Linking species distribution and territorial planning to the management of the native forests in Chile

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Elisavet Zoupanidou, June 2023

Directeur : Prof. Anthony Lehmann, Faculté des Sciences

Abstract

Species distribution modelling (SDM) is widely used in ecology and conservation. To develop effective long-term management and conservation strategies, it is crucial to have a comprehensive understanding of the distribution of different species and the key biophysical factors that influence the structure and dynamics of the forest. This information can help us make to predict future distributions in the face of climate change, human-assisted invasions and many other ongoing environmental changes, and to take proactive measures to protect and preserve ecosystems.

This work aimed to determine the potential and current spatial distribution of native tree species based on a diverse dataset of 14 species from 3 different locations in the region of Los Lagos, Chile. A further aim was to superimpose the distribution of main native species, with the current forest management policy framework to provide basic information for the conservation and management of the species. For this, a Maxent model was developed to quantify the relationship between species occurrence and key environmental variables (including water, topography, and climate as variables). Species habitats were mainly influenced by temperature variables, and

secondarily by precipitation variables. The results of this study and the distribution maps of the native species provide decision-makers with an opportunity to review and adjust the native forest zoning at a provincial scale.

Introduction

Chile has an important forest sector based on plantations of exotic species, primarily *Monterey pine* (*Pinus radiata*) and several species of eucalyptus (*Eucalyptus spp*.), and an extensive area of temperate rainforests with unique ecological features and conservation. These temperate rainforests represent the second largest remaining area of this type in the world (Donoso 1995, Wilcox 1996) and are internationally recognized for their ecological importance (Olson and Dinerstein 1998; Stattersfield et al. 1998). They sequester vast quantities of carbon that contribute to global climate regulation, control flooding, purify water, cycle nutrients, and soil, and house an incredible array of species that provide the genetic material for valuable new products and a foundation for the resilience of natural systems

Chile's temperate forests, despite their ecological importance and currently under threat, have experienced a long history of destruction and, over the past 30 years, have been threatened by land-use changes and mismanagement. The main causes of deforestation and forest degradation include a substitution of forestry plantations for native species, selective logging, illegal logging, land use change, and intentional forest fires (Neira et al. 2002; Altamirano et al. 2013). These economic incentives, together with the current forestry policy in Chile, have promoted the establishment of large–scale plantations of pine and eucalyptus, many of which have resulted in the clearing of precious native forests. These plantations provide most of the timber needed for the domestic and export markets. The result is a dramatic loss of biodiversity, soil erosion, and changes in the water level of streams. The table below describes the forest type classification as incorporated into Chile’s national forest legislation, and was the basis for the land register analysis carried out for CONAF (CONAF et al., 1999).

Table 1 CHILE'S FOREST TYPES (FROM NORTH TO SOUTH OF THE COUNTRY). Donoso, 1981

FOREST TYPE	LOCATION	DOMINANT SPECIES AND KEY ASSOCIATED SPECIES
Sclerophyllous	Coastal Mountain Range: 30º50'S to 36º30'S. Central Valley: 30º50'S to 37º50'S. Andean Mountain Range: 32º00'S to 38º00'S.	*Espino (Acacia caven), quillay (Quillaja saponaria), maitén (Maytenus boaria), trevo (Trevoa trinervis), guayacán (Porliera chilensis), and algarrobo (Propopis alba).*
Chilean Palm	Isolated Populations starting at 34º30'S.	*Chilean palm (Jubaea chilensis) with litre (Litrea caustica), peumo (Criptocarya alba), boldo (Peumus boldo), maitén, and espino.*
Roble - Hualo	Coastal Mountain Range: 32º50'S to 36º30'S Andean Mountain Range: 34º30'S to 36º50'S.	*Roble (Nothofagus obliqua), hualo (Nothofagus glauca), peumo, maitén, quillay, litre, avellano (Gevuina avellana), and radal (Lomatia hirsuta).*
Cordilleran Cypress	Found in non-contiguous populations in the Andean Mountain Range from 34º35'S to 44º00'S	*Cordilleran cypress (Austrocedrus chilensis), peumo, boldo, maitén, and quillay.*
Roble-Raulí-Coigue	Andean and Coastal Mountain ranges between 36º30'S and 40º30'S	*Roble, raulí (Nothofagus alpina), and coigue (Nothofagus dombeyi). These are mainly secondary forests or a mix of these three species with luma (Amomyrtus luma) and arrayán (Luma apiculata).*
Lenga	Found from 36º50'S to 56º00'S and at the altitudinal vegetation limit in the Andean Mountain Range up to 45º00'S.	*Coigue, roble, araucaria (Araucaria araucana), ñirre (Nothofagus antarctica), and Magellanic coihue (Nothogagus betuloides).*
Araucaria	Found in non-contiguous populations in the Coastal Mountain Range from 37º40'S to 38º40'S. Andean Mountain Range: 37º27'S to 40º48'S.	*Araucaria, coigue, roble, ñirre, canelo (Drimys winteri), and lenga (Nothofagus pumilio*
Coigue-Raulí-Tepa	Coastal Mountain Range: 38º00'S to 40º30'S. Andean Mountain Range: 37º00'S to 40º30'S.	*Coigue, raulí, tepa (Laureliopsis philippiana), trevo, and olivillo (Aextoxicon punctatum).*
Evergreen	Coastal Mountain Range: 38º30'S to 47º00'S. Andean Mountain Range: 40º30'S to 47º00'S.	*Tepa, luma, canelo, and tineo (Weinmannia trichosperma)*
Alerce	Found in non-contiguous populations in the Coastal Mountain Range from 39º50'S to 41º15'S	*Alerce (Fitzroya cupressoides), Magellanic coihue, Chiloé coigue*

	and in the Andean Mountain Range from 40º00'S to 43º00'S.	*(Nothofagus nitida), prickly-leafed mañío (Podocarpus nubigena), tineo, and Guaitecas cypress (Pilgerodendron uviferum).*
Guaitecas Cypress	From 40º00'S to 53º00'S.	*Guaitecas cypress, Chiloé coigue, prickly-leafed mañío.*
Magellanic Coihue	From 47º00'S to 55º30'S	*Lenga, tineo, prickly-leafed mañío, Magellanic coihue, and Guaitecas cypress.*

The state of conservation of Chilean forests is a topic of growing concern among the general public as well as national and international conservation organizations (Arriagada et al., 2016). The most recent evaluation shows that only a small portion of forestry activities is adequately managed and forest types are poorly represented, and reserve size in many regions is inadequate. Only 29 per cent of the total area of native forests is protected through inclusion in the National System of Protected Wildlands (SNASPE), the state's protected areas system (CONAF et al., 1995),

Because the majority of the forest land is in private hands, its long-term conservation through inclusion under the SNASPE is not the only solution. The state's main role is to promote the management of native forest and forestry plantations, implement legislation, and administer the SNASPE. The forest industry plays an important role through the ownership and management of extensive forested lands; it has increased the contribution of forest product exports to the country's gross domestic product through the industrialization of the sector (e.g., increasing the number of paper and pulp processing plants). Small landowners hold a significant share of forest land, with its use restricted mostly to fuelwood collection and shelter for livestock during winter months. Finally, the main goals and objectives of many environmental NGOs are to promote forest stewardship, develop conservation plans for natural resources, and serve as a catalyst for civil society's support of the protection of species and ecosystems.

For management planning and conservation strategies in the long term, it is necessary to know the species distribution and main biophysical aspects that determine the structure and dynamics of the forest (Peri et al., 2021). Prediction and mapping of potentially suitable habitats for native species are critical for monitoring and restoration of declining native populations in their natural habitat (Gaston, 1996). However, distribution data on threatened and endangered are often sparse (Ferrier et al., 2002, Engler et al., 2004). Predictive habitat models statistically relate the geographical distribution of species or communities to their present environment using statistical techniques and geographic information systems (GIS) (Guisan & Zimmermann, 2000). In the last decades, techniques based on specific regression/modelling methods (e.g., generalized linear and additive models, random forests, boosted regression trees) have been combined with species presence/absence data obtained from vegetation surveys (Elith et al., 2011).

In this context, the maximum entropy method (Maxent), is software for modelling species niches and distributions by applying a machine-learning technique called maximum entropy modelling. The software uses presence-only species records, which minimizes the relative entropy between two probability densities (estimated from occurrence data and from the landscape) defined in covariate space (Phillips et al., 2006). This generates a species distribution model (SDM) as a function of climate, topography, and location, and has been used to predict the ranges of plant diseases and insects, model the distributions of species, communities, and ecosystems, assess the impact of climate, land use, and other environmental changes on species distributions (Thomas et al., 2004; Yi et al., 2014; Bradie and Leung, 2017). Maxent became a powerful tool for remote areas with low available species data (Hirzel et al. 2001) Kumar & Stohlgren (2009) used Maxent to predict potentially suitable habitats for *Canacomyrica monticola*, a threatened and endangered tree species in New Caledonia. Similarly, Zhang et al. (2019) studied the impact of climate change on the geographical future distributions of rare tree species to provide a reference for the conservation management of these species in southwestern China. This software uses remote sensing to develop SDM maps that use only presence data. The general aim of this work was to determine the potential and current spatial distribution of 14 species and to provide basic information aimed at the conservation and management of the species. For this, a Maxent model was developed to quantify the relationship between species occurrence and key environmental variables (including water, topography, and climate as variables), and the current land cover of the region was overlapped to evaluate the potential conservation of the species forests under the different conservation categories.

Methods

Study area

The study area was contacted in the Los Lagos region in Chile. The location of our study (Figure 1) is in the mid-southern regions of Chile in the temperate rainforest zone, with vegetation that struggles against the prevailing westerly gales (Luebert and Pliscoff, 2006). In the transition from the Mediterranean region of central Chile to the temperate forests (35°–38° S), *Nothofagus obliqua* and *Nothofagus alpina* are more abundant, and evergreen species (*Nothofagus dombeyi*, *Laureliopsis philippiana* [*Monimiaceae*], *Drimys winteri* [*Winteraceae*]) dominate the landscape in the southernmost Los Lagos region (39°–43° S) (Urrutia-Jalabert et al., 2018). The data was collected in three dairy farms where native forests are present and privately owned. Two of them are located in the Osorno Province, Puyehue Commune. The third dairy is located further south, in the province of Llanquihue, commune of Fresia.

The three dairy farms are dominated by evergreen forests also known as RO-RA-CO (Roble-Raulí-Coigüe), as well as some plantations of exotic species such as eucalyptus, insigne pine, oregon pine or alamos. The RO-RA-CO forest type owes its name to the three main species of *Nothofagus* found in it. *Roble (N. obliqua Mirb.obliqua (Mirb.) Oerst.), Raulí (N. alpina (Poepp. Endl.) Oerst.)* and *Coihue (N. dombeyi (Mirb.) Oerst.)* The RO-RA-CO forest type corresponds to stands of any of the three species or a combination of them and generally has more than 50% of the individuals with a Diameter at Breast Height (DBH) greater than 10 cm per hectare (Donoso Zegers, 1981). The RO-RA-CO is the fourth largest forest type in Chile and covers 10.8 % of the country's total area (CONAF 2011). Types of land cover are important for exploring anthropic intervention. The land cover distribution map (Figure 3) shows the land use and land cover in the region. These include the following classes: water, trees, flooded vegetation, crops, built area, bare ground, snow/ice, cloud, and rangeland. Primary forests account for 52% of land cover in the region. High mountains areas (68.7 % the in Los Lagos area) represent a refuge for primary forest formations with their slopes, isolation, and high legal protection (Hora et al. 2022)

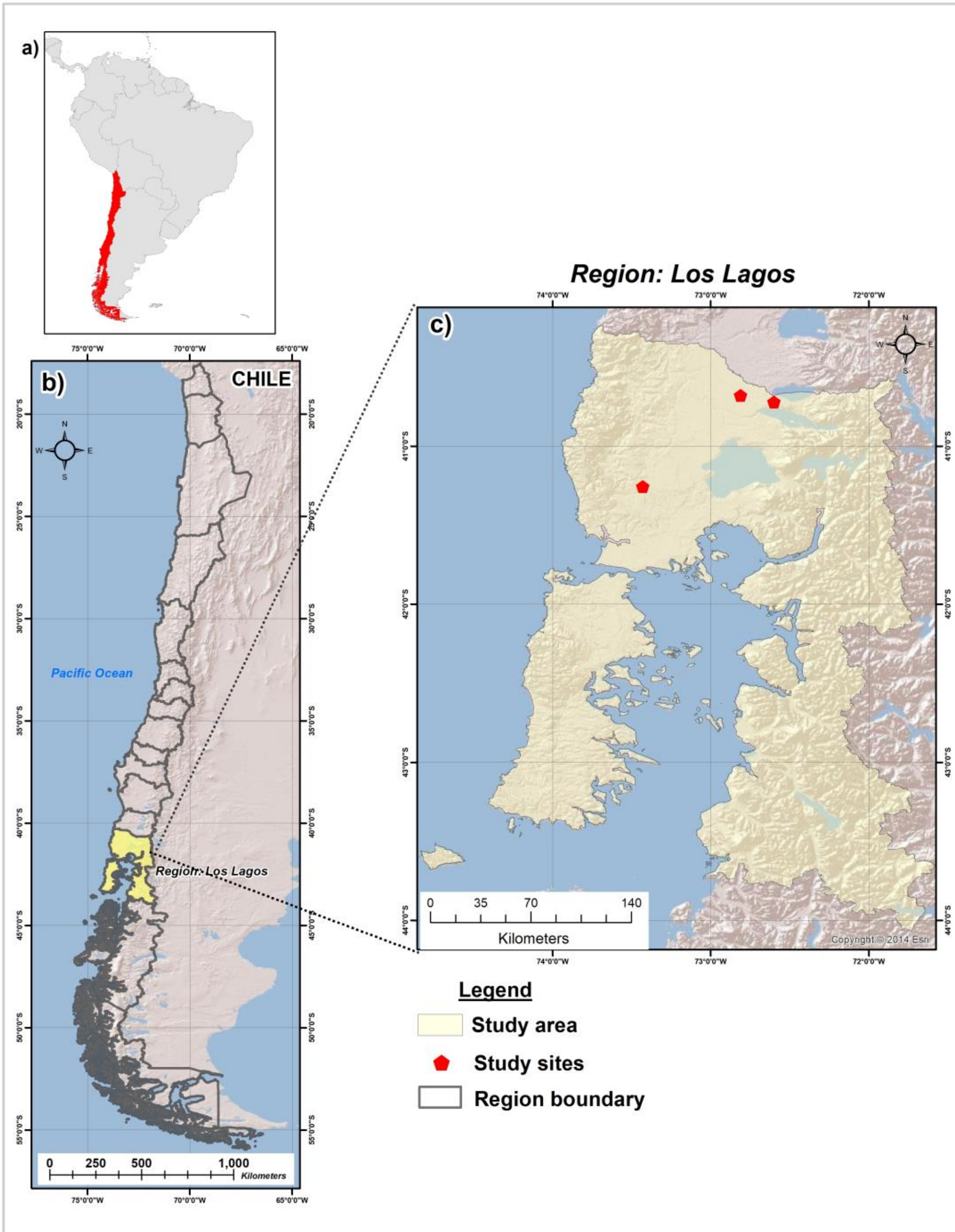

Figure 1 (A) Study area analyzed in Chile (B) Los Lagos region (C) Location of farms

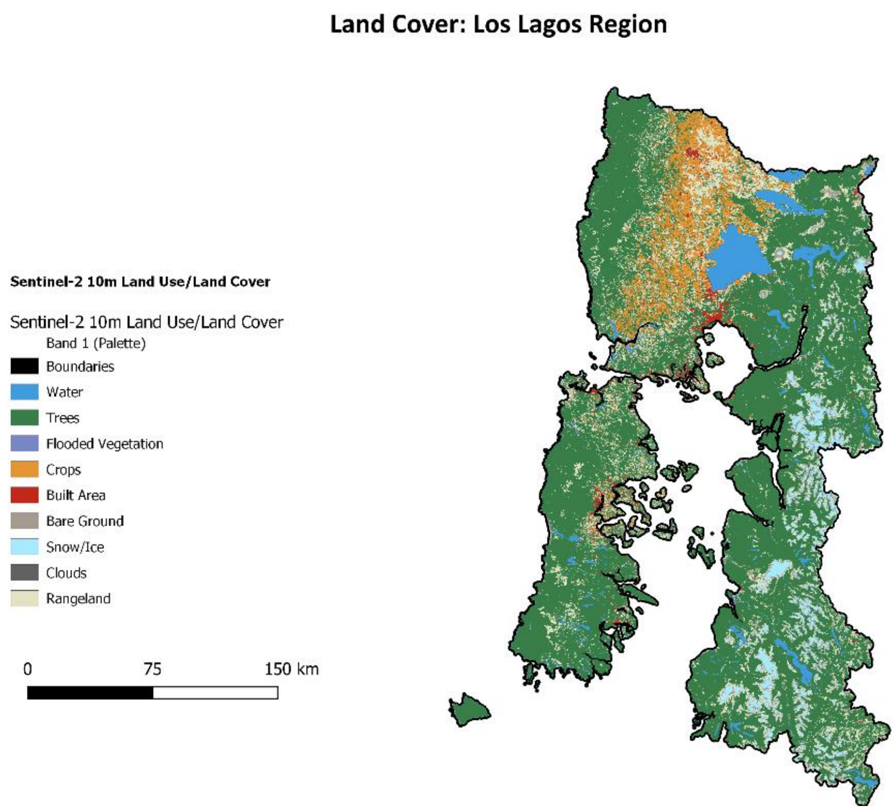

Figure 2 Land use and land cover map of the Los Lagos region

Potential distribution/ Species occurrence data collection

The study used the Maxent software Version 3.4.4 to predict the geographic distribution of native tree species with presence-only data. Maxent estimates a target probability distribution by finding the probability distribution of maximum entropy (that is most spread out or closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution (Phillips et al., 2006). When Maxent is applied, the pixels of our study area make up the space on which the Maxent probability distribution is defined. The model predicts the suitability and probability of a species by integrating/assuming the suitable environmental condition and the input data with species information, generating an output layer that can be interpreted as a predicted distribution of species. For the modelling, we explored potential explanatory climatic variables derived from data provided by the Intergovernmental Panel on Climate Change (IPCC; New et al., 1999). The elevation variable was used in addition to the climatic data. The IPCC dataset comprises a suite of seven climate elements: precipitation, mean temperature, diurnal temperature range, wet-day frequency, vapour pressure, cloud cover, and ground frost frequency. The statistical evaluation of machine learning algorithms can be interpreted based on the Area under the Curve (AUC) of a receiver operator characteristic (ROC) (Fawcett, 2006). The sensitivity designed against [1 – specificity] is the ROC which specifies the percentage of true positives (omission error) and specificity percentage of false negatives (commission error). Model performance can be accepted widely when the sensitivity and specificity maintain an equilibrium.

Table 2 Native species present in the study area.

Present species in the three farms	**Number of samples**
Aextoxicon punctatum	*6*
Amomyrtus luma	*15*
Caldcluvia paniculata	*10*
Drimys winteri	*30*
Eucryphia cordifolia	*48*
Gevuina avellana	*14*
Laureliopsis philippiana	*16*
Lomatia ferruginea	*3*
Lomatia hirsuta	*32*
Luma apiculata	*10*
Nothofagus dombeyi	*14*
Nothofagus obliqua	*19*
Persea lingue	*15*
Rhaphithamnus espinosus	*14*

Results

The AUC generated from the ROC plot ranges from 0 to 1. Identifying and eliminating the highly correlated values while performing a model helps easily interpret the model outcomes. The maxent model for the 14 species presented satisfactory results, with an AUC value of AUC scores for these models shown in Table 3. The model output provided satisfactory results with both training and test data sets. Although Maxent offers acceptable results even with a limited available sample size, it requires an appropriate distribution of occurrence points in the ecological space rather than the geographical space. The limitation of this study is the variability of the sample in the ecological space. Two sample locations are close to each other, and more sample covering other ecological spaces in the region of Los Lagos would provide a more accurate representation of the habitat suitability for the native tree species.

Table 3 Maxent model analysis (Analysis of omission/commission)

Present species in the three farms	Training data - AUC	Test data - AUC	Random prediction - AUC
Aextoxicon punctatum	0.997	0.996	0.5
Amomyrtus luma	0.997	0.996	0.5
Caldcluvia paniculata	0.997	0.996	0.5
Drimys winteri	0.996	0.996	0.5
Eucryphia cordifolia	0.996	0.996	0.5
Gevuina avellana	0.996	0.996	0.5
Laureliopsis philippiana	0.997	0.996	0.5
Lomatia ferruginea	0.997	0.996	0.5
Lomatia hirsuta	0.996	0.996	0.5
Luma apiculata	0.996	0.996	0.5
Nothofagus dombeyi	0.997	0.996	0.5
Nothofagus obliqua	0.997	0.996	0.5
Persea lingue	0.996	0.996	0.5

Rhaphithamnus espinosus	0.996	0.996	0.5

The potential sites of the distribution of the 14 species are generated on a map using the Maxent model. Four variables, annual precipitation, precipitation during the driest month, precipitation during the driest month and warmest quarter layers respond to the probable distribution of invasive species. The permutation and contribution of each environmental variable for the native species are represented in Table 4.

To reduce multi-collinearity among the 14 variables, the ecoregion variable, a categorical variable describing potential vegetation classes, was eliminated from the model. The following Figure 3 shows the results of the jackknife test of variable importance. The environmental variable with the highest gain when used in isolation is ecoregion variable, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is the elevation (h_dem), which therefore appears to have the most information that isn't present in the other variables. The results were similar for all native species.

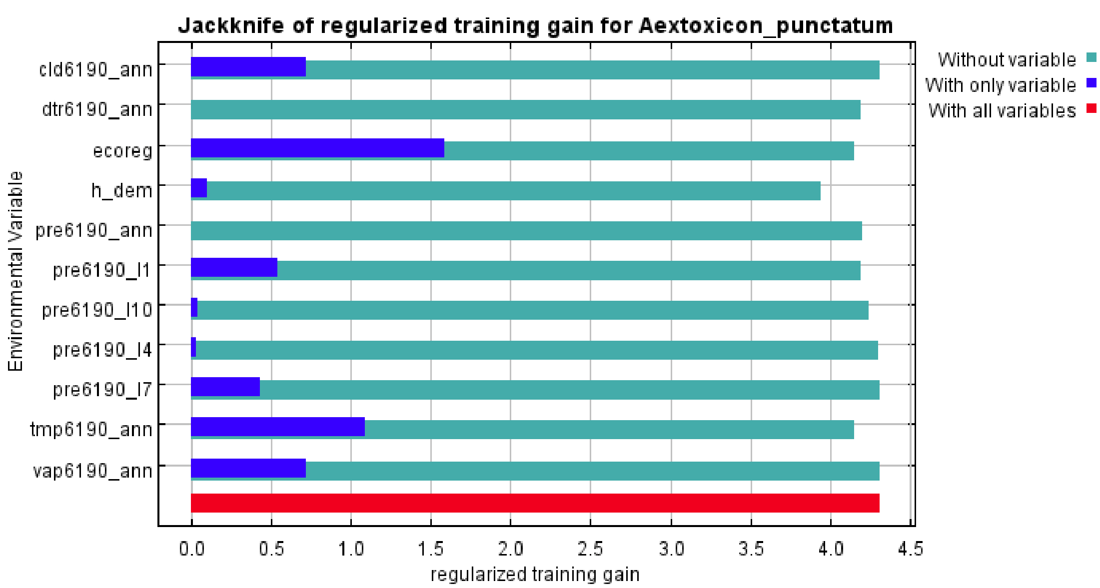

Figure 3. Example of the Jackknife test for evaluating the relative importance of environmental variables for Aextoxicon punctatum species.

Species distribution maps showed the size of the study area recognized as high potential habitats The values of the potential distribution of the 14 species from the model output range from 0.002 to 0.99. The area observed with less distribution is 0.002 for a low and possible enormous invasion expansion as 0.99 for a highly distributed area. The current range of four native species is shown in Figure 4. The maps obtained from Maxent can be compared with land use change classes, as shown in Figure 2. Areas with higher elevations are unsuitable habitats, whereas agricultural areas are potential habitats for native tree species.

Table 4 Percentage of the contribution of each environmental layer in predicting the species distribution.

Present species in the three farms	***Aextoxicon punctatum, Amomyrtus luma, Caldcluvia paniculate, Laureliopsis philippiana, Lomatia ferruginea***		***Drimys winteri, Eucryphia cordifolia, Gevuina avellana, Lomatia hirsuta, Persea lingue, Rhaphithamnus espinosus***		***Luma apiculata***		***Nothofagus dombeyi, Nothofagus obliqua***	
	Percentage of contribution	Permutation value	Percentage of contribution	Permutation value	Percentage of contribution	Permutation value	Percentage of contribution	Permutation value
tmp6190_ann	43.7	70.8	44.7	37.5	45.8	58.1	44.1	68
pre6190_l7	24.3	0	26.8	9.4	28.7	31.8	25.8	0.6
h_dem	15.1	8	14.3	22.8	13.8	4.3	13.5	1.1
cld6190_ann	9.9	1.3	10.3	13.2	9.9	4	11.4	11.2
pre6190_l4	3	4.3	2.8	14.8	1.4	1.2	3.4	2.8
dtr6190_ann	1.8	1.1	0	0	0	0	0	0
pre6190_l1	1.3	1.6	0.9	2.4	0.1	0	0.5	0.1
pre6190_ann	0.5	11.7	0	0	0	0	0	0
pre6190_l10	0.2	1.2	0.1	0	0.3	0.6	0.5	0
tmn6190_ann	0	0	0	0	0	0	0	0
frs6190_ann	0	0	0	0	0	0	0	0

tmx6190_ann	0	0	0	0	0	0	0	0
vap6190_ann	0	0	0	0	0	0	0.8	16.2

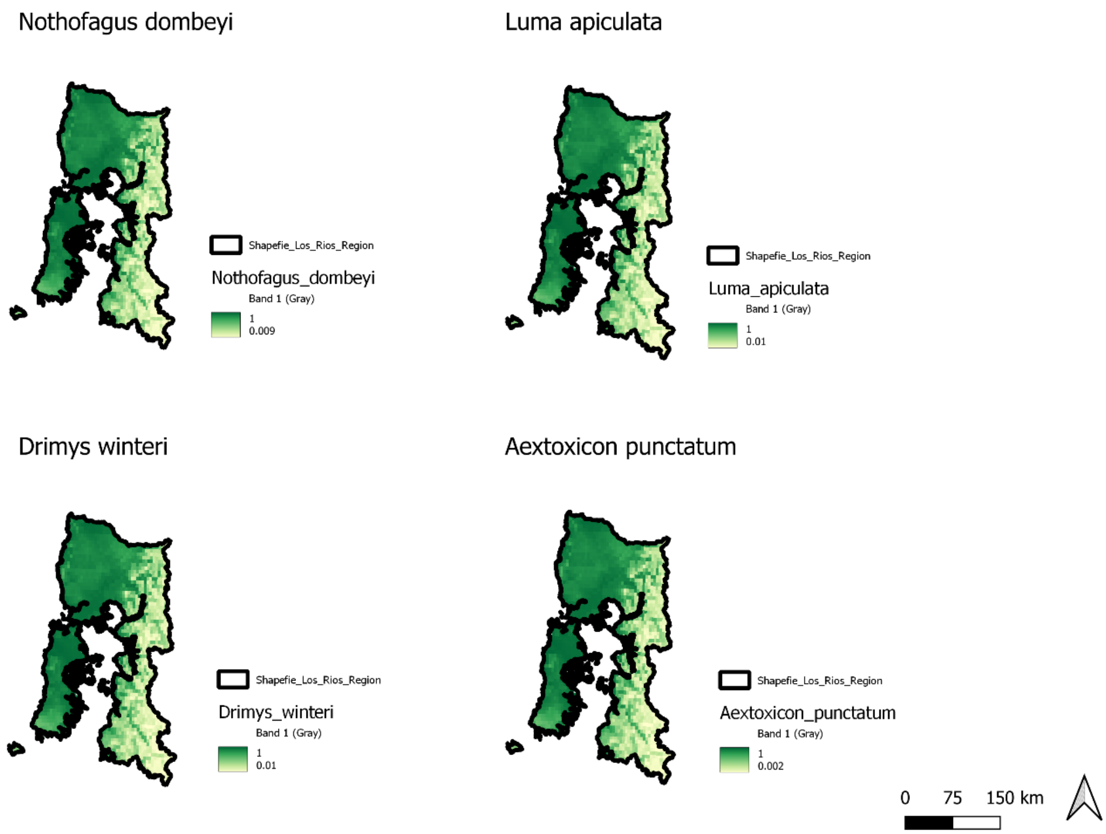

Figure 4. Maxent's Potential habitat suitability maps of native species in the study area

Conclusions and discussion

A habitat suitability model based on maximum entropy theory was developed to evaluate and predict the existence and potential habitat quality of 14 native tree species. Current suitable habitats for the native species were predicted in the study area where populations of these species are already known to exist, but the suitable habitat was also predicted in areas where the species is known to be absent due to agricultural/crop production. Notably, the current potential distribution size is significantly larger than the present occurrence. At the regional scale, the climate is the main factor in determining the species distribution. Our results suggest that a larger area is climatically suitable for the native tree species included in the study. Species distribution modelling generates valuable information for the conservation management of rare and endangered native tree species.

Although an extensive portion of the study area was predicted to be environmentally suitable for rehabilitation of the native tree species, the largest portion of this area is intensively cultivated, or area used by livestock operations and unlikely to be practically available for expansion of native tree species. Therefore, and according to ERPD (Ministry of Agriculture, Chile 2016), the conservation action plans in Chile, the priority for the next decade will be to 1) protect the most degraded habitats from further extraction and destruction, 2) restoration of native forests with emphasis on the provision of water resources and 3) establish logging management and sustainable forest harvest measures. The study findings reinforce the ERPD in Chile, which provides financial incentives to private owners who manage native forests for productive or preservation purposes. This study can be advanced by using more sample points covering other ecological spaces in the region of Los Lagos. This information can be of great help in protecting vulnerable habitats from the effects of climate change and other future modifications. Additionally, it's crucial for conservation planners and rangeland managers who are working to prevent the extinction of these species.

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