Cost-effective priority areas for the conservation of the Maulino coastal forest and Cost-effectiveness gains by considering climate change effects in reserve network planning of *Nothofagus alessandrii* (Ruil)

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This Dissertation is dedicated to my mother Ana, to my wife Esther and to my late grandfather, Carlos, who has inspired many aspects of my life.

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Executive Summary

The most common vegetation in the Maule region of central Chile is sclerophyllous forest. The microclimate weather on the west oriented hillsides of the coastal range of the Maule region, however, allows the occurrence of the mesophyllous Maulino coastal forest (Torres-Díaz, *et al.,* 2007; Santelices *et al*., 2011). Its floristic composition is characterized with deciduous tree species, evergreen-sclerophyllous trees and shrubs (Santelices *et al*., 2011). This forest is represented by formations dominated by species of the genus *Nothofagus*, such as *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble). It harbors endemic plants and, in particular, highly threatened tree species of the *Nothofagus* genus (Villalobos & Huenchuleo-Pedreros, 2010; Santelices *et al*., 2011).

The *Nothofagus* genus is part of the *Fagacea* family and includes 40 species only located to the south of the equator (Villalobos & Huenchuleo-Pedreros, 2010). Nearly all *Nothofagus* species are concentrated in the south center of Chile, specifically, in the Chilean forests amidst the latitudes 33°S and 55.5°S (San Martín & Sepulveda, 2002; Villalobos & Huenchuleo-Pedreros, 2010; Silva-Muñoz, 2012). *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble) has a vulnerable state of preservation according to the "International Union for Conservation of Nature (IUCN)". This forest is refuge of the most threatened *Nothofagus* species of the country: *Nothofagus alessandrii* (San Martín *et al*., 2006; Santelices *et al*., 2011). Along with *Gomortega Keule* and *Pitavia punctata*, the IUCN assigns these three trees a critical conservation status (IUCN, 2001; San Martín & Sepulveda, 2002; Arnold *et al*., 2009; Silva-Muñoz, 2012). According to Olivares *et al.* (2005), *Nothofagus alessandrii* is at the verge of extinction if no specific conservation measures are applied.

The Maulino coastal forest is situated in 16 municipalities in the west side of the Maule region and covers 53,945 hectares, representing 13% of the region's coastal forest area. The extent of the Maulino coastal forest including its *Nothofagus alessandrii* remnants was substantially reduced from the expansion of agriculture as well as plantations of the exotic pine species *Pinus radiata*. Furthermore, the Maulino coastal forest is viewed as vulnerable to further damage from climate change (Olivares *et al*., 2005).

Global warming is predicted to alter the dispersal of global flora (Pliscoff, 2013) and, consequently, the habitat for vulnerable and critically threatened species. With likely climate change effects on the Maulino coastal forest, *Nothofagus alessandrii* may be in particular danger (Olivares *et al*., 2005; San Martín *et al*., 2006; Santelices *et al*., 2012). Much of its remaining environment exists in fragments of Maulino coastal forest, surrounded by *Pinus radiata* plantations. The pine invades the Maulino coastal forest, placing additional pressure on the *Nothofagus alessandrii* (Olivares *et al*., 2005).

According to the Chilean law, Decree Law 2,186 (Organic Law of Expropriation Procedure), the Chilean conservation agencies cannot implement protected areas on private land without compensating landowners for financial losses. Thus, funds for extra preservation of nature are in particularly short stock in Chile (Pliscoff, 2013). Therefore, funds for preservation must be employed very efficiently (Wilson *et al.,* 2009; Pliscoff, 2013). To optimize conservation planning from cost-effectiveness point of view, spatial conservation priorities must be identified that meet intended biodiversity targets while reducing conservation costs (Barth, 2016). With respect to the Maulino coastal forest, such an optimization is the central objective of this thesis.

There are several methods and tools to optimize costs associated with conservation planning. One of them is spatial conservation prioritization. Spatial conservation prioritization is a biogeographic economic procedure used for determining sites for biodiversity preservation that optimally equilibrates the achievement of conservation goals and cost (Pliscoff, 2013; Duarte *et al,* 2014). It uses quantitative, spatially explicit data to recognize places for the location of funds for preservation. In addition to this, these methods, allow incorporated the effect of climate change in the research (Wilson *et al.,* 2009; Pliscoff, 2013).

Here, I present a regional analysis of cost-effective spatial conservation priorities that accounts for opportunity costs linked to the renunciation of the profits coming from agriculture or forestry production in Chile’s Maule region. The focus is on how agricultural and forest areas and their subsequent land uses compete with the Maulino coastal forest for space. The analysis uses modeled species distribution data that incorporate climate change effects. With this research, I seek to reduce the economic impact of forest biodiversity preservation in central Chile – hoping to, simultaneously, (i) limit impacts on regional livelihoods and (ii) increase the prospects for the realization of a well-designed network of protected natural sites for the Maulino coastal forest and its species.

I performed the analysis with the conservation planning software Marxan. Marxan recognizes cost-effective priority sites that reach a preset conservation targets (Ball *et al.,* 2009). In addition to biogeographical data of the Maulino coastal forest and *Nothofagus alessandrii*, I used spatial data on the main economically relevant land use types in the study area and two distribution models of *Nothofagus alessandrii*: a "current distribution model" and a "future distribution model". The future distribution model was used to incorporate climate change effects.

I examined three scenarios in the analysis: a current vegetation data scenario of the Maulino coastal forest, and two modeled scenarios of *Nothofagus alessandrii* (current and future model scenarios of *Nothofagus alessandrii*). One level of protection for each scenario was used and a range of Marxan adjustments (BLM and SPF) were explored. The final output is a set of cost-effective reserve networks for the preservation of the Maulino coastal forest and for the preservation and restoration of *Nothofagus alessandrii* forest.

The costs for implementing optimized reserve networks vary from € 1.7 to € 3.6 million: as a function of the required protection grade and the compactness (BLM) of the reserve network.

Pinus radiata plantings would be the most affected commercial land use, representing 34% to 40% of the overall surface of the proposed reserve networks. On the other hand, agriculture land comprises only between 0.7% and 1.5%. In part, the low percentage of agriculture is a cost-minimizing result of the spatial optimization process as the opportunity cost of agricultural land is higher than that for *Pinus radiata* plantations.

When was taking into account the influence of climate change in *Nothofagus alessandrii*, the reserve networks produced in the future scenario have a small economic impact. This is because the future scenario surface represents half of the surface of the current scenario. This results in smaller reserve networks. This reduction is because many areas today suitable for *Nothofagus alessandrii* are forecast to be not suitable in the future for this species as a consequence of climate change.

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Acronyms and abbreviations

AFR100	African Forest Landscape Restoration Initiative
BCN	Biblioteca del congreso nacional (National congress library)
BIOCLIM	Bioclimatic analysis and prediction system
BLM	Boundary length modifier
CBA	Cost Benefit Analysis
CBD	Convention on biological Diversity
CEPAL	Comisión Económica para América Latina y el Caribe
CLP	Chilean Pesos
CONAF	Corporación Nacional forestal (National Forestry Corporation)
CONAMA	Corporación Nacional del Medio Ambiente (National Environmental Corporation)
COP 20	20th annual Conference of the Parties on Convention on Climate Change (UNFCCC)
CR	Critically Endangered
D.L.	Decree Law
DSS	Decision Support System
FAO	Food and Agriculture Organization
€	Euros
GBRMPA	Great Barrier Reef Marine Planning Authority
GHG	Greenhouse gases
GIS	Geographic Information System
GPFLR	Global Partnership on Forest and Landscape Restoration
ha	hectares
INE	Instituto Nacional de Estadísticas (National Institute of Statistics)
IRR	Internal Rate of Return
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
Km	kilometers
km^2	Square kilometre
Marxanio	Marxan web application
m	meters
mha	million hectares

m.a.s.l	meters over sea level
n/a	not applicable
NCEAS	National Center for Ecological Analysis and Synthesis
NGOs	Non-governmental organization
NMFS	The U.S. National Marine Fisheries Service
NPV	Net Present Value
OC	Opportunity Costs
ODEPA	Oficina de Estudios y Políticas Agrarias (Office of Agricultural Studies and Policies)
Pacmara	Pacific Marine Analysis and Research Association
PUs	Planning units
QGis	Quamtum Gis 1.8.0 – Lisboa software
RN	Reserve Network
SA	Simulated annealing
SDMs	Species distribution models
SNASPE	Sistema Nacional de Áreas Silvestres Protegidas del Estado (National System of Protected Wild Areas of the State)
SCP	Spatial conservation prioritization
SDG	Sustainable Development Goals
SPF	Species penalty factor
SUSTAIN	Sustainability and inclusion strategy for growth corridors in Africa
$	American Dollars
TNC	The Nature Conservancy
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Conventionon Climate Change
WGI	Working Group I
WRI	World Resources Institute

1. Statement of the Problem

The Maule region is one of the fifteen Chilean administrative divisions. This region located in central Chile, is bordered in the north with the Libertador Bernardo O'Higgins region, the south with the Bío Bio region, in the east with Argentina and west by the Pacific Ocean (Silva-Muñoz, 2012; BCN, 2017).

The central part of Chile is considered as a biodiversity hotspot by the environmental organization "Conservation International" (Myers *et al*., 2000; Conservation International, 2011). This hotspot encompasses 397,142 km² of north-central Chile and the western tip of Argentina, ranging from the coast of the Pacific Ocean to the the Andes mountain peaks, representing some 40% of Chile's terrestrial surface (Myers *et al*., 2000; Conservation International, 2011; Silva-Muñoz, 2012).

Although the Maule region is part of a biodiversity hotspot, it is the region of Chile that has suffered the highest rates of loss of its native forests compared to other regions of the country, such as the regions situated more near to the chilea Patagonia in the south of Chile, where the biggest concentration of native forest is located. The loss of the native forests in this region is due to different land uses still carried out there; especially, *Pinus radiata* planting and some agricultural activities (Santelices *et al*., 2011; Silva-Muñoz, 2012).

The most common vegetation in the Maule region is sclerophyllous forest. However, the climatic environment on the western oriented hillsides of the coastal range allows the growth of the Maulino coastal forest, which consists of two deciduous species of the *Nothofagus* genus (San Martín & Sepulveda, 2002). The *Nothofagus* genus is part of the *Fagacea* family and includes 40 species only located in the south of the equator (Villalobos & Huenchuleo-Pedreros, 2010). Almost all *Nothofagus* species are found in forests between latitudes 33°S and 55.5°S in central and southern Chile (San Martín & Sepulveda, 2002; Silva-Muñoz, 2012).

The Maulino coastal forest located in the Maule region’s coastal range covers 33,700 hectares, or 7% of the region’s total coastal forest area. The remaining 93% belongs to mostly to *Pinus radiata* and other exotic forest plantations (Corporación Nacional Forestal (CONAF), 2013).

The Maulino coastal forest is mainly comprised of the roble-hualo forest type, which is widely spread in the Mediterranean region of Chile, especially in the coastal range and the Andes Mountains. From the south of the Mataquito River (35°S latitude) to the Itata River (36° – 30°S latitude), this forest type is called "Maulino coastal forest" if found in the coastal range of the Maule region and "Maulino forest" when found in the Andes Mountains of the Maule region (Donoso, 1981; Silva-Muñoz, 2012).

The floristic composition of the Maulino coastal forest is characterized with deciduous tree species and sclerophyllous evergreen trees and shrubs. The Maulino coastal forest is represented by formations predominated by species of the *Nothofagus* genus, such as *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble). Depending on the conditions of the sites, in this forest can also be found species with higher moisture requirements (e.g., *Persea lingue*, *Guevina avellana*, *Lomatia dentata*, *Gomortega keule*, *Pitavia punctata*, *Nothofagus dombeyi*, *Nothofagus nervosa, Nothofagus antarctica* and *Nothofagus alessandrii*) or lower moisture requirements (e.g., *Peumus boldus*, *Citronella mucronata*; Arnold *et al*., 2009).

The Maulino coastal forest is composed of endemic arboreal species and those of more temperate climates that are of great floristic importance to conservation. Among the first are the *Nothofagus alessandrii* (ruil), *Gomortega keule* (queule) and *Pitavia punctata* (pitao) and among the latter are, for example, *Embothrium coccineum* (notro), *Saxegothea conspicua* (mañio), *Weinmannia trichosperma* (tineo) and *Nothofagus nervosa* (raulí), among others (Arnold *et al*., 2009).

Nothofagus alessandrii is a special case hereafter referred to as ruil, the endemic species stems from central Chile, defined as "Critically Endangered" (CR) by the Red List conservation status (IUCN, 2001; Villalobos & Huenchuleo-Pedreros, 2010). From the late 19th centuria, ruil and the Maulino coastal forest were destroyed and fractured, and today the ruil forest is threatened by tree monocultures consisting mostly of fast-growing exotic species (e.g., *Pinus radiata*; Donoso *et al*., 2004; Villalobos & Huenchuleo-Pedreros, 2010).

In 2013, the National Forestry Corporation (CONAF) mapped 339 hectares of ruil. These hectares of ruil are not a continuous mass of forest; on the contrary, they are distributed or located within fragments of Maulino coastal forest. These fragments of Maulino coastal forest containing ruil total 1,223 hectares (CONAF, 2013) are circled by plantations of *Pinus radiata*, making the ruil the species with the most high extinction risk in Chile (Olivares *et al*., 2005; Villalobos & Huenchuleo-Pedreros, 2010; Santelices *et al*., 2011; Santelices *et al*., 2012b; Silva-Muñoz, 2012).

From a cultural and ecological point of view, the ruil is emblematic for the Maule region, represented in its coat of arms and an endemic species of this region as well. In addition, the ruil is also considered as a relic or living fossil because it is the most ancient *Nothofagus* in the southern hemisphere. This has transformed the ruil into a symbol and element of regional identity for its inhabitants (Olivares *et al*., 2005; Silva-Muñoz, 2012).

Many efforts to protect this species have been attempted. In 1985, CONAF declared ruil as a threatened species that demands protection (Villalobos & Huenchuleo-Pedreros, 2010). It was proclaimed as a national monument by act N°13 of the Chilean State ten years later (1995). In 2004, Conservation International listed ruil as a threatened species in their Red Data Book for Chilean Terrestrial Flora. It was only in 2007 that ruil finally obtained top conservation priority status as a species (Santelices, 2009; Conservation International, 2011; Silva-Muñoz, 2012).

Nowadays, just 24 hectares of ruil are protected under state administration by the National Forestry Corporation (CONAF) in Los Ruiles National Reserve. This reserve encompasses a surface of 45 hectares separated in two sectors: “El Fin”, located in the municipality of Empedrado and “Los Ruiles”, located in the municipality of Chanco. Thus, 7% of the overall surface of ruil forest belongs to the Chilean government and the remaining 93% to small landholders and forest companies (Olivares *et al.,* 2005; Santelices *et al*., 2011; Silva-Muñoz, 2012).

Due to the scale of the fragmentation that the forest has suffered and because of the ownership type that this forest has, mainly small farmers, efforts to preserve the ruil has been a difficult task. For this reason, one way to preserve it is by compensating forest owners as an incentive to initiate conservationist measures (Silva-Muñoz, 2012), while Olivares *et al*. (2005) suggest it is more suitable to compensate them after the fact. Moreover, the creation of buffer zones around the fragments of forest that contains ruil must be an essential part of its future conservation efforts (Olivares *et al.,* 2005; Silva-Muñoz, 2012).

To date, few studies with an economic perspective have been done in Chile for the conservation of ruil forest. In 2006 Silva-Muñoz used choice experiment to carry out an monetary valuation of environmental services supplied by the ruil forest in the Maule region. He found that the willingness to pay of the local people for the conservation of the ruil forest was between 371 to 787 Chilean pesos monthly per family.

In 2006, Schollenberg uses an auctioning scheme for ruil conservation contracts. She demonstrated that auction formats promise to yield substantial cost reduction in comparison to traditional instruments in environmental policy. As a consequence, government budgets and international funding allocated to ruil conservation could be employed more efficiently if this method is used.

In 2006 too, Villalobos & Huenchuleo-Pedreros employed the contingent valuation approach to design a proposal for the development of a scheme of payments for the provision of environmental services, from the economic valuation of the ruil forest. They found a positive willingness to pay from the respondents by contributing to a fund to environmentally protect it.

More recently, in 2012 Silva-Muñoz performed a cost-benefit analysis to different production activities that are being performed or could be performed in the area where ruil forest is located in order to calculate the opportunity cost that represents the conservation of the forest. He found that the opportunity cost for the conservation was 225,587 Chilean pesos per hectare, if *Pinus radiata* plantation is considered as the main activity perform in the area.

Despite the existence of some studies on the ruil forest, research has not yet been done on the determination of cost-effective priority sites for the establishment of reserve networks for the preservation and restoration of ruil forest and the Maulino coastal forest.

Restoration of ruil and the Maulino coastal forest as well as identifying cost-effective priority areas for conservation is important, as it allows for incorporating monetized costs and benefits to create or expand reserve networks for these forests at the lowest possible cost while avoiding politically or economically costly areas.

In light of the competing interests at play, a more likely and defensible implementation of these reserve networks takes place. The idea of this is that low-priced reserve networks have a higher probability to be executed (Ardron *et al.,* 2010; Duke *et al.,* 2013). Thereby, a manner to preserve the Maulino coastal forest and the ruil forest could be perform a study to detect cost-effective priority areas for creation of reserve networks for the Maulino coastal and ruil forests.

In addition to this, it is essential to delve into the climate change effect, excluding reserve networks areas that in the future will be no more adequate for the survival of the species, since one potential climate change effect in the area of study is the southward range shift of the Maulino coastal and ruil forests. Thus, newly suitable potential habitats may show up (Silva-Muñoz, 2012). Alarcon & Cavieres (2015) estimate "that the present range of these species will change in the future due to climate change effect in the study area, since their results show that the suitable land for these forests is moving southward" (Alarcon & Cavieres, 2015).

With approximately 90% of the ownership of the still existing Maulino coastal forest in private hands, the acceptance of the conservation proposals of this research by private owners will be essential. That is why this study seeks to determine cost-effective reserve networks so that the impact is not so high for different social and economic realities that prevail in the area.

To identify cost-effective priority areas for conservation of important sites for terrestrial biodiversity or areas with high concentrations of endemic species, as the case of the Maulino coastal forest and ruil, various methodologies have been developed. The application of reserve selection algorithms being one of them (Wilson *et al*., 2009; Moilanen & Ball, 2009; Pliscoff, 2013). These algorithms choose the minimum collection of areas (quadrants, hexagons, natural boundaries or administrative boundaries) that maximizes the biological metric of interest (species richness, endemism, etc; Pliscoff, 2013).

The conservation planning study of the Maulino coastal and ruil forests conducted here is designed to preserve 17% of the former and identify areas for restoring and preserving the latter, taking into account how climate change is going to impact this endangered species.

The “Strategic Plan for Biodiversity 2011-2020 of the Convention on Biological Diversity (CBD)” was taking into account when choosing a 17% conservation target. Under the plan, the government commits to improve reserve network management effectiveness and increase worldwide coverage of natural reserves from 13% to 17% of the landscape by 2020, focusing on relevant sites for conservation, like biodiversity hotspots (UNEP/CBD 2011; Barth, 2016).
In addition, my study wants to help to the fulfillment of two international and two regional strategies for biodiversity preservation:

- The “Aichi Biodiversity Targets”, which according to UNEP/CBD (2011) are: “Twenty realistic goals implemented within the framework of the Strategic Plan for Biodiversity 2011–2020, a worldwide decade-long plan for preserve biodiversity and the benefits it provides to all” (UNEP/CBD 2011).

- The “initiative 20 x 20”, backed by $ 2 billion American dollars in private funds, is an effort by countries in Latin America – including Chile – to change the course of land degradation, restoring 20 million hectares by 2020 (WRI, 2014).

- The “Maule Biodiversity Strategy”, which goal is preserving the biodiversity of the Maule region through the preservation of the sustainability of its ecosystems and species. It is a strategy for biodiversity conservation implemented to establish an appropriate degree of official protection for all the relevant ecosystems of the region (CONAMA, 2002). In this plan, the community, the private sector, and the public administration perform a key part, since together they can decide what is to be preserved and why, actively cooperating to achieve that objective (CONAMA, 2002).

- The “Maule Regional Strategy 2008–2020”, specifically Objective 10, states: "Contribute to the environmental sustainability of the Maule region, positioning itself as a clean region and a region that respect for nature" (Regional Government of Maule, 2008).

The goal of my study is to use a spatial conservation prioritization tool for prioritizing areas for the preservation of the Maulino coastal forest and for the preservation and restoration of ruil forest, through reserve networks design.

This study uses Marxan as the spatial conservation prioritization planning tool to identify sets of zones that fulfil conservation targets at the lowest expense, making it easier to analyze trade-offs by helping consumers to evaluate to what degree each alternative fulfils the conservation and socioeconomic goals (Game & Grantham, 2008; Ardron *et al*., 2010).

For the analysis of the Maulino coastal forest, I used information of its current distribution and the location of the current reserves. For the analysis of ruil, I used its current distribution, the location of current reserves and two distribution models of the current and future distribution of the ruil forest (CONAF, 2013; Alarcon & Cavieres, 2015**).** The distribution of the Maulino coastal and ruil forests and the location of the reserves have been provided by CONAF, as well as two distribution models of ruil created in 2015 by Alarcon & Cavieres.

I worked with two distribution models of ruil in order to examine the influence of climate change on their range and determine which places are apt for restoration; in case future conservation and restoration programs get implemented in the region. In addition, for both cases (Maulino coastal forest and ruil), I used different land use data as the socio-economic variable of our research to find the opportunity cost that represents the preservation of the Maulino coastal forest and ruil. This opportunity cost was used as the economic input in Marxan.

It is important to mention that this PhD thesis is an extension of my master's project "Opportunity Costs of the Conservation of *Nothofagus alessandrii* in the Maule region, Chile and the Impact of Climate Change on its Distribution Area". For that reason, information of that study was used in this PhD thesis too. I used some background information about the study area, the Maulino coastal forest, the *Nothofagus alessandrii*, and opportunity costs, as well as some economic analysis from the master project, specifically the opportunity cost of *Pinus radiata* plantation, was already performed then. Sections overlapping with the Master's thesis are, if appropriate, indicated by a reference to "Silva-Muñoz, 2012". Thus, all the analysis present in this PhD thesis are new, with the exception of the calculation of the opportunity cost of *Pinus radiada* plantations, that was obtain from "Silva-Muñoz, 2012". The analysis carry out in my PhD thesis are the detection of cost-effective priority areas for the preservation of the Maulino coastal forest and the determination of cost-effectiveness gains by considering climate change effects in reserve network planning of ruil, as it is stated in the title of this thesis.

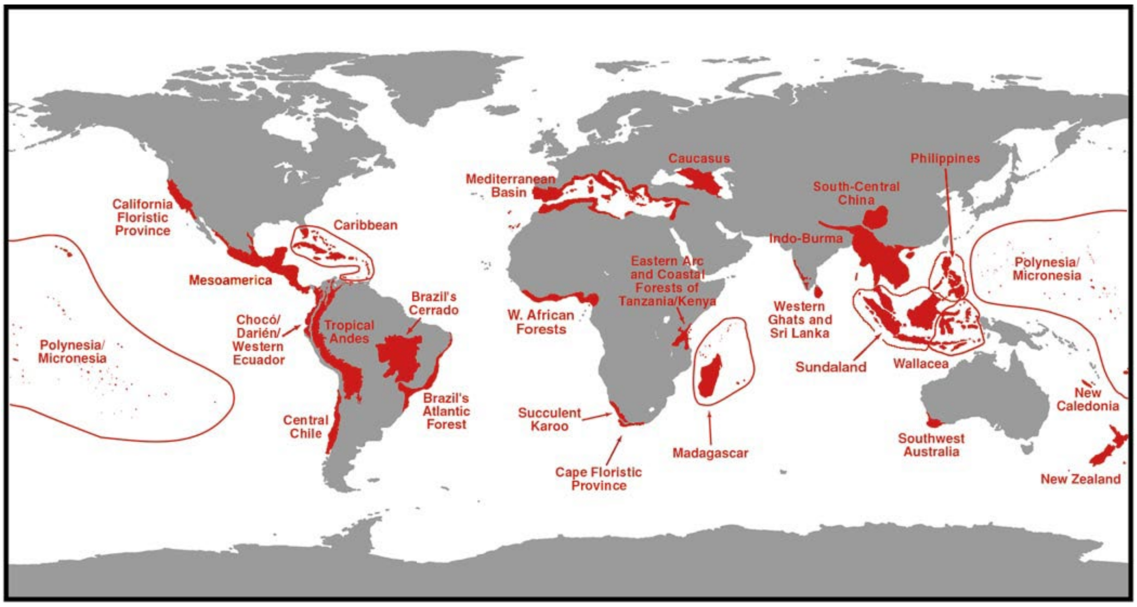
2. Review of the Literature

2.1. Maulino coastal forest

The Maulino coastal forest is a Mediterranean forest. Mediterranean forests cover 2% of the worldwide land area (Wade *et al*., 2003; Arnold *et al.,* 2009) and are distributed in six ecoregions in five biogeographic areas (Olson & Dinerstein, 2002; Arnold *et al.,* 2009). Both South America's Mediterranean forests and shrub formations can be found only in Chile and belong to the world's 238 biologically most valuable ecoregions (Olson & Dinerstein, 2002).

Furthermore, Chilean Mediterranean forests constitute a considerable part of one of the 25 hotspots considered to be a priority for conservation worldwide, as shown in Figure 1 (Myers *et al.,* 2000; Arnold *et al.,* 2009).

Figure 1: The 25 hotspots

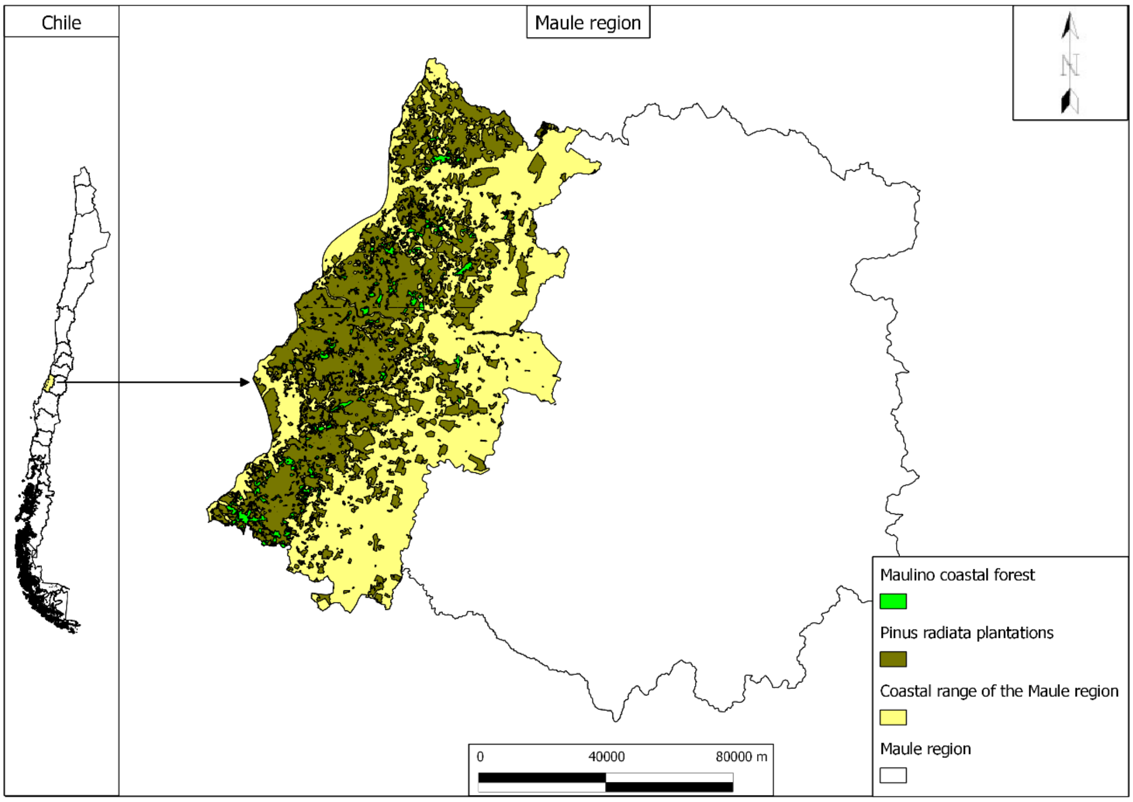


Source: Myers *et al.,* 2000.

The total area of Chile's Mediterranean forests is estimated at 533,400 hectares and extends between the 4th region and the 8th region of the country (Arnold *et al.,* 2009). This forest type concentrates in Chile's sixth and seventh regions, which represent 60% of the total surface area of Mediterranean forests located there (Arnold *et al.,* 2009). The forest has suffered a high degree of fragmentation, which is estimated to range at about 74%. Human intervention is accountable for almost 90% of that figure (Wade *et al*., 2003; Arnold *et al.,* 2009), only exceeded by Europe's fragmentations of temperate broadleaf forests and the Asian mangroves and dry tropical forests (Arnold *et al.,* 2009; Silva-Muñoz, 2012).

The Mediterranean forests are constituted by different forest groups, the Maulino coastal forest being one of them. The Maulino coastal forest is shared by sixteen municipalities of the Maule region coastal area totaling 33,747hectares, which is about 7% of the Maule region's total coastal forest area. The area of fast growing exotic species plantations (mainly *Pinus radiata*), covers, in contrast, in the same place, 402,793 hectares, and constitutes 93% of the Maule region's total coastal forest area (Figure 2; CONAF, 2013).

Figure 2: Forestry area in the coastal range of the Maule region

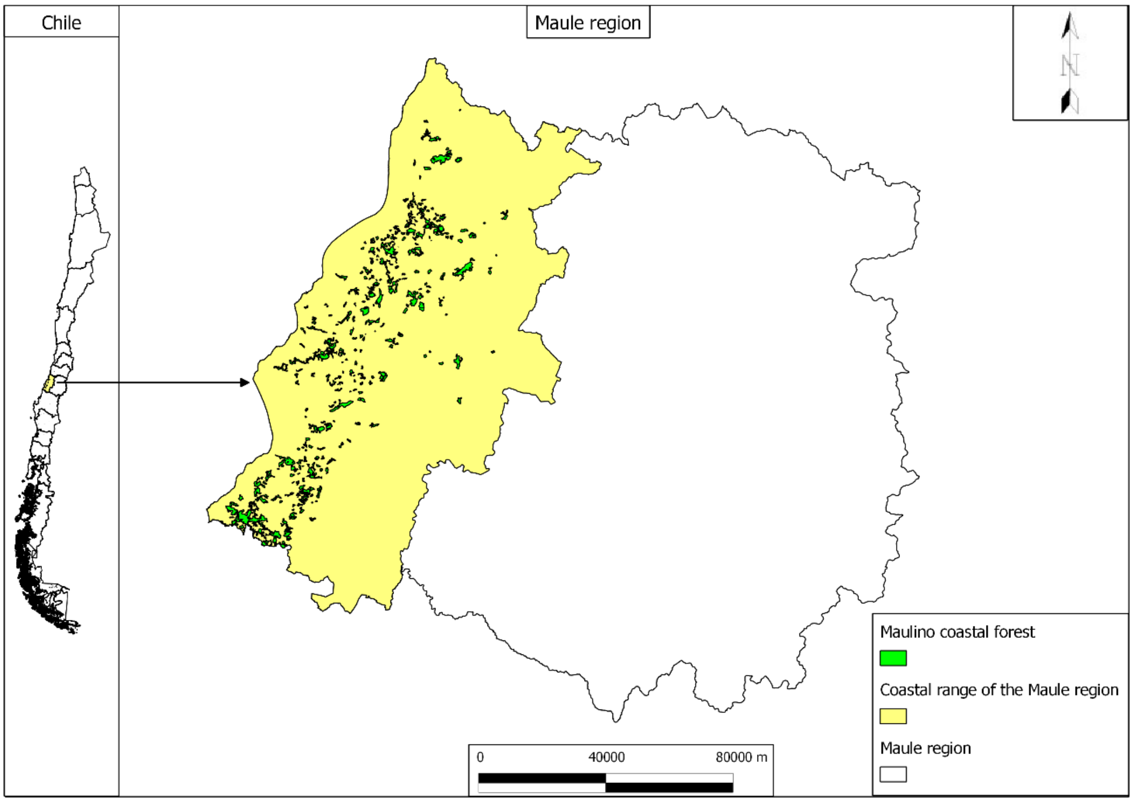


Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

The area of the Maulino coastal forest has a rich floral biodiversity containing 596 species, of which 58% are native and 42% endemic. A significant amount of them have conservation problems which are cataloged as endangered and vulnerable by CONAF (Arnold *et al.,* 2009; Silva-Muñoz, 2012).

The Maulino coastal forest's floristic composition (Figure 3) is characterized by deciduous tree species and evergreen-sclerophyllous trees and shrubs. In this forest species of the *Nothofagus* genus such as *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble) are particularly predominant. Depending on the conditions of the sites, they appear accompanied by species with higher moisture requirements (e.g., *Persea lingue*, *Guevina avellana*, *Lomatia dentata*, *Gomortega Keule*, *Pitavia punctata*, *Nothofagus dombeyi*, *Nothofagus nervosa* and *Nothofagus alessandrii*) and lower moisture requirements (e.g., *Peumus boldus*, *Citronella mucronata*; Arnold *et al.,* 2009).

Figure 3: Remnant of the Maulino coastal forest



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

Endemic arboreal species of great floristic importance for conservation, such as *Nothofagus alessandrii* (ruil), *Gomortega Keule* (queule), *Pitavia punctata* (pitao), *Embothrium coccineum* (notro), S*axegothea conspicua* (mañio), *Weinmannia trichosperma* (tineo) and *Nothofagus nervosa* (raulí) can also be found in the Maulino coastal forest (Arnold *et al.,* 2009; Silva-Muñoz, 2012).

Despite the existence of species of great floristic importance for conservation, as a part of the Mediterranean forest, the Maulino coastal forest has suffered high degrees of anthropogenic fragmentation. The degradation and reduction process suffered by the Maulino coastal forest is characterized by two main phenomena: a high rate decline in native forests, at least until the year 2000, and a sharp size decrease of the fragments of native forests (Arnold *et al.,* 2009; Silva-Muñoz, 2012).

