	tapitapi, titoki, titongi, tokitoki, tongitongi, topitopi	✓	✓			✓		✓	✓	37
3	ARISER	*Aristotelia serrata* (J.R. Forst. & G.Forst.) W.R. B.Oliv. (1921)	Wineberry, makomako	Mako, makomako		✓	✓		✓		✓	✓	35
4	ASPSCA	*Asparagus scandens* Thunb. (1794)	Climbing asparagus	-					✓				3
5	BEITAR	*Beilschmiedia tarairi* (A. Cunn.) Benth. & Hook. f. ex Kirk (1889)	Taraire	Taraire	✓				✓	✓	✓	✓	88
6	BEITAW	*Beilschmiedia tawa* (A. Cunn.) Benth. & Hook. f. ex Kirk (1889)	Tawa, tawaroa	Tawa, tawa rautangi					✓		✓	✓	48
7	BRAREP	*Brachyglottis repanda* J. R.Forst. & G.Forst. (1775)	Bushman's friend, rangiora	Kōuaha, pukapuka, pukariao, puke-rangiora, rangiora, raurākau, raurēkau, whārangi, whārangi-tawhito		✓	✓	✓	✓		✓	✓	18
8	BUDDAV	*Buddleja davidii* Franch.	Buddleia, butterfly bush, summer lilac	-									*
9	CALTUG	*Calystegia tuguriorum* (G.Forst.) R.Br. ex Hook.f. (1854)	Climbing convolvulus, New Zealand bindweed	Pauwhiwhi, pawhiwhi, rarotawake							✓	✓	11

(continued on next page)

(*continued*)

	Code	Preferred species name	Local name	Maori name	TI	EC	GS	WE	BF	SH	NS	WE	Fr
10	CARAUS	*Carmichaelia australis* R.Br. (1825)	North Island broom	Tainoka, tawao;maukoro, makaka		✓					✓	✓	39
11	CARSER	*Carpodetus serratus* J.R. Forst. & G.Forst. (1776)	Marble leaf, Motorbike tree	Piripiriwhata, punawata, putaputawata, putawata;					✓		✓	✓	69
12	CLEFOE	*Clematis foetida* Raoul (1846)	-	-							✓	✓	6
13	CLEFOR	*Clematis forsteri* J.F. Gmel. (1791)	Small white clematis	Pikiarero, pōānanga, pōhue, pōhuehue, pōpōhue, puatataua, puataua, puatautaua, puawānanga, puawhānanga							✓	✓	7
14	CLEPAN	*Clematis paniculata* J.F. Gmel. (1791)	White clematis	Pikiarero, pōhue, pōpokonui-a-hura, pūānanga, puapua, puatataua, puataua, puatauataua, puawānanga, puawhānanga					✓		✓	✓	8
15	CLEVIT	*Clematis vitalba* L.	Old man's beard, traveller's joy	-					✓				3
16	COPARB	*Coprosma arborea* Kirk (1877) [1878]	Mamangi, tree coprosma	Māmāngi						✓	✓	✓	8
17	COPARE	*Coprosma areolata* Cheeseman (1885) [1886]	Thin-leaved coprosma	Aruhe					✓	✓	✓	✓	80
18	COPGRA	*Coprosma autumnalis* Colenso (1887)	kanono, manono	Kākawariki, kanono, kānonono, kapukiore, karamū-kueo, kawariki, kueo (fruit), manono, pāpāuma, patutiketike, raurākau,raurēkau, tapatapauma, toherāoa					✓	✓	✓	✓	29
19	COPPRO	*Coprosma propinqua* A. Cunn. (1839)	Mingimingi	Mīki, Mingi, Mingimingi					✓	✓	✓	✓	112
20	COPPXR	*Coprosma propinqua x robusta*	-	-						✓	✓	✓	7
21	COPRHA	*Coprosma rhamnoides* A.Cunn. (1839)	-	-					✓	✓	✓	✓	77
22	COPRIG	*Coprosma rigida* Cheeseman (1886) [1887]	-							✓	✓	✓	15
23	COPROB	*Coprosma robusta* Raoul (1844)	Glossy karamu	Kākaramū, kākarangū, karamū, kāramuramu, karangū		✓		✓	✓	✓	✓	✓	37
24	COPROT	*Coprosma rotundifolia* A.Cunn. (1839)	Round-leaved coprosma	-					✓	✓	✓	✓	10
25	COPSPA	*Coprosma spathulata* A. Cunn. (1839)	-	-						✓	✓	✓	16
26	COPVIR	*Coprosma virescens* Petrie (1878) [1879]	-	-						✓	✓	✓	*
27	CORARB	*Coriaria arborea* Linds. (1868)	tree tutu	Pūhou, tāweku, tūpākihi, tutu		✓			✓		✓	✓	7
28	CORAUS	*Cordyline australis* (G. Forst.) Endl. (1833)	Cabbage tree, giant dracena, grass palm, palm lily, sago palm, ti, ti kouka	Kāuka, kiokio, kōuka, tī, tī awe, ti kōuka, tī para, tī pua, tī rākau, whanake			✓	✓	✓	✓	✓	✓	29
29	CORLAE	*Corynocarpus laevigatus* J.R.Forst. & G.Forst. (1776)	Karaka, karaka nut	Karaka, kōpī			✓	✓	✓	✓	✓	✓	42
30	COTCOC	*Cotoneaster coriaceus* Franch. (1890)	-	-		✓	✓	✓					3
31	CUPMAC	*Cupressus macrocarpa* Hartw. (1847)	Macrocarpa, Monterey cypress	-				✓					*
32	CYADEA	*Cyathea dealbata* (G. Forst.) Sw. (1801)	Ponga, punga, silver fern	Kaponga, kātote, ponga, punga							✓	✓	136
33	CYAMED	*Cyathea medullaris* (G. Forst.) Sw. (1801)	Black mamaku; black tree fern, mamaku	Katātā, kōrau, mamaku, pītau							✓	✓	24
34	CYASMI	*Cyathea smithii* Hook.f. (1854)	Ponga, Smith's tree fern, soft tree fern	Kātote, neineikura, whē							✓	✓	18
35	CYSTOP	*Cystopteris speciosa* Bernh. (1805)	-	-							✓	✓	*
36	DACCUP	*Dacrydium cupressinum* Sol. ex G.Forst. (1786)	-	-					✓		✓	✓	*
37	DACDAC	*Dacrycarpus dacrydioides* (A.Rich.) de Laub. (1969)	Kahikatea, white pine	Kahika, kahikatea, kaikatea, katea, kōaka, koroī	✓	✓		✓	✓	✓	✓	✓	248
38	DICFIB	*Dicksonia fibrosa* Colenso (1844)	Golden tree fern, whekī-ponga	Kuranui-pākā, kurīpākā, pūnui, tūkirunga, wekī, whekī, whekī-kōhunga							✓	✓	15

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	Code	Preferred species name	Local name	Maori name	TI	EC	GS	WE	BF	SH	NS	WE	Fr
39	DICSQU	*Dicksonia squarrosa* (G. Forst.) Sw. (1801)	Harsh tree fern, rough tree fern	Atewheki, pakue, pēhiakura, tiotirawa, tūākura, tūōkura, uruuruwhenua, wheki̅							✓	✓	325
40	DISTOU	*Discaria toumatou* Raoul (1844)	Matagouri, wild Irishman	Tūmatakuri, tūmatakuru, tūturi							✓	✓	97
41	DODVIS	*Dodonaea viscosa* Jacq. (1760)	Akeake, sticky hop-bush	ake, ake rautangi, akeake		✓	✓	✓			✓	✓	9
42	DYSSPE	*Dysoxylum spectabile* (G.Forst.) Hook.f. (1864)	Kohekohe, New Zealand's mahogany	Kohe, kohekohe, kohepi (flowers), kohepu (flowers), koheriki, māota (flowers)	✓				✓	✓	✓	✓	31
43	ELADEN	*Elaeocarpus dentatus* (J. R.Forst. & G.Forst.) Vahl (1794)	-	Hangehange, hīnau, pōkākā, whīnau	✓				✓		✓	✓	6
44	ELAHOO	*Elaeocarpus hookerianus* Raoul (1846)	-	Mahimahi, pōkākā, puka, whīnau	✓				✓		✓	✓	12
45	ERYXSY	*Erythrina × sykesii* Barneby & Krukoff (1974)	Coral tree	-					✓	✓			14
46	FREBAN	*Freycinetia banksii* A. Cunn. (1837)	Kiekie	Kiekie							✓	✓	*
47	FUCEXC	*Fuchsia excorticata* (J. R.Forst. & G.Forst.) L.f. (1781)	Fuchsia, tree fuchsia	Hōnā (fruit), kōhutuhutu, kōnini (fruit), kōtukutuku, māti (fruit), tākawa (fruit)		✓		✓	✓		✓	✓	35
48	FUCPER	*Fuchsia perscandens* Cockayne & Allan (1926) [1927]	-	-						✓	✓	✓	*
49	GENLIG	*Geniostoma ligustrifolium* A.Cunn. (1839)	-	-					✓		✓	✓	60
50	GRILIT	*Griselinia littoralis* (Raoul) Raoul (1846)	Broadleaf	Huariki (fruit), kāpuka, māihīhi, pāpāuma, paraparauma, tapatapauma				✓	✓		✓	✓	14
51	GRILUC	*Griselinia lucida* (J.R. Forst. & G.Forst.) G. Forst. (1786)	Puka	Akakōpuka, akapuka, puka, pukatea							✓	✓	*
52	HEDARB	*Hedycarya arborea* J.R. Forst. & G.Forst. (1776)	Pigeonwood, porokaiwhiri	Kaiwhiri, kaiwhiria, kōporokaiwhiri, pōporokaiwhiri, pōporokaiwhiria, porokaiwhiri, porokaiwhiria, poroporokaiwhiria					✓	✓	✓	✓	70
53	HEDHEL	*Hedera helix* L.	English ivy, ivy	-					✓				*
54	HOHANG	*Hoheria angustifolia* Raoul (1844)	Mountain lacebark, narrow-leaved houhere	Houhi, houhi-puruhi, puruhi		✓		✓			✓	✓	16
55	HOHSEX	*Hoheria sexstylosa* Colenso (1884) [1885]	Graceful lacebark, lacebark	Houhere, houhiongaonga		✓		✓			✓	✓	27
56	ILEMIC	*Ileostylus micranthus* (Hook.f.) Tiegh. (1894)	Mistletoe, small-flowered mistletoe	Pikirangi, pirinoa, pirirangi, pirita					✓		✓	✓	*
57	KNIEXC	*Knightia excelsa* R.Br. (1810)	New Zealand honeysuckle. rewarewa	Rewarewa	✓			✓	✓	✓	✓	✓	63
58	KUNROB	*Kunzea robusta* de Lange & Toelken (2014)	-	-	✓		✓		✓	✓	✓	30	
59	LEPSCO	Leptospermum scoparium J.R.Forst. & G.Forst. (1776)	Red tea tree, tea tree, Mānuka	Kahikātoa, kātoa, mānuka, pata, rauiri, rauwiri		✓	✓	✓	✓		✓	✓	196
60	LEUFAS	*Leucopogon fasciculatus* (G.Forst.) A.Rich. (1832)	Mingimingi, tall mingimingi	Hukihukiraho, kaikaiatua, mānuka-rauriki, mikimiki, mingi, mingimingi, ngohungohu, tūmingi					✓		✓	✓	*
61	LEYFOR	*Leycesteria formosa* Wall. (1824)	himalaya honeysuckle	-					✓				*
62	LIGLUC	*Ligustrum lucidum* W.T. Aiton	Broadleaf privet, tree privet	-									*
63	LIGSIN	*Ligustrum sinense* Lour.	Chinese privet, small-leaf privet	-					✓				*
64	MELALP	*Melicytus aff. alpinus* (Blondin) (nom. inv.)	Porcupine shrub	-						✓	✓	✓	*
65	MELMIC	*Melicytus micranthus* (Hook.f.) Hook.f. (1852)	Swamp mahoe	Manakura					✓	✓	✓	✓	*
66	MELRAM	*Melicytus ramiflorus* J. R.Forst. & G.Forst. (1776)	Māhoe, whiteywood	Hinahina, inaina, inihina, māhoe, moeahu		✓	✓		✓	✓	✓	✓	184
67	MELSIM	*Melicope simplex* A. Cunn. (1839)	Poataniwha	Poataniwha, tātaka					✓	✓	✓	✓	*

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	Code	Preferred species name	Local name	Maori name	TI	EC	GS	WE	BF	SH	NS	WE	Fr
68	METCOL	*Metrosideros colensoi* Hook.f. (1852)	-	-				✓	✓		✓	✓	29
69	METDIF	*Metrosideros diffusa* (G. Forst.) Sm. (1797)	White rata	Rātā				✓	✓		✓	✓	25
70	METFUL	*Metrosideros fulgens* Sol. ex Gaertn. (1788)	Akakura, akatawhitawhi, Scarlet rata, vine rata	Aka, akakura, akatawhitawhi, akatawhiwhi, amaru, kahika, kahikahika, rata; ratapiki				✓	✓		✓	✓	*
71	METPER	*Metrosideros perforata* (J.R.Forst. & G.Forst.) A.Rich. (1832)	Clinging rata, small white rata, Akatea	Aka, akatea, akatorotoro, koro, torotoro, whakapiopio				✓	✓		✓	✓	47
72	METROB	*Metrosideros robusta* A. Cunn. (1839)	Northern rata, rata	Rātā		✓		✓	✓		✓	✓	*
73	MUEAUS	*Muehlenbeckia australis* (G.Forst.) Meisn. (1841)	Large-leaved muehlenbeckia, pōhuehue	Pōhuehue, puka					✓		✓	✓	75
74	MUEAXI	*Muehlenbeckia axillaris* (Hook.f.) Endl. (1848)	-	-					✓		✓	✓	*
75	MUECOM	*Muehlenbeckia complexa* (A.Cunn.) Meisn. (1841)	Scrub pohuehue, small-leaved pohuehue, wire vine	Pōhue, pōhuehue, pōpōhue, tororaro, waekāhu		✓					✓	✓	16
76	MYOLAE	*Myoporum laetum* G. Forst. (1786)	Ngaio	Ngaio		✓		✓	✓		✓	✓	*
77	MYRAUS	*Myrsine australis* (A. Rich.) Allan (1947)	Māpou, red mapou, red matipo	Māpau, māpou, mataira, matipou, takapou, tāpau, tīpau				✓	✓	✓	✓	✓	85
78	NESLAN	*Nestegis lanceolata* (Hook.f.) L.A.S. Johnson (1958)	white maire	Maire, maire raunui, maire rauriki					✓		✓	✓	22
79	OLEAVI	*Olearia avicenniifolia* (Raoul) Hook.f. (1864)	mountain akeake	Akeake				✓			✓	✓	*
80	OLEPAN	*Olearia paniculata* (J.R. Forst. & G.Forst.) Druce (1917)	Akiraho, golden akeake	Akepiro, akiraho				✓			✓	✓	51
81	OLERAN	*Olearia rani* (A.Cunn.) Druce (1917)	Heketara	Akewharangi, heketara, ngungu, taraheke, tātaraheke, wharangi-piro				✓			✓	✓	*
82	PARCAP	*Parsonsia capsularis* (G. Forst.) DC. (1844)	Akakaikiore, New Zealand jasmine, small flowered jasmine	Akakaikiore, akakiore, kaikū, kaikūkū, kaiwhiria, tōtoroene, tōtorowene					✓		✓	✓	*
83	PARHET	*Parsonsia heterophylla* A.Cunn.	Akakaikiore, New Zealand jasmine	Akakaikiore, akakiore, kaihua, kaikū, kaiwhiria, poapoa, tautauā, tawhiwhi, tūtae-kererū					✓		✓	✓	45
84	PASTET	*Passiflora tetrandra* Banks ex DC. (1828)	New Zealand passion flower, New Zealand passionfruit, Kohia	Aka, akakaikū, akakaikūkū, akakōhia, akakūkū, akatororaro, kāhia, kaimanu, kohe, kohia, kōhia, kūpapa, pōhue, pōpōhue					✓		✓	✓	*
85	PENCOR	*Pennantia corymbosa* J. R.Forst. & G.Forst. (1776)	-	Ahikōmau, hine-kaikōmako, kahikōmako, kaikōmako					✓		✓	✓	51
86	PHOTEN	*Phormium tenax* J.R. Forst. & G.Forst. (1776)	Flax, harakeke, lowland flax, New Zealand flax, swamp flax	Harakeke, harareke, kōrari		✓		✓	✓		✓	✓	*
87	PHYOCT	*Phytolacca octandra* L.	Dyeberry, inkweed, red ink plant	-					✓				*
88	PHYTRI	*Phyllocladus trichomanoides* G.Benn ex D.Don (1832)	Celery pine, tanekaha	Ahotea, nīko, tānekaha, tanekaha, tāwaiwai, toatoa	✓				✓		✓	✓	*
89	PINRAD	*Pinus radiata* D.Don	Monterey pine, radiata pine	-	✓								41
90	PIPEXC	*Piper excelsum* G.Forst. (1786)	-	-							✓	✓	*
91	PITEUG	*Pittosporum eugenioides* A.Cunn. (1840)	Lemonwood, tarata	Kīhihi, tarata		✓		✓	✓		✓	✓	*
92	PITTEN	*Pittosporum tenuifolium* Sol. ex Gaertn. (1788)	Black matipo, kohukohu	Kaikaro, kōhūhū, kohukohu, koihu, kōwhiwhi, māpauriki, pōhiri, pōwhiri, rautāwhiri, tāwhiri, tawhiwhi				✓	✓		✓	✓	33
93	PODTOT	*Podocarpus totara* D. Don (1832)	Tōtara	Amoka, tōtara	✓	✓		✓	✓		✓	✓	302
94	PRUTAX	*Prumnopitys taxifolia* (Sol. ex D.Don) de Laub. (1978)	Black pine, black pine, matai	Kāī, kākāī, māī, mataī					✓		✓	✓	*
95	PSEARB	*Pseudopanax arboreus* (L.f.) K.Koch (1859)	Five-finger, whauwhaupaku	Houhou, parapara, puahou, tauparapara, whau, whaupaku, whauwhau, whauwhaupaku		✓		✓	✓	✓	✓	✓	77
96	PSEAXI	*Pseudowintera axillaris* (J.R.Forst. & G.Forst.) Dandy (1933)	Horopito, lowland horopito, lowland pepper tree;	Puhikawa; horopito					✓		✓	✓	*

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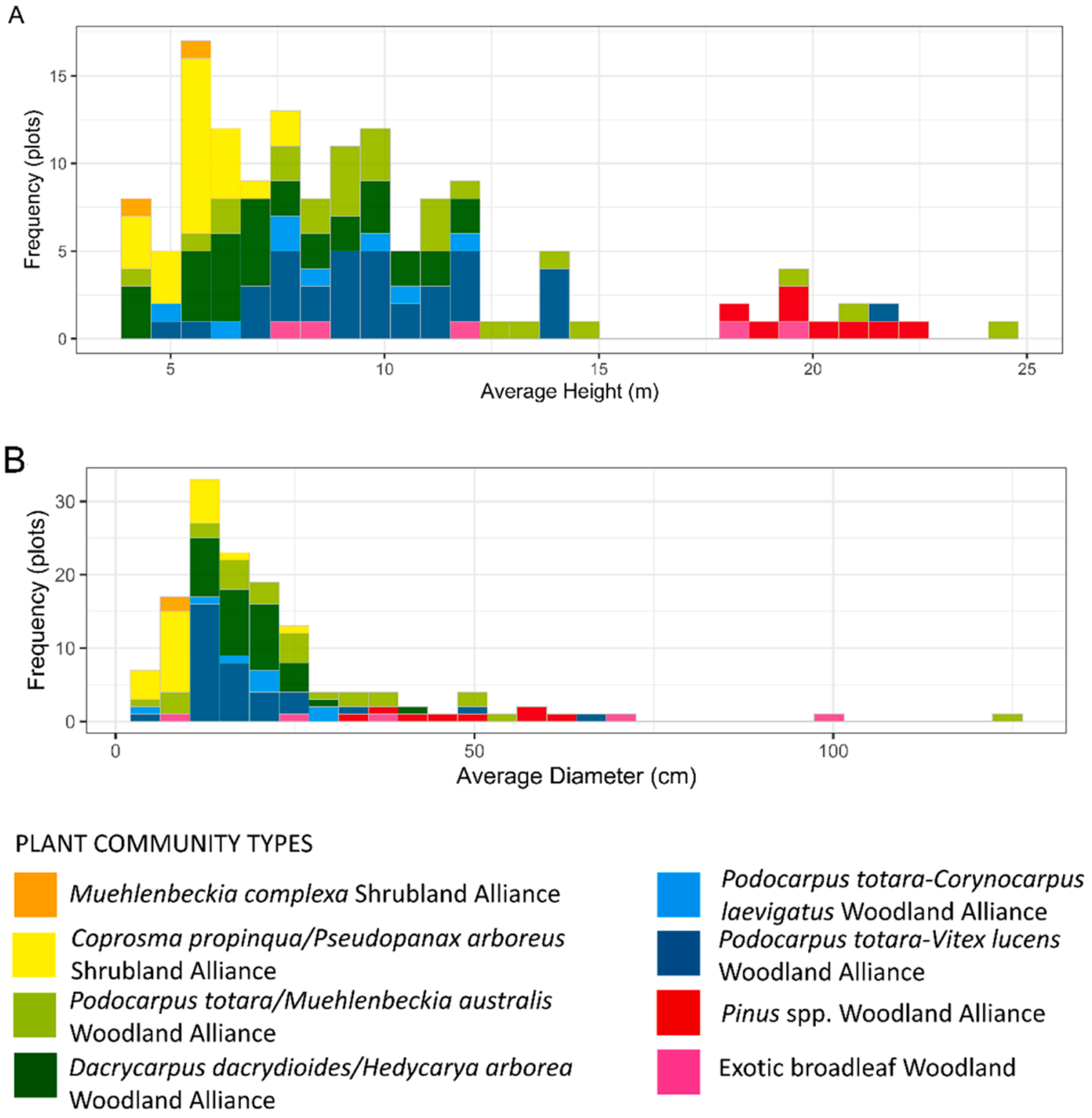
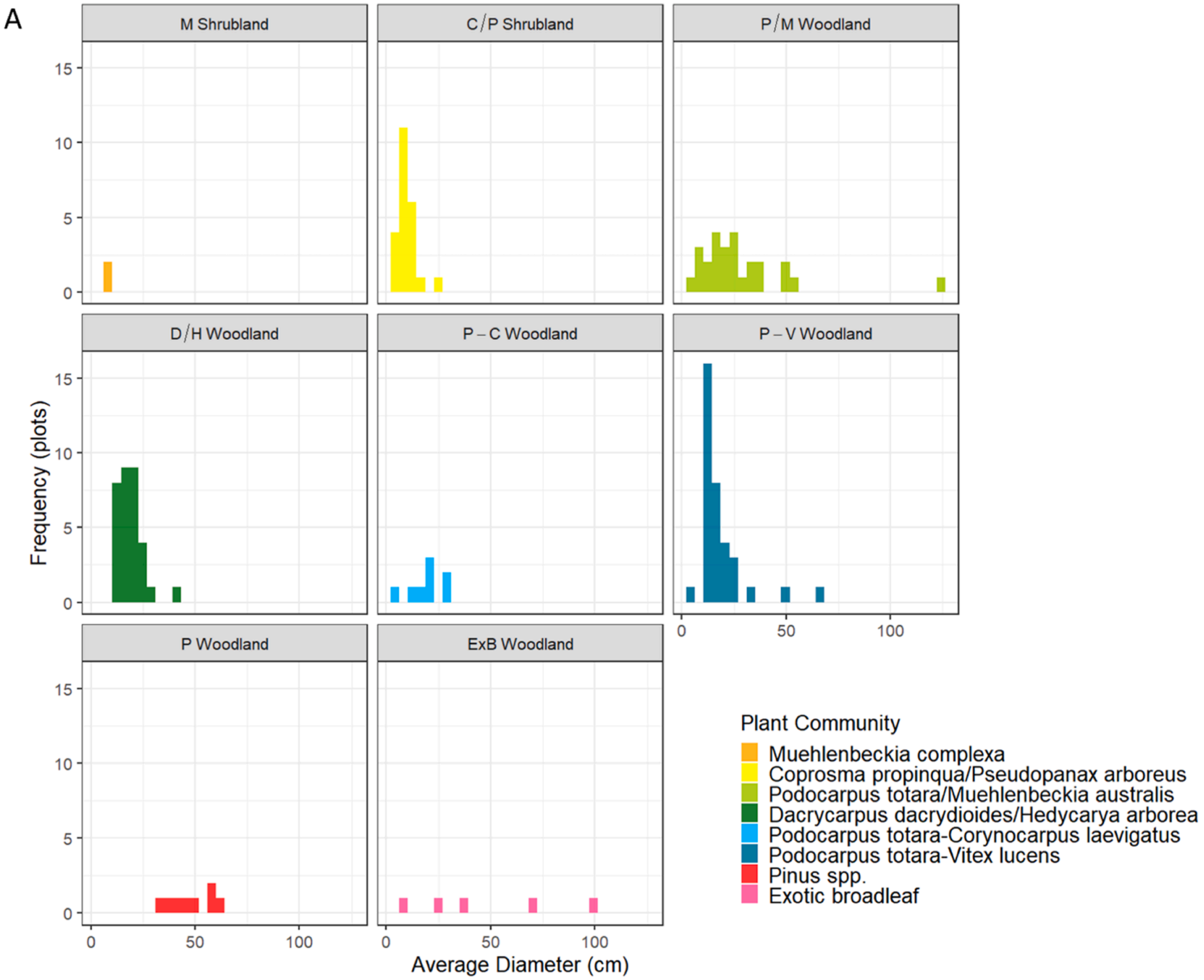
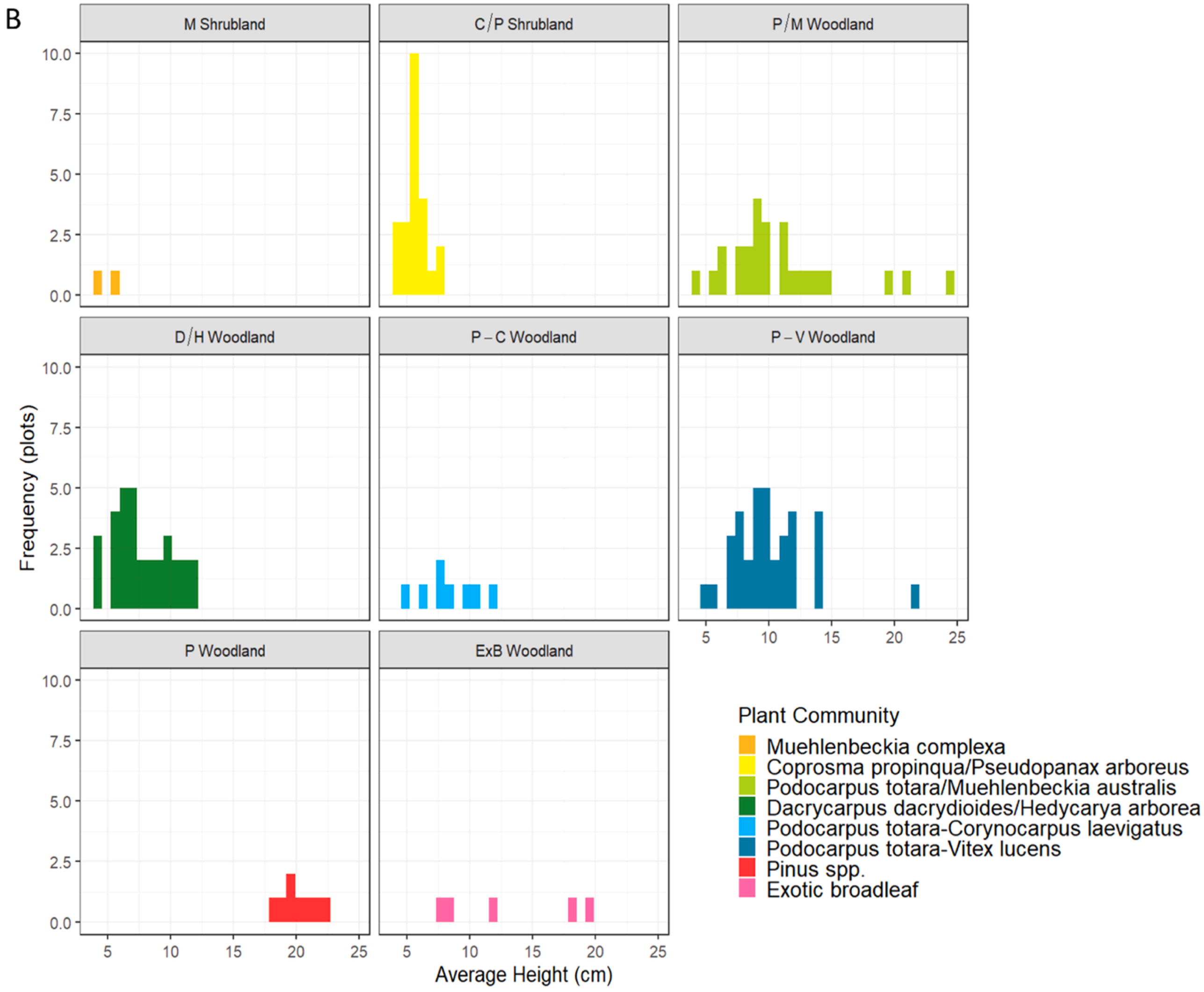
	Code	Preferred species name	Local name	Maori name	TI	EC	GS	WE	BF	SH	NS	WE	Fr
97	PSECOL	*Pseudowintera colorata* (Raoul) Dandy (1933)	Alpine pepper tree, horopito, mountain horopitor, pepper tree	Ramarama, red horopito, ōramarama					✓		✓	✓	*
98	PSECRA	*Pseudopanax crassifolius* (Sol. ex A. Cunn.) K.Koch (1859)	Horoeka, lancewood	Hoheka, horoeka, koeka, kokoeka, ohoeka				✓	✓	✓	✓	✓	63
99	RAUANO	*Raukaua anomalus* (Hook.) A.D.Mitch., Frodin & Heads (1997)	-	-					✓		✓	✓	*
100	RHASOL	*Rhabdothamnus solandri* A.Cunn.	New Zealand gloxinia	Kaikaiatua, mātā, mātātā, taurepo, waiūatua					✓		✓	✓	*
101	RHOSAP	*Rhopalostylis sapida* H. Wendl. & Drude (1878)	Feather duster palm, nīkau, nikau palm	Nīkau					✓		✓	✓	177
102	RIPSCA	*Ripogonum scandens* J. R.Forst. & G.Forst. (1776)	Kareao, supplejack	Akapirita, kakareao, kakarewao, kareao, karewao, kekereao, pirita, taiore					✓		✓	✓	41
103	ROSRUB	*Rosa rubiginosa* L.	Apple-scented rose, eglantine, sweet brier	Mihinare					✓				*
104	RUBCIS	*Rubus cissoides* A.Cunn. (1839)	Bush lawyer	Taraheke, taramoa, tātaraheke, tātarāmoa					✓		✓	✓	*
105	RUBFRU	*Rubus fruticosus* L.	Blackberry	-					✓				*
106	RUBSCH	*Rubus schmidelioides* A. Cunn. (1839)	Bush lawyer, white-leaved lawyer, tātarāmoa	Tātarāmoa					✓		✓	✓	*
107	RUBSQU	*Rubus squarrosus* Fritsch (1886)	Leafless lawyer, yellow-prickled lawyer						✓		✓	✓	
108	SALALB	*Salix alba* L.	Golden willow, silver willow, white willow	-			✓						*
109	SALCIN	*Salix cinerea* L. (1753)	Grey willow	-			✓						*
110	SALXFR	*Salix* × *fragilis* L.	Crack willow	-			✓						*
111	SAMNIG	*Sambucus nigra* L.	Elderberry, black elder, elder	-					✓				*
112	SCAGEN	*Scandia geniculata* (G. Forst.) J.W.Dawson (1967)	-	-							✓	✓	*
113	SCHDIG	*Schefflera digitata* J.R. Forst. & G.Forst. (1776)	Seven-finger	Kohi, Kotētē, Patate, Patatē, Patē, Patētē		✓		✓	✓		✓	✓	*
114	SENGLS	*Senecio glastifolius* L.f. (1782)	Holly-leaved senecio	-									*
115	SOPMIC	*Sophora microphylla* Aiton (1789)	Kōwhai, small-leaved kowhai, Weeping kowhai	Kōwhai	✓	✓		✓	✓	✓	✓	✓	*
116	STRHET	*Streblus heterophyllus* (Blume) Corner (1962)	Milk tree, small-leaved milk tree, Turepo	Ewekuri, tāwari, tūrepo							✓	✓	*
117	URTFER	*Urtica ferox* G.Forst. (1786)	Ongaonga, tree nettle	Ongaonga, taraonga, taraongaonga							✓	✓	5
118	VERSAL	*Veronica salicifolia* G. Forst. (1786)	Koromiko	Kōkōmuka, kōkoromiko, kōkoromuka, korohiko, korokio, koromiko, koromuka							✓	✓	1
119	VERSTR	*Veronica stricta* Banks & Sol. ex Benth. (1846)	Koromiko	Kōkōmuka, Kōkoromiko,kōkoromuka, korohiko, korokio, koromiko, koromuka							✓	✓	1
120	VITLUC	*Vitex lucens* Kirk (1897)	New Zealand oak (English), pūriri (English)	Kauere, pūriri	✓				✓	✓	✓	✓	40
121	WEIRAC	*Weinmannia racemosa* L.f. (1781)	Kāmahi	Kāmahi, tawhero, tōwai	✓	✓		✓	✓		✓	✓	18
122	BRACHY	*Brachyscome species* (Cass.) (1816)	-	-					✓		✓	✓	1
123	CLEMAT	*Clematis species* L. (1753)	Clematis	Akakaikū, akakaikūkū, aka-kōpū-kererū, akakūkū, hokokūkū, pōānanga, pōhue, pōtaetae, puatataua, puatororaro, upokonui-a-ura					✓		✓	✓	14
124	COPROS	*Coprosma* J.R.Forst. & G.Forst. (1775)	Coprosma, looking-glass plant, mirror plant	-						✓	✓	✓	112
125	RUBUS	*Rubus* L. (1753)	Blackberry, bramble, brier, dewberry, raspberry	-					✓		✓	✓	1
126	PINUS	*Pinus* L. (1753)	Pine	-							✓		14
127	PRUNUS	*Prunus* L. (1753)	Cherry, peach, plum;	-					✓		✓		7
128	SALIX	*Salix* L. (1753)	Willow	-		✓					✓		11

Appendix 3. Cumulative histogram of Diameter at breast height (DBH) (cm) and height (m) of eight plant community types: A) Distribution of average DBH of all plots in three sheep and beef farms, B) Distribution of average height of all plots in three sheep and beef farms



Appendix 4 Frequency histograms of frequency of Mean Diameter at breast height (DBH) (cm) and Mean height (m) of all plots of eight plant community types: A) Histogram of frequency average DBH of all plots in three sheep and beef farms by plant community types, B) Histogram of frequency average height of all plots in three sheep and beef farms by plant community types





Appendix 5 Mean and standard deviation (Mean ± Standard deviation) of carbon stocks per hectare of eight plant community types (t C ha-^{1})

Carbon pools	Components	*Muehlenbeckia complexa* shrubland alliance	*Coprosma propinqua/ Pseudopanax arboreus* shrubland alliance	*Podocarpus totara/ Muehlenbeckia australis* woodland alliance	*Dacrycarpus dacrydioides/ Hedycarya arborea* woodland alliance	*Podocarpus totara-Corynocarpus laevigatus* woodland alliance	*Podocarpus totara-Vitex lucens* woodland alliance	*Pinus* spp. woodland alliance	Exotic broadleaf woodland
Above-ground	Live stem	6.88 ± 16.13	49.83 ± 55.57	194.06 ± 141.78	133.76 ± 67.43	92.46 ± 64.92	120.18 ± 100.56	187.31 ± 92.74	244.43± 226.53
	Coarse woody debris	0	1.78 ± 2.91	3.11 ± 4.81	5.64 ± 10.01	4.26 ± 12.06	2.81 ± 5.59	7.4 ± 5.21	0.02 ±0.06
	Shrub	2.28 ± 1.89	0.2 ± 1.00	0	0	0	0	0	2.31 ± 5.66
	Total aboveground	9.16 ± 15.13	51.82 ± 55.31	197.16 ± 141.99	139.4 ± 66.53	96.72 ± 66.36	122.99 ± 101.40	194.71 ± 91.49	246.76 ± 223.6
Below-ground	Belowground	2.29 ± 3.78	12.95 ± 13.83	49.29 ± 35.50	34.85 ± 16.63	24.18 ± 16.59	30.75 ± 25.35	48.68 ± 22.87	61.69 ± 55.9
Soil	Soil carbon	16.77 ± 2.78	14.55 ± 5.89	17.49 ± 3.67	19.00 ± 6.62	18.30 ± 4.72	24.29 ± 4.72	18.82 ± 4.98	19.69 ± 6.99
Total Carbon		28.22 ± 18.63	79.33 ± 72.20	263.94 ± 178.79	193.25 ± 81.77	139.21 ± 86.86	178.02 ± 126.71	262.21 ± 112.17	328.14 ± 276.87

Appendix 6 Mean, standard deviation (Mean ± Standard deviation), and sum of carbon stocks per hectare of three sheep and beef farms and all plots (t C ha^{-1})

Carbon pools	Components	Kaipara		Ruapehu		Hurunui		Average Plot	
		Mean±SD	Sum	Mean±SD	Sum	Mean±SD	Sum	Mean±SD	Sum
Aboveground	Live stem	128.12 ± 117.5	6277.68	163.66 ± 110.91	10638.18	50.26 ± 72.3	1558.08	127.41 ± 114.16	18473.93
	CWD	3.43 ± 7.01	167.93	4.38 ± 7.8	284.98	1.39 ± 2.66	42.94	3.42 ± 6.8	495.85
	Shrub	0	0	0.21 ± 1.72	13.86	0.6 ± 1.43	18.58	0.22 ± 1.34	32.45
	Total aboveground	131.54 ± 117.86	6445.61	168.26 ± 110.23	10937.02	52.25 ± 71.85	1619.61	131.05 ± 114.32	19002.23
Belowground	BGB	32.89 ± 29.47	1611.4	42.07 ± 27.56	2734.26	13.06 ± 17.96	404.9	32.76 ± 28.58	4750.56
Soil	Soil carbon	23.03 ± 7.36	1128.67	18.22 ± 5.60	1184.22	15.00 ± 5.35	465.13	19.16 ± 6.87	2778.01
Total carbon		187.46 ± 147.46	9185.67	228.55 ± 137.44	14,855.49	80.31 ± 91.45	2,489.64	174.44 ± 143.53	26,530.81

Appendix 7 Summary of mean and standard deviation (Mean ± Standard deviation) of carbon stocks per hectare of three structural plant community types (t C ha^{-1}): Shrubland alliances, Native-dominated woodland alliances, and exotic-dominated woodland alliances

Carbon pools	Shrubland alliances	Native-dominated woodland alliances	Exotic-dominated woodland alliances
Total aboveground carbon stock	43.29 ± 52.60	145.20 ± 106.26	217.02 ± 156.37
Total soil carbon stock	14.99 ± 5.44	20.39 ± 6.96	19.19 ± 5.69
Total belowgroundcarbon stock	10.82 ± 13.15	36.30 ± 26.56	54.25 ± 39.09
Total Carbon stock	69.11 ± 68.02	201.89 ± 132.63	290.46 ± 193.40

Appendix 8. Summary of mean (μ) of total carbon stock and other ecosystem functions (Mean EF), mean total carbon stock (tC ha^{-1}) and mean scores of other ecosystem functions: timber provision, gully stabilization, wine erosion reduction, wind erosion reduction, animal shelter, source of bird foods, increasing native biodiversity, less invasive weeds, and less community flammability; and abundance and richness, of eight plant community types

Row Labels	μ EF	μ total Carbon Stock	μ timber provision	μ gully stabilisator	μ soil erosion reduction	μ wind erosion reduction	μ animal shelter	μ source of food for birds	μ increasing native biodiversity	μ inverted Invasive weeds	μ inverted Community flammability	μ Abundance	μ Species Richness
Corposma propinqua/ Pseudopanax arboreus Shrubland Alliance	5.50	79.33	0	8.79	11.21	11.96	0.92	6.04	17.29	17.29	2.56	Average of Abundance	3.46
Dacrycarpus dacrydioides/ Hedycarya arborea Woodland Alliance	4.32	193.25	3	1.72	4.91	4.56	2.84	2.75	18.44	18.66	1.85	17.33	4.75
Exotic broadleaf Woodland	2.41	328.14	0	2	0	0.17	2	2.33	0.33	2	1.14	18.66	1.67
Muehlenbeckia complexa Shrubland Alliance	4.38	28.22	2.83	0.67	7	3.5	0	2.83	29.5	29.5	2.72	5.50	2.67
Pinus spp. Woodland Alliance	2.08	262.21	4.13	0	0	0	0	0	0	4.13	1.27	29.66	1.00
Podocarpus totara/ Muehlenbeckia australis Woodland Alliance	3.52	263.94	4	0.12	4.42	4.42	3.46	1.62	5.96	5.96	1.28	4.16	2.58
Podocarpus totara-Corynocarpus laevigatus Woodland Alliance	4.29	139.21	4.38	2.63	7.13	7.88	5.13	1.63	8.87	8.88	1.35	6.00	2.25
Podocarpus totara-Vitex lucens Woodland Alliance	5.48	178.02	7.97	0.71	5.69	7.26	2.08	9.37	18.34	18.37	2.16	8.88	5.60

Appendix 9 Summary Z-score of eight plant community types on mean total carbon stock (tC ha^{-1}) and mean scores of other ecosystem functions: timber provision, gully stabilization, wine erosion reduction, wind erosion reduction, animal shelter, source of bird foods, increasing native biodiversity, less invasive weeds, and less community flammability relative to the z-score of other plant community types

Row Labels	µ total Carbon Stock	µ timber provision	µ gully stabilisator	µ soil erosion reduction	µ wind erosion reduction	µ of animal shelter	µ source of food for birds	µ increasing native biodiversity	µ inverted Invasive weeds	µ inverted Community flammability
Corposma propinqua/ Pseudopanax arboreus Shrubland Alliance	-1.04	-1.28	2.34	1.64	1.74	-0.64	0.91	0.48	0.45	1.22
Dacrycarpus dacrydioides/ Hedycarya arborea Woodland Alliance	0.09	-0.11	-0.12	-0.03	-0.1	0.45	-0.19	0.59	0.59	0.09
Exotic broadleaf Woodland	1.43	-1.28	-0.03	-1.35	-1.19	-0.031	-0.33	-1.17	-1.18	-1.04
Muehlenbeckia complexa Shrubland Alliance	-1.55	-0.18	-0.49	0.52	-0.36	-1.16	-0.16	1.67	1.75	1.48
Pinus spp. Woodland Alliance	0.78	0.32	-0.72	-1.35	-1.24	-1.16	-1.11	-1.19	-0.95	-0.83
Podocarpus totara/ Muehlenbeckia australis Woodland Alliance	0.79	0.28	-0.68	-0.17	-0.13	0.8	-0.57	-0.62	-0.76	-0.82
Podocarpus totara- Corynocarpus laevigatus Woodland Alliance	-0.45	0.42	0.19	0.56	0.72	1.74	-0.57	-0.34	-0.45	-0.7
Podocarpus totara- Vitex lucens Woodland Alliance	-0.07	1.82	-0.483	0.17	0.57	0.02	2.03	0.58	0.56	0.59

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