According to Echeverría *et al*. (2006), who conducted a study on land use change in the zone comprised by the Maule and Cobquecura rivers in the southern part of the Maule region. The annual rate of native forest decrease in this area was “5% between 1975 and 1989 and 3% between 1990 and 2000”. This indicates a reduction rate between 7 to 10 times higher than the average decrease in forests in South American between 1990 and 2005 (FAO, 2007; Arnold *et al.,* 2009; Silva-Muñoz, 2012).

As to the reduction of average size of fragments of Maulino coastal forest, Echeverría *et al*. (2006) found that, in 2000, just 3% of the forest area surveyed included areas which are greater than 1000 hectares and 69% included areas smaller than 100 hectares. He also found that from 1975 to 2000, in a 25-year period, half of the Maulino coastal forests existing at the start of the interval were changed by *Pinus radiata* plantations (Silva-Muñoz, 2012).

The main causes of the decline and fragmentation of the Maulino coastal forest are two: a) the transformation of historical land use (forests land into agricultural land), as a consequence of the colonization in Chile’s south, and b) the replacement of native forests for fast-growing forest plantations, mainly of *Pinus radiata* (Arnold *et al.,* 2009; Silva-Muñoz, 2012). The consequences of the first cause existed up to the mid-20th century, whereas the second one began to gain importance after the development of a forestry economy in Chile which was, from the 1970s, based on plantations (Silva-Muñoz, 2012). In addition to these two causes, another important factor in the fate of the Maulino coastal forest has been its step-by-step degradation as a consequence of cutting trees for energy purposes (timber and coal) without any sustainability criteria (Arnold *et al.,* 2009; Silva-Muñoz, 2012).

The Maulino coastal forest, as a kind of Mediterranean forest, is mainly composed by the forest type roble-hualo (Silva-Muñoz, 2012). This forest type was identified by Donoso in 1981 and is widely spread in the Mediterranean region of Chile, and in particular in the coastal range and the Andes Mountain (Donoso, 1981). This forest type is constituted by *Nothofagus glauca* and *Nothofagus obliqua*; although the predominant species in the coastal range of the Maule Region is *Nothofagus glauca* (hualo; Donoso, 1981; Arnold *et al.,* 2009; Silva-Muñoz, 2012).

A species of significant importance for this forest type in the Maule region coastal range is hualo, which forms almost pure forests on the slopes of hills, which are called "transitional forests" or "Maulino coastal forests". Moreover, in this forest we found others species such as *Persea lingue*, *Lomatia hirsuta*, *Gevuina avellana*, C*ryptocarya alba*, *Peumus boldus*, *Lithraea caustica* as well as some *Nothofagus* as ruil (Donoso, 1981; Silva-Muñoz, 2012).

The forest type roble-hualo includes five subtypes, depending on the floristic and structural perspective (Donoso, 1981). These subtypes are:

a) Northern coastal forests of roble or hualo: situated in the upper part of the cords of the coastal range between latitudes 32°50'S and 35°S as clumps of small extension. These fragments are open, nearly pure and with relatively little understory composed of Sclerophyllous species (Donoso, 1981; Silva-Muñoz, 2012).

b) Andean roble forests: located from 34°30'S (Colchagua) to the Ñuble River. At the north of Lontue River, isolated forests appear at 1,000 m.a.s.l., which grow towards the south and can, depending on the latitude, be associated with *Austrocedrus chilensis* (ciprés) and some Sclerophyllous species. Towards the south of the Lontué River, the forests are of a higher density (Donoso, 1981; Silva-Muñoz, 2012).

c) Hualo forests: grow in the coastal range rolling hills, between the Mataquito, Itata and Lontué Rivers. They usually form quite very pure forest, which, nevertheless, can to some degree be mixed with roble and ciprés (Donoso, 1981; Silva-Muñoz, 2012).

d) Ruil forests: a small amount of fragments that occupy wet areas embedded in the hualo forest masses of the Maule region coastal range. The ruil forest fragments are pure as a rule, but some hualo trees can be found there at the top (Donoso, 1981; Silva-Muñoz, 2012).

e) Hydrophilic forests of streams: located in humid areas. Relatively dense forests, generally made up of a canopy of *Nothofagus dombeyi*, *Nothofagus obliqua*, *Persea lingue*, *Aextoxicon punctatum,* among others (Donoso, 1981; Silva-Muñoz, 2012).

From these five subtypes of roble-hualo forest type, just the hualo forest subtype (c) and the ruil forest subtype (d) appear in the coastal range of the Maule region. These two subtypes form the Maulino coastal forest (Donoso, 1981). This is why the most emblematic species of the Maulino coastal forest are the hualo (*Nothofagus glauca*) and ruil (*Nothofagus alessandrii*) ones, which respectively enjoy a conservation status as vulnerable and critical designated by the IUCN (Silva-Muñoz, 2012). These two species are briefly described below.

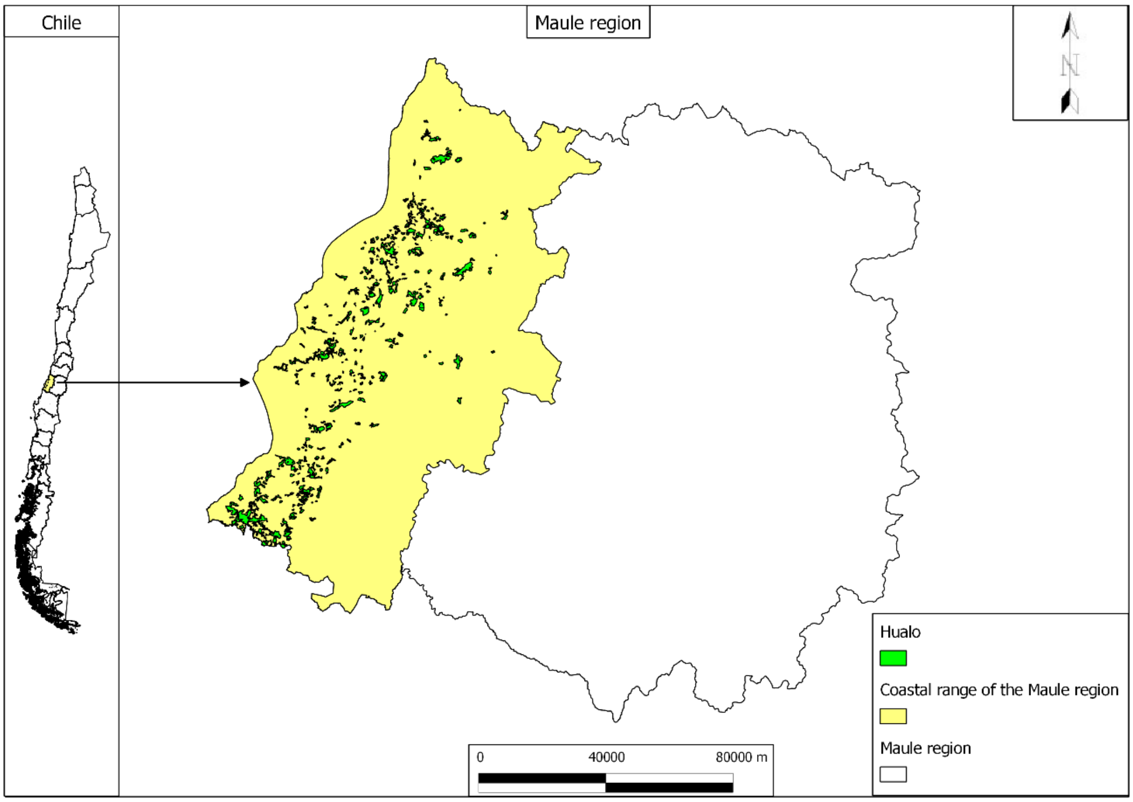
2.1.1 Hualo (*Nothofagus glauca*)

Hualo forests are located within the Mediterranean climate area, with very specific temperature and conditions. Hualo is the most characteristic species of the Maulino coastal forest. This species is an endemic one of central Chile and considered vulnerable by the IUCN, appearing in pure or mixed formations with other species, mainly roble (roble-hualo forest type; Arnold *et al.,* 2009; Gonzalez, 2015).

The original coverage of the roble-hualo forest type before European colonization is estimated at 950,000 hectares of which just 188,300 hectares remained in 1997, 80% of which located in the Maule region (Arnold *et al.,* 2009; Silva-Muñoz, 2012). A great fragmentation between its forests can be observed today, with two separate main populations: the coastal mountain range and the Andean mountain (Silva-Muñoz, 2012; Gonzalez, 2015).

In the Maule region, 161,973 hectares of hualo existed in 2013, of which 128,226 hectares are found in the slopes of the Andes mountain range and the remaining 33,747 hectares in the coastal range of the Maule Region, distributed in separate fragments (Figure 4) between forest plantations and agricultural-livestock land (CONAF, 2013). It is estimated that forests with hualo presence located in the coastal range originally extended from latitude 34°45' to 36°30' south. Hualo is probably one of the forest formations in Chile that has over time suffered most decreases caused by different agents of forest use and destruction (Arnold *et al.,* 2009; Silva-Muñoz, 2012; CONAF, 2013).

Figure 4: Current distribution of hualo in the coastal range of the Maule region



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

In the coastal range of the Maule region, the hualo allocation is similar to the distribution of the Maulino coastal forest because hualo is this forest's main component (Gonzalez, 2015). Information available on the specific distribution of hualo populations is quite insufficient. However, we can say that, among hualo coastal populations, the largest concentration of remnants exists in the provinces of Talca and Cauquenes, since 93% of the total roble-hualo forest type of coastal populations is sited in the coastal zone of the Maule region (Arnold et al., 2009; Silva-Muñoz, 2012; Becerra & Simonetti, 2013; Gonzalez, 2015)

2.1.2 Ruil (*Nothofagus alessandrii*)

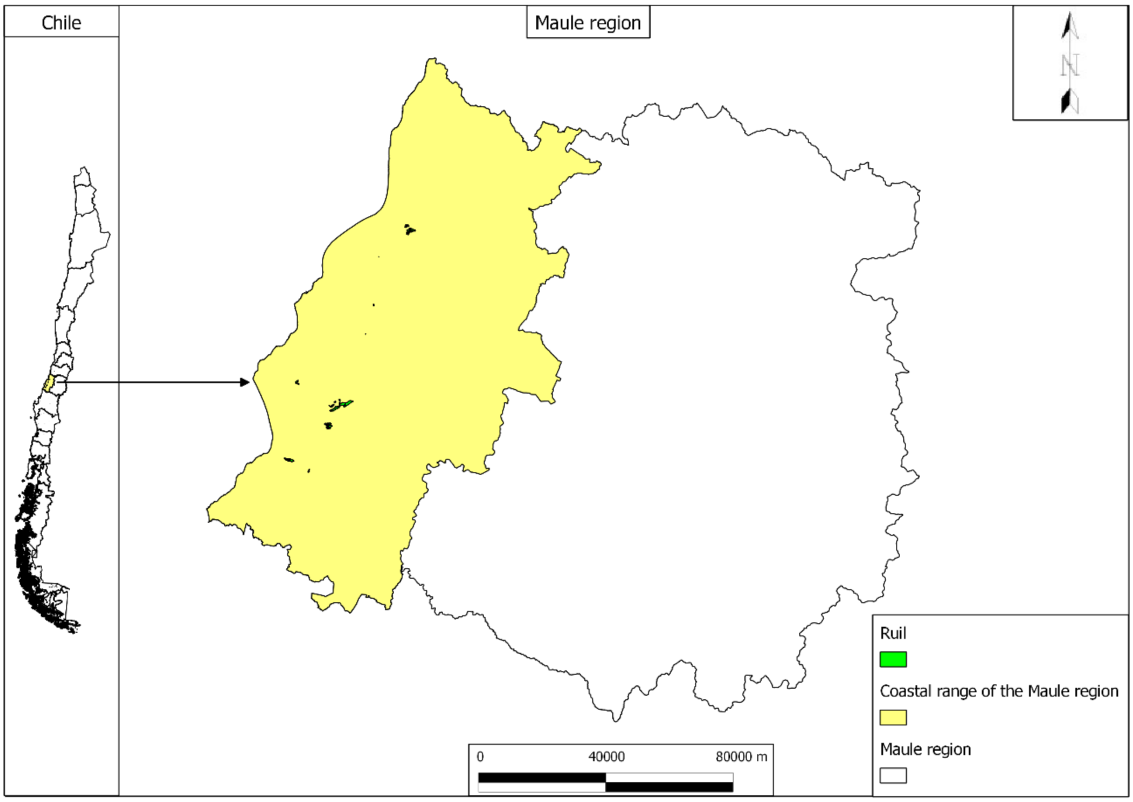
Ruil is an endemic tree from central Chile. It is one of the 10 native South American *Fagaceae* and is the oldest and primitivest species of the *Nothofagus* genus in South America as well (Santelices, 2009; Santelices *et al*., 2012b; Silva-Muñoz, 2012).

Once, this species was a widely distributed one, nowadays its distribution is being confined to the slopes of the coastal range of the Maule region, in forests situated in the west face of the coastal range at altitudes of 150 to 500 m.a.s.l., and under the direct influence of the Pacific Ocean (Olivares *et al*., 2005; Silva-Muñoz, 2012).

This area of ruil forest extends between Huelon (35°05'S and 72°04'W) in the Municipality of Curepto, province of Talca, and the north bank of the Curanilahue River (35°49'S and 72°31'W), in the Municipality of Chanco, province of Cauquenes (San Martín & Sepulveda, 2002). In a rectilinear projection, the ruil species occupies an area of at the most 100 km in length (Santelices, 2009; Silva-Muñoz, 2012).

In this small geographical area, ruil forests show a fragmented distribution pattern (Figure 5). The number of fragments is estimated between 186 and 195, their different forms and area, however, ranging from less than 1 to 60 hectares (San Martín & Sepúlveda, 2002; Santelices, 2009; Silva-Muñoz, 2012).

Figure 5: Current distribution of ruil in the coastal range of the Maule region



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

According to Troncoso and San Martin (1988), the hillsides of the coastal range including the ruil species were transformed in places of refuge or confinement for the ruil species, since during last glaciations the western slope of the coastal range was not filled with fluvial Andean material during the Quaternary (Silva-Muñoz, 2012).

Nowadays, the ruil fragments are encircled by an array of vegetation composed of native and exotic species. The array of vegetation with native species represents natural vegetation (Maulino coastal forest), which involves endemic generic taxa of subantarctic character, Mediterranean and other kinds (Santelices, 2009; Silva-Muñoz, 2012).

Regarding the ownership structure of remaining ruil fragments, the ruil forest current area extends to 339 hectares divided into two areas: private and state land, distributed on 15 geographical areas and 39 private properties (Silva-Muñoz, 2012). There is a national reserve called "Los Ruiles" that exists under state administration (CONAF) and covers 45 hectares, only 24 hectares of the whole surface of the reserve "Los Ruiles" being, however, ruil forest. Two forest companies, "Bosques de Chile" and "Celco", which together account for 73 hectares. The remaining 241 hectares are in the hands of 32 small landholders, the majority of them living in great poverty with incomes earned mainly by breeding cattle, charcoal production and small orchards. Hence, the Chilean State owns about 7% of ruil forest total area, whereas the remaining 93% is owned by small landholders and forest companies (Olivares *et al*., 2005; Schollenberg, 2006; Silva-Muñoz, 2006; Silva-Muñoz, 2012).

All of these have led to the ruil forest being known as the country's most threatened tree species (San Martín & Sepúlveda, 2002; Olivares *et al*., 2005; Santelices, 2009).

2.1.3 Threats for the conservation of ruil and the Maulino coastal forest

The main threats faced by ruil and the Maulino coastal forest are primarily human intervention, as humans are considered as the principal modifying agent and landscape degrader (Santelices, 2009). In the early twentieth century, the Maulino coastal forest and ruil forests suffered slash and burn due to the wish of replacing them by cereal crops and vegetables. However, the forests could regenerate. In addition, the indiscriminate extraction of the best specimens of these forests and the lack of resource management plans worsen its consequent degradation (Santelices, 2009; Silva-Muñoz, 2012).

The current distribution area of ruil and the Maulino coastal forest coincides with the area in which the largest forestry activities of the Maule region are concentrated. This is because this area is intensively planted with fast-growing trees, mainly *Pinus radiata* plantations (Santelices, 2009; Silva-Muñoz, 2012). The impact of these forestry activities can be observed in a reduction of coverage and change in the distribution pattern of the Maulino coastal forest and the ruil forest. As ruil is concerned, the mentioned activities have led to the increase of fragmentation, habitat modification and the extinction of populations associated with these forests, in some places (Santelices, 2009; Silva-Muñoz, 2012).

Table 1 shows the main types of land use that nowadays affect the conservation of ruil and the Maulino coastal forest (CONAF, 2013).

Table 1: Land uses in the coastal range of the Maule region

Land uses	Area in hectares
Maulino coastal forest	33,747
Fast growing exotic species plantations (mainly *Pinus radiata*)	402,793
Grassland	341,572
Agriculture	166,109

Source: Author's elaboration with information provided by CONAF 2013

According to Donoso (1993), ruil populations decreased by nearly 60% between 1983 and 1991 as an outcome-out of the plant of *Pinus radiata* plantations. Additionally, ruil was locally used as a source of timber and fuel, which has contributed to its decline along with other factors such as seasonal fires and habitat loss due to introduction of grazing and exotic species (Olivares *et al*., 2005; Silva-Muñoz, 2012).

Nowadays, the constant and increasing replacement or invasion of Maulino coastal forests and ruil fragments by *Pinus radiata* plantations has been another important source of pressure, additionally exerted on the natural distribution area of ruil and the Maulino coastal forest (Santelices, 2009; Silva-Muñoz, 2012). Historical elements of this process have been the *Pinus radiata* and *Eucalyptus globulus* plantations. These species are found in forest plantations as a consequence of the replacement of existing native flora (Gómez & San Martín, 2007). Such activity began in the Maule region extensively since 1971, with the construction of the industrial pulp mill in the coastal city of Constitución (Gómez & San Martín, 2007; Santelices, 2009; Silva-Muñoz, 2012).

The fragments of ruil which are surrounded by *Pinus radiata* plantations are in a worse situation in comparison to those fragments that are surrounded by more mixed vegetation of native forest and *Pinus radiata* (Olivares *et al*., 2005; Silva-Muñoz, 2012). In places where ruil remnants still are in a relatively conserved state, the species does not show an important dynamic recuperation or expansion. This can be described by an alteration of the general habitat of the species (Olivares *et al.,* 2005; Silva-Muñoz, 2012).

The replacement of ruil for *Pinus radiata* plantations is leading to the extinction of both habitat and species. This has contributed to the alteration of the habitat of ruil in terms of soil, isolation and exposition to direct negative influences, and also contributed to the decline of ruil due to the absence of buffer zones separating ruil from *Pinus radiata* plantations (Olivares *et al.,* 2005; Schollenberg, 2006; Silva-Muñoz, 2012). The main reason for *Pinus radiata* threat on the Maulino coastal forest and ruil, is its higher capacity to get water and its ability to colonize suitable sites (Villalobos & Huenchuleo-Pedreros, 2010). In Addition, *Pinus radiata* seems, in many cases, to easily out-compete native trees (Schollenberg, 2006; Silva-Muñoz, 2012).

According to Bustamante & Grez (1995), these forests could be in a process of inbreeding in their own fragments due to the fact that ruil and the Maulino coastal forest have been divided and encircled by Pinus radiata plantations (Santelices*,* 2009; Santelices *et al*., 2012b). Thus, there would be no propagation dynamic to ensure variability. They maintain that this situation can, in the short term, lead to the inevitable extinction of the ruil forests and all the biodiversity associated with this type of forest if the necessary measures to avoid it are not taken (Santelices, 2009; Silva-Muñoz, 2012).

Another variable that threatens the survival and integrity of ruil and the Maulino coastal forest is the climate change, because it is altering its habitat and favors the progress of species of the Sclerophyllous forest. The high diversity of the Sclerophyllous species that invade ruil fragments constitutes a fracture of the original forest and is interpreted as sclerophyllication process (San Martín & Sepúlveda, 2002; Silva-Muñoz, 2012), although the progress of sclerophyllous elements began already in the late middle Miocene (Santelices, 2009; Silva-Muñoz, 2012).

According to Conservation International, another problem faced by ruil and the Maulino coastal forest is connected with the land tenure situation which prevails in the country (Schollenberg, 2006; Conservation International, 2011; Silva-Muñoz, 2012). Basically, there is no public land available for the setting-up of new areas for environmental protection. In view of the country's economic and legal situation, to purchase private land for protection purposes is complicated and very costly for the government. Therefore, cooperation between the government, the private sector and individuals has a decisive importance for long-term biodiversity conservation (Schollenberg, 2006; Conservation International, 2011; Silva-Muñoz, 2012).

Besides all these threats faced by ruil and the Maulino coastal forest, scientific research carried out on these forests is scarce and the results obtained are widely dispersed and have not considerably led to their recovery (Olivares *et al*., 2005; Silva-Muñoz, 2012). All these factors and the difficult natural regeneration of the ruil species demand all kinds of actions aimed to the achievement of new knowledge to reverse the environmental condition of ruil and the Maulino coastal forest (Santelices, 2009; Silva-Muñoz, 2012).

2.2. Spatial conservation prioritization

Spatial conservation prioritization constitutes a modeling process that tries to determine priority areas for preservation and that explicitly and quantitatively make use of biological and socioeconomic factors towards the realization of a conservation network design (Carwardine *et al*., 2008; Wilson *et al*., 2009; Desmet *et al*., 2010; Duarte *et al*., 2014). It is a type of evaluation with the objective of supplying the decision making process with data to solve a specific conservation planning problem (Ferrier & Wintle, 2009). The aim of this procedure is to determine priority areas for biodiversity preservation to alleviate the drivers that endanger biodiversity, along with investment in different conservation activities including, among others, fire management, control of encroaching species and land restoration (Wilson *et al*., 2009; Kukkala & Moilanen**,** 2013).

Spatial conservation prioritization deals mainly with planning decisions that involve a so-called "spatial choice", which means that, as a reaction to some overall constraints of the total amount of action allowed, the managers have to choose the best place to locate this action within the region of interest (Ferrier & Wintle, 2009). Such "actions" could be different land uses or management that affects preservation of biodiversity in a specific area in a positive way (e.g. protection or restoration) or negatively (e.g. biodiversity degradation for agriculture activities; Ferrier & Wintle, 2009)

Spatial conservation prioritization makes use of data and principles from other ecological fields, such as "metapopulation modeling, population viability analysis, species distribution modeling and uncertainty analysis" (Moilanen & Ball, 2009). Moreover, it acknowledges the importance for spatial conservation of both the use of explicit biological criteria and the incorporation of socio-economic indicators to meet conservation objectives in a much more cost-effective manner (Duarte *et al.*, 2014). This represents the main advantage of spatial conservation prioritization, since it allows us to reach the aimed goals at the lowest cost (Duarte *et al.*, 2014).

Spatial conservation prioritization often makes use of decision-theoretic methods from applied mathematics as site or reserve selection algorithms, such as simulated annealing and genetic algorithms (Moilanen & Ball, 2009). These algorithms are applied to identify the "best possible reserve network" (Stewart & Possingham, 2005; Moilanen & Ball, 2009; Kukkala & Moilanen, 2013). Spatial conservation prioritization makes use of distribution information with different biodiversity features (Wilson *et al*., 2009). According to Kukkala & Moilanen **(**2013) "the distribution data can include genes, species, ecosystem services, types of habitat, ecosystem processes, etc. Some socioeconomic variables can be used, for instance, the cost of land, opportunity costs to interested parties and diverse information on man-made factors, which may in the future affect land use and landscape composition" (Kukkala & Moilanen**,** 2013). This makes spatial conservation prioritization useful to any preservation actions related to the election of places for the implementation of wildlife parks that affect preservation outcomes (Kukkala & Moilanen**,** 2013).

As the biodiversity preservation is restricted by funds and investments in conservation must, therefore, be prioritized (Wilson *et al*., 2009). Spatial conservation prioritization is from an economic perspective the act of employing spatial analysis of quantitative information (e.i. maps) to identify places for preservation investment. This process is considered as more systematic, rigorous and accountable than the opportunistic allocation of conservation funds (Wilson *et al*., 2009; Kukkala & Moilanen**,** 2013).

Actions aimed to the achievement of the conservation goals imply also related costs that need to be factored into the spatial conservation prioritization (Kukkala & Moilanen**,** 2013). These costs may be both direct financial implementation costs (e.g. acquisition and/or management costs), or indirect costs such as costs related to lost land availability for other purposes (opportunity costs; Wilson *et al.,* 2009). In planning activities, costs mostly work as constraints on the realization of conservation benefits. Planning must, therefore, aim to maximize overall level of conservation benefit achieved subject to fixed total costs. Examples of this can be an annual budget for reserve acquisition, environmental incentive funding and a limit on land area that can be excluded from a new urban development (Wilson *et al.,* 2009; Kukkala & Moilanen**,** 2013).

The conservation prioritization problem deals with the effective and knowledgeable assignment of funds available for preservation (Moilaen *et al*., 2009). This is a relevant issue for any person who deals with conservation management, and has been approached by the way of a series of optimization methods as the heuristic, qualitative, and quantitative solution ones (Moilaen *et al*., 2009). Application of optimization techniques brings furnish powerful tools to tackle conservation problems. As funds available to conservation organizations are insufficient, considering the threats faced by biodiversity, application of optimization methods may be of particular importance to achieve best results (Moilaen *et al*., 2009).

According to Game & Grantham (2008) and Moilaen *et al.* (2009), some common types of conservation prioritization problems can be used in spatial conservation prioritization:

a) The "minimum set coverage problem", which objective is the efficient use of resources. The intention of it, is locating a solution that reaches all conservation targets at minimum costs (Moilaen *et al*., 2009).

b) The "maximal coverage problem", a perspective applicable if funds are insufficient to reach all targets, the attainment of a solution that satisfies the largest number of conservation targets with a given budget constraint being the goal (Moilaen *et al*., 2009).

c) The "utility maximization problem", a generalized form of the "maximal coverage problem", aiming to maximize conservation value obtainable with limited resources.

The difference between “utility maximization” and “maximal coverage” is that for the first one conservation value is defined in a more general way than just the number of targets achieved (Game & Grantham, 2008; Moilaen *et al*., 2009).

Several conservation planning tools or software packages to be used in special conservation prioritization are available (Game & Grantham, 2008; Regan *et al*., 2009). The most used one are Marxan and Zonation, which deal with different conservation prioritization problems to face the conservation goal (Regan *et al*., 2009). For instance, Marxan uses the “minimum set coverage problem” whereas Zonation uses the “maximal coverage problem”. As the purpose of our research is to determine cost-effective priority areas, we decided to use the Marxan planning tool for our analysis.

2.2.1 Marxan

In 2000 Ball and Possingham of Australia developed “Marxan conservation planning software for decision support in reserve system design” (Game & Grantham, 2008), build on the thought that a decision maker has a big number of potential places to choose for the implementation of new sites for preservation (Game & Grantham, 2008). They might want to create a reserve network built up from chosen planning units that would also solve problems with several economic, ecological and social factors (Game & Grantham, 2008).

Marxan is supposed to resolve a special type of "reserve design problem" recognized as the “minimum set problem”, meaning the minimum needed to represent biodiversity features at the smallest cost (Game & Grantham, 2008; Ardron *et al.,* 2010). Preservation targets are here set for the biodiversity features (Game & Grantham, 2008). Marxan choose places that depict those targets for a least possible overall cost, while enabling give more or less attention on spatially grouping the selected sites (Moilaen *et al*., 2009).

In the “minimum set problem”, biodiversity components we want to preserve are considered as restrictions to the solutions (Game & Grantham, 2008). Based on understanding information concerning to “species, environments and other important biodiversity features” (Game & Grantham, 2008). Marxan goal is to produce reserve networks as a combination of sites that consider user-defined biodiversity targets with minimal expense (Game & Grantham, 2008; Ardron *et al*., 2010; Desmet *et al*, 2010). In such a case the logic is that is more likely that less expensive or less disruptive reserve networks will be implemented (Desmet *et al*, 2010). Furthermore, the attainment of some particular targets for all conservation features furnishes a steady foundation for the expansion of a reserve network in the years to come (Desmet *et al*, 2010).

Ardron *et al*. (2010) said that Marxan can be employed in various conservation features used in reserve network design, for example "genes, species, types of vegetation, ecosystems or substitutes for them" (Ardron *et al*., 2010). It can also incorporate culturally relevant features such as patrimony ones (e.g. religious and archaeological sites). Habitat condition and distribution area can also be incorporated by means of the definitions of targets. Marxan permits the incorporation of other biotic and abiotic features for the representation of nature (Regan *et al*., 2009).

Marxan is conceived to determine planning units groups which reach a range of targets at the lowest cost. By changing the representational targets, it can be employed to scan the balance between biodiversity representation and cost. Marxan incorporates a connectivity measure between planning units, which can be made the planning units accessible or inaccessible for physical, political or social reasons (Regan *et al.,* 2009; Ardron *et al.,* 2010).

Marxan gives information regarding the best set of reserve networks that are produced from the "selection frequency" of sites from many solutions (Ball *et al.,* 2009). The "selection frequency" corresponds to the frequency of the runs in which a site is chosen according to the extent to which it reaches the conservation objectives (Regan *et al.,* 2009). The output of Marxan can be transformed and included to maps by external programs, such as Quantum Gis (Qgis), Arcgis and Zonae Cogito, which are simple to understand and used for conservation planning and stakeholder discussion (Game & Grantham, 2008; Regan *et al.,*2009; Ardron *et al*., 2010).

Marxan has an adaptable algorithm selection that contains options for simulated annealing, iterative improvement, heuristics or a mix of these (Game & Grantham, 2008; Regan *et al.,* 2009; Ball *et al.,* 2009). This allows Marxan to be employed in different manners that vary from the production of fast demonstrative outcomes to the production of efficient outcomes adjusting an existing or suggested arrangement of planning units (Game & Grantham, 2008; Regan *et al.,* 2009; Ball *et al.,* 2009).

Simulated annealing was the optimization algorithm used in my study. According to Moilanen & Ball (2009) Simulated annealing (SA) is “an optimization method developed in the 1980 from an algorithm originally used in the 1950, which mimics the annealing of metals. In simulated annealing new solutions candidates are generated and evaluated iteratively. Improving solutions are always accepted, but also non-improving solutions may be accepted, which gives the algorithm the ability to escape local optima” (Moilanen & Ball, 2009).

The basic aim of the “simulated annealing algorithm” is to provide every feasible configuration of sites with a numeric performance score (“value of the objective function”; Game & Grantham, 2008; Moilanen & Ball, 2009; Ardron *et al*., 2010). This means that after comparing different groups of possible preservation zones with the objectives and costs defined by the user, the group of zones that reach the goal at the lowest cost is determined (Moilanen & Ball, 2009; Ardron *et al*., 2010). In other words, as Ardron *et al*. (2010) said “to build the ideal reserve network, each planning unit should be reviewed according to its values. Based upon the deployment and mirroring of such features over a broader zone, the features (biodiversity - related targets and a metric of cost, menace or opportunity) inside a planning unit could be meaningful on their own without being the best overall option” (Game & Grantham, 2008; Ardron *et al*., 2010).

Thus, Marxan’s main purpose is to reduce the total cost of the portfolio whilst achieving preservation objectives in a narrow network of sites, via what is known as the “objective cost function”, which needs to reflect the desire for a specific reserve system (Game & Grantham, 2008; Ardron *et al*., 2010).

According to Game & Grantham (2008) “Marxan's objective cost function merges the overall cost of the reserve network with any penalty for unfulfilled environmental objectives, conceived in such a way that the less the value, the better” (Game & Grantham, 2008).

In the following two pages and paragraphs it is shown how Ball *et al.,* (2009) presented mathematically the problem Marxan faces**:**

According to Ball *et al.,* (2009) Marxan finds good solutions for:

“Minimize the objective function: Expression 1”

$$\sum_{i=1}^{M} c_i x_i + \text{BLM}\left(\sum_{i=1}^{M} x_i l_i - 0.5\sum_{i=1}^{M} x_i \sum_{k=1}^{M} x_k b_{ik}\right)$$

“Subject to the constraints to ensuring that all representation targets are fulfilled: Expression 2”

$$\sum_{i=1}^{M} a_{ij} x_i \geq t_j \sum_{i=1}^{M} a_{ij} \quad \text{for all} \quad j = 1, \ldots N,$$

$$x_i \in \{0, 1\} \quad \text{for all} \quad i = 1, \ldots M,$$

“Where:

- i is the planning unit or site
- j is the conservation feature type
- x_i is the monitoring variable that assumes the value of 1 if location i is within the reserve system and the value 0 if not
- c_i is the cost of location i
- l_i is the perimeter or boundary length of location i
- b_{ik} is the common boundary length of locations i and k.
- a_{ij} formulates the base data matrix that shows the richness of the conservation feature type j in planning unit i,
- tj is the target fraction, with
- N the set of conservation features and M the set of locations (Stewart & Possingham, 2005).
- BLM is the boundary length modifier”

“Expression 1 is the objective function reducing a linear combination of planning unit costs and reserve network perimeter, weighted by a BLM parameter” (Stewart & Possingham, 2005; Ball *et al.,* 2009).

“The first term in Expression 1 is the total cost of the reserve network”

$$\sum_{i=1}^{M} c_i x_i$$

“It is a penalty related with the cost of all the places (planning units) that are in the reserve” (Ball *et al*., 2009).

“The second term in Expression 1 is the total reserve boundary length”

$$\mathrm{BLM}\left(\sum_{i=1}^{M} x_i l_i - 0.5\sum_{i=1}^{M} x_i \sum_{k=1}^{M} x_k b_{ik}\right)$$

This expression is a penalty associated with the form of the reserve network. When the boundary length is small the reserve network has a more compact form, on the other hand when it is big, the reserve network has a more fragmented form (Ball *et al*., 2009). Basically, this expression allows the addition of a cost (or benefit) for introducing sites that will contribute to having a more compact reserve network (Ball *et al*., 2009).

For reducing the perimeter of the reserve networks, related to its cost the BLM parameter is used. The BLM values could be small or big, this depends on the focus of the analysis, since small BLM values are used when is important to reduce the cost of the reserve networks, on the other hand, when is important reduce fragmentation; a larger BLM must be used (Stewart & Possingham, 2005).

Expression 2 are the restriction that ensures that all conservation features reach a defined conservation target, for example, keep in the reserve networks 17% of the total surface of one species (Stewart & Possingham, 2005).

$$\sum_{i=1}^{M} a_{ij} x_i \geq t_j \sum_{i=1}^{M} a_{ij} \quad \text{for all} \quad j = 1, \ldots N,$$

$$x_i \in \{0, 1\} \quad \text{for all} \quad i = 1, \ldots M,$$

The target for a specific conservation feature, t, is the quantity of that feature that must be added in the reserve network (Ball *et al*., 2009).

Acording to Ball *et al*. (2009) Expression 1 and 2 are "the problem's basic formulation, Marxan solves this problem by putting together the Expression 1 (objectives) and Expression 2 (constraints) in an objective function, turning restrictions into a new penalty clause. This signifies that those planning units that do not meet all conservation targets are able to be assigned a value, which is practical for the annealing procedure" (Ball *et al*., 2009).

Species Penalty Factor (SPF) – an extra penalty – could be incorporated into the problem's basic formulation. The SPF is set for the conservation features, in order to ensure the inclusion of a defined amount (target) of each conservation feature in the final reserve networks (Ball *et al.,* 2009). In this way, Marxan would consider more important to meet the target of the conservation features that have a higher SPF value, so the PU or sites that contain conservation features with small SPF values shall not be considered for inclusion in the final reserve networks (Ball *et al.,* 2009).

In summary the basic formulation of the problem plus the new penalty (SPF) can be presented as follow:

Objective Function = ΣCost + (BLM *ΣBoundary) + Σ(SPF*Penalty)

SPF is the "Species Penalty Factor", that regulates the influence of the sanction for not reaching the target of each species (Ardron *et al*., 2010).

For Game & Grantham (2008), the "objective function" plus a SPF in Marxan adopts the next form (Game & Grantham, 2008):

$$\overbrace{\sum_{PUs} Cost}^{①} + \underbrace{BLM \sum_{PUs} Boundary}_{③} + \overbrace{\sum_{ConValue} SPF \times Penalty}^{②} + \underbrace{CostThresholdPenalty(t)}_{④}$$

Source: Ardron *et al.,* 2010.

“Where:

1 is the overall cost of the reserve network (mandatory)

2 is the penalty for not properly depicting conservation features (mandatory)

3 is the overall reserve boundary length, multiplied by a modifier (on request)

4 is the penalty for breaching a pre-established cost limit (on request)”

Clauses 1 and 3 might be seen as costs, while Clauses 2 and 4 might be seen as the penalties for different non-compliances. Term 4 is used when there specific budget requires accomplishment or the reserve networks design is subject to cost constraints – which here is not the case. This term can be very helpful in the early phases of planning towards exploring practical conservation target ranges based on known cost constraints (Game & Grantham, 2008; Ardron *et al*., 2010).

With respect to outputs produced by Marxan, there are two standards outputs: “the best solution and the summed solution”. The best solution output displays the reserve network with the lowest score (cheapest one), whereas the summed solution output shows how many times each PU was considered to be part of a reserve network (Ball *et al*., 2009).

The objective function is important because it automates the selection process allowing assign a value to any possible reserve network, facilitating the election of an appropriate reserve network (Ardron *et al.*, 2010). Marxan works by constantly trying different selections of planning units towards the betterment of the total reserve network value, allowing with it, as Game & Grantham said in 2008 “find good solutions to a mathematically well-specified problem without ambiguity on the software’s goals” (Game & Grantham, 2008). Marxan’s objective is to generate reserve networks in which the biodiversity targets are achieving at the less possible cost, if possible with small boundary lengths because larger boundary length has negative effects in the reserve networks (e.g. increase management costs, edge effects, and reduced connectivity; Ardron *et al.*, 2010)

In order to find the optimal values to run Marxan, Ardron *et al.,* (2010) recommend making a parameter calibration with relevant Marxan parameters like BLM, target and SPF.

2.2.2 Parameter calibration or Sensitivity analysis

Parameter calibration seeks to discover how sensible the outcomes of modeling are to alterations in the data or parameters by examining whether results obtained with different input data or different parameters – like BLM, targets or SPF values – produce considerably similar or substantially different results (McCarthy, 2009; Ardron *et al.*, 2010). It offers feedback on what data and parameters do and do not make big differences in the solutions generated (Ardron *et al.*, 2010).

Parameter calibration determines how much the forecast of a model changes founded on a specific input parameter changes. The sensitivity of a variable is named elasticity if changes in the prediction and the input parameter are stated proportionally (McCarthy, 2009). Parameter calibration has a key role in model building and analysis, helping simplify a model, exploring a wide range of model prediction outcomes, and identifying critical parameters, those management should focus on and those requiring more information (McCarthy, 2009; Ardron *et al.*, 2010).

According to Game & Grantham (2008), McCarthy (2009) and Ardron *et al.* (2010) the first two steps in parameter calibration are deciding what data/parameters to test and which measures are use to compare results. Items that might be tested usually include different data/parameters, such as target levels, SPFs values, BLMs values, costs, planning unit size and shape among others (Game & Grantham, 2008; Ardron *et al*., 2010). The solutions of the parameter calibration according to Game & Grantham (2008), McCarthy (2009) and Ardron *et al.* (2010) as well, "have a number of unique traits, such as total cost, number of targets exceeded, spatial distribution and congruence", total area and perimeter of the reserve networks, specific planning units in the solution, etc (Game & Grantham, 2008; McCarthy, 2009; Ardron *et al*., 2010).

Marxan provides a platform called "Marxanio" for performing parameter calibration and sensitivity analysis (Regan *et al.,* 2009; Watts, 2016). Marxanio is a web app for systematic conservation planning that runs on the Nectar research cloud (providing software and services that allow researchers to quickly store, access, and analyze data remotely and autonomously) with graphical interface for its users (Nectar, 2018). Watts (2016) said that "Marxanio allows uploading and downloading the completed analysis in a user-friendly web interface with one's own Marxan datasets, editing targets, SPF and BLM, conducting parameter testing, sensitivity analysis and analysis, visualizing output maps, figures and tables” (Watts, 2016).

2.3. Marxan: Background and State of the Art

Marxan is a decision-support tool originally created for the design of a marine protection network in Australia. From that time on, it has spread and been applied in many parts of the globe (Pliscof, 2013). Marxan is among the most widely used software to perform conservation planning or territorial prioritization of places that contain a high percentage of biodiversity or have a high conservation value, in order to integrate these places in existent reserve networks or create new ones for them (Ardron *et. al.,* 2010; Loos,2011). In addition, this spatial conservation prioritization tool has being used in conjunction with Species Distribution Models (SDMs) to evaluate reserve systems, to see if they are located in sites that really are adequate for the survival of the species of interest for the conservation plan, and to identify places with high concentration of vulnerable species or high biodiversity indexes (Loos,2011).

As previously mentioned, in 2000 at the University of Adelaide in Australia a young doctoral student named Ian R. Ball, supervised and funded by the Professor Dr. Hugh Possingham, began to work in his doctoral thesis, with which he develops a program called SIMAN (Ball *et al.,* 2009). This thesis and the SIMAN program were the basis for another program called SPEXAN created for Ian R. Ball and the Professor Dr. Hugh Possingham as well, to satisfy the requirements of the "Great Barrier Reef Marine Planning Authority (GBRMPA)" in its 2003 - 2004 re-zonification schedules. Then the tool that everyone knows today as Marxan was evolved as a changed version of SPEXAN create by Dr. Ian R. Ball and the Professor Dr. Hugh Possingham (Ball *et al.,* 2009).

Dr. Ian R. Ball and the Prof. Dr Hugh Possingham, decided to name the program Marxan as an acronym that merges MARine, and SPEXAN, which in turn is an acronym for SPatially EXplicit ANnealing. Since basically in its origins Marxan was a prolongation of the existing SPEXAN program, which was a program funded by the Australian Ministry of the Environment to be applied in the conception of marine reserves (Ball *et al.,* 2009). In the beginning, SPEXAN was envisioned as a self-contained program without a Geographic Information System (GIS) user interface to show portfolios and supporting geographic data, unlike Marxan, which does have a Geographic Information System (GIS) user interface (Ball *et al.,* 2009).

Although Marxan has begun as a doctoral thesis project and it started as a tool that was used only in research fields, it also has been used more and more in applied projects out of the academia (Ardron *et. al.,* 2010).

Marxan has become a popular tool, when the Australian Ministry of the Environment saw the potential and usefulness that this tool has for environmental conservation, especially for be use as a conservation tool to perform marine reserve design in their coastal areas (Game & Grantham, 2008). It was considered by the Australian Ministry of the Environment as a key tool to be used for them in reserve network design, in order to identify marine and terrestrial areas to preserve in their future conservation planning projects (Ardron *et. al.,* 2010). So much was the appreciation of the Australian Ministry of the Environment for this spatial conservation prioritization tool, that they have decided to use this tool in the conception and assessment of existent protect areas and the subsequent redesign of them, as was the case of the Great Barrier Reef marine reserve network in Queensland, Australia, the world's biggest marine conservation zone (Game & Grantham, 2008).

The Australian Ministry of the Environment employs Marxan to rebuild the Great Barrier Reef marine reserve. They consider Marxan as an invaluable administrative instrument for the protection of the biological diversity and the regulation of the exploitation of their coastal marine assets (Game & Grantham, 2008). For the Australian Ministry of the Environment the employment of Marxan in conservation planning was essential, because Marxan allow them to generate solid preservation strategies. With Marxan they not only consider the biodiversity factors as the main component of their conservation plans, they also were able to consider the socio-economic factors, as consequence of that, they were able to weighing the benefits of protecting biodiversity against the sustainable utilization of marine resources (Game & Grantham, 2008). As Marxan is the only conservation planning tool that incorporate socio-economic factors during the design process and no after, as is usually done in conservation planning, the tool was very attractive for them since its creation. From here and after Marxan begun to be an important conservation planning tool for the Australian Ministry of the Environment and begun to be involve in all the conservation planning projects of them (Game & Grantham, 2008).

Over time the popularity of this tool grew up and began to be used on the other side of the world, for the creation of marine reserves. In addition to the Australian Ministry of the Environment, Marxan has been used by organizations and governments in many countries, for additional offshore conservation planning solutions (e.g., the Baltic Sea, Galapagos Islands, Gulf of Mexico, Connecticut/New York, British Columbia, Central California Coast, and Channel Islands of California among many others (Game & Grantham, 2008; Ardron *et. al.,* 2010; Loos,2011). Specifically, in the United States of America one of the most common uses that Marxan has had, has been the identification of new fishing zones, which are compatible with the protection of marine biodiversity and to control over exploitation of the marine resources (Ardron *et. al.,* 2010).

Marxan is also widely employed for The Nature Conservancy (TNC, Ardron *et. al.,* 2010). The Nature Conservancy first sponsored an integration of SPEXAN and ArcView Geographic Information System (GIS) for its ecoregional planning processes and nowadays Marxan is an important element of the consistent planning software employed for them in the Global Marine Initiative. The United States National Marine Fisheries Service (NMFS) has funded the advance of Marxan to give expert guidance on their implementation to salmon recovery planning (Ardron *et. al.,* 2010). The World Wide Fund for Nature employed Marxan to delineate a comprehensive worldwide set of Marine Protected zones, it was the base for the design of the Roadmap for the Recovery of the marine ecosystems that they used to request to the United Nations (UN) the creation of marine reserves networks on the high seas (Ardron *et. al.,* 2010).

Although the use of Marxan has been very popular in the creation of marine reserves, Marxan has also been very much used in the design of terrestrial reserves and has been applied in the decision making process for the protection of the terrestrial biodiversity's. For example, Marxan has been use for: in The North American Wilderness Project; in the Selection of conservation focus sites for global populations of mammal species; for ecosystem service management in some parks in United States, among many other cases and other Biodiversity related applications or examples of use in decision-making processes around the world (Ardron *et. al.,* 2010).

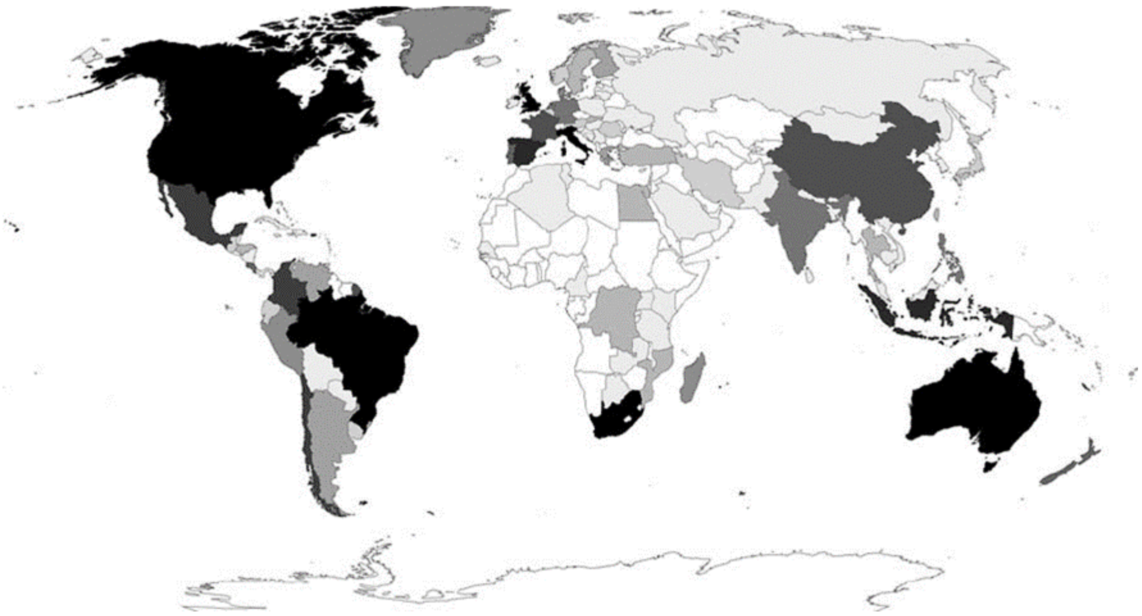
As were in Australia and the United States of America, another place where Marxan has become a very popular tool to use in conservation planning has been Canada, where there is even a center called Pacmara (Pacific Marine Analysis and Research Association) which is according to Pacmara.org "a Canadian non-profit association of scientific practitioners committed to creating and strengthening capabilities in marine and coastal planning in Canada and internationally". This organization has a close relation with the creators of Marxan, with whom Pacmara maintains a very tight collaboration to further develop, instruct, divulge, conduct courses and provided information about the use of Marxan around the word (Ardron *et. al.,* 2010).

In Europe on the other hand, Marxan has been no so popular as in Australia and North America. Those who have used Marxan the most in Europe have been Spanish researchers for studies carried out in the Iberian Peninsula. It is very relevant to keep in mind that Europe is the cradle (Finnish Environment Institute) of another very popular conservation planning tool used with the same purpose that Marxan has, this conservation planning tool is called Zonation (Segan *et al.,* 2008). This tool is the most used in Europe in conservation planning or at least have the same level of popularity that Marxan has (Segan *et al.,* 2008). Perhaps the reason behind this situation, is because Zonation was made in Europe unlike Marxan that was created in Australia. Maybe this is why the use of Zonation has been spread more rapidly in Europe that Marxan has (Segan *et al.,* 2008). Many Authors say that both, Marxan and Zonation, serve the same purpose (identify areas to protect or design reserve systems). But the truth is that although they are used for the same purpose, for many, the choice of one or another tool must be carefully carried out, since to decide which tool use in the analysis first must be taken into account the objective of the research or study (Segan *et al.,* 2008).

Zonation unlike Marxan, is normally used when there is no interest in incorporating the socio-economic factor in the analysis, the only thing that matter is the protection of the ecosystem regardless the cost of it. On the other hand, Marxan is appropriate to use when the socio-economic factors are relevant for the creation of a reserve system (costs), although Marxan could be also use when socio-economic factor is not considered in the analysis (Segan *et al.,* 2008).

With respect to the use of Marxan in other places like Africa, Asia and South America, the use of Marxan is increasing especially in countries like Brazil and China. In general, Marxan is being successfully employed in hundreds of spatial conservation planning projects all over the globe (Ball *et al.,* 2009). Figure 6 Displays the global deployment of Marxan players.

Figure 6: The use of Marxan in the world



Source: Ball *et al.,* 2009.

Figure 6 show that the application of Marxan has been largely applied all over the world. The zones with darker colors indicate where there are more Marxan users, on the other hand the zones in white is where no users of Marxan are found (Ball *et al.,* 2009)

According to Ball *et al.,* (2009) the users of Marxan were more than 1700 individuals and more than 1200 institutions from more than 100 countries. Apparently, since 2009 Marxan users have continued to grow three times more than that time, since according to the official Marxan Website (Marxan.org) the users of this tool have been increasing quite a bit, as they said: “From 2011, Marxan has been retrieved 14,222 times by 6,708 subscribers from 4,701 organizations in 184 nations. The constituents of this fellowship originate from over 220 colleges, The United Nations, the IUCN, NGO's and over 50 state agencies”.

Another important thing to emphasize about Marxan is that over the years many organizations have supported with funds and research the development of it, among them are: the department of the Environment and Energy of the Australian government; the Natural heritage trust (an Australian government initiative); ECOTRUST; Great Barrier Reef Marine Park Authority (Australian government); The National Center for Ecological Analysis and Synthesis (NCEAS) (which is an independent research affiliate of the University of California, Santa Barbara); The department of conservation Te papa atawbai from the New Zealand government; The ministry of Natural Resources and Forestry of Ontario (Canada); The Nature Conservancy (TNC); The University of California (United State of America) and The University of Queensland in Australia (Game & Grantham, 2008; Ball *et al.,* 2009; Ardron *et. al.,* 2010).

In addition, to helps to identify sites to preserve through conservation objectives in the most efficient way in the sense of creating the least impact or creating the least conflict with other events that exist in the area (Game & Grantham, 2008; Ball *et al.,* 2009). Marxan offers a range of conservation planning support services, starting with the creation of new reserves units, informing on the efficiency of the current parks, and the formulation of multifunctional zoning schemes for environmental asset administration (Ardron *et. al.,* 2010). In addition, Marxan can be used in both terrestrial and marine conservation decision making process. It can assist make intelligent choices that takes into consideration a wide range of concerns, parties and trade offs in a cost effective and spatially efficient way (Ardron *et. al.,* 2010).

The main reason for Marxan popularity is that unlike other tools as Zonation, Marxan was mainly designed to incorporate the socio-economic factor in the conservation prioritization process. Marxan is also a free tool with free access, it is easy to use and there is a lot of information about the program and help forums to learn about Marxan (Ball *et al.,* 2009). Furthermore, Marxan is acknowledged as a suitable instrument to perform conservation planning by the academia, governments and NGOs. There are NGOs, such as Pacmara and TNC who are dedicated to disseminating and teaching this program, online or conducted courses around the world (Ball *et al.,* 2009).

In addition, this software can be employed in association with a wide variety of Geographic Information System (GIS) tools. Furthermore, its output and results are easy to understand by the decision makers and are easy to explain to the stakeholders of a project (Ball *et al.,* 2009).

In summary taking in to account what Game & Grantham (2008), Ball *et al.* (2009) and Ardron *et. al.* (2010), among others, said about Marxan, it is possible to affirm, that Marxan's popularity growth thanks to the following reasons:

(i) It is a free and open source (tool - software) that can run on different operating systems (Windows, Linux or Mac) that produce objective, transparent, and repeatable results (Ardron *et. al.,* 2010).

(ii) Marxan is successfully tested in a number of scenarios, it has a gratis e-learning and support programs, which are offered to ensure that people have the best possible experience with the program (Ardron *et. al.,* 2010).

(iii) The entry data files for Marxan are text files which is possible to edit in any text editor (Ardron *et. al.,* 2010).

(iv) The software works with several kinds of simple formatting, such as comma-delimited values or tab-delimited values, which facilitate editing in programs such as Microsoft Excel, OpendOffice.org, Calc, Arc-View, R (Game & Grantham, 2008; Ball *et al.,* 2009; Ardron *et. al.,* 2010).

(v) It could be employed as a stand-alone program or as a complement to another DSS. (Decision Support System), like for example C-Plan, CLUZ, PANDA or Vista. These DSSs eliver visual outcomes (maps and graphs) and facilitate the interpretation and manipulation of Marxan's inputs and outputs (Ardron *et. al.,* 2010).

(vi) It is readily available on the web at no charge. It is a self contained application that does not require any other program to execute, although a GIS is needed to process the data, build the input files and visualize the outcomes (Ball *et al.,* 2009; Ardron *et. al.,* 2010).

(vii) It is intended to assist in computerizing the conservation planning exercise so that a group of conservation managers can provide multiple options for conservation planning. It may also be utilized to provide a variety of alternative design options to the preconceived parks or nature preservation zones. It would also be able to be employed to provide options and responses where the contribution of key local actors is greatly appreciated and a commitment to the outlook for achievable outcomes is being pursued (Game & Grantham, 2008; Ball *et al.,* 2009; Ardron *et. al.,* 2010).

2.4. Climate change and spatial distribution models

Throughout history, the world climate has been constantly evolving, and with it both ecosystems and species – and the well – established connection between them shows that rapid variations in the climate affect ecosystems and species ability to adapt, resulting in biodiversity reduction (Shah, 2014).

The "Intergovernmental Panel on Climate Change" (IPCC, 2007) explain climate change as "an alteration of climate due to a variation in the average value and/or variability of climatic conditions, persisting for a long time and caused either by human activities or natural phenomena" (IPCC, 2007; CBD, 2018). This climate change is presented as a correlation between changes in concentrations of greenhouse gases (GHG) emissions and global temperature (IPCC, 2007; Silva-Muñoz, 2012; CBD, 2018).

Atmospheric gases such ascarbon dioxide and methane act likea greenhouse – hence, greenhouse gases (GHG) – capturing heat and warming the planet. The normal amount of these gases are climbing by via releases of it from man-made activities, like fossil fuel burning, agriculture and land use, warming the earth's surface and lower atmosphere while raising temperatures, among many other adverse changes (CBD, 2018).

In general, the temperature of the earth is determined from the balance between solar radiation, the energy produced by the terrestrial surface and the effects of GHG in the atmosphere. GHG trap heat in the atmosphere's near-surface layers (troposphere) and produce a warm and habitable environment (IPCC, 2007; Silva-Muñoz, 2012). Without the presence of GHG, the incident radiation would be equal to the radiation reflected from the earth's surface, resulting in a temperature of -18°C. Under natural conditions of concentrations of GHG in the atmosphere, reflected terrestrial radiation is absorbed by the atmosphere and re-emitted in all directions, leading to temperatures conducive to life (IPCC, 2007; Silva-Muñoz, 2012).

Through man-made actions, GHG emissions have dramatically grown in the past 150 years. Therefore, the atmosphere absorbs and re-emits more radiation causing an increase in temperature (Silva-Muñoz, 2012). According to CBD (2018) increasing GHG levels are by now altering the climate, as the "Intergovernmental Panel on Climate Change's (IPCC) Working

Group I (WGI) Fourth Assessment Report exposed that the mean temperature of the world has rose by an average of 0.76°C and the average sea level increased by 12 to 22 cm over the past one hundred years, having an impact on the entire planet, from Antarctica to the tropics" (CBD, 2018).

The gloomy report predicts a boost rise in temperatures of 1.4°C to 5.8°C by 2100, with the impact being a higher average sea level rise worldwide, shifts in rainfall patterns, and a greater number of persons at a greater peril of contracting dangerous "vector-borne diseases" such as malaria (CBD, 2018).

The effect of rising GHG emissions on the climate will keep impacting biological diversity either directly or in conjunction with other triggers of change (CBD, 2018), of which there is wide evidence. The Millennium Ecosystem Assessment warns that by 2100, climate change is foreseen to be the major cause of biological diversity reduction and already forcing biodiversity to either adapt via lifecycle changes, shifting habitat, or by developing new physical characteristics (CBD, 2018).

The changing climate translates into vulnerability as a consequence of the altered habitats – several species have to either adjust or move to areas with favorable conditions, given that even little changes in average temperatures can significantly impact ecosystems (Hoffman, 2015).

It is argued that climate change magnifies other threats to biodiversity conservation, such as habitat deterioration, pollution, poaching, and propagation of exotics invasive species (Araújo, 2009). The current biota was influenced by fluctuating Pleistocene (1.8 million years) high levels of CO2, as well as temperature and rainfall, dealing with evolutive shifts and adapting natural strategies to survive (CBD, 2003). However, this climate change happened over a long span of time in a scenery not as divided as the actual one and with few or no stress from man's actions (CBD, 2018). Today, because of the rapidity of current global climatic events, natural adaptability through mutation and natural selection is probably playing a comparatively less important part in the immediate future (CBD, 2018).

Many species have been confined as a consequent of habitat fragmentation in comparatively small zones compared to previously, resulting in reduced genetic variability (CBD, 2003; Marambe *et al.,* 2009). Warming above the temperature ceiling achieved in the Pleistocene

Era will pressure ecosystems and their species over the current standards seen in the recent evolutionary past stemming from global climatic change (CBD, 2003; Marambe *et al.,* 2009; CBD, 2018).

Moreover, once-extensive vegetation habitats have been shrunk in surface and fragmented into a tiny area. Human activities like agriculture, settlement and industrialization have extended over the last centuries, clearing large swathes of woods, prairie and headlands in their wake, reducing and fragmenting habitat to the point of limiting the capacity of some species to drift to zones with favorable conditions (Hoffman, 2015).

In some cases, the localization of specific climatic conditions for some species will change notably and the warming climate will involve that some species can no longer live in their regular habitat and will need to move to more apropieted climatic conditions (Marambe *et al*., 2009; Hoffman, 2015). In many others, however, such move could not be feasible because of adverse environmental parameters, man-made or geographic obstacles, and rivalry with other species located there (Marambe *et al*., 2009; Hoffman, 2015).

Although only little prove of present-day species disappearance induced by climate change exists, studies propose that it could overcome habitad obliteration as the largest worldwide danger to biodiversity in the decades ahead (Bellard *et al*., 2012). Species with scarce numbers or breeding successes, prone to certain environments or kinds of diets are less able to adjust (Araújo, 2009). Their ability to settle in new areas is likely to be of great value as a reaction to climate change, but it will differ from taxon to taxon and zone to zone. – a challenge likely to be that much greater in highly deteriorated landscape (Araújo, 2009), considering that more than 75% of the world' s in land biomes are now exhibiting signs of disturbance resulting from human activity and land use (Parry *et al*., 2007; Willis & Bhagwat, 2009).

Predicting biodiversity's reaction to climate change perform a significant part in warning scientists and decision-makers about possible future risks, boosts ascription of biotic alterations to climate change, and helps craft proactive strategies towards reducing its impacts on the biota (Bellard *et al*., 2012) – and a rising awareness that such approaches must advance the impact of climate change (Araújo & Rahbek, 2006). To date – unless directly affected by human activities – the traditional approach to preserving biodiversity has been to assume that species ranges are changing at a fairly slow rate (Araújo, 2009).

Several models have been made to anticipate the effect of climate change on nature in past years (Bellard *et al*., 2012). Their results have suggested, with alarm, that in the next century many plants and animals will become extinct (Parry *et al*., 2007) and tropical rainforests will disappear en masse (Huntingford *et al.,* 2008; Willis & Bhagwat, 2009).

Studies modeling species range changes presume that species envelopes are described by a tiny group of ambient elements (Bellard *et al*., 2012). This focus implies habitat suitability models – or "niche models" or "bioclimatic envelopes" – proving the variety of temperatures, precipitation and other variables that a species need to survive, and is used to forecast the likely range of species for future climatological conditions (Elith & Leathwick, 2009; Bellard *et al*., 2012; Hoffman, 2015).

It is then likely to forecast species envelope for the coming climate scenarios to establish the possible distribution of the appropriate climate area for a species, since these envelope models (also known as Species Distribution Models - SDMs) link present-day species surfaces to various climatic factors, thereby defining the bioclimatic envelope for the species (Soberon & Nakamura 2009; Elith & Leathwick, 2009; Sinclair *et al*., 2010; Bellard *et al.,* 2012).

SDMs link species distribution data to environmental conditions like climate or land cover information derived from remote sensing (Reiniken *et al*., 2016). The two main aims of SDMs are prediction and understanding (Reiniken *et al*., 2016). An example for prediction refers to where to look for the species and where to protect it. An example for understanding would be determining the main factors influencing species distribution or the impact of a disturbance (e.g., a road; Elith & Leathwick, 2009).

SDMs are extensively employed in the scientific literature, but they have also been applay to lead preservation choices: for example, in recognize and safeguarding important habitats, in reserve selection, in restoration and in detect sensitive areas to biological invasions (Guisan *et al.*, 2013; Reiniken *et al.,* 2016). Due to their relative easiness and data accessibility for model construction, the SDMs are being applied very often to perform evaluations on how the biodiversity, ecosystems, and nature in general, is going to react to the emerging climatological circumstances that are coming in the years to come, and thus be prepared to face those future events. But at the same time SDMs are garnered influence far beyond academia (e.g., IPCC 2007; Araújo, 2009).

SDMs use present-day species distributions and combines them with climate factors to evaluate species-climate associations and forecast distributions in future climate scenarios (Elith & Leathwick, 2009; Reiniken *et al.,* 2016). Thus, the SDMs produce maps displaying geographic variation in site suitability for a specific species. SDMs are in general building on the register of species presence-absence, presence, or abundance (Elith & Leathwick, 2009; Reiniken *et al*., 2016). These models are more and more considering the possible impacts that climate change could have on biodiversity and therefore propose a way of include these impacts into biodiversity modeling (Elith & Leathwick, 2009; Reiniken *et al.,* 2016).

Generally speaking, prioritizing spatial conservation will be untrustworthy if build only on a species geographic length, since it will incorporate many sites inadequate for it. The utilization of SDMs in spatial conservation prioritization permits more accurate identification of suitable sites for the species (Elith & Leathwick, 2009; Reiniken *et al.,* 2016). SDMs, therefore, give one of the most potent ways of surpassing scarcity seen often in distributional data linking it to a set of geophysical and atmospheric forecasters. Conceptually, this can be perceived as a solution for the problems caused by both, inadequate sampling, and noise (natural variability and errors) in the observations, and, if done carefully, can decrease considerably the effect of sampling biases. Use of SDMs allows more precise detection of places likely to maintain a species (Elith & Leathwick, 2009).

2.5. Socio-economic aspects

Socio-economic aspects have been employed in conservation planning to assess the reserve networks instead of included it on its design (Stewart & Possingham, 2005; Duarte *et al*., 2014). Until two decade ago evaluations of socio-economic aspects were mostly managed as a post filter of chosen zones since at that time conservation planning studies just considered the biological aspects of interest species (Duarte *et al*., 2014).

Although nowadays “systematic conservation planning” mainly focuses on solving the cost-effectiveness problem (how to accomplish the maximum preservation considering short founds), a lot of consideration has been dedicated to the biotic features (Naidoo *et al*., 2006). Most conservation planning simplifies economic costs, employing just the area of the planning units as the cost variable to use in the analysis (Naidoo *et al*., 2006).

Conservation costs are often trumped by biological factors in spatial conservation prioritization and are more prone to be examined in the chosen locations only on the basis of biological evidence or believed to be spatially homogenous (Duarte *et al*., 2014). This pro-biology procedure used in conservation planning presumes that all the sites have the same cost – a misconception, as not all the sites could have the same cost, because it depends on the different land-use or activities that carry out there. The costs can differ between sites and must be regarded carefully in conservation planning (Naidoo *et al*., 2006).

Naidoo & Adamowicz (2006) suggest that it is crucial to incorporate socioeconomic variables in the course of the selection process in "conservation planning" – like opportunity costs – and not only explicit biological criteria, in order to accomplish conservation goals more efficiently. Since the integration of socioeconomic variables in the spatial conservation planning processes is the form to accomplish the conservation goals at the lowest cost (Duarte *et al*., 2014).

According to Wilson *et al.* (2009) the few that incorporate costs have revealed that priority areas change if costs are incorporated. They have also exemplified the inadequacies related with presuming that costs are spatially uniform, or include costs in post hoc analyses. Their discovery shows that we can find our conservation goals at a lower overall cost if these are formally regarded from the beginning of the prioritization process (Naidoo *et al*., 2006, Wilson *et al.,* 2009).

These kinds of studies show that including cost data has an impact on conservation planning outcomes. Since it is possible to preserve an ecosystem at a portion of the cost, if socio-economic variables are considerate from the beginning. Hence, to include the costs variable in conservation planning is as relevant as the biological aspects (Naidoo *et al*., 2006).

The exchange among the price of wood and farming and species conservation goals were estimated in other research to use it as cost in reserve network design (Naidoo *et al.,* 2006), including the net benefits of activities occurring on lands selected in conservation planning programs (e.g. stockbreeding, agricultural and wood yields) by looking at the commercial value of commodities and the prices of production materials (Naidoo *et al.,* 2006).

In a number of contexts, efficiency profits from the incorporation of costs in conservation planning have been exposed. Naido (2006) affirms that Ando *et al.* (1998) said "that conservation acquisition cost differ across the study area, so by incorporating costs and biodiversity in conservation planning, biological targets may be reached at 25 – 50% of the costs of a conservation plan that just considering the biodiversity's geographical variability" (Ando *et al*., 1998; Naidoo *et al*., 2006).

An Oregon research carried out by Polansky *et al*. in 2001, discovered that the costs of preserving species were barely 10% of those that disregard the spatial variability of opportunity costs of conservation (Polasky *et al.,* 2001). Thus, conservation programs that incorporate data on costs and species are more cost-effective than those that pay no attention to the costs (Naidoo *et al.,* 2006).

The majority of conservation costs are paid by governments or conservationist groups. Some times preservation acts do not result in a direct financial burden to that organization itself. For instance, a state directive might forbid the conversion of forest to agricultural land, perhaps accomplishing conservation objectives and requiring no payments. Although no require direct payments are required, such regulatory actions might impose "opportunity costs" to the community for gone chances for economical utilization of the piece of land (e.g., agriculture; Naidoo *et al*., 2006).

A cost-effective reserve network of priority areas in conservation planning is comprehensive, representative and appropriate at the lowest-cost possible. Cost-effectiveness is crucial since it make easy the potential growth of a network of selected areas through the wise use of conservation funds and is easier to defend (Stewart & Possingham, 2005; Wilson *et al.,* 2009; Ardron *et al*., 2010).

There are various costs that can be employed in spatial conservation prioritization, like social, actual and setup costs, acquisition (meaning the acquiring of property rights, management, transaction) costs related to determining and bargaining with landholders, and opportunity costs, since the value of projected usage varies among system users when including planning units in the network (Ando *et al*., 1998; Naidoo & Adamowicz, 2006; Wilson *et al.,* 2009).
According to Wilson *et al.* (2009), there are different kinds of cost usable for making cost-effective spatial prioritization with Marxan:

a) Cost equals area: Many spatial prioritization evaluations explain the cost of a planning unit as the planning unit area and the biodiversity representation targets within a minimal land or sea area (Wilson *et al.,* 2009). According to Ardron *et al*. (2010) and others authors “in this instance, the geographical disparity in the cost of several preservation activities is not taken into account and might not lead to the discovery of the most economically viable sites for preservation” (Carwardine *et al*., 2008; Wilson *et al.,* 2009; Ardron *et al*., 2010; Barth, 2016).

b) Cost equals foregone opportunities (opportunity costs): Conservation is often regarded as conflict with different uses of land and sea. Opportunity cost information can be employed to detect zones that reduce this conflict while reaching biodiversity conservation objectives (Naidoo & lwamura 2007; Wilson *et al.,* 2009; Barth, 2016).

c) Cost equals the expense of each conservation action: here to determine priority areas are used the cost for the purchase of the land or management cost of the reserve netwoks (Carwardine *et al*., 2008; Wilson *et al.,* 2009; Barth, 2016).

In my study, opportunity cost was the economic variable used as input in the Marxan analysis. This cost – also known as alternative cost –, is the value (not a benefit) of a choice, comparative to an alternative (Rus, 2010). When an option is chosen from two reciprocally exclusive alternatives, the opportunity cost is the "cost" incurred by not joining coupling the benefit related with the alternative choice (Buchanan, 2008). The opportunity cost is the social gain lost in the best available option waived in order to execute a project. The opportunity cost of a project is the gain that are lost as consequence of undertaking that project instead of another (Rus, 2010).

The opportunity cost concept shows the basic association between scarcity and choice and is the established assessment of the most economically important alternative or opportunities dismissed – meaning the value forfeited or sacrificed in order to secure a higher one embodied in the chosen object (Buchanan, 2008). Thus, it measures what could have been earn by the next-best utilization of an asset (Naidoo *et al.*, 2006), and what was given up when making that choice.

By definition, opportunity costs imply two basic ideas: (i) the idea of a lost opportunity (i.e. that any inversion, business or use of resources has an alternative investment, activity or purpose), and (ii) the idea of a cost, which means that the lost opportunity could generate economic benefits (Pirard, 2008; Silva-Muñoz, 2012).

For land use, according to Rus (2010), "the opportunity cost is the net benefit lost in the best feasible substitute employment of these fields". For example, when the best alternative use is in agriculture, the market price of land will reflect the discounted market value (net present value) of agricultural production activities performed there (Rus, 2010). Thus, the opportunity cost for preserving environmental assets on arable land is the revenue lost through alternative land use (Sinden, 2004). Variation in agricultural earnings will result in land value changes: hence measuring one or the other as the opportunity cost becomes possible (Middleton *et al.,* 1999; Sinden, 2004; Silva-Muñoz, 2012).

The literature on calculating agricultural and forestry land values has generally used net present value (NPV) as the opportunity cost. According to Naidoo *et al.* (2006) and Rus (2010), to calculate the opportunity cost the discounted cash flow index called net present value (NPV) must be used which is also used for investment project evaluation. Naidoo & Adamowicz, (2006) said that "several studies had employed the explicit or implicit commercial land prices to calculate the opportunity costs engaged in setting aside protected areas with the NPV".

The NPV is the most employed and adopted discounted cash flow metric for the assessment of capital projects. Rus (2010) said that "an investment project is typically marked by a finite series of net cash flows al (l= 0.1.2.....$\underline{s}$), where al stands for the augmented cash flow that is awaited at time $\underline{s}$".

Acording to Naidoo & Adamowicz, (2006) "to calculate the NPV, the annual rental value of a piece of land is assumed to be equal to its annual net cash flow, whereas the market price of a piece of land equals the discounted future net cash flow the parcel is expected to generate" (Sinden, 2004; Naidoo & Adamowicz, 2006; Silva-Muñoz, 2012).

The conventional formula for net present value is:

$$\text{NPV} = a_0 + \sum_{s=1}^{t} a_s (1+i)^{-s}$$

Where $\underline{a}$ are cash flows, $\underline{s}$ is the year and $\underline{i}$ is the discount rate (Riggs, 1977).

Ross in 1995 said that “this formula proposes that the NPV of a given project is the sum of the current values of its net cash flows, i.e. the sum of current values view”. Here each investment is evaluated over its entire use life based on the cash flows it is projected to generate. The result is a measure of whether the multi-period investment creates value, a positive NPV (Ross, 1995).

The simplest statement of the NPV rule is that projects with negative NPVs should be rejected and only those with positive NPVs undertaken (Ross, 1995). That implies, from several investment options, just those that generate a positive NPV are acceptable. If all options have the same duration then the one with the highest NPV should be selected.

2.6. Buffer zones as an option to protect the Ruil forest

According to Martino (2001), exist a large number of known definitions for buffer zones (e.g., Sayer, 1991; Wells & Brandon, 1993; Meffe & Carrol, 1994). For Wells & Brandon (1993) “the buffer zones are sites contiguous to preserved areas where land use is limited to some degree, offering an added layer of defense while supplying important benefits to adjacent rural villages” (Martino, 2001).

In addition, for Sayer (1991) “buffer zones are those sites on the margins of a national park or similar reserve, in which restrictions are enforced on the utilisation of existing environmental resources or particular governance approaches are adopted to scale up the conservation value of the area” (Martino, 2001). Meffe & Carroll (1994) defined buffer zones as an area encircling the central core area where non-destructive human actions are permitted (Martino, 2001).

Setting up buffer zones is an important tool for protecting national parks according to Miller *et al*. (2001), given that they mitigate the negative impacts on protected areas (Silva-Muñoz, 2012). Ahmad in 2013 states that Lynagh & Urich (2002) said that a "buffer zone is a piece of ordinarily used land, often delicate and especially sensitive to environmental destruction which is administered with dual aims, preservation, and progress, where buffers zones conceptually are restricted to actions such as investigation, teaching, training, pleasure and leisure and recreation. The flaring of flora, the logging of existing forests, the building of structures and the establishment of crops are often forbidden in buffer zones." (Lynagh & Urich, 2002; Ahmad, 2013). The buffer-zone idea can be used in almost any human activities taking place close to a conservation area (Wells & Brandon 1993; Lynagh & Urich, 2002; Ahmad, 2013).

For Martino (2001), buffer zones "are created because there is an obligation to safeguard the preserve areas from the people and the devastating actions that are carry out outside the reserve but impact preservation inside". Martino also said that "there are researchers arguing that the use of buffer zones must be to help to make life better for the surrounding population, in such a way as, to prevent these people from invading conservation areas, and there are others researchers arguing that the reserve protection should be their main goal, with the benefits to the local people taking a second place" (Martino, 2001; Ahmad, 2013).

According to Mwalyosi (1991), buffer zones with not totally limited land use are vital towards reducing dispute across borders between the reserve and adjacent settlements, giving an additional layer of defense to the reserve while giving valued gains to the neighboring settlements (Mwalyosi, 1991; Martino, 2001).

For Ahmad (2013), buffer zones offer some biological, social and ecological gains caused by the geographical growth of the preservation area that maintains human influence far away. Martino (2001) said that "Some of these gains are: The buffer zones serve as a fence to prevent intrusion of intruders, it is a protection against storm damage, a extension of wild environment, it reduced edge effects, and improved ecosystem services supplied by the conservation area". The common gains are; stop wildlife damage to crops and to people living near the reserve (Martino, 2001; Ahmad, 2013).

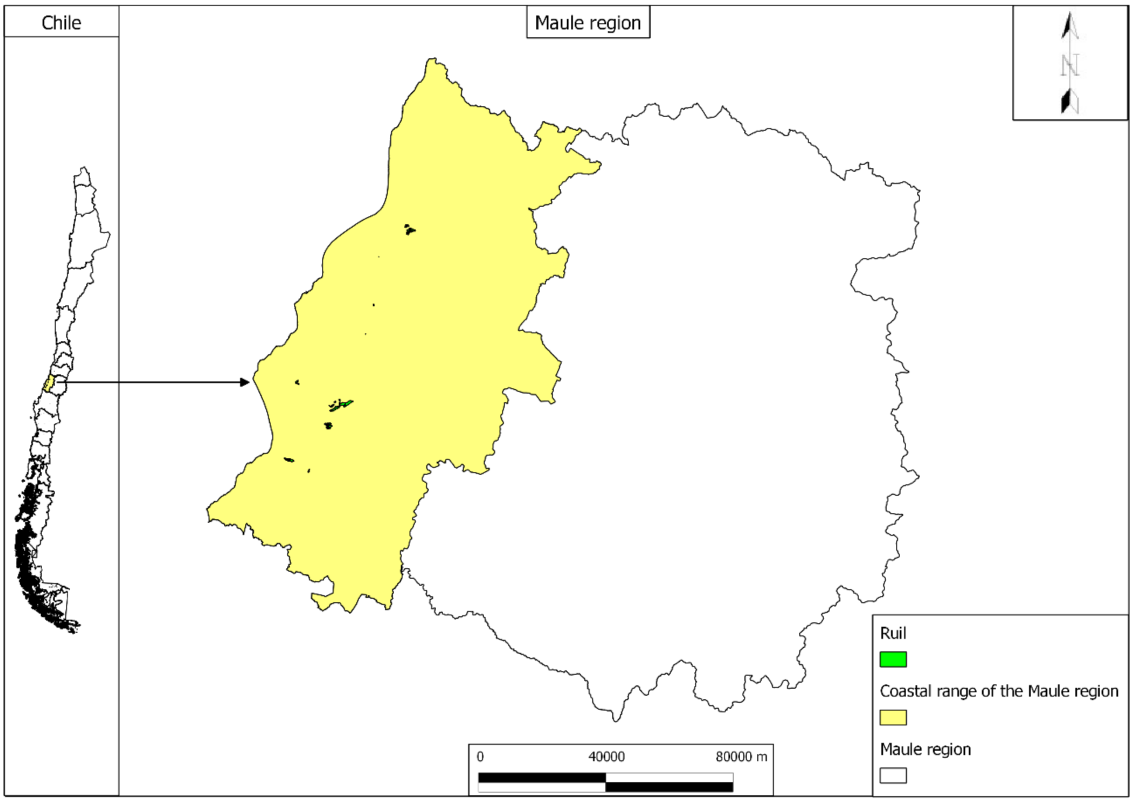
According to Jotikapukkana *et al*. (2010), "buffer zones act as an expansion of core areas and also supply goods and services to the people". In addition, Jotikapukkana *et al*. (2010), added "Buffer zones can raise the number of uncommon and unique species because they give further available land for their development". Moreover, buffer zones may help fauna displacements by transform hard borders into soft borders, and act as corridors (Jotikapukkana *et al.,* 2010).

In conclusion, as Neumann said in 1997, "the central idea behind the buffer zones concept is that are territories that are contiguous to national parks and protected areas where man-made uses are limited to those that keep the environmental safety of the conservation area as well as deliver environmental services to nearby populations" (Neumann, 1997).

With respect to my study, from all the above cited definitions of buffer zone, the ones made by Sayer (1991) and Jotikapukkana *et al*. (2010), are the definitions that are closer to the buffer zone concept that I want to use in my study. As the buffer zone that I want to use for the ruil must be an area that surrounds the ruil fragments with the objective of protection and separation of ruil fragments from the negative activities that are currently afecting it (*Pinus radiata* plantation). At the same time, this buffer zone must be an extension of the core areas, as new land to be restored with ruil (if is needed) and to provide enviromental services to the comunity.

Since, according to Olivares *et al.* (2005) and San Martin (2011, personal communication), the implementation of buffer zones is an important mechanism for the preservation of ruil forest to stop the constant and increasing replacement or invasion of ruil fragments by *Pinus radiata*. In particular, buffer zones are important to avoid the invasion of *Pinus radiata* to the remaining fragments of ruil forest (Figure 7); since these fragments are inserted in a mass of *Pinus radiata* plantations (Becerra & Simonetti, 2013), as shown in Figures 8 and 9.

Figure 7: Remaining fragments of ruil forest

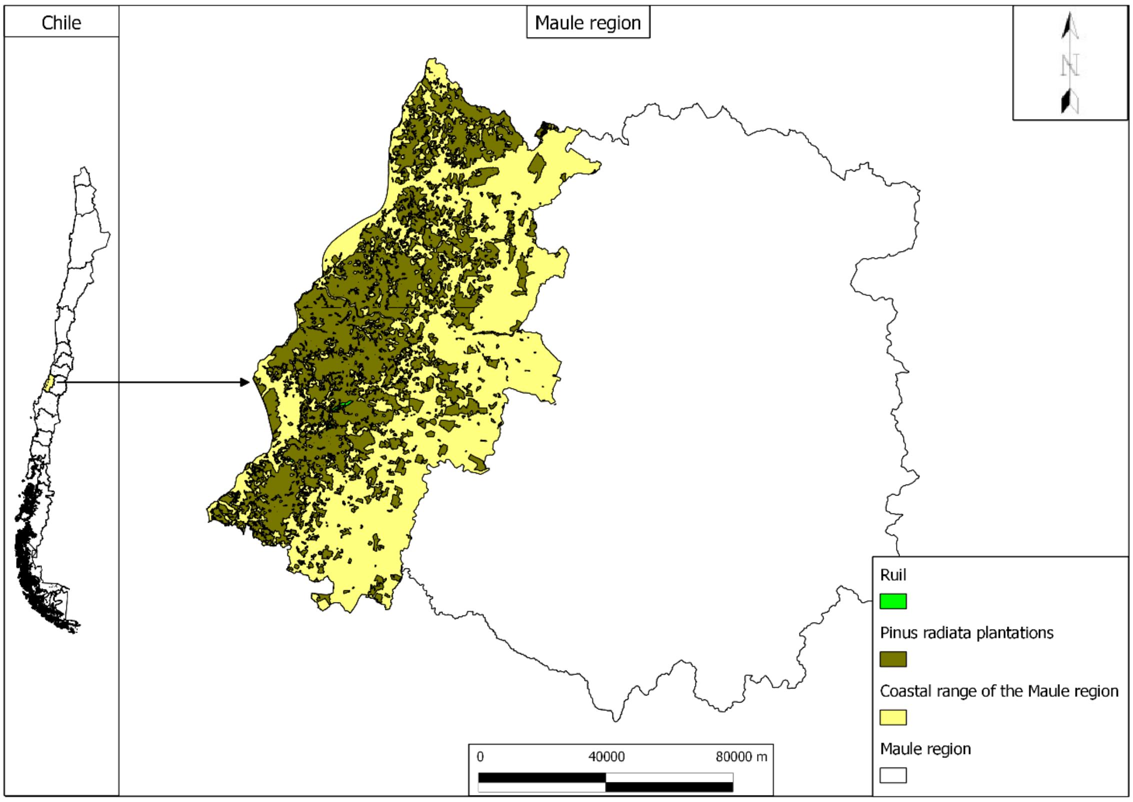


Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 8: Pictures of two different sectors with ruil surrounded by *Pinus radiata* plantations

Source: Olivares *et al*., 2005.

Figure 9: Ruil and *Pinus radiata* plantations



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

As it can be seen in Figure 9, the areas of ruil coincide with areas of greater forestry production in the Maule region. *Pinus radiata* plantations completely surround the ruil forest. The direct impact of this activity is reflected in a reduction in coverage and changes in the distribution pattern of ruil as is shown in Figure 7, taking into account that before human intrusion the ruil forest surface area was much greater than today. As result of this intrusion, the ruil forest has suffered extreme fragmentation, serious habitat modification and – in some places – the extinction of populations associated with ruil (Olivares *et al*., 2005; Silva-Muñoz, 2012).

The homogeneity of *Pinus radiata* plantations and the absence of a buffer zone between them and the ruil stands are environmental factors that contribute to promoting the invasion of *Pinus radiata* into ruil forest areas. This implies a high vulnerability of these forests to the invasion of *Pinus radiata* due to the efficient dispersion that this species has (San Martín & Sepúlveda, 2002; Silva-Muñoz, 2012).

In addition, *Pinus radiata* threatens the ruil due to its higher capacity to compete for resources, especially water, and its efficient mechanism of seed dispersion by wind, that allow *Pinus radiata* seeds get better zones (San Martín *et al.,* 2006; Villalobos & Huenchuleo-

Pedreros, 2010; Silva-Muñoz, 2012). From here arises the importance of creating buffer zones to separate the ruil forest from *Pinus radiata* plantations, since the buffer zones could protect ruil forest fragments from the invasion of *Pinus radiata* seeds (Olivares *et al*., 2005; San Martín *et al.,* 2006; Villalobos & Huenchuleo-Pedreros, 2010; Silva-Muñoz, 2012).

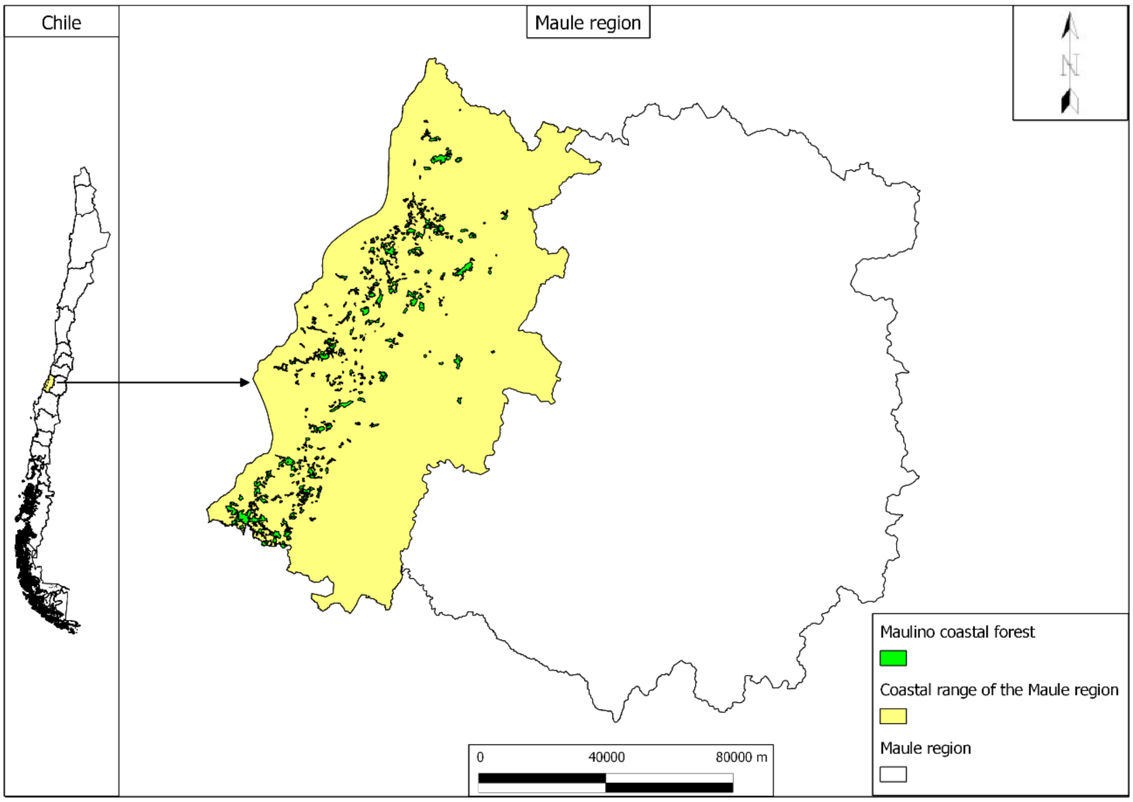
The implementation of the buffer zones could be done by paying the owners of the land that will be part of it an adequate amount of money depending on the economic losses (opportunity cost) that the owners will have for allowing the implementation of the buffer zone in their properties. This money can come directly as a government subsidy delivered by CONAF, or as it was suggested by Villalobos & Huenchuleo-Pedreros in 2006, an environmental preservation fund for the protection of ruil could be created in the Mule region, in order that the regional community, local universities, private enterprise, and government can make contributions for its conservation.

3. Methods

3.1. Study area

The study area corresponds to the coastal range of the Maule region in Chile (Figure 10).

Figure 10: Coastal range of the Maule region and the Maulino coastal forest



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

The Maule region is located in the south-central Chile (34°41'S and 36°40'S) and has an area of 30,296 km^2, representing 4% of the country's surface. The regional capital is Talca; it is located 250 km south of the Chilean capital, Santiago. The region is divided into four provinces and 30 municipalities and its estimated population in 2010 was 1,007,831 inhabitants. Its population represents 6% of the national population and subdivided into 66% as urban and 34% rural populations, respectively, and it is the area which exhibits the most significant percentage of rural population in the country. The Maule region is delimited by the the Pacific Ocean to west, by Argentina to the east, by the O´Higgins region to the north and by the Bío-Bío region to the south (Silva-Muñoz, 2012; INE, 2017).

In terms of geographical aspects, this region presents five very different longitudinal units: a coastal strip characterized by rocky beaches, vast expanses of dunes and wetlands; a coastal range dominated by *Pinus radiata* plantations and small fragments of ancient native forests dominated by endemic *Nothofagus;* a central depression rich in agricultural crops dominated by vegetable crops, fruit trees and vineyards; the Andes foothills dominated by endemic *Nothofagus* and finally an unknown high part of Andes Mountains dominated by volcanoes, high plains and wetlands (Olivares *et al.,* 2005; Silva-Muñoz, 2012).

The climatic condition that characterizes the Maule region is a temperate climate of Mediterranean type, with differences in the north-south direction, having a dry season of six months in the north and four months in the south. The average temperature is 19°C, with extremes of 30°C, during the summer period, while in winter, the average minimum temperature is 7°C (BCN, 2017). On the coastal range of the Maule region, the temperate Mediterranean climate predominates, with moderate temperatures throughout the year. In the longitudinal valley there is a warm Mediterranean climate that changes to temperate Mediterranean climate up to the mountains (over 2,000 m a.s.l. approximately), presenting a decrease in temperatures and increased in precipitation (BCN, 2017).

The economy in the coastal range of the Maule region is based mainly on forestry and agricultural activities, with forestry being the most important. At the beginning of the 21st century, *Pinus radiata* and *Eucalyptus globulus* plantations transformed the coastal range of the Maule region into the forestry center of the country (INE, 2007; Silva-Muñoz, 2012). Thus, *Pinus radiata* is the most common species in the forestry plantations, since it is used to produce wood chips for the pulp mills located in the municipalities of Constitution and Licanten (INE, 2007; Silva-Muñoz, 2012). The agriculture sector is based on traditional crops, mainly wheat and legumes, as well as wine production. Wine production is one of the most relevant activities in the Maule region, since 40% of the total vineyards of Chile are concentrated here. However, in recent years, the production of berries has increased, such as blackberry, strawberry, and blueberry (INE, 2007; Silva-Muñoz, 2012).

From a biogeographical point of view, the Maule region is a zone of great floristic abundance and elevated rates of endemic species. Much of the habitat of endemic trees species such as *Nothofagus alessandrii* (ruil), *Gomortega keule* (queule), and *Pitavia punctata* (pitao) is found here (San Martín *et al.,* 2006). This area has been recognized by the international scientific community as a biodiversity "hotspot", meaning a territory of global relevance that is under immense human pressure (Myers *et al*., 2000; Silva-Muñoz, 2012). Despite their importance, these species are on the edge of extinction, since the study area has been intensely cultivated during the last 200 years (San Martín *et al.,* 2006). This has caused the decrease of the surface of above-mentioned species – especially the ruil forests, since these have been replaced by *Pinus radiata* plantations (Pliscoff & Fuentes, 2008; BCN, 2017).

In the Maule region there are six national reserves administered by CONAF:

1. The "Radal Siete Tazas National Reserve". It is located 100 km northeast from Talca, in the Municipality of Molina. It has an area of 5,026 hectares. In this protected area predominates the high Andean steppe of the Maule region and deciduous forest (*Nothofagus*), formed by the forest type roble-hualo. As far as flora is concerned, some species with conservation problems present here are the *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble) and with regard to the safeguarding of wild fauna, important is the presence of *Pudu puda* (pudu) which has a vulnerable conservation status (CONAF, 2018).

2. "Los Ruiles National Reserve". This reserve is divided into two parts: "El Fin" in the Municipality of Empedrado with an area of 16 hectares and "Los Ruiles" in the Municipality of Chanco with 29 hectares, resulting in a total of 45 hectares between both. As far as flora is concerned, Los Ruiles National Reserve is rich in native forest, since the reserve is formed by the Maulino coastal forest, rich in *Nothofagus glauca* (hualo). In addition to hualo other species with conservation problems as *Pitavia punctata* (pitao), and *Nothofagus alessandrii* (ruil), both with a critical conservation status according to the IUCN, are present here. With regard to the safeguarding of wild fauna, important is the presence of *Pudu puda* (pudu) which has a vulnerable conservation status (CONAF, 2018).

3. "Los Queules National Reserve" is located 153 km southwest from Talca in the Municipality of Pelluhue. It has an area of 147 hectares covered by wooded vegetation with large trees. The unit stands out for the protection of the *Gomortega keule* (queule) species with a critical conservation status according to the IUCN. In addition to queule this reserve protect the *Pitavia punctata* (pitao) and *Berberidopsis corallina* (michay rojo) also with critical conservation status, among others species of the *Nothofagus* genus as *Nothofagus glauca*

(hualo). With respect to the protection of wildlife there are presence of *Pudu puda* (pudu) which has a vulnerable conservation status and other species with conservation problems as the *Conepatus chinga* (chingue), *Galictis cuja* (quique), *Lycalopex culpaeus* (culpeo fox), *Pseudalopex griseus* (chilla fox) (CONAF, 2018).

4. “Laguna Torca National Reserve” is located in a lacustrine system composed of the Torca Lake and the Vichuquén Lake at 124 km northwest from Talca in the Municipality of Vichuquen. It has an area of 604 hectares. The reserve constitutes the principal humid environments of Central Chile, since it has a great density and variety of birds. The unit stands out for the preservation of wildlife species, which is formed by fish, birds and mammals. For fish, the *Basilichthys australis* (Chilean pejerrey) stands out, birds number more than 90 species, and among the mammals are the *Myocastor coypus* (coipo), the *Lycalopex culpaeus* (culpeo fox) and the *Galictis cuja* (quique) (CONAF, 2018).

5. The “Federico Albert National Reserve” is located 174 km southwest from Talca in the Municipality of Chanco. It has an area of 145 hectares. Its name is for the German professor and biologist Federico Albert, who saved the Municipality of Chanco from being lost due to the advance of the dunes through the plantation of trees to forming a biological defence against the progress of the dunes. Its flora consists of a great variety of trees, such as *Eucalyptus globulus* (eucalyptus), *Pinus radiata* (pinos), *Cupressus* (cipres), *Quercus suber* (alcornoques) and *Acacia dealbata* (aromos). However, the forest has witnessed the growth of native species such as *Peumus boldus* (boldo), *Cryptocarya alba* (peumo), *Lomatia dentate* (corcolén) and *Aristotelia chilensis* (maqui) (CONAF, 2018).

6. *“*Altos de Lircay National Reserve” is located 66 km east from Talca in the Municipality of San Clemente on the Andean foothills of the Maule region. It has an area of 12,163 hectares. In this protected area predominates the high Andean steppe of the Maule region and a deciduous forest (*Nothofagus*), formed by the forest type roble-hualo. Some species with conservation interest present here are the *Nothofagus glauca* (hualo) and *Nothofagus obliqua* (roble). With respect to wildlife, the unit stands out for the protection of *Pudu puda* (pudu) and the *Felis concolor* (puma) (CONAF, 2018).

3.2. Data

In my analysis I used the following data:

- Data related to costs, income and profitability of *Pinus radiata* plantations in the Maule region obtained from "Gestion Forestal (2011)". This is a program of the Chilean government to research and disseminate information on the forestry sector in Chile (Gestion Forestal, 2011). For details about the program, refer to appendix 1.

- Data related to costs, income and profitability of *Cabernet Sauvignon* vineyards in the Maule region obtained from a study of characterization of the production chain and marketing of the wine industry, conducted by the office of studies and agricultural policies (ODEPA) from the Ministry of Agriculture of the Chilean Government (ODEPA, 2015). For details, refer to appendix 2.

- Shapefiles of the Maulino coastal forest obtained from the Chilean National Forestry Corporation (CONAF, 2013).

- Shapefiles of the remaining fragments of ruil forest obtained from the Chilean National Forestry Corporation (CONAF, 2013).

- Shapefiles of the National System of Protected Wild Areas of the State (SNASPE; CONAF, 2013).

- Shapefiles data on the different land uses carry out in the Maule region, especially in the distribution area of the Maulino coastal forest that was provided by CONAF (2013).

- Shapefiles of two species distribution models (SDMs, current and future) of ruil forest from a study made by Alarcón & Cavieres (2015). They built the species distribution models using niche modeling, selecting 8 climatic indicators with the smallest correlations from the WorldClim - a worldwide climatological databank for present-day climatic parameters - and six future climate scenarios for the year 2050 (Alarcón & Cavieres, 2015). Then, Alarcón & Cavieres (2015) modeled species distribution employing 8 different techniques that are provided via the BIOMOD R program (R Development Core Team 2012; Alarcón & Cavieres, 2015).

The SDMs of ruil produced by Alarcón & Cavieres (2015) were used in order to consider climate change effects in reserve network planning for ruil, in order to see how the reserve network designs change when the climatic aspect is considered in the analysis and to determine appropriate zones for restoring ruil forest.

I used *Pinus radiata* and *Cabernet Sauvignon* vineyards data, since they are the most profitable activities that are performed in the distribution area of the Maulino coastal forest (Gestion Forestal, 2011; ODEPA, 2015). In addition, *Pinus radiata* is the main threat that the conservation of the Maulino coastal forest and the species present in it as the ruil forest are facing.

I used the future distribution model of ruil in order to consider the effect of climate change in the ruil distribution area, and I used the current distribution model of ruil to know which places are suitable nowadays to restore this forest.

The total surface of the Maulino coastal and ruil forests are 338 km^2 for the Maulino coastal and 12 km^2 for the ruil, respectively. The total surface of the two distribution models considered in this study are 422 km^2 for the current distribution model of ruil and 239 km^2 to the future distribution model respectively.

3.3. Spatial conservation prioritization

3.3.1 Conservation planning software Marxan

To measure the link between biodiversity preservation and opportunity cost I used the "Marxan conservation planning software" (version 2.43) as Loos in 2011 stated “it has two main solutions: the summed solution and the best solution. The best solution consists exclusively on the planning units that were chosen in the process and had the smallest total objective function cost. While the summed solution is a tally of how many instances a planning unit was selected” (Ball *et al*., 2009; Loos, 2011). Game & Grantham (2008) say that the Marxan-generated solutions can be classified as “feasible or infeasible". The solutions were considered as feasible if it met all the preservation objectives. On the contrary, the solutions were considered infeasible if it does not meet one or more preservation objectives (Game & Grantham, 2008; Ardron *et al*., 2010). The best solution was the Marxan output used in my study.

Additionally, in my study I have used others software to support the analysis with Marxan, such as used the Quantum Gis 1.8.0 – Lisboa (QGIS) and Zonae Cogito software, and the Marxanio web app to run the Marxan analyses, test parameters and examine the results.

Quantum Gis 1.8.0 – Lisboa (QGIS), according to Qgis project (2018), Qgis is a "no cost open source program that is employed to build, modify, display, analyze and display geographic data". It was established as a Source Forge project in June of 2002, is intended to be an easy-to-use GIS, with standard characteristics and functions. It has a plug-in call QMarxan Toolbox that provides data preparation and results analysis processing tools for Marxan (Qgis, 2018).

Zonae Cogito software (The Ecology Centre, University of Queensland, Australia) serves as a tool to assist decision making and the administration of databases for Marxan with the help of open source GIS software components, is available for free and a very easy and solid manner of running Marxan's test and reviewing the results (Game & Grantham, 2008; Ardron *et al*., 2010; Watts *et al.,* 2011; Giakoumi *et al*., 2012). The integrated open source software eliminates the need for purchasing expensive Geografic Information System (GIS) programs to run Marxan (Watts *et al.,* 2011; Giakoumi *et al*., 2012).

As Watts (2016) said "Marxanio is a web app for systematic conservation planning, with a web graphical user interface for Marxan end-users that is executed in the Nectar investigation cloud. It enables uploading our own Marxan datasets, editing targets, SPF and BLM; conducting parameter testing, sensitivity analysis and analysis; display of charts, graphs, diagrams and output datatables, and downloading the completed analysis in an easy-to-use web interface" (Watts, 2016).

In my study I mainly used Quantum Gis 1.8.0 – Lisboa (QGIS), Zonae Cogito and Marxanio for editing Marxan settings and input data files, running Marxan tests, dynamically viewing the reports of Marxan tests, and calibrating Marxan parameters as a complement to Marxan (Watts *et al.,* 2011; Watts, 2016; Qgis, 2018). In addition to Quantum Gis (Qgis), Zonae Cogito and Marxanio, the R software package was also used in my study to plot the results obtained with Marxanio.

3.3.2 Reserve networks design

In my study the design of the reserve networks was based on seven elements: (a) conservation scenarios, (b) buffer zone, (c) Planning Units (PUs), (d) opportunity cost, (e) target (level of protection in terms of representation), (f) Boundary Length Modifier (BLM) to reduce fragmentation levels, and (g) Species Penalty Factor (SPF).

a. Conservation scenarios

For the analysis of the Maulino coastal forest, I considered just one scenario named "the Maulino coastal forest scenario".

- The Maulino coastal forest scenario is important to determine which zones of the Maulino coastal forest are more cost-effective areas to be part of a reserve network for the preservation of this forest. The main input used here were the current distribution of the Maulino coastal forest, the remaining fragments of ruil forest and the shapefiles of the SNASPE. In this scenario, I have considered two conservation features: a) the distribution of the Maulino coastal forest and b) the remaining fragments of the ruil forest. I used the remaining fragments of ruil as a conservation feature, to include it in the reserve networks, given that ruil forest is part of some fragments of Maulino coastal forest but not all of it.

For the ruil forest case, in order to see cost-effectiveness gains by considering climate change effects in the generation of reserve networks for ruil forest, two conservation scenarios were considered in my study:

- The first scenario is the "ruil current model scenario". Within this scenario, the effect of climate change is not considered. This scenario is important because it allows me identify suitable zones for the establishment of ruil forest in case restoration programs for ruil are carried out in the zone now. The main input used here were the current distribution model of ruil forest as determined by Alarcón & Cavieres (2015), and the remaining fragments of the ruil forest (nowadays). In this scenario, I have considered one conservation feature: the current distribution model of ruil determined by Alarcón & Cavieres (2015).

- The second scenario is the "ruil future model scenario". In this case, the influence of climate change was considered in the analysis. This scenario is important because it allows me to identify zones that will continue being suitable for the development of ruil forest in the future. This allow us to focus our efforts on preserving and restoring ruil forest in these areas, since they will continue being suitable. The main input used here were the future distribution model of ruil as determined by Alarcón & Cavieres (2015), and the remaining fragments of ruil forest that coincide with the future distribution model. In this scenario, I have considered one conservation feature: the future distribution model of ruil determined by Alarcón & Cavieres (2015).

I included the remaining fragments of ruil in the analysis of ruil forest and climate change, as an element that must be part of each reserve networks in both scenarios (current and future models scenarios).

The use of current and future ruil distribution models determined by Alarcón & Cavieres (2015) allows me to follow the recommendation of Smith *et al*. (2009), who suggests setting targets based on the original amount of each feature in the region before habitat is lost. Habitats that have been transformed by mostly human activities can be considered as suitable for the spread of the species in question. Hence, the current and future model scenarios are used to identify suitable areas for establishing ruil forest that can be included in a restoration (reforestation) program, adding climate change effects in the future scenario to see cost-effectiveness gains by considering those effects when creating ruil forest reserve networks.

b. Buffer zone

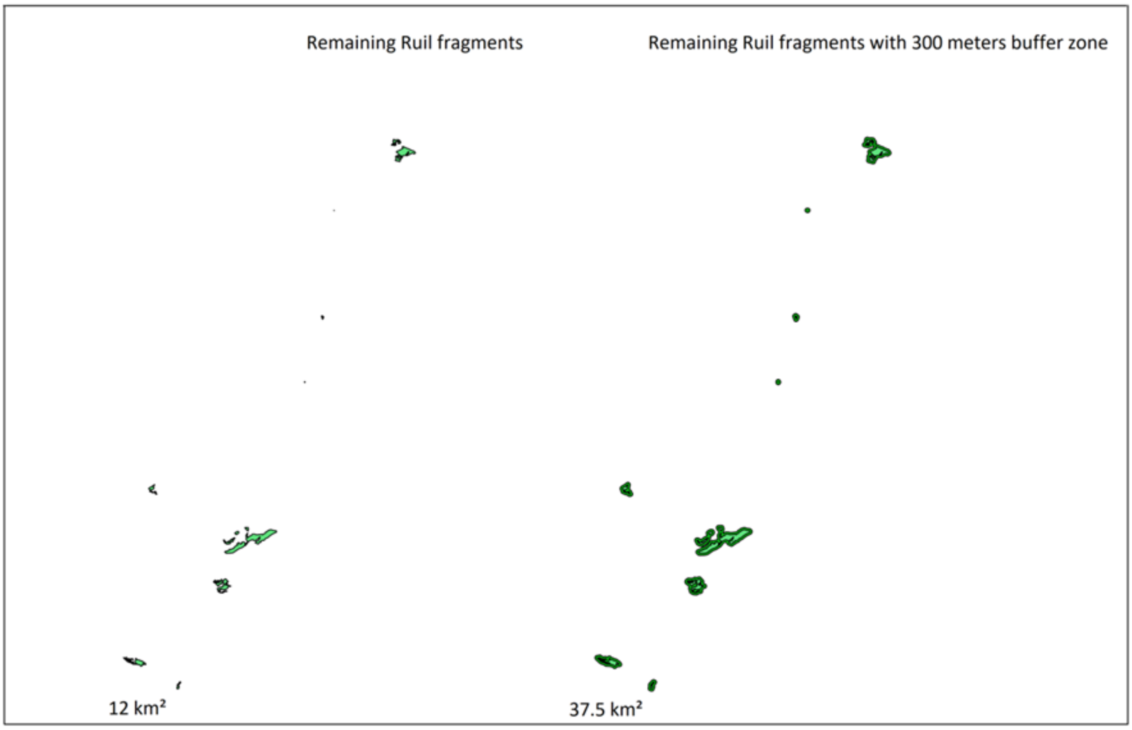
In the current and future models scenarios of ruil forest, a buffer zone of 300 meters of width was applied to the ruil fragments prior to the analysis with Marxan in order to incorporate an extra measure of protection to the ruil forest fragments.

I decided to use a buffer zone of 300 meters of width to include a barrier that could separate the current fragments of ruil forest from the agricultural and forestry's activities that surround them and negatively affecting it – specifically *Pinus radiata* plantations. Buffer zones are a highly suitable way to protect ruil and avoid its extinction in the view of Olivares *et al.* (2005). Thus, future conservation plans must consider creation of these zones essential towards preserving this species.

In 2011 San Martin said that it is not possible to determine with accuracy the necessary size of the buffer zone width for ruil forest, since there is no information about this matter. However, he added that if the dispersion of the *Pinus radiata* seeds from the surrounding *Pinus radiata* plantations is considered as the variable for determining the buffer zone size, it should have at least 300 meters of width (San Martin, 2011(personal communication)).

For that reason, following the recommendation of Olivares *et al.* (2005) and San Martin (2011 (personal communication)), I applied buffer zones of 300 meters of width to the remaining fragments of ruil forest before running Marxan, as an additional protection measure. As a result, the total surface of the remaining fragments of the ruil plus a buffer zone of 300 meters corresponds to 37.5 km^2 (Figure 11). This new surface (ruil fragments plus a buffer zone) was used in the analysis with Marxan in order to include the buffer zone as a barrier for negative external factors that could affect the forest. Thus, this additional measure for ruil forest preservation is present in the reserve networks produced by Marxan.

Figure 11: Ruil without and with a buffer zone of 300 meters



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

Note: This figure is not made to scale, so it does not present a scale bar, as it has only been made to give to the reader an idea of how the fragments of ruil would look with and without a buffer zone.

On the other hand, a buffer zone was not considered as an additional protection measure for the Maulino coastal forest case, since where it exists happens to be the buffer zone of the ruil fragments. Furthermore, given that the Maulino are bigger than the ruil forests, a buffer zone for them is less urgent and would be much more expensive due to the considerably larger perimeter.

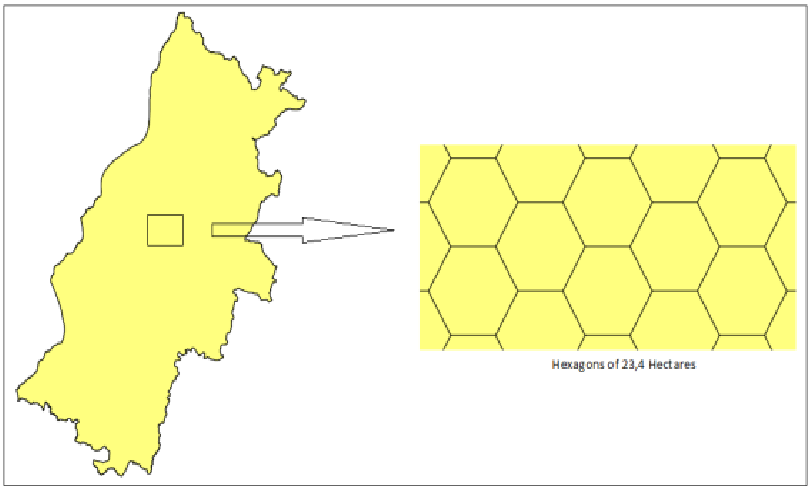
c. Planning units (PU)

According to Game & Grantham (2008) "As building blocks of a reserve system, planning units can be based on physical, organisational or high-handed features and of any scale or form" (Loos, 2006; Game & Grantham, 2008). They are the units that Marxan evaluates and selects to form solutions.

Three equilateral shapes – triangles, squares and hexagon – can be joined together to form grids, with the latter two being the most common used for reserve planning (Loos, 2006). Marxan analyses have used mostly hexagonal planning units, although squares have been used by a good number as well (Miller *et al*., 2003; Geselbracht *et al.,* 2005; Loos, 2006). Acording to Loos (2011), who said that "reasons for the square unit use are not found in the literature, while when hexagonal units are used, explanations varying from solutions appear more natural , their form, as a ring, has a relatively poor relationship between the border and the area ratio, they have a fairly smooth performance and a perimeter and surface ratio smaller than that of a squares" (Loos, 2006; Loos, 2011).

Hence, following the recommendation of Loos (2006) in my study, I decided to use hexagonal units to define cost-effective priority sites for conservation of the Maulino coastal and ruil forests. I generated a geo-referenced set of planning units, assessing the respective conservation value of each planning unit with respect to their cost, conservation features, target species, etc. The study area was split in 43,025 planning units, each of which formed hexagons of 23 hectares (Figure 12). I used the QMarxan plug-in included in the Quantum Gis 1.8.0 Lisboa software (QGIS), to divide the region in planning units and create all the input files for Marxan.

Figure 12: Distribution of the study area with the hexagonal division



Source: Author's elaboration with information provided by CONAF 2013 and the use of the software Quantum Gis 1.8.0 – Lisboa

The detailed spatial arrangement of hexagons is zoomed in the right part of the figure

Note: This figure is not made to scale, so it does not present a scale bar, as it has only been made to give to the reader an idea of how the study area would look divided in Planing Units.

d. Opportunity cost

The individual PU costs are used by Marxan to calculate the overall solution (objective function) value and to produce the cost of the reserve network. The PU cost can be based on factors like PU area, financial or social cost, or a combination thereof (Loos, 2006).

In my study I used opportunity cost as the economic variable in the Marxan analysis. To calculate the opportunity cost and PU cost, I performed a cost-benefit analysis to two production activities carried out in the distribution area of Maulino coastal forest: *Pinus radiata* plantations and *Cabernet Sauvignon* vineyards. I chose these activities since they have the highest profitability in the study area and are developed in the distribution area of the Maulino coastal forest. The objective was to calculate the opportunity cost of not developing this area's more profitable production activities (*Pinus radiata* plantations and *Cabernet Sauvignon* vineyards).

Regarding *Pinus radiata* plantations, the following information presented in the analysis was mainly obtained from "Gestión Forestal" (Gestion Forestal, 2011), a program of the Chilean government that researches and disseminates information about the forestry sector in Chile (Gestion Forestal, 2011). This program provided information on costs, income and profitability of *Pinus radiata* plantations from the interior and coastal dry-land of the Maule Region (study area), the area where the Maulino coastal and ruil forests are located (Gestion Forestal, 2011). For details, refer to appendix 1.

The financial analysis was then performed accordingly (Table 2). Discount rates of 6%, 8%, 10% and 12% have been used to evaluate Chilean forestry project profitability (Gestion forestal, 2018) – I settled on a 10% discount rate of to examine *Pinus radiata* plantation profitability, as some authors like Bueno & Brito (2001); Sotomayor *et al*. (2002); Abadi (2003); Abadi *et al.* (2006); Toral *et al*. (2005); Gestion Forestal (2011); Gestion Forestal (2018) and Goldenberg *et al.* (2018) have done. In the analysis, the plantation management system taking into account aligns with "multi-purpose management". According to Sotomayor *et al.* (2002), you obtain a variable production target this way, because it produces saw logs and wood chips. The data for my study was obtained from a *Pinus radiata* plantation with this scheme provided by Gestion forestal (2011; Silva-Muñoz, 2012).

The Subsidies granted under Chilean Decree Law 701 subsidies governing management of forestry plantations and native forests was also considered (CONAF, 2011) For details, refer to appendix 3 Chilean Forestry Laws Subsidies. Two Subsidies are given under the law: one for planting density (1,250 trees per hectare for multi-purpose management) and another bonus for pruning and thinning trees (CONAF, 2011). By including these subsidies, the study analyzes opportunity cost from a private financial point of view and not a welfare economic one (Silva-Muñoz, 2012).

Table 2: Opportunity cost of one hectare (ha) of *Pinus radiata*

Year	Costs (CLP/ha)	Activity	Earnings (CLP/ha)	Activity
0	582,960	Establishment 1,250 pl/ha	0	n/a
1	12,000	weed control	293,800	Forest subsidy of 75% for the establishment of the forest
2	12,000	weed control	0	n/a
3	0	n/a	58,760	Forest subsidy of 15% for the establishment of the forest
12	322,120	Harvest of 47.9 m3/ha and transport	299	Pulp wood logs Sale
1 to 21	2,000	Administration	0	n/a
21	2,671,600	Harvest 397,264 m3/ha and transport	6,979,840	Sale of wood with knots > 18 cm diameter and pulp. Sale wood without knots
NPV	225,587CLP			
10%	331.41€			
IRR	13%			

Source: Silva-Muñoz, 2012.

With respect to *Cabernet Sauvignon* vineyards, the following information presented in the analysis was mainly obtained from a study of characterization of the production chain and marketing of the wine industry developed for the office of studies and agricultural policies from the Chilean Ministry of Agriculture (ODEPA, 2015). The purpose of the study was to research and disseminate information about the wine industry in Chile. This study provided information on costs, income and profitability of *Cabernet Sauvignon* vineyards from the Maule region.

With that information, the financial analysis was performed (Table 3). A 10% discount rate was used in the financial analysis as was recommended by Yáñez (2006) and Lobos *et al*. (2014) for evaluation of vineyards projects. The vineyard management scheme considered in the analysis corresponds to vineyards with drip irrigation. This scheme is the most common in the central zone of Chile for *Cabernet Sauvignon*. Cost and revenues data come from ODEPA (2015). For details, refer to appendix 2.

Table 3: Opportunity cost of one hectare (ha) of *Cabernet sauvignon* vineyards

Year	**Costs (CLP/ha)**	**Activity**	**Earnings (CLP/ha)**	**Activity**
0	2,961,163	Establishment 4,545 pl/ha	n/a	n/a
1	307,108	Labor, Machinery, Agricultural inputs, etc.	n/a	n/a
2	694,610	Labor, Machinery, Agricultural inputs, etc	n/a	n/a
3	794,844	Labor, Machinery, Agricultural inputs, freight, etc.	848,000	Annual Production
4	1,157,471	Labor, Machinery, Agricultural inputs, freight, etc.	1,908,000	Annual Production
5 to 20	1,557,022	Labor, Machinery, Agricultural inputs, freight, etc.	2,650,000	Annual Production
NPV	2,578,693 CLP			
10%	3,441.49€			
IRR	16%			

Source: Author's elaboration with information from ODEPA (2015).

As the two distribution models of the ruil forest (current and future) used here have considered agricultural land as suitable land for ruil's restoration. The most profitable economic activity that could be performed in the study area's agricultural land was considered. This profitable economic activity is *Cabernet Sauvignon* vineyards, in which the profitability of one hectare of the vineyards was used as the opportunity cost, representing one hectare of agricultural land in a reserves network to restore ruil forest (Table 3).

Thus, to determine the opportunity cost of these agricultural lands considered in the current and future distribution models of ruil made by Alarcón & Cavieres (2015), I looked at *Cabernet Sauvignon* vineyards as the most profitable agricultural activity that can be carried out in the agricultural land present in the distribution models. On the other hand, for the forestry land that was considered the current and future distribution models of ruil made by Alarcón & Cavieres (2015), *Pinus radiata* plantation was considered as the most profitable economic activity that could be performed in the forestry lands of the study area.

With the opportunity cost for not planting or eliminate a hectare of *Pinus radiata* and *Cabernet Sauvignon* vineyard, I proceeded to determine the cost of each PU. This cost is based on the land uses that are developed within it: agriculture or forestry. First, I determined which land uses are being present within each PU with the use of Qgis software and information provided by CONAF (2013). Then, the area of each land use present in the PU was calculated.

Later, the cost of the PUs was calculated, considering the opportunity cost for allocating a hectare of forestry or agriculture land in a reserve network, for the restoration of the ruil forest. Subsequently, I calculated the area of the Maulino coastal and ruil forests that is contained in each PU. For this purpose, I used shape files of Maulino coastal forest, shape files of the remaining fragments of ruil forest, shapes of the native forest census (CONAF, 2013), shape files of SNASPE (national reserves) and the shape files of the two distribution models of the ruil (Alarcón & Cavieres, 2015).

It is important to mention that in the Maule region there are seven land use types according to CONAF (2013). These land uses types are: agricultural land, native forest, forest plantations, grasslands, wetlands, urban e industrial areas and others.

In my study, four land uses were considered: agricultural land, native forest land, forest plantations, and grasslands. The others three were left out of the analysis because they cannot change its land use status. Thus, to determine the opportunity cost of the land uses considered here, as it was mention before, I considered the *cabernet sauvignon* for the agriculture land use and the opportunity cost of *Pinus radiata* for native forest, forest plantations and grasslands. As it was stated above, these activities were considered as they are the most profitable in the area.

In sum, the opportunity cost that would be considered for maintaining a Maulino coastal forest and ruil is the opportunity cost for not planting *Pinus radiata*. Since the land where the Maulino coastal forest and ruil are located is apt for forest plantations. For the grassland the opportunity cost will be the opportunity cost for not planting *Pinus radiata* too, since these soils are usually used for *Pinus radiata* plantations as well. And, as previously mentioned for the agricultural land selected in the reserve networks produced for Marxan for the restoration of the Maulino coastal forest and ruil forest, the opportunity cost will be *cabernet sauvignon* vineyards.

e. Conservation features and Targets

A "conservation feature" is a quantifiable and geographically identifiable biodiversity element within a reserve network chosen as the focus of the preservation plan. (Game & Grantham, 2008; Ardron *et al*., 2010). These features can be describable at different ecological levels such as species, communities, habitat, populations, and genetic subtypes (Loos, 2006; Game & Grantham, 2008; Ardron *et al*., 2010).

For Ardron *et al.* (2010) targets, on the other hand, are "quantitative values of each conservation feature included in the final reserve network", and usually vary based on their relative importance: rare or vulnerable conservation features are often assigned a higher target. A range of targets could be examined in a Marxan analysis, allowing stakeholders to visualize solution sizes and configurations (Loos, 2006; Game & Grantham, 2008; Ardron *et al.,* 2010).

I follow the guidance of Ardron *et al*. (2010) to define these targets, who said they could be set using a country mandate, organization mission statement or an existing legal framework. Most nations are signatories to international agreements or have promulgated laws to preserve a certain proportion of particular species or habitats, such as the "EU Birds and Habitats Directives". Other organizations and stakeholders have mission statements committing to certain targets created in tandem with project-specific ecological assessments, thereby providing a guideline for setting ecological targets and defending them both publicly and in the court room (Ardron *et al.,* 2010).

Thus, for the Maulino coastal forest scenario, I used two conservation features and two targets. The conservation features were the spatial arrangement of the Maulino coastal forest and the remaining fragments of ruil forests. The two targets were a 17% for Maulino coastal forest and 90% for ruil forest.

For the ruil forest scenarios (current and future models scenarios), one conservation feature was used in each one. In the current model scenario of ruil, the current distribution model of ruil made by Alarcon & Clavieres (2015) was used as the conservation feature. On the other hand, in the future model scenario of ruil, the future distribution model of ruil made by Alarcon & Clavieres (2015) was used as the conservation feature. The current and future models scenarios of ruil (Alarcón & Cavieres, 2015) were used as the modeled presence of site suitability for ruil and the target established for the two conservation features was 17%.

The remaining fragments of ruil with a buffer zone of 300 meters of width were added to the current and future models scenarios before running Marxan as a currently protected area (reserve) to be part of the new reserve networks. I used QGIS to calculate how much of each PUs is already reserved, in order to classify them as already reserved or available to be considered as a reserve. Then, when Marxan is running, it will start adding PUs to this protected area to produce a cost-effective reserve networks.

To choose a 17% target value, as reference/guideline I took two strategic objectives of the "Strategic Plan for Biodiversity 2011–2020 of the Convention on Biological Diversity" (UNEP/CBD, 2011) For details, refer to appendix 4. In it governments commit to improving governance efficiency and expanding the world wide range of natural reserves from 13% to 17% of the terrestrial mass by 2020, focusing on zones with considerable biodiversity (Barth, 2016).

The two objectives of the "Strategic Plan for Biodiversity 2011–2020", were strategic objectives C and D:

- Objective C: "Enhancing the state of biological diversity by ensuring that the environment, wildlife and genetic diversity are properly managed and protected". Point 11 stresses:

    - "In 2020, not fewer than 17% of land and interior areas and 10% of marine and coastal zones (i.e., those in particular important for biodiversity and ecosystems), must be conserved through protected area systems administered in an effective and equitable manner, environmentally meaningful, have a good connection and effective and well-managed safeguarding zones systems and use other conservation measures that are integrable with the wider lands and seascapes" (UNEP/CBD 2011).

- Objective D: “Increase the benefits of biodiversity and ecosystem services for all”, as the following points stress:

  - Point 14: “Ecosystems that deliver critical amenities such as water, health, well being and livelihood services and that take in consideration all the requirements of the female population, native peoples, grassroots actors and institutions and the impoverished of vulnerable people must be restored and safeguarded by 2020” (UNEP/CBD 2011).

  - Point 15: “By 2020, using conservation and restoring at least 15% of degraded lands will contribute to alleviate and respond to climate change while warding off desertification, increasing ecosystem resilience to carbon stocks, and contributing to biodiversity” (UNEP/CBD 2011).

In the Maulino coastal forest scenario, in addition to a 17% target, another level of representation was used for ruil forest: a 90% target. This target was set following the recommendation of San Martin (2011, personal communication), who postulated that in order to preserve ruil, at least 90% of its total area must be protected or conserved. Another reason to choose this target was the critical conservation status of the ruil according to CBD.

In the ruil forest scenarios (current and future models scenarios) a 17% target was also used. This 17% target was chosen considering the two strategic objectives of the “Strategic Plan for Biodiversity 2011–2020 of the Convention on Biological Diversity” (UNEP/CBD 2011) mentioned before, plus the “Initiative 20x20” (WRI, 2014) For details, refer to appendix 4. This effort from Latin America countries – Chile included – and the Caribbean strive to change the course of land degradation, restoring 20 million hectares by 2020, of which Chile commits to restore 0.5 million hectares by then (WRI, 2014). As part of this goal, the reserve networks generated for this study in the climate change scenarios (current and future models scenarios of ruil) can be considered as potential restoration areas for ruil and Maulino coastal forest and contribute to the “Initiative 20x20”.

In addition, to the two previous initiatives, I have also considered The Regional Development Strategy Maule 2020 and The Maule Biodiversity Strategy. For details about the initiatives refer to appendix 4.

f. Boundary Length Modifier (BLM)

Ardron *et al.* (2010) stated that “the boundary length modifier (BLM) is a Marxan setting that monitors the impact of a solution’s perimeter (i.e. boundary length) on the value of the objective function – the higher the BLM, the higher the objective function’s value” (Game & Grantham, 2008; Ardron *et al.,* 2010). It rises the agglomeration of chosen places by penalizing high fragmentation outcomes (Loos, 2006). The selection process would only consider conservation value of each PU only if BLM were not used, and not the PU location relative to all other selected PUs (Walther & Pirsig, 2017). Walther & Pirsig (2017) said that “very fragmented systems are frequently chosen, with the PUs being spread over long ranges”. Marxan thereby uses the BLM to encourages solutions connecting several PUs directly (Walther & Pirsig, 2017).

Since clustered (compact) solutions are easier to manage and monitor than highly fragmented areas they become more viable for management purposes (Geselbracht *et al.,* 2005). As the perimeter (boundary length) decreases, the area of the solution area increases as normally more PU’s are needed to form adjacent clusters (Lieberknecht *et al.,* 2004; Loos, 2006).

According to Stewart & Possingham (2005), to determine an efficient BLM it is important to understand it as an arbitrary value that will vary between study areas and must be determined through experimentation.

The ideal BLM avoids a fragmented solution while not disproportionally increasing the size of the solution (Stewart & Possingham, 2005). Part of the process for determining the BLM are visual outputs inspections – as Loos in 2006 and 2011 said “a very basic plotting task can be used to find a departure place to refine the data” (Loos, 2006; Loos, 2011).

Stewart & Possingham (2005) as Game & Grantham (2008) suggest that to ascertain an optimal BLM the following next steps must be followed:

1. “Reiterate the Marxan test with a range of dissimilar values for the BLM, while keeping all other parameters unchanged (ceteris paribus)”.

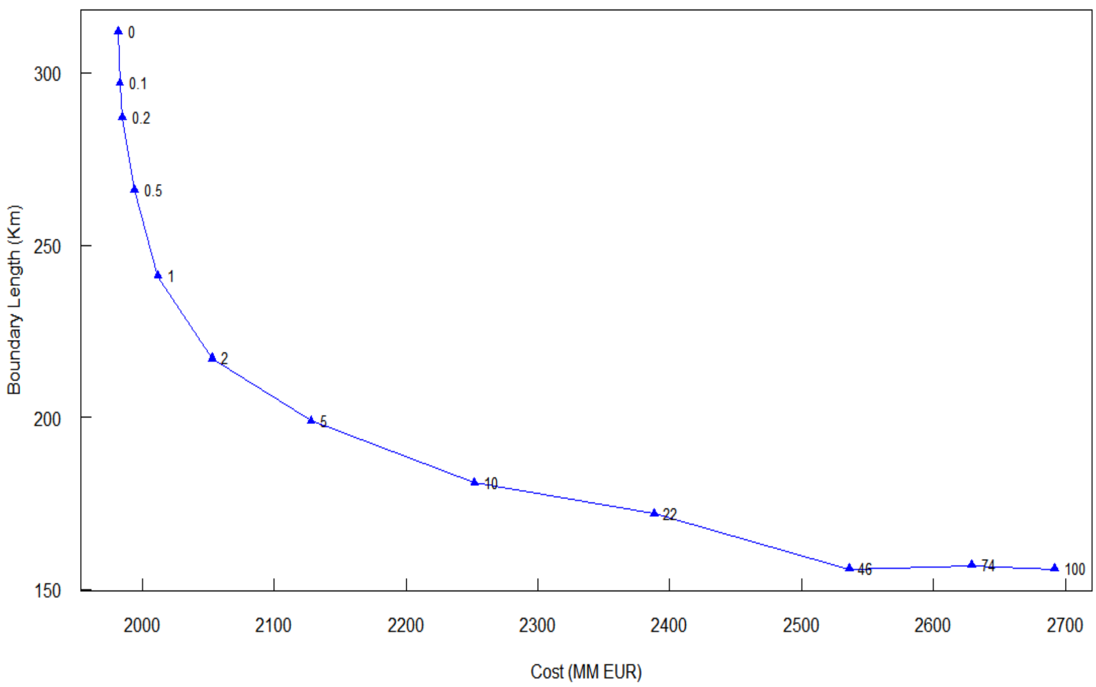
2. “Recording of the BLM used in every scenario, the length of the entire park reservation system margin and the average cost of the solutions in neighboring columns in a calculation sheet”.

3. “For all the different BLM values, plotting total reserve boundary length versus total cost”.

Thus, to find an optimal BLM for the Maulino coastal forest scenario and for the two ruil scenarios (current and future models scenarios of ruil), I followed the recommendation made by Stewart & Possingham (2005) as Game & Grantham (2008) mention before. The recommended steps were conducted using the Marxan web application “Marxanio” (Watts, 2016). This application has a section to do a parameter calibration with some relevant parameters of Marxan, such as BLM, in order to find the optimal BLM to run Marxan. To plot the results of the BLM calibration, I used the R software.

The BLM calibration for determine the optimal BLM for the Maulino coastal forest scenario is presented in Figure 13.

Figure 13: Boundary length modifier testing graph in the Maulino coastal forest



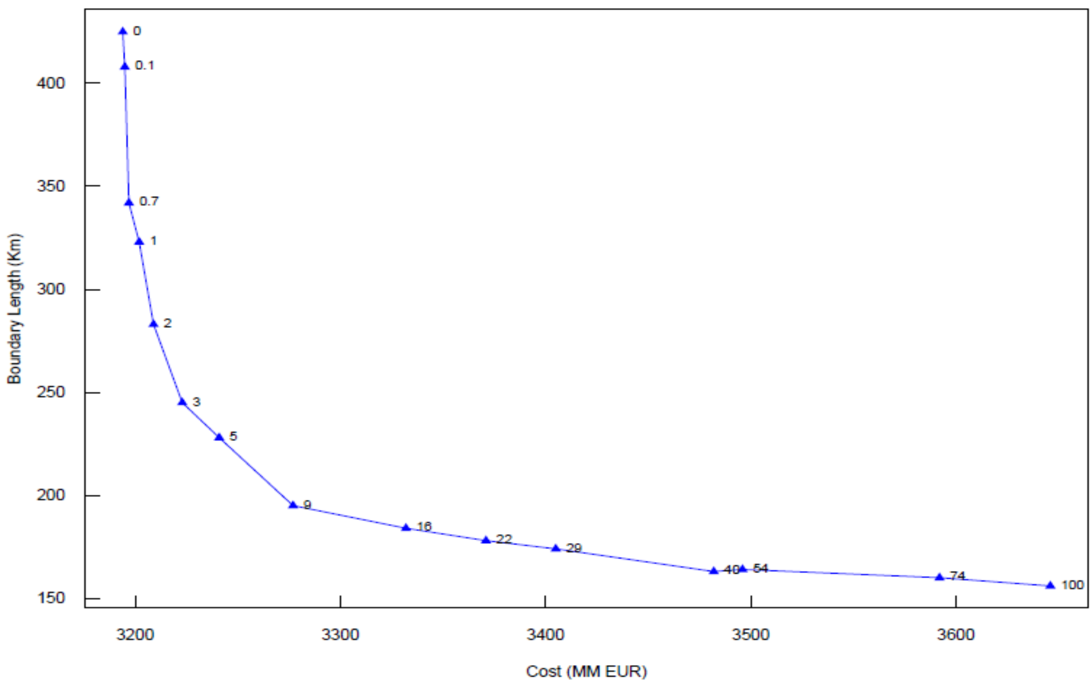
Source: Author’s elaboration with Marxanio results and the use of the R software

As shown in this Figure, the optimal BLM to run Marxan is 2. The boundary length and the cost are quite unchanged till the modifier has got to 2, at which moment there is a big rise in cost. It is a natural break in the tendency of the cost, since from this point the increase of the cost is more notorious.

For the final Marxan runs in the Maulino coastal forest scenario, I decided to use six BLM values, four BLMs values from the calibration in Marxanio (2, 46, 74 and 100) and two BLMs values included arbitrarily (150 and 200), in order to obtain more compact reserve networks and to offer different reserve networks to the decision-makers in terms of design and cost.

For the ruil forest and climate change scenarios (current and future models scenarios), the BLM calibrations for each scenario are presented in the Figures 14 and 15.

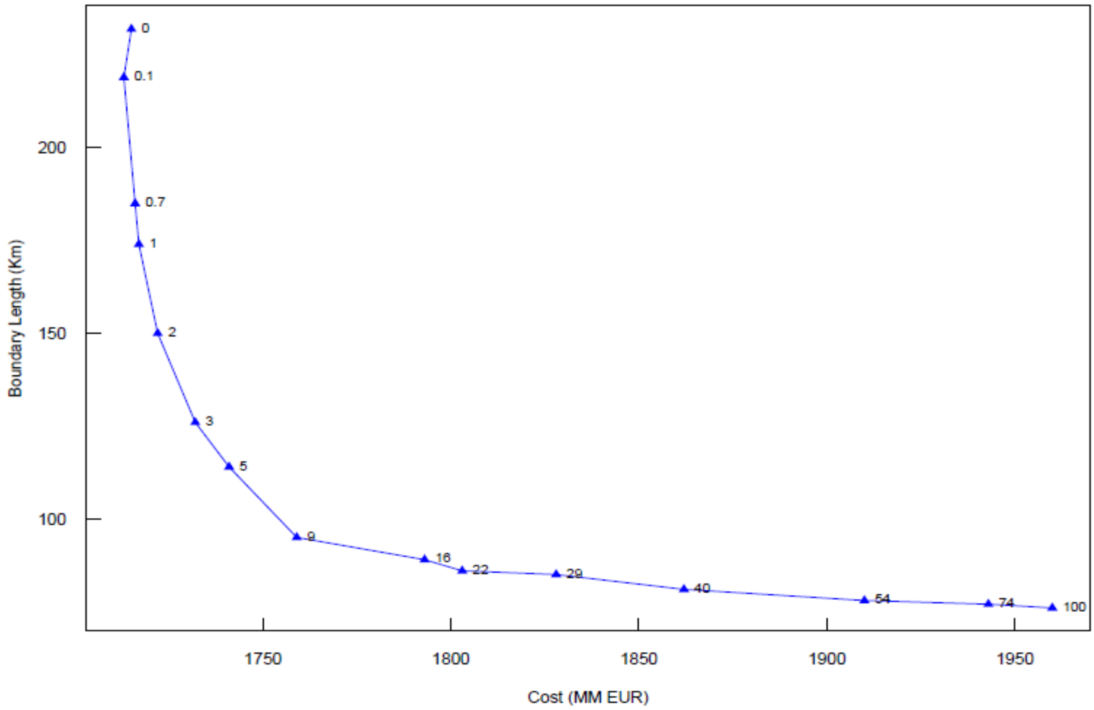
Figure 14: Boundary length modifier testing graph in the current model scenario



Source: Source: Author's elaboration with Marxanio results and the use of the R software

As Figures 14 illustrate, the optimal BLM to run Marxan in each scenario is 9. The boundary length and the cost are quite unchanged till the modifier has got to 9, at which moment there is a big rise in cost.

Figure 15: Boundary length modifier testing graph in the future model scenario



Source: Author's elaboration with Marxanio results and the use of the R software

As Figures 15 illustrate, the optimal BLM to run Marxan in each scenario is 9. The boundary length and the cost are quite unchanged till the modifier has got to 9, at which moment there is a big rise in cost.

For the final Marxan runs in the ruil forest scenarios (current and future models scenarios of ruil) I decided to use six BLM values, four BLMs values from the calibration in Marxanio (9, 22, 40 and 74) and two BLMs values included arbitrarily (100 and 200), in order to obtain more compact reserve networks and to offer different reserve networks to the decision-makers in terms of design and cost.

g. Species penalty factor (SPF)

Game & Grantham (2008) said that "the species penalty factor (SPF) is a multiplier used to assess the size of the penalty which must be inserted to the objective function if conservation feature targets in a reserve scenario are not fulfilled - the more elevated the value, the more severe the penalty (big), and the more emphasis placed by Marxan to ensure the feature target is met" (Game & Grantham, 2008; Ardron *et al.,* 2010).

When several conservation features must appear in a reserve network, The SPF can be explained how a particular form of highlight the significance of several conservation features and their importance in being fully represented, so choosing appropriate SPF values is essential to reach good results in Marxan (Game & Grantham, 2008; Ardron *et al.,* 2010). Hence, “features with high conservation value may have a greater SPF value than those of a less important nature” (Game & Grantham, 2008). Those with very low SPF values solution could miss their target. This is because the costs of selecting additional PUs to achieve the representation target are bigger than minor sanctions for failing to meet protection targets. Conversely, Marxan’s capacity to meet suitable outcomes will be affected if it is too high and the the simulated annealing algorithm cannot explore as much possibilities in the solution process, so it tends to generate less dissimilar results at greater average costs (Game & Grantham, 2008; Ardron *et al*., 2010).

For Game & Grantham (2008) and Ardron *et al*. (2010) the SPF setting is essential for achieving successful outcomes. They recommended that regardless the number of conservation features present in the scenarios (one or more conservation features), the SPF should always be use in the analysis. They argued that it provides more balance and robustness in order “to be sure that the suite of solutions that Marxan is delivering is near the most economical or optimal cost” (Game & Grantham, 2008; Ardron *et al*., 2010).

Given the aforementioned – and because I realize that having one conservation feature per scenario does not guarantee the conservation feature target will be met, after running Marxan a few times indeed these targets were not met, especially when considering that Marxan looks at a combination of variables when designing a reserve network (e.g. target, BLM and PUs cost) and not just the conservation feature target. Thus, in my study I decided to use determined SPF values for the conservation features taken into account.

In order to determine appropriate SPFs, some experimentation will often be needed, since each problem has a different appropriate SPF value or set of values that depend on the “BLM and the corresponding planning unit costs” (Game & Grantham, 2008; Ardron *et al*., 2010). If the targets of one or two features are consequently lost even when all other features are appropriately depicted, raising the SPF for these features might be appropriate (Game & Grantham, 2008; Ardron *et al*., 2010).

I used the "Marxanio" web application to find the optimal SPF to run Marxan in each conservation scenario as Ardron *et al*. (2010) recommended, since it has a section to make parameter calibration or sensitivity analysis to some relevant Marxan parameters (e.g., SPF, BLM and target; Watts, 2016). Table 4 shows the Marxanio settings used to obtain the SPFs for the conservation scenarios.

Table 4: Marxanio settings

Concervation scenario	Concervation targets	BLMs	SPF min – SPF max
Maulino coastal forest scenario	17% and 90%	0, 2, 46, 74, 100, 150 and 200	1 – 10000
Ruil current model scenario	17%	0, 9, 22, 40, 74, 100 and 200	1 – 1000
Ruil future model scenario	17%	0, 9, 22, 40, 74, 100 and 200	1 – 1000

Source: Author's elaboration

Tables 5, 6 and 7 show the values that I obtained when running Marxan in Marxanio with the BLMs values that I used in my analysis and different SPFs values, in order to find the optimal SPF to run Marxan in each scenario. The SPFs that I determined for the Maulino coastal forest scenario and for the two ruil forest scenarios (current and future models scenarios) are highlighted in yellow in Tables 5, 6 and 7.

Table 5: SPF Calibration for Maulino coastal forest scenario

SPF	BLM 0 shortfall (m^2)	BLM 2 shortfall (m^2)	BLM 46 shortfall (m^2)	BLM 74 shortfall (m^2)	BLM 100 shortfall (m^2)	BLM 150 shortfall (m^2)	BLM 200 shortfall (m^2)
1	7928	39764	1476	2676	891	433	164
2	4816	5166	719	145	26	242	132
3	2015	1710	123	0	100	0	60
6	300	279	0	24	0	0	0
12	42	166	0	0	0	0	13
22	4	0	0	0	0	0	0
40	11	0	0	0	0	5	0
74	0	0	0	0	0	0	0
136	0	0	0	0	0	0	0
251	0	0	0	0	0	0	0
464	0	0	0	0	0	0	0
858	0	0	0	0	0	0	0
1585	0	0	0	0	0	0	0
2929	0	0	0	0	0	0	0
5412	0	0	0	0	0	0	0
10000	0	0	0	0	0	0	0

Source: Author's elaboration with Marxanio results

Table 6: SPF Calibration for ruil current model scenario

SPF	BLM 0 shortfall (m^2)	BLM 9 shortfall (m^2)	BLM 22 shortfall (m^2)	BLM 40 shortfall (m^2)	BLM 74 shortfall (m^2)	BLM 100 shortfall (m^2)	BLM 200 shortfall (m^2)
1	90934	9436	5106	1083	136	534	78
2	40735	4896	714	357	76	0	0
3	18489	129	1066	252	69	0	0
4	9866	194	0	0	0	40	0
6	3162	145	0	149	0	15	0
10	708	362	0	0	0	0	0
16	0	128	13	0	0	0	0
25	0	0	0	26	0	0	0
40	0	0	0	0	0	8	0
63	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0
158	0	0	0	0	0	0	0
251	0	0	0	0	0	0	0
398	0	0	0	0	0	0	0
631	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0

Source: Author's elaboration with Marxanio results

Table 7: SPF Calibration for ruil future model scenario

SPF	BLM 0 shortfall (m^2)	BLM 9 shortfall (m^2)	BLM 22 shortfall (m^2)	BLM 40 shortfall (m^2)	BLM 74 shortfall (m^2)	BLM 100 shortfall (m^2)	BLM 200 shortfall (m^2)
1	59399	4527	718	1834	1921	881	92
2	38146	4680	1032	800	987	460	0
3	16263	120	672	739	402	196	0
4	1742	935	92	0	0	196	4
6	1196	0	0	0	1	0	0
10	665	244	0	0	29	0	0
16	106	0	24	0	0	0	0
25	0	0	0	3	0	0	0
40	0	0	0	0	0	0	0
63	0	4	0	0	0	0	0
100	0	0	0	0	0	0	0
158	0	0	0	0	0	0	0
251	0	0	0	0	0	0	0
398	0	0	0	0	0	0	0
631	0	0	0	0	0	0	0
1000	0	0	0	0	0	0	0

Source: Author's elaboration with Marxanio results

The previous tables show an iterative calibration of individual SPF values for the conservation features made with the web application "Marxanio". The yellow rows indicate SPF values where the target of the conservation features were accomplished for all the BLMs used in the analysis. Shortfall values greater than zero indicate that the targets were not met. Thus, I chose the SPF values which met the target in all the BLMs used here as the optimal SPF in my analysis with Marxan.

For the Maulino coastal forest scenario, a 74 SPF value was used as the optimal SPF to run Marxan for the two conservation features: Maulino coastal forest and the remaining fragments of ruil forest. After some runs were sorted out, I noticed that the two features accomplish their targets of 17% and 90%, respectively. Therefore, the two features are adequately represented in the reserve networks generated after running Marxan.

In the current and future model scenarios of ruil, I used the yellow values as the optimal SPFs to run Marxan. These values were 63 and 100, respectively. After some runs were sorted out I determined that the target of 17% was accomplished in each scenario. Thus, the two conservation features (the ruil's current and future distribution models) are adequately represented in the reserve networks generated after running Marxan in the current and future model scenarios of the ruil forest.

As result, the target was met every time Marxan was run with the optimal SPF value. Thus, as previously mentioned, having only one conservation feature to create a reserve networks does not guarantee that Marxan is going to meet the conservation target, given that Marxan also consider other variables like the BLM and PUs cost to produce reserve networks at the lower possible cost. On the other hand, the SPF aims to make sure that the target is met, producing the rise of the cost of the reserve.

3.3.3 Running Marxan

To perform the trade-off analysis, I have determined a set of modeling scenarios that constitute different combinations of target level and BLM values for different reserve design elements (Tables 8 and 9).

Table 8: Design components for the analysis with Marxan in the Maulino coastal forest scenario

Desing components	Marxan Implementation	Scenario Settings
Target (Maulino coastal forest and ruil representation)	To represent Maulino coastal forest and ruil fragments	17% and 90%
Species penalty factor (SPF)	SPF indicates "the significance of reaching the target of a species"	74
Boundary Length Modifier (BLM)	Promote reserve clumping to avoid fragmentation	2, 46, 74, 100, 150 and 200

Source: Author's elaboration

The use of percentages for the targets of the Maulino coastal and ruil forests means that I entered in Marxan the amount of the total area of the species that I want to keep in the reserve networks. For example, if I use 17% and 90% as in my case, it means that I want a final reserve network that contains 17% of the whole Maulino coastal forest surface and 90% of the ruil forest surface.

As the BLMs used in the analysis are six (2, 46, 74, 100, 150 and 200), my analysis produced six potential reserve networks for the Maulino coastal forest scenario with different levels of fragmentation or compactness given by the different BLMs.

Table 9: Design components for the analysis with Marxan for the current model scenario and future model scenario of ruil

Desing components	Marxan Implementation	Scenario Settings
Target (ruil models representation)	a) to represent ruil current distribution model b) to represent ruil future distribution model	17% 17%
Species penalty factor (SPF)	SPF indicates "the significance of reaching the target of a species"	63 in the current distribution model and 100 in future distribution model scenarios
Boundary Length Modifier (BLM)	Promote reserve clumping to avoid fragmentation	9, 22, 40, 74, 100 and 200

Source: Author's elaboration

In the current and future models scenarios of the ruil forest I did not assign a target for its current surface (remaining fragments of ruil) as it was done in the Maulino coastal forest scenario, since I only wanted to analyze the SDMs of ruil forest in these scenarios. For that reason, I decided to consider all the surface of the remaining fragments of ruil plus a buffer zone of 300 meters of width to these fragments as a reserve, in order to include all of them in the new reserve networks. Thus, Marxan can consider the current area of ruil with the buffer zone as an important area to be included in the new reserves networks for the current model scenario. Since Marxan allows to include existing reserves or any site that is important to preserve for the community or decision makers within the new reserve networks.

In the future model scenario of ruil, the remaining fragments of forest with the buffer zone that coincides with the future distribution model were considered as a reserve too, in order that Marxan can consider this area of ruil with the buffer zone as an important area to be included in the new reserves networks for the future model scenario. The reason for considering just the fragments of ruil with the buffer zone that coincides with the future distribution model is because the ruil forest fragments that do not coincide with the future distribution model are in an area that would be unsuitable in the future; hence, those fragments were discarded.

The target considered in the current and future model scenarios was 17% for both distribution models of the ruil forest. This is the total area of ruil's SDMs that I want to keep in the reserve networks. As the representation targets was 17% and the BLM were six (9, 22, 40, 74, 100 and 200) my analysis produced twelve reserve networks, of which six belong to the current and six to the future model scenario of the ruil.

As Stewart & Possingham did in 2005 and as was recommended by Game & Grantham in 2008 and Ardron *et al*. in 2010, I execute Marxan with "the adaptive annealing schedule and performed 1,000 repeat runs". Then, as Stewart & Possingham (2005) said "Marxan produced a set of condensed data that included the objective function score, the number of planning units, the cost and the boundary length of the reserve network" among other values (Stewart & Possingham, 2005). I used Marxan to generate reserve networks for the three conservation scenarios analyzed here (Maulino coastal forest scenario, ruil current model scenario, and ruil future model scenario). The reserve networks generated with the current and future models scenarios were used to determine opportunity cost and area as well as to see the change in the results when the climate change effect is considered in conservation planning.

In order to see the reserve networks obtained after running Marxan, these reserve networks were mapped to show how these could actually look like and see the differences between reserve networks. These reserve networks maps are presented in the results section together with tables that contain the main values that I obtained in each one of the reserves networks generated in the three scenarios.

4. Results

In the results chapter, I show the results obtained in two analyses:

1. Prioritization made for the conservation of the Maulino coastal forest.

2. Prioritization made for the two distribution models of ruil forest (current distribution model and future distribution model) to identify suitable areas to be restored with ruil forests, and determine changes in the reserve networks in terms of cost and area when considering climate change effects during reserve network planning.

4.1. Results of the Maulino coastal forest scenario

I assessed reserve networks in terms of level of representation (target) and compactness (BLM) of the Maulino coastal forest.

As explained in section 3.3.2 (e) (Conservation Features and Targets), I decided to use a 17% target for the Maulino coastal forest and a 90% for the ruil forest. The 17% target was defined based on "Strategic Plan for Biodiversity 2011–2020" (UNEP/CBD 2011) and the "Initiative 20x20" (WRI, 2014). On the contrary, the 90% target for the ruil was defined arbitrarily, since I only considered the recommendations made by San Martin (2011, personal communication), who postulated that in order to preserve ruil forest at least 90% of its total area must be protected.

4.1.1 Marxan analysis for the Maulino coastal forest scenario

The values of the reserve networks produced by the utilization of Marxan in the Maulino coastal forest scenario are shown in Table 10.

Table 10: Reserves networks of the Maulino coastal scenario

Reserve networks	Target	BLM	Obj. Functions value	Cost (€)	Boundary Length (km)	Area (km²)	Area (ha)
1	17% & 90%	2	3,645,669	2,705,715	469,977	81	8,141
2	17% & 90%	46	12,777,080	2,813,250	216,605	85	8,488
3	17% & 90%	74	17,216,906	2,985,226	192,320	87	8,713
4	17% & 90%	100	20,497,992	3,037,992	174,600	92	9,166
5	17% & 90%	150	27,069,489	3,351,489	158,120	98	9,812
6	17% & 90%	200	34,261,334	3,464,134	153,986	101	10,103

Source: Author's elaboration with Marxan results

The costs shown in the table are those of each reserve networks. These values represent the costs of preserving and protecting 17% of the Maulino coastal forest and 90% of ruil forest, respectively. This cost is the opportunity cost of implementing the reserve network and preventing any relevant economic activity in the area, such as *Pinus radiata* plantations.

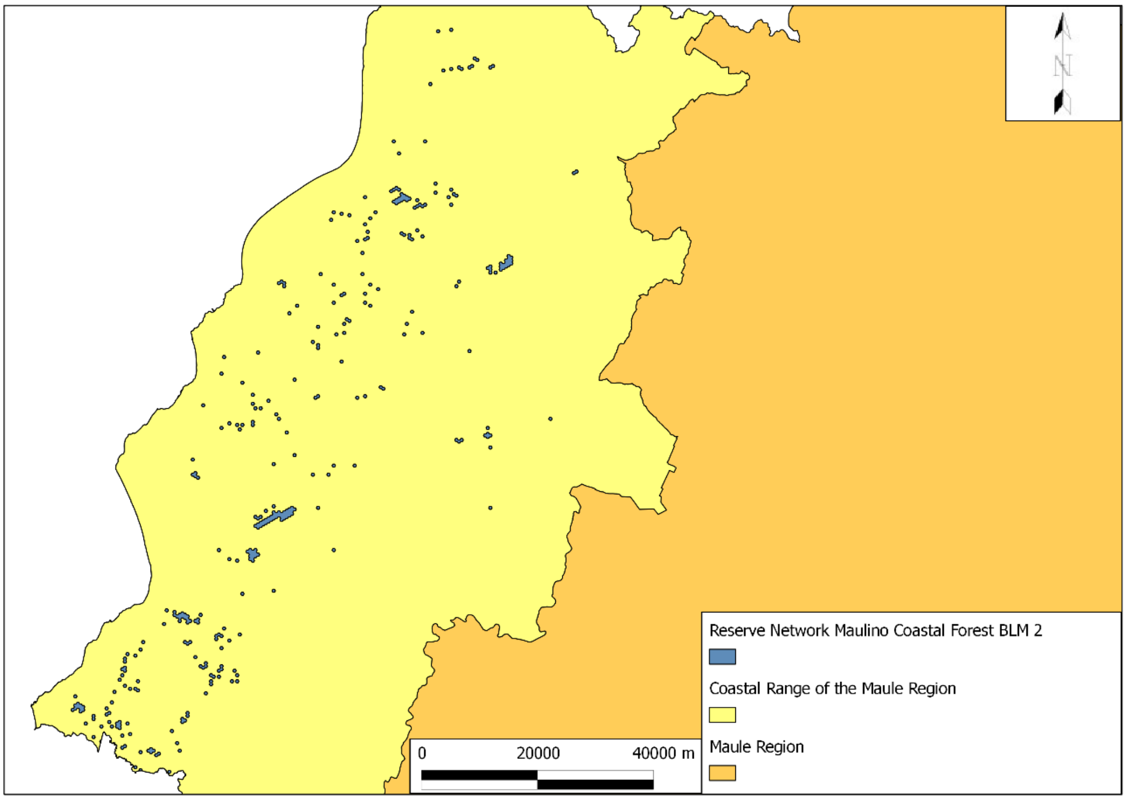
For the levels of representation used in this study (target: 17% and 90%) it can be seen that the cost of the reserve network increases as the BLM increases. Thus, the reserve networks with the highest cost is the one in which a BLM of 200 was used, this value is € 3,464,134.

On the other hand, if we consider the lowest BLM used in this study, BLM 2, the value is lower, € 2,705,715. According to the BLM calibration process recommended by Stewart & Possingham (2005), this represents the optimal BLM for the analysis.

The representation value 17% for the Maulino coastal forest was considered in order to reach the goal proposed in "the Convention on Biological Diversity for 2020". The cost of the reserve networks to achieve that goal range from € 2,705,715 for a BLM 2 to € 3,464,134 for a BLM 200, depending on the degree of compactness required. The total area of reserve networks ranges from 81 to 101 km².

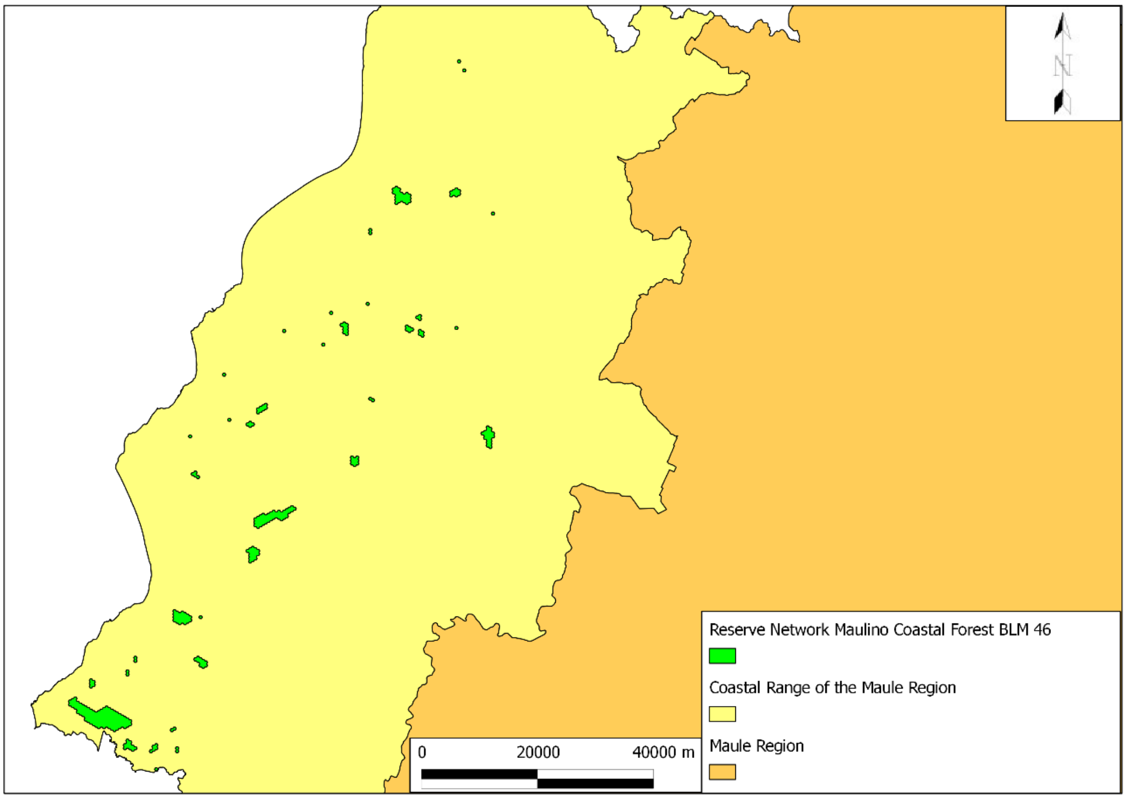
The reserve networks for the Maulino coastal forest and the ruil forest were obtained without considering a buffer zone for the either. As explained previously, a buffer zone was only considered for the remaining fragments of the ruil forest in the analysis of its current and future models scenarios, presented in the next section. On the other hand, in the Maulino coastal forest scenario, the reserves located in the study area (Los Ruiles) was included in the new reserve networks generated by Marxan. The reserve networks generated by Marxan for the Maulino coastal forest scenario are presented in the following.

Figure 16: Reserve network with 17% of Maulino coastal forest representation and 90% of ruil representation and BLM 2



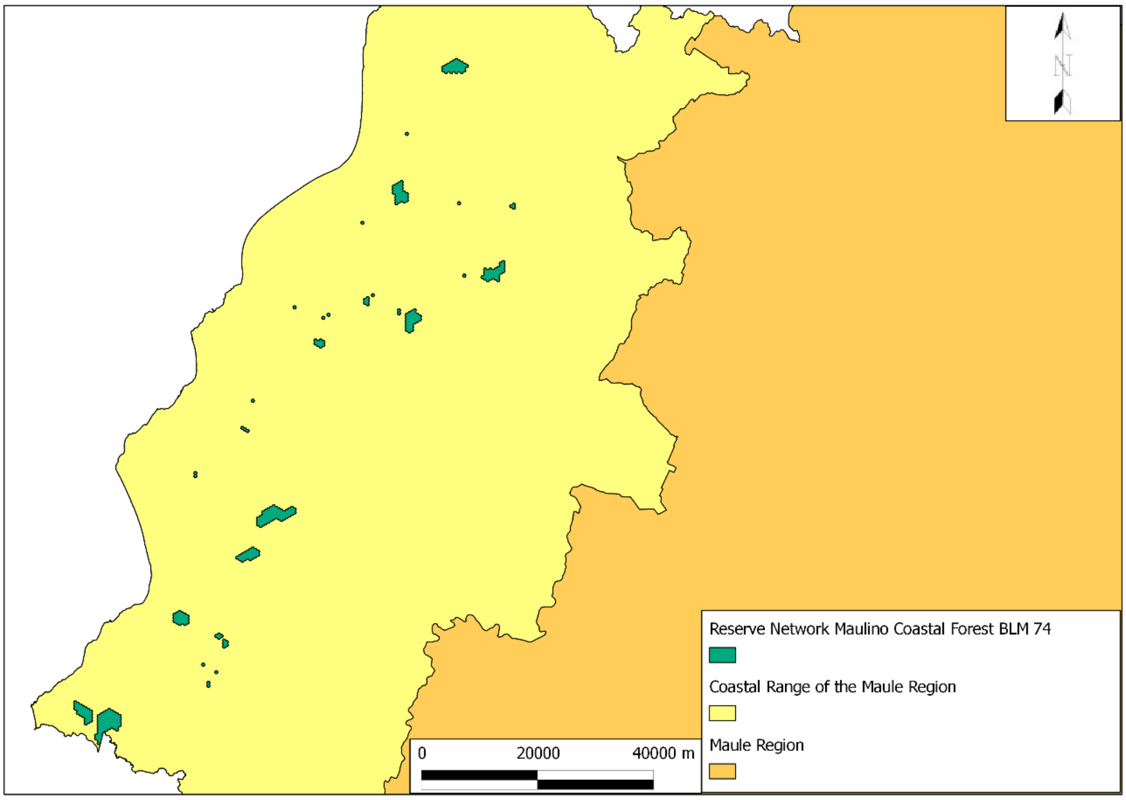
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 17: Reserve network with 17% of Maulino coastal forest representation and 90% of Ruil representation and BLM 46



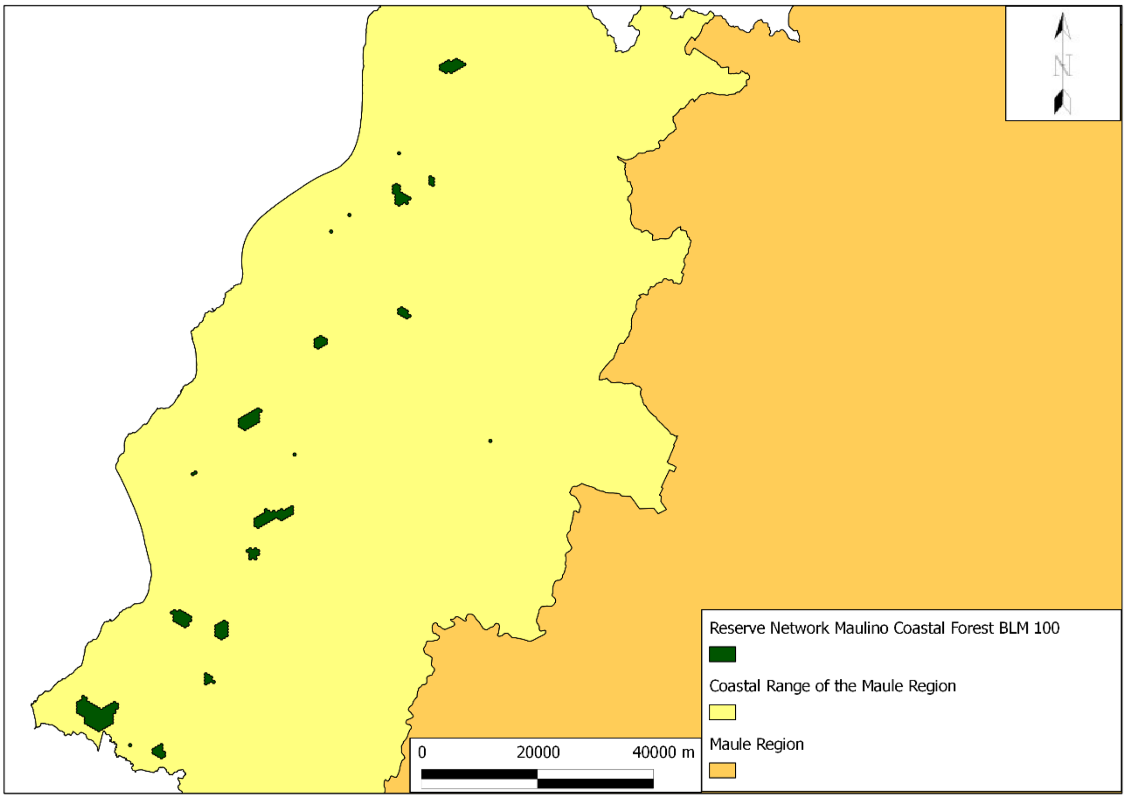
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 18: Reserve network with 17% of Maulino coastal forest representation and 90% of ruil representation and BLM 74



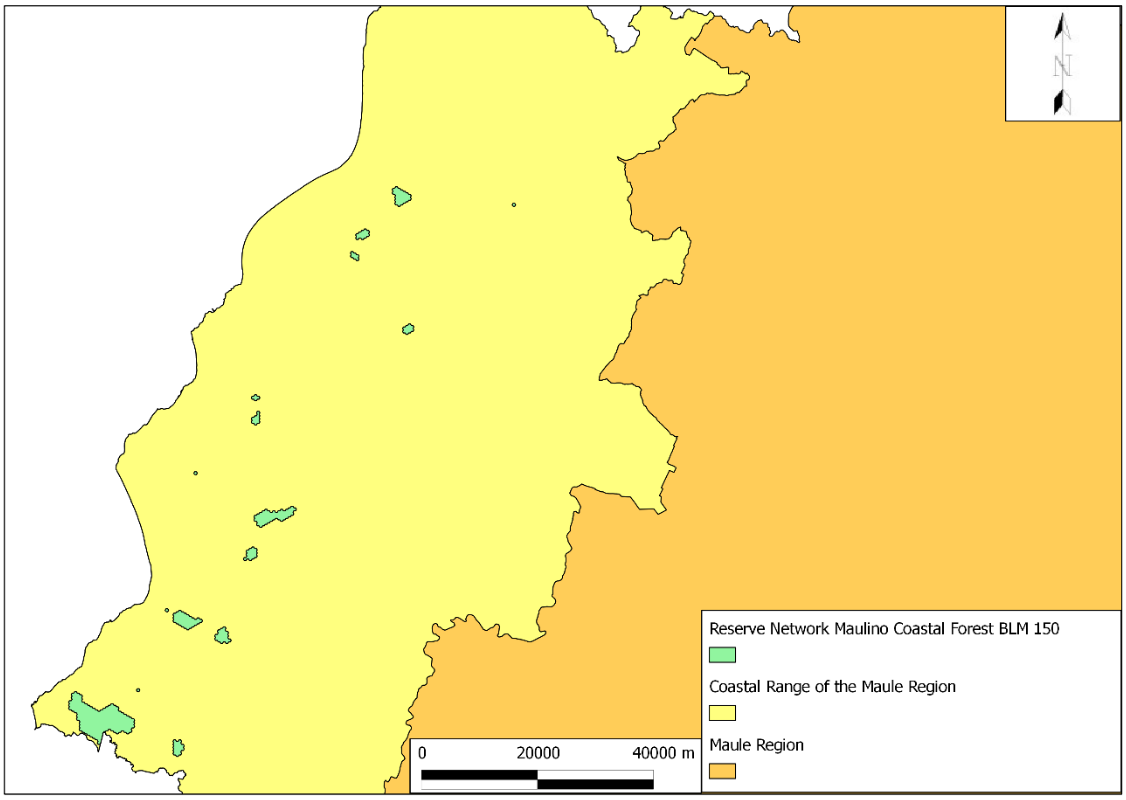
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 19: Reserve network with 17% of Maulino coastal forest representation and 90% of ruil representation and BLM 100



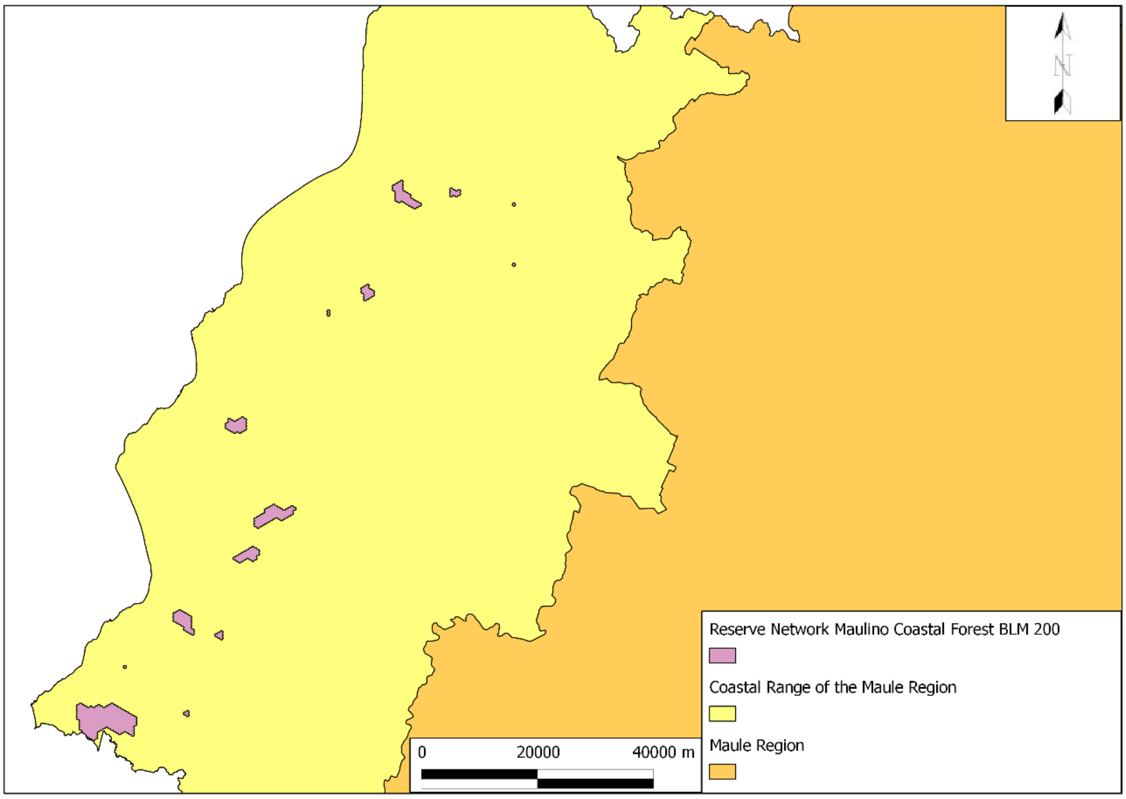
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 20: Reserve network with 17% of Maulino coastal forest representation and 90% of ruil representation and BLM 150



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 21: Reserve network with 17% of Maulino coastal forest representation and 90% of ruil representation and BLM 200



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

4.2. Results of ruil current and future models scenarios

Here, the reserve networks for the current and future distribution model scenarios of ruil forest were generated in terms of representation (target) and compactness (BLM).

The conservation features considered were a) the current distribution model of the ruil in the current model scenario, and b) the future distribution model of the ruil in the future model scenario. The idea behind the use of the future distribution model was considering climate change effects in reserve network planning in order to make a comparison between the reserve networks generated in the current with those generated in the future model scenario.

As for the Maulino coastal forest case, here also a 17% target was considered for the ruil forest distribution models (current and future) based on the "Strategic Plan for Biodiversity 2011–2020" (UNEP/CBD 2011) and the "Initiative 20x20" (WRI, 2014).

The remaining fragments of ruil forest were also considered in the generation of the reserve networks by Marxan. Here, in contrary to the Maulino coastal forest scenario, a buffer zone was implemented to the remaining ruil fragments as an extra measure for its conservation before running Marxan.

4.2.1 Marxan analysis for the current model scenario of ruil

The values of the reserve networks produced by the use of Marxan in the current model scenario are shown in Table 11.

Table 11: Reserves networks of the current model scenario of ruil

Reserve networks	Target	BLM	Obj. Functions value	Cost (€)	Boundary Length (km)	Area (km²)	Area (ha)
1	17%	9	5,684,010	3,286,410	266,400	92	9,236
2	17%	22	7,575,449	3,351,449	192,000	93	9,283
3	17%	40	10,096,073	3,448,073	166,200	94	9,400
4	17%	74	15,379,823	3,480,623	160,800	94	9,423
5	17%	100	19,036,923	3,556,923	154,800	95	9,447
6	17%	200	32,909,341	3,629,341	146,400	97	9,704

Source: Author's elaboration with Marxan results

For the level of representation for the current distribution model of ruil forest used in this study (target: 17%) it can be seen that the cost of the reserve network increases as the BLM increases. Thus, the reserve network with the highest cost was the one in which a BLM of 200 was used. This value is € 3,629,341 for a reserve network, with a representation level of 17% of the ruil forest.

On the other hand, if we consider the lowest BLM used in this section, BLM 9, the value obtained is lower and this value is € 3,286,410 for a reserve network, with a 17 % representation level of the ruil. According to the BLM calibration process recommended by Stewart & Possingham (2005), this represents the optimal BLM for the analysis.

If the representation value of 17% is considered in order to reach the goal proposed under the "Strategic Plan for Biodiversity 2011–2020" (UNEP/CBD 2011) and the "Initiative 20x20" (WRI, 2014), the cost of the reserve networks range from € 3,286,410 for a BLM 9 to € 3,629,341 or a BLM 200 – a considerable difference of € 342,931. This difference depends on the degree of compactness required. The total area of reserve networks ranges from 92 to 97 km².

With respect to the area of the land uses that will be displaced in each reserve network proposed for the current model scenario and as is shown in Table 12 and Figure 22, the major land use that will be displaced will be *Pinus radiata* plantation, followed by grassland. Instead, the impact in agriculture will not be so high in comparison with the others land uses. With respect to *Pinus radiata* plantations, the area impacted ranges between 32 km² in the reserve network 5 to 35 km² in the reserve network 1. For the case of grassland, it ranges between 28 km² in the reserve network 4 to 34 km² in the reserve network 5.

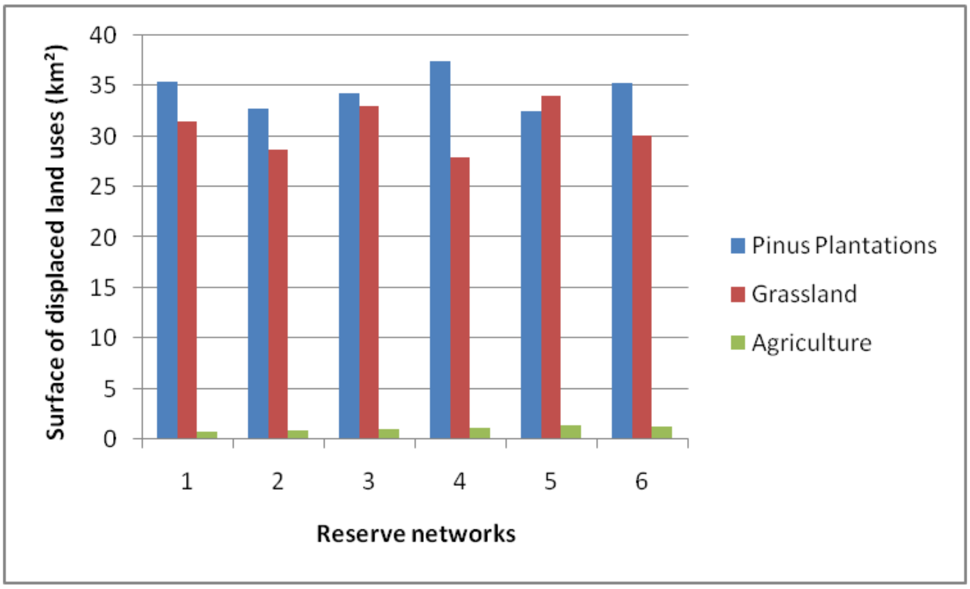
Table 12: Land uses surface in km² present in each reserve network of the current model scenario of ruil

Reserve networks in order of increasing BLM (BLM)	**1 (9)**	**2 (22)**	**3 (40)**	**4 (74)**	**5 (100)**	**6 (200)**
Maulino coastal forest (km²)	25	31	26	28	27	30
Pinus Plantations (km²)	35	33	34	37	33	35
Grassland (km²)	32	29	33	28	34	30
Agriculture (km²)	0.7	0.9	1.1	1.2	1.4	1.3

Source: Author's elaboration with Marxan results

As the ruil is part of the Maulino coastal forest, it will be left unchanged. On the other hand, the other land uses (*Pinus radiata* plantation, grassland and agriculture) that are part of the reserve network will be considered as suitable land for the restoration of the ruil forest as part of the Initiative 20x20. Figure 22 shows the surface of land uses displaced in each reserve network that could be used to restore ruil forest in the Maule region as part of the initiative 20x20.

Figure 22: Land uses surface displaced in each reserve network of the current model scenario of ruil



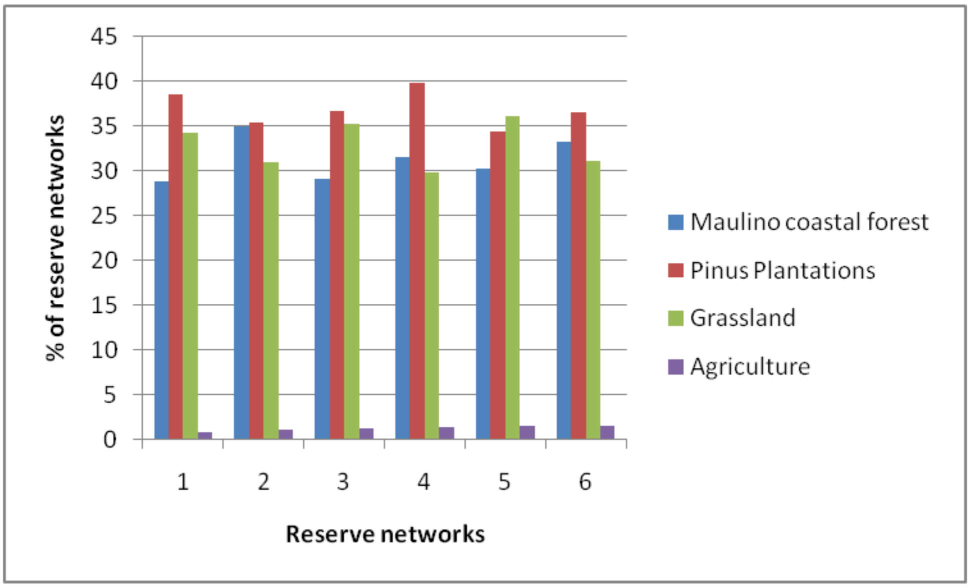
Source: Author's elaboration with Marxan results

Table 13: % of land use surface in relation to the total reserve network in the current model scenario of ruil

Reserves networks in order of increasing BLM (BLM)	1 (9)	2 (22)	3 (40)	4 (74)	5 (100)	6 (200)
Maulino coastal forest (% of the total RN)	27	33	27	29	28	31
Pinus Plantations (% of the total RN)	38	35	37	40	34	36
Grassland (% of the total RN)	34	31	35	30	36	31
Agriculture (% of the total RN)	0.8	1	1.1	1.2	1.5	1.4

Source: Author's elaboration with Marxan results

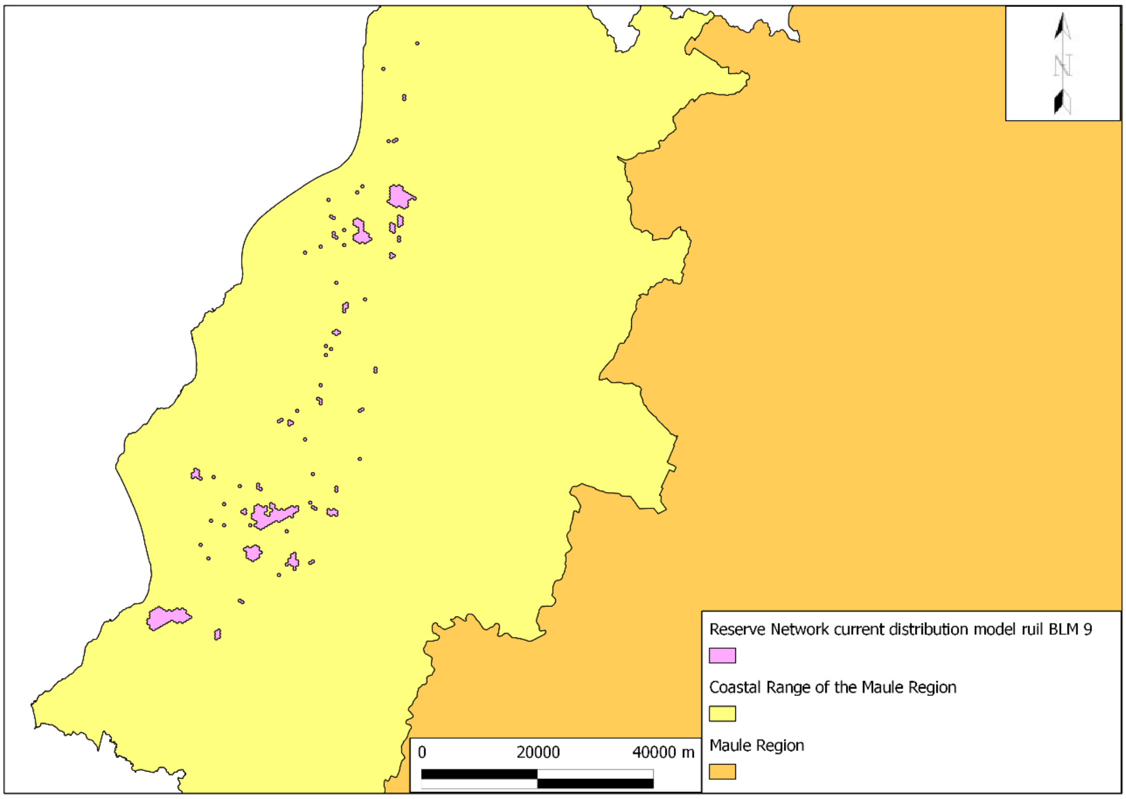
Figure 23: % of land use surface in relation to the total reserve network in the current model scenario of ruil



Source: Author's elaboration with Marxan results

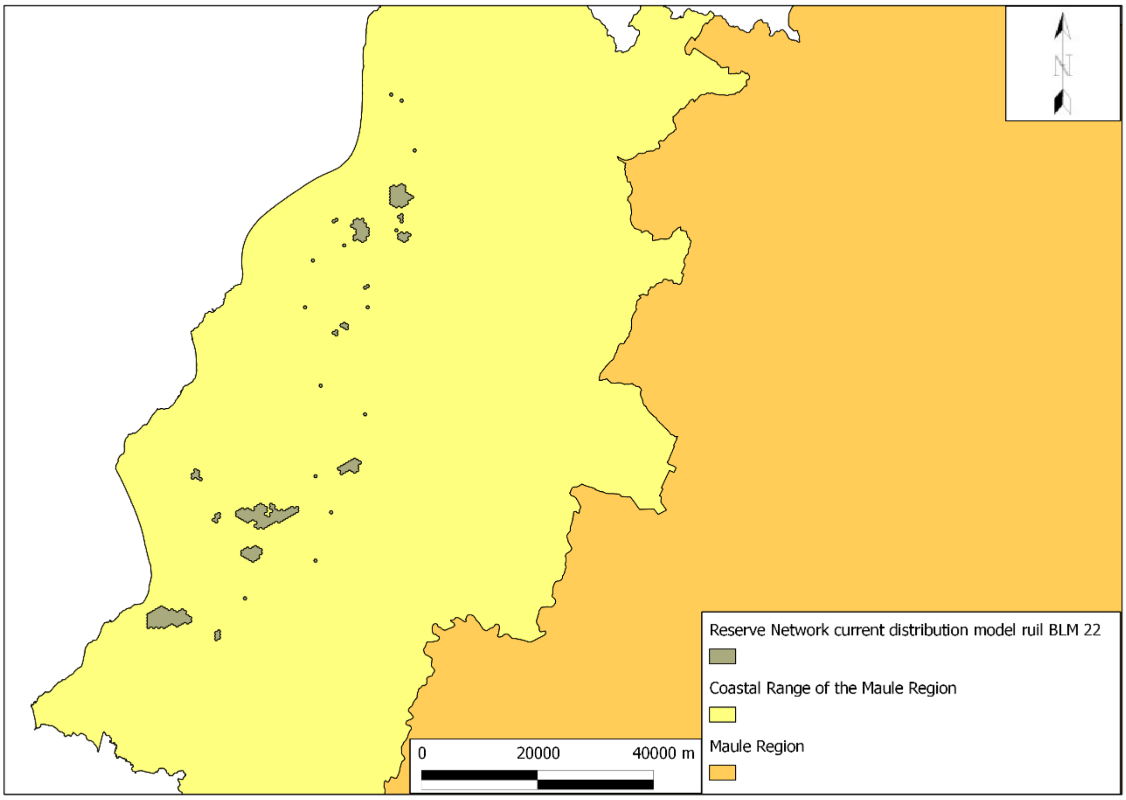
The reserve networks obtained in the analysis for the current model scenario of ruil are presented in the following.

Figure 24: Reserve network with 17% of current distribution model of ruil and BLM 9



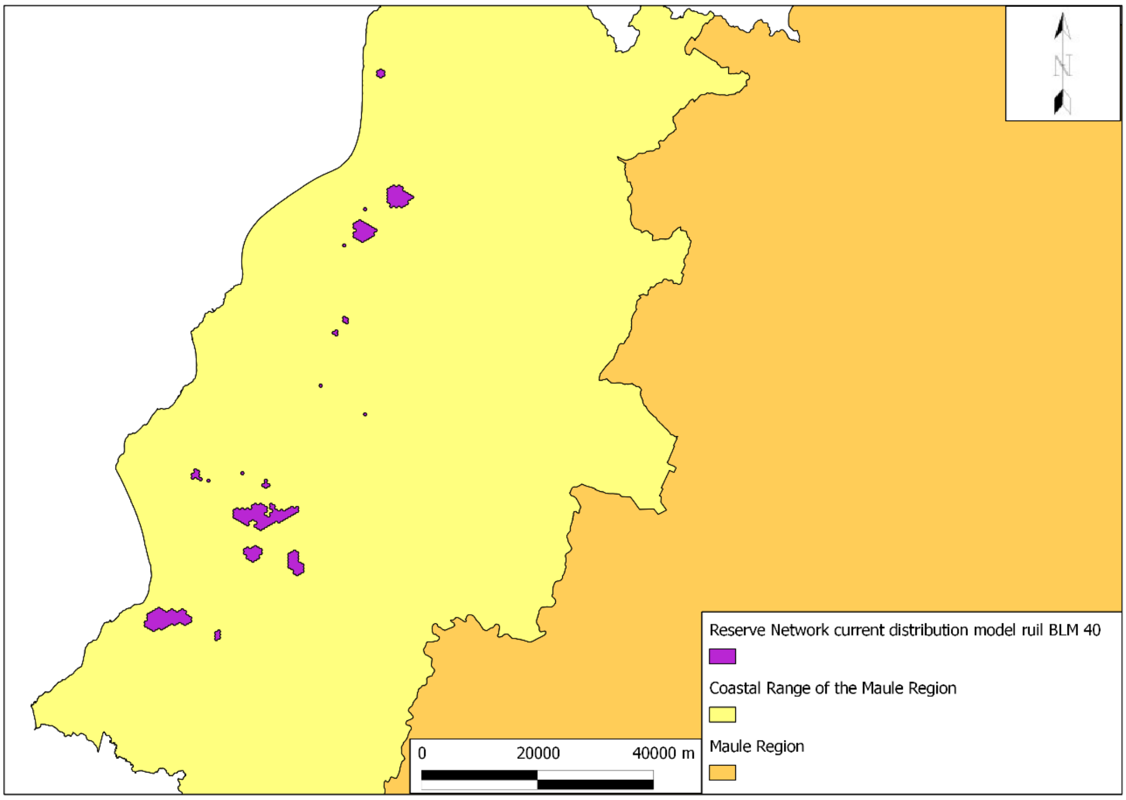
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 25: Reserve network with 17% of current distribution model of ruil and BLM 22



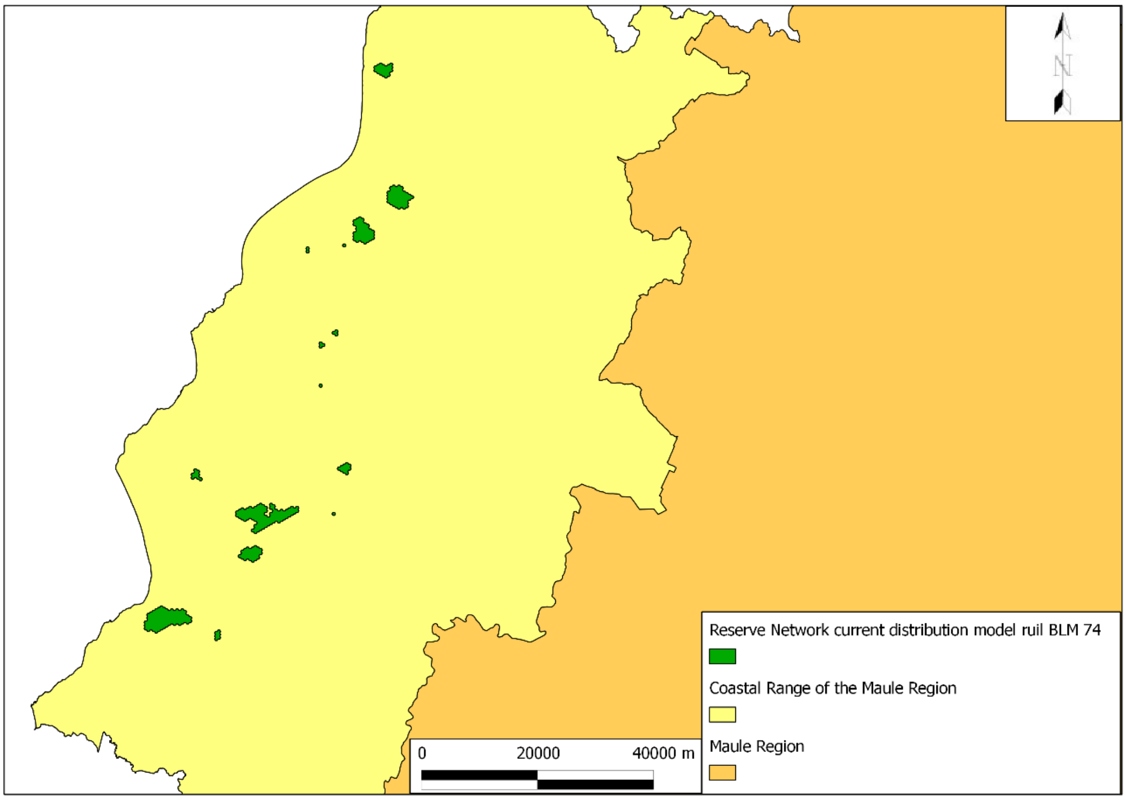
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 26: Reserve network with 17% of current distribution model of ruil and BLM 40



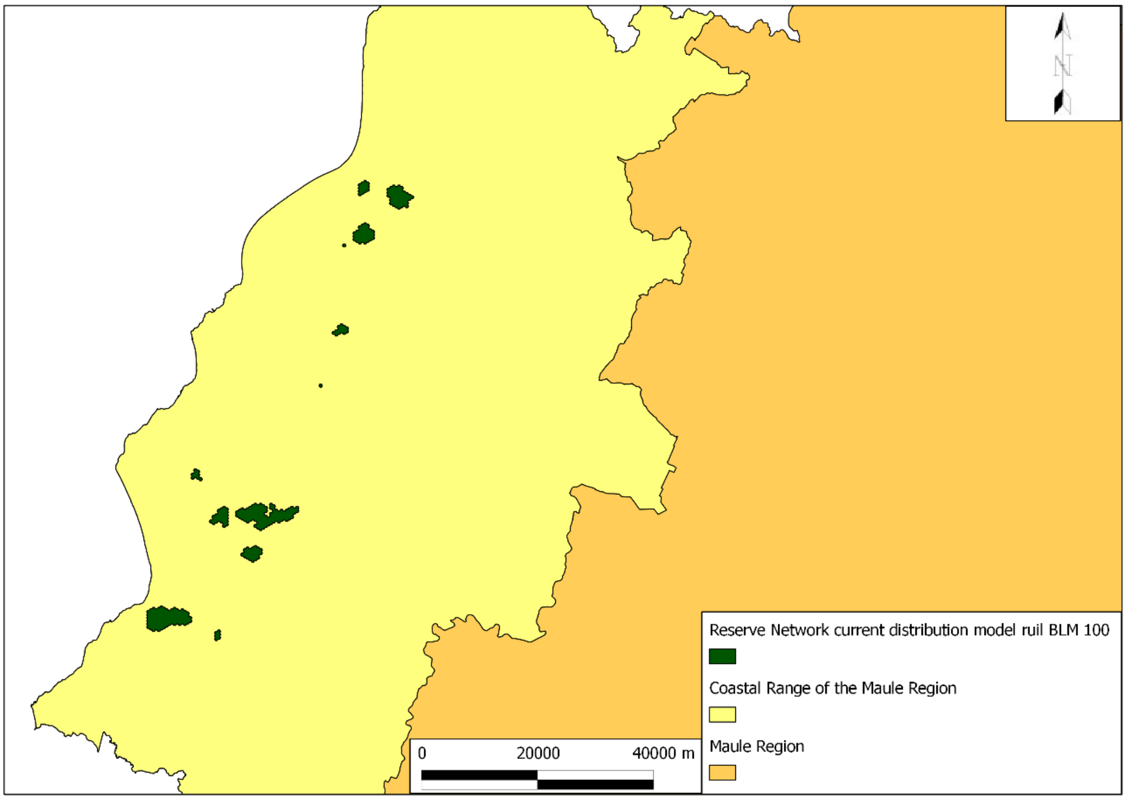
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 27: Reserve network with 17% of current distribution model of ruil and BLM 74



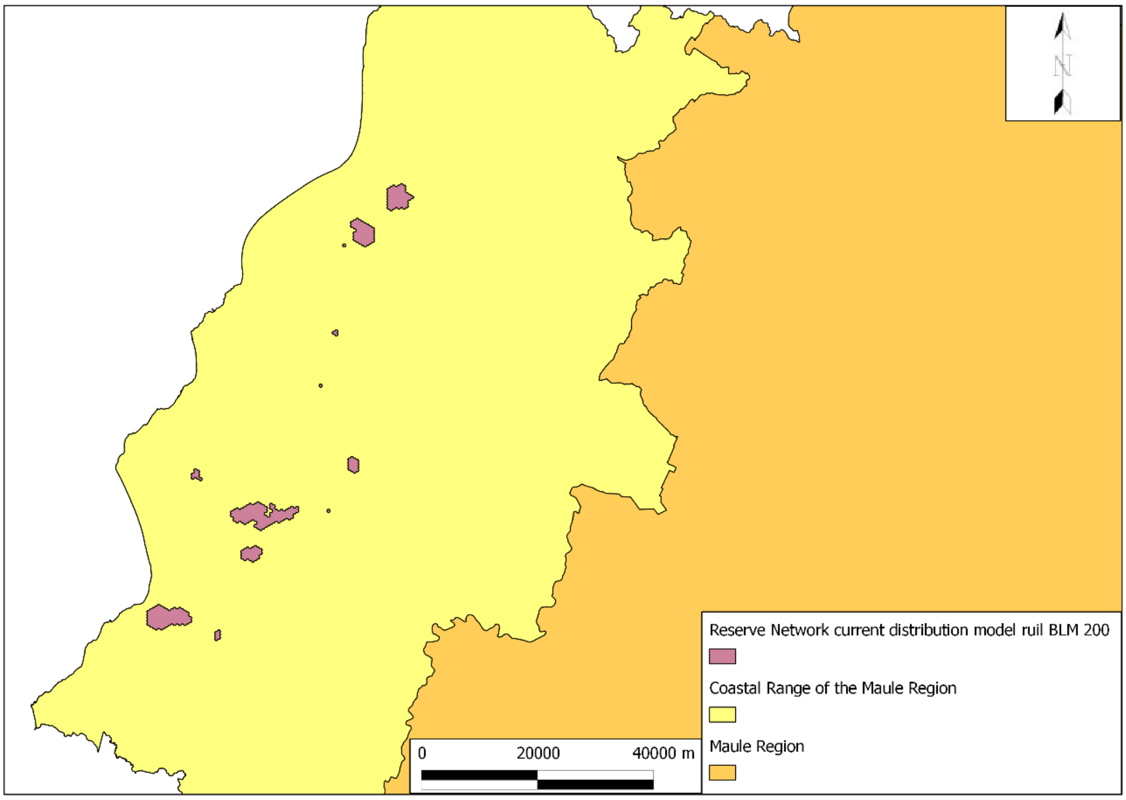
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 28: Reserve network with 17% of current distribution model of ruil and BLM 100



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 29: Reserve network with 17% of current distribution model of ruil and BLM 200



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Table 14 shows that an area between 2,476 and 3,053 hectares of the Maulino coastal forest with ruil presence would remain protected if one of these reserve networks are implemented to preserve and restore the ruil forest. At the same time, in these reserve networks, there are between 6,230 and 6,850 hectares of suitable land to be restored with ruil in order to change the critical conservation status afflicting ruil forest has and at the same time contribute to the initiative 20x20.

Table 14: Maulino coastal forest area to preserve and suitable land to restore the ruil in current model scenario

Reserve networks in order of increasing BLM (BLM)	Reserve networks Total area (ha)	Maulino coastal forest area which will be preserved (ha)	Suitable land to restore the Ruil (ha)
1 (9)	9,236	2,476	6,760
2 (22)	9,283	3,053	6,230
3 (40)	9,400	2,550	6,850
4 (74)	9,423	2,763	6,660
5 (100)	9,447	2,657	6,790
6 (200)	9,704	3,034	6,670

Source: Author's elaboration with Marxan results

4.2.2 Marxan analysis for the future model scenario of ruil

The reserve networks generated by the application of Marxan in the future model scenario of ruil are shown in the Table 15.

Table 15: Reserves networks of the future model scenario of ruil

Reserve networks	Target	BLM	Obj. Function values	Cost (€)	Boundary Length (km)	Area (km²)	Area (ha)
1	17%	9	2,815,298	1,746,098	118,800	48	4,817
2	17%	22	3,637,150	1,841,950	81,600	50	4,981
3	17%	40	4,972,811	1,876,811	77,400	50	5,004
4	17%	74	7,462,643	1,957,043	74,400	50	5,027
5	17%	100	9,358,908	1,978,908	73,800	51	5,097
6	17%	200	16,635,793	1,995,793	73,200	51	5,144

Source: Author's elaboration with Marxan results

For the level of representation of the future distribution model of ruil used in this study (target: 17%) it can be seen that the cost of the reserve network increases as the BLM increases. Thus, the reserve network with the highest cost is the one in which a BLM of 200 was used. This value is € 1,995,793 for a reserve network with a representation level of 17% of the ruil forest.

On the other hand, if we consider the lowest BLM used in this section, BLM 9, the value obtained is € 1,746,098 which is lower than that obtained with the BLM of 200, showing a difference of € 249,695 between the lowest and highest value.

If the representation value of 17% is considered in order to reach the goal proposed under the “Strategic Plan for Biodiversity 2011–2020” (UNEP/CBD 2011) and the “Initiative 20x20” (WRI, 2014), the reserve networks cost range from € 1,746,098 for a BLM 9 to € 1,995,793 for a BLM 200, depending on the degree of compactness required. Furthermore, the whole area of the reserve networks ranges from 48 to 51 km².

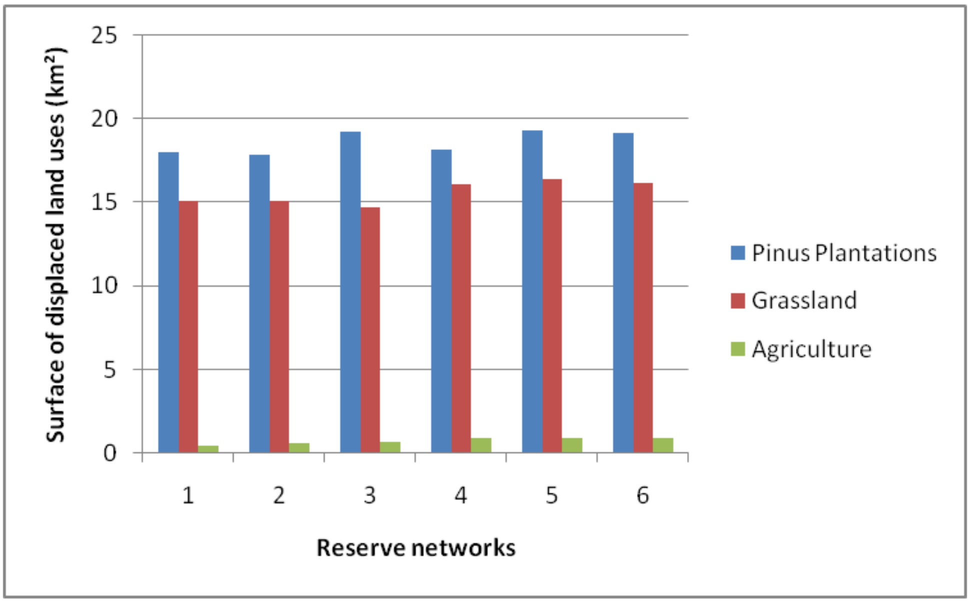
With respect to the land uses that will be displaced in each reserve network, proposed for the future model scenario and as shown in Table 16 and Figure 30, the major land use that will be displaced will be *Pinus radiata* plantations followed by grassland.

Table 16: Land uses surface in km² present in each reserve network of the future model scenario of ruil

Reserve networks in order of increasing BLM (BLM)	1 (9)	2 (22)	3 (40)	4 (74)	5 (100)	6 (200)
Maulino coastal forest (km²)	15	16	15	15	14	15
Pinus Plantations (km²)	18	18	19	18	19	19
Grassland (km²)	15	15	15	16	16	16
Agriculture (km²)	0.5	0.6	0.7	0.9	0.9	0.9

Source: Author’s elaboration with Marxan results

Figure 30: Land uses displaced in each reserve network in the future model scenario of ruil



Source: Author's elaboration with Marxan results

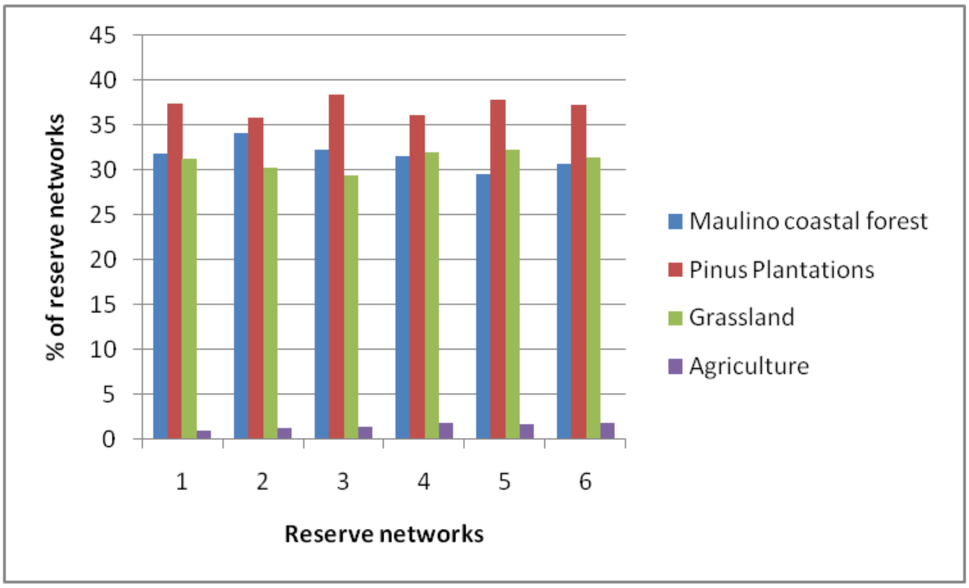
The agricultural impact will not be as high when compared with others. With respect to the *Pinus radiata,* the area impacted will be 18 km² or 19 km². For grasslands, it will be 15 km² or 16 km².

Table 17: % of land use surface with respect to the total reserve network in the future model scenario of ruil

Reserve networks in order of increasing BLM (BLM)	**1 (9)**	**2 (22)**	**3 (40)**	**4 (74)**	**5 (100)**	**6 (200)**
Maulino coastal forest (% of the total RN)	31	33	32	30	28	30
Pinus Plantations (% of the total RN)	37	36	38	36	38	37
Grassland (% of the total RN)	31	30	29	32	32	31
Agriculture (% of the total RN)	1	1.2	1.4	1.9	1.8	1.8

Source: Author's elaboration with Marxan results

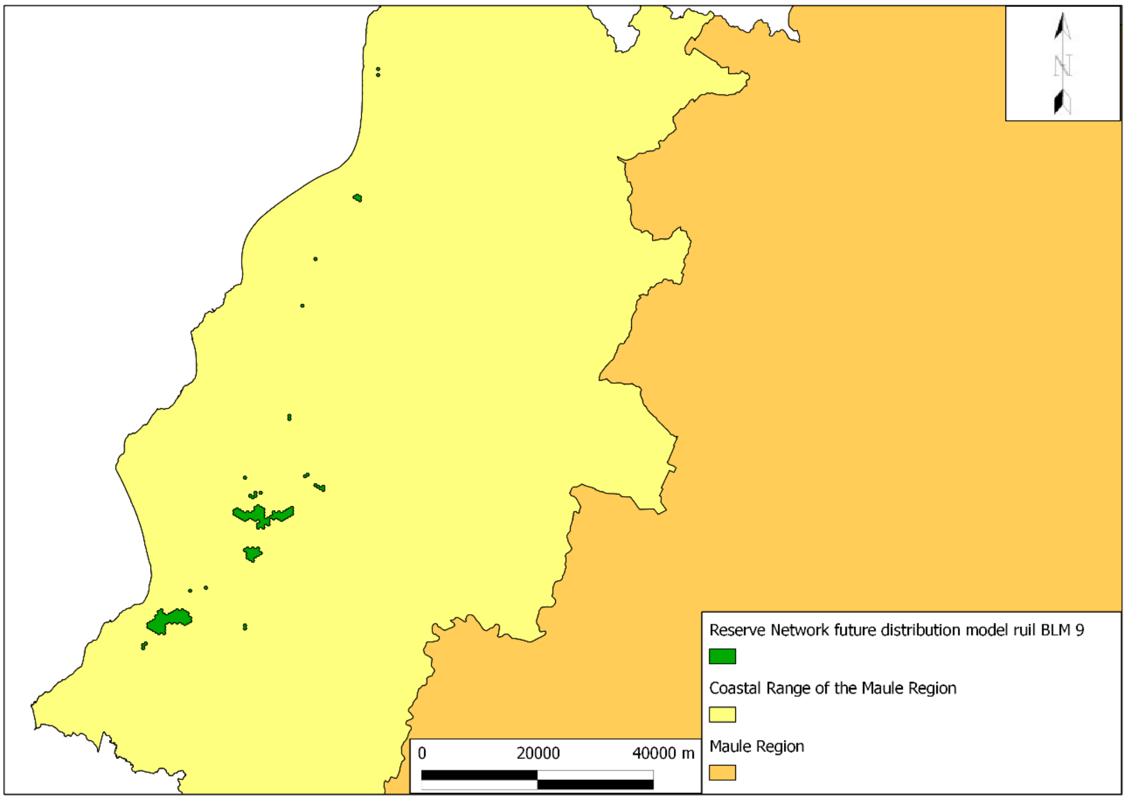
Figure 31: % of land use surface with respect to the total reserve network in the future model scenario of ruil



Source: Author's elaboration with Marxan results

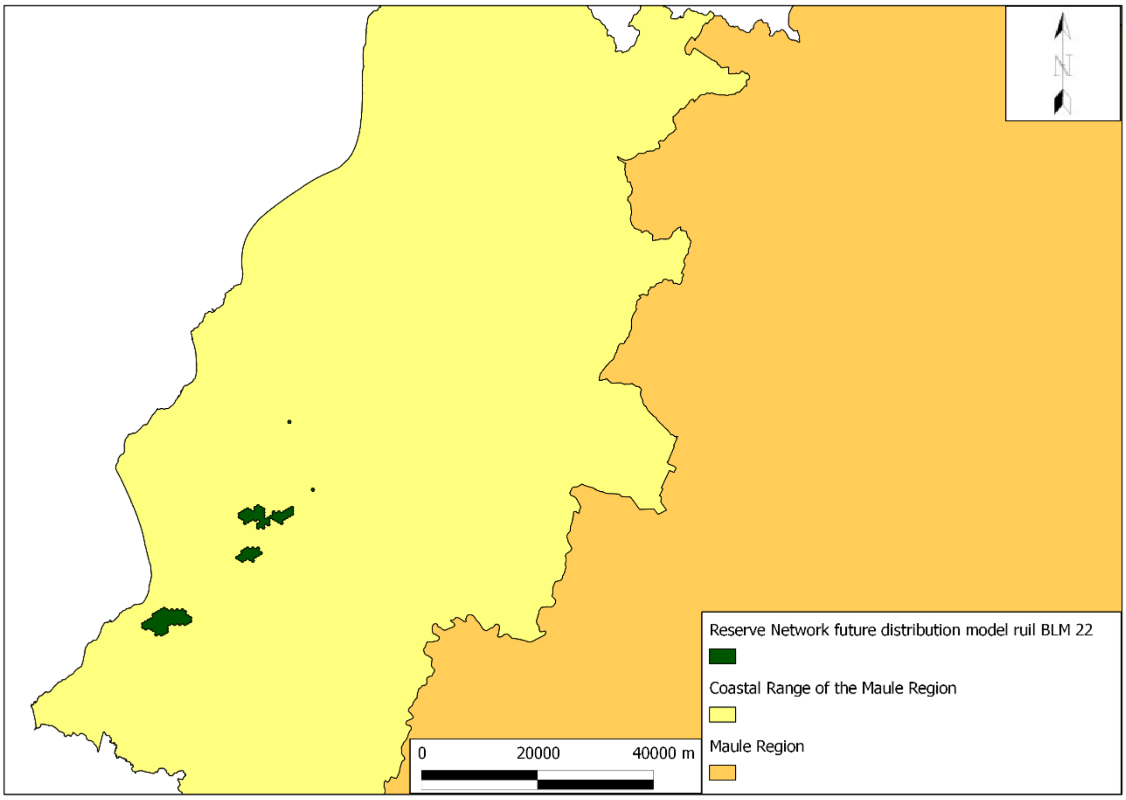
The reserve networks obtained in the analysis of the future model scenario of ruil are presented as follows.

Figure 32: Reserve network with 17% of future distribution model of ruil and BLM 9



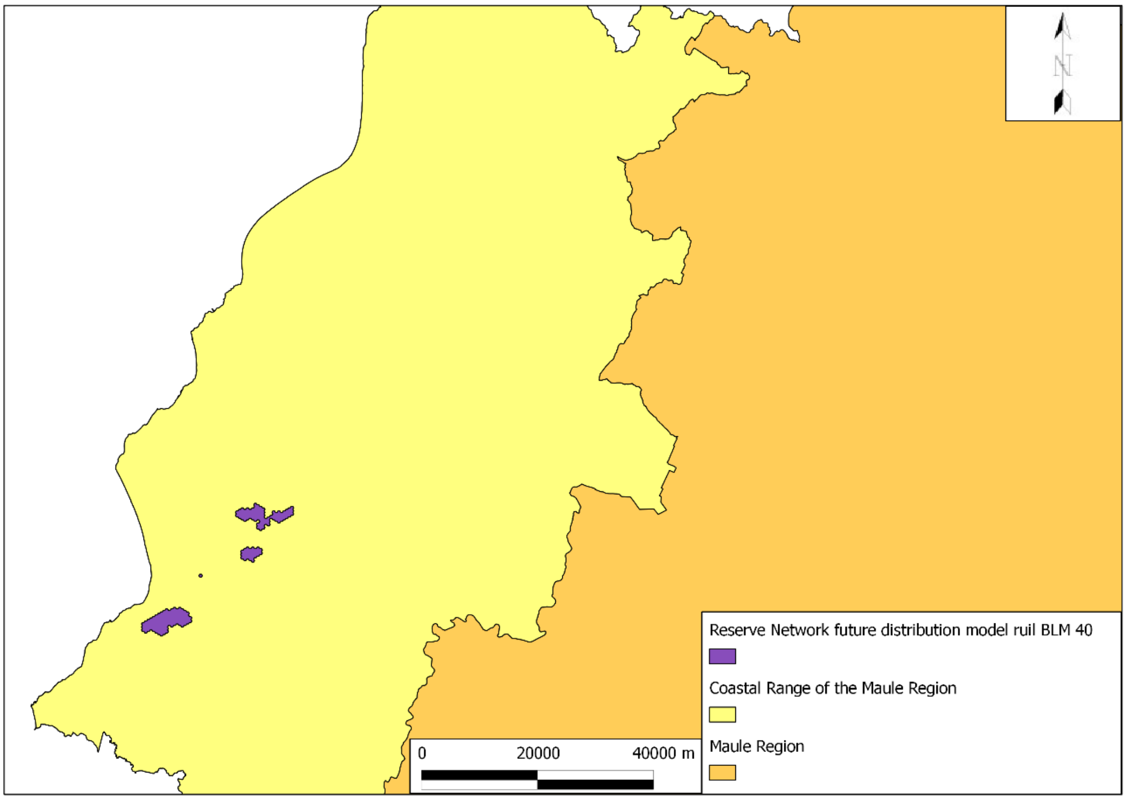
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 33: Reserve network with 17% of future distribution model of ruil and BLM 22



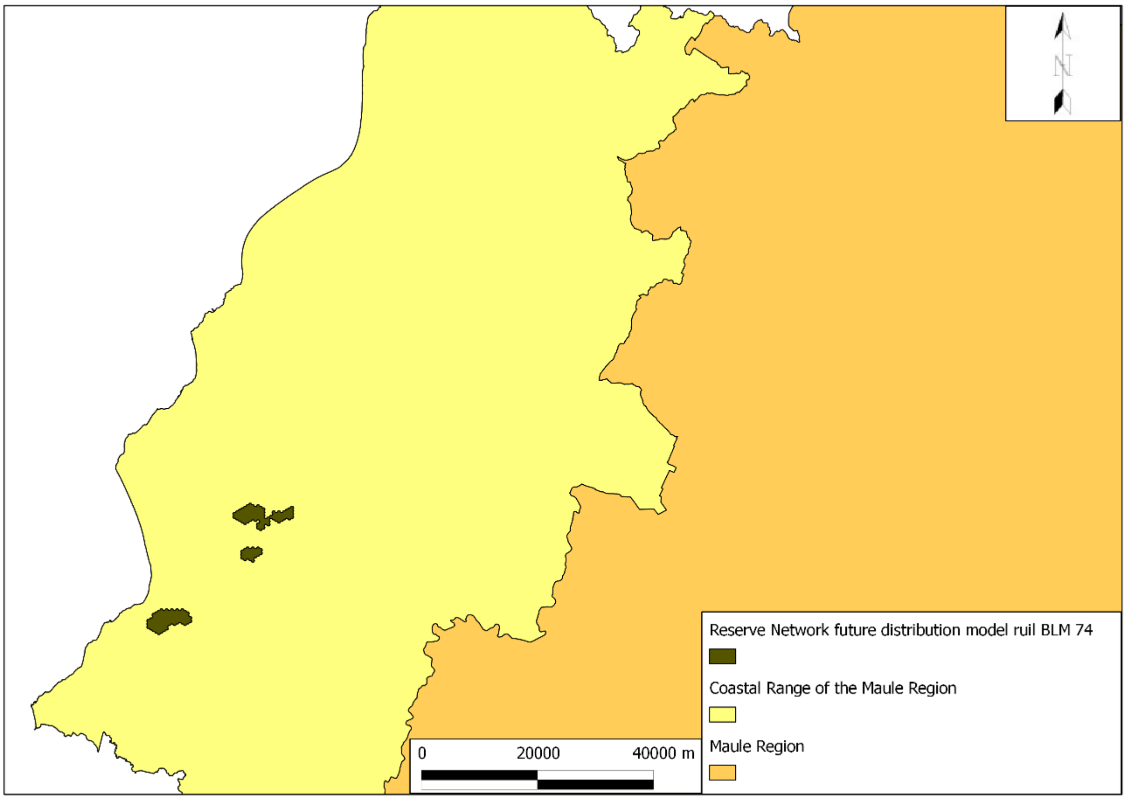
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 34: Reserve network with 17% of future distribution model of ruil and BLM 40



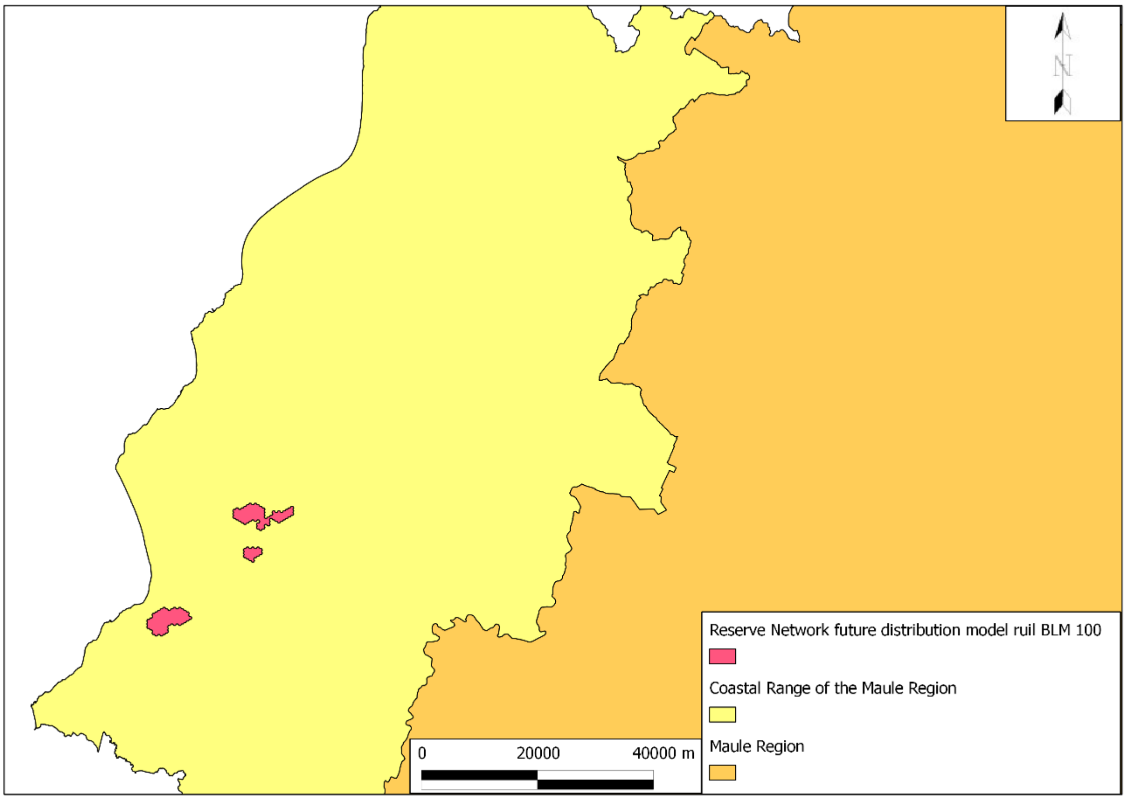
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 35: Reserve network with 17% of future distribution model of ruil and BLM 74



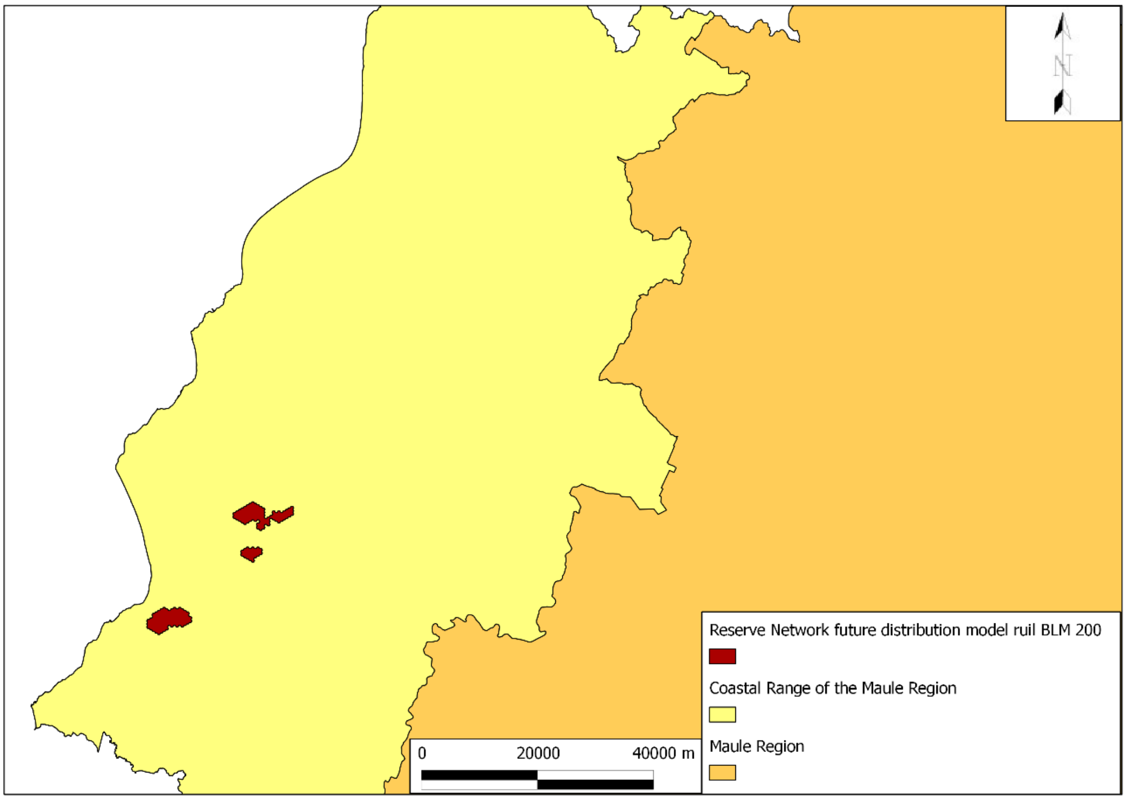
Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 36: Reserve network with 17% of future distribution model of ruil and BLM 100



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Figure 37: Reserve network with 17% of future distribution model of ruil and BLM 200



Source: Author's elaboration with Marxan results and the use of the software Quantum Gis 1.8.0 – Lisboa

Reserves networks with high BLM values (74, 100 and 200) are practically the same in shape and have only very minor differences slightly varying in cost and area size (Table 15). However, they represent the appropriate land for the establishment of the ruil naturally or through reforestation, considering the effect of the climatic change in the future model scenario in the Maule region.

As Table 18 shows, an area between 1,434 and 1,621 hectares of Maulino coastal forest with ruil presence would remain protected if one of these reserve networks are implemented to preserve and restore ruil. At the same time, in these reserve networks there are between 3,358 and 3,663 hectares suitable to be restored with ruil in order to change the critical conservation status that it has and at the same time contribute to Initiative 20x20.

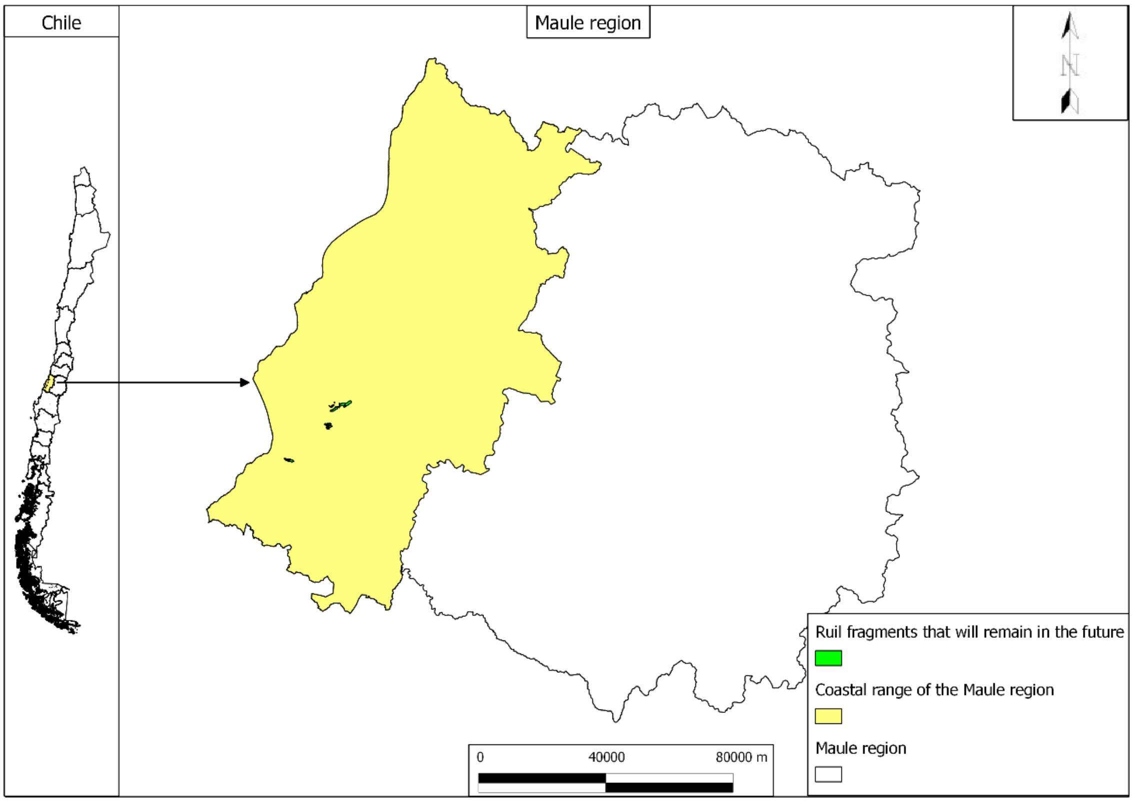
Table 18: Maulino coastal forest area to preserve and suitable land to restore the ruil in future model scenario

Reserve networks in order of increasing BLM (BLM)	Reserve networks Total area (ha)	Maulino coastal forest area which will be preserved (ha)	Suitable land to restore the Ruil (ha)
1 (9)	4,817	1,459	3,358
2 (22)	4,981	1,621	3,360
3 (40)	5,004	1,539	3,465
4 (74)	5,027	1,510	3,517
5 (100)	5,097	1,434	3,663
6 (200)	5,144	1,511	3,633

Source: Author's elaboration with Marxan results

Figure 38 shows the fragments of the forest where ruil will exist in the future model scenario.

Figure 38: Future fragments of forest with ruil



Source: Author's elaboration with information provided by CONAF and Alarcon & Cavieres (2015) and the use of the software Quantum Gis 1.8.0 – Lisboa

4.2.3 Current model scenario of ruil vs Future model scenario of ruil

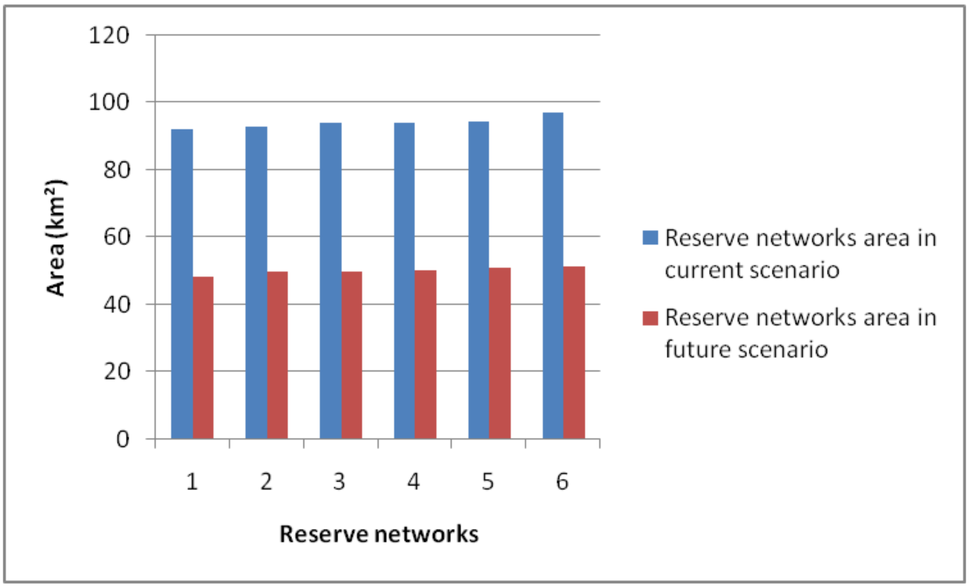
The land suitable for ruil was considerably reduced in the future scenario as is shown in Table 19 and Figure 39.

Table 19: Reserves networks total area in the current model scenario and the future model scenario

Reserve networks in order of increasing BLM (BLM)	Reserve networks Total area in current model scenario (ha)	Reserve networks Total area in future model scenario (ha)	Difference between reserve networks area of the current and future model scenarios	% of the difference
1 (9)	9,236	4,817	4,419	48
2 (22)	9,283	4,981	4,302	46
3 (40)	9,400	5,004	4,396	47
4 (74)	9,423	5,027	4,396	47
5 (100)	9,447	5,097	4,350	46
6 (200)	9,704	5,144	4,560	47

Source: Author's elaboration with Marxan results

Figure 39: Reserve networks total suitable land for the ruil conservation and restoration in the current and future models scenarios



Source: Author's elaboration with Marxan results

As illustrated shown in Table 19 and Figure 39, the reduction of the area of reserve networks in the future model scenario is quite significant with respect to the area of reserve networks in the current model scenario, since the surface of the reserve networks generated in the future is almost half of the area of the reserve networks of the current model scenario. As is shown in Figure 39, the area of the future was smaller than the area of the current model scenario. Because the area of reserve networks ranges from 92 to 97 km² in the current model scenario and from 48 to 51 km² in the future model scenario. Thus, the future model scenario has reserves network that has half of the area of the reserve networks of the current model scenario, which makes them more cost-efficient and easier to implement.

Tables 20 and 21 show that the area of the Maulino coastal forest presents in the reserve networks and the area of suitable land to restore the ruil in the future model scenario also decrease 50%.

Table 20: Maulino coastal forest area which will be preserved in current model scenario vs future distribution model scenario

Reserve networks in order of increasing BLM (BLM)	Maulino coastal forest area preserved in current model scenario (ha)	Maulino coastal forest area which will be preserved in future model scenario (ha)	Maulino coastal forest difference between current and future model scenarios (ha)	% of difference
1 (9)	2,476	1,459	1,017	41
2 (22)	3,053	1,621	1,432	47
3 (40)	2,550	1,539	1,011	40
4 (74)	2,763	1,510	1,253	45
5 (100)	2,657	1,434	1,223	46
6 (200)	3,034	1,511	1,523	50

Source: Author's elaboration with Marxan results

Table 21: Suitable land to restore the ruil in the current model scenario vs Suitable land to restore the ruil in the future model scenario

Reserve networks in order of increasing BLM (BLM)	Suitable land to restore the ruil in the current model scenario (ha)	Suitable land to restore the ruil in the future model scenario (ha)	Difference between current and future model scenarios suitable land to restore the ruil (ha)	% of difference
1 (9)	6,760	3,358	3,402	50
2 (22)	6,230	3,360	2,870	46
3 (40)	6,850	3,465	3,385	49
4 (74)	6,660	3,517	3,143	47
5 (100)	6,790	3,663	3,127	46
6 (200)	6,670	3,633	3,037	46

Source: Author's elaboration with Marxan results

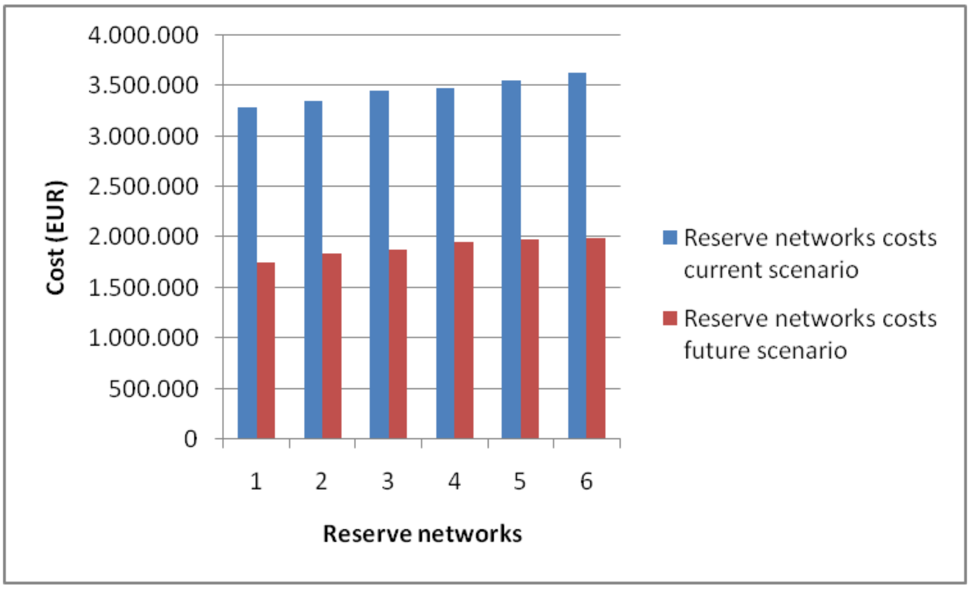
Table 22 and Figure 40 show that the cost in each reserve networks in the future are lower than those in the current scenario. The reason for this decrease in the cost is the reduction of the area of the reserve networks in the future model scenario.

Table 22: Reserves networks cost of the current vs future model scenarios of ruil

Reserve Networks in order of increasing BLM (BLM)	Cost (€) current model scenario	Cost (€) future model scenario	Difference (€) current vs future model scenario	% of difference
1 (9)	3,286,410	1,746,098	1,540,312	53
2 (22)	3,351,449	1,841,950	1,509,499	55
3 (40)	3,448,073	1,876,811	1,571,262	54
4 (74)	3,480,623	1,957,043	1,523,579	56
5 (100)	3,556,923	1,978,908	1,578,016	56
6 (200)	3,629,341	1,995,793	1,633,547	55

Source: Author's elaboration with Marxan results

Figure 40: Reserve networks costs in the current and future models scenarios



Source: Author's elaboration with Marxan results

5. Discussion

This study contributes to the conservation of the native forest of the Maule region incorporating socioeconomic variables and climate change effects in conservation planning. With all its limitations, it is the first study to accomplish such an important analysis. The objective of including socioeconomic variables and the climate change in the analysis was to achieve the conservation goals more efficiently, while not only focusing on biological criteria like what been done until now in this type of studies in the Maule region. To date, only in 2009 did one initiative of several public and private institutions (Arnold *et al.,* 2009) try to find zones of great importance for the environment or biodiversity in the Maule region to be proposed as preservation sites. However, this initiative was based only on biological and ecological aspects, without considering the social-economic factors and climate change effects in the region. Essentially, they made an arbitrary clustering of conservation areas according to their perspective (biological criteria and location, etc). In addition, my study is innovative as, to my knowledge, none of the previous studies used species distribution models to determine zones suitable for the species conservation and/or restoration in the Maule region.

For this reason, the principal purpose of this research was to determine cost-effective priority areas for preservation and restoration of the Maulino coastal forest and ruil. To do so, a spatial prioritization approach in the coastal range of the Maule region in central Chile was used. At the same time, I wanted to determine cost-effectiveness gains by considering climate change effects in reserve network planning of ruil. To do that, I used two species distribution models of ruil, a current and a future distribution model to determine zones that will still be suitable for ruil despite climate change impacts. At the same time, I wanted to identify cost-effective areas devoid of ruil or Maulino coastal forest that can be considered areas apts for being restored with both species in the Maule region's coastal range.

As main inputs for the analysis I used the distribution of the Maulino coastal forest, the current distribution of ruil and two distribution models of ruil (current and future models distribution of ruil). The two distribution models were used to integrate climate change effects on reserve network design. In addition, an economic variable (opportunity cost) was included in all analyses considering the different land uses performed in the study area. I used a spatial prioritization technique known as "Marxan" to determine cost-effective reserve networks.

As it is shown in the figures presented in the results section, the options that provide better reserve networks for the Maulino coastal forest scenario and for the ruil current and future models scenarios are those that use a BLM equal or greater than 100. This means that, the reserve networks generated with BLM equal or greater than 100 are more compact and less fragmented than the others. This makes these reserves networks easier to implement and manage.

The cost that represents the implementation of the reserve networks ranges from:

a) € 2.7 million to € 3.5 million in the Maulino coastal forest scenario, being the reserve network with a BLM of 2 the one with the lowest cost in this scenario;

b) € 3.2 million to € 3.6 million in the current model scenario of ruil, being the reserve network with a BLM of 9 the one with the lowest cost in this scenario; and

c) € 1.7 million to € 2 million in the future model scenario of ruil, being the reserve network with a BLM of 9 the one with the lowest cost in this scenario.

The results of the analysis for the three conservation scenarios analyzed in this study ((a) Maulino coastal forest scenario, (b) Current model scenario of ruil and (c) Future model scenario of ruil) show that the most cost-effective reserve network in each scenario are the ones where the optimal BLM were used. The BLM 2 for the Maulino coastal forest scenario and BLM 9 for the Current and Future model scenarios of ruil. Since the reserve networks that were produced when was used these BLM values (2 and 9) has less potential economic impact that the others. However, although being the most economical, these reserve networks has a negative factor that limits their choice, as these are highly fragmented (Figures 16, 24 and 32). This makes these reserve networks more difficult to implement and to manage for the decision makers.

On the other hand, when in each scenario were used high BLM values (BLM 150 and BLM 200 in the Maulino coastal forest scenario and BLM 100 and BLM 200 in the Current and Future model scenarios of ruil). The reserve networks generated using these BLM values (100, 150 and 200) have a more compact outcome (Figures 20 and 21 in the Maulino coastal forest scenario, Figures 28 and 29 in the Current model scenario of ruil and Figures 36 and 37 in

Future model scenario of ruil). Due to their spatial compactness, they have a more realistic chance of being implemented and are more viable for management purposes given that they are easier to manage and monitor than highly fragmented areas. However, they are not very cost-effective, since they are the ones that present the most expensive conservation values for the three scenarios. This is due to the fact that when the perimeter (boundary length) decreases, the area of the solution increases because more planning units are typically needed to form contiguous clusters.

The future model scenario has the most cost-effective reserve networks, since it has the lowest opportunity cost. This shows that the adoption of species distribution models to incorporate the climate change effect in the analysis helps produce more accurate and cost-effective reserve networks, since they are not integrating areas that in the medium-term could disappear, resulting in significant financial losses.

The reserve networks of the Maulino coastal forest scenario and the reserve networks of the current and future model scenarios of ruil have a significant area and cost, especially in the current model scenario. If we considered that more than 90% of the owners of these forests are small farmers, whose properties have a relatively small surface, this may lead that the affected landowners oppose the implementation of the proposed reserve networks. For this reason, the monetary incentives that could be given to the owners of the land that will be part of the reserve networks generated here must be commensurate with the profits that they would lose from the activities performed there, such as from *Pinus radiata* planting. If this cost is not covered by the government, it is necessary to show alternatives to the owners of the area which could be developed as a replacement of losses that they will have for the implementation of the reserve networks. One way to encourage acceptance of the reserve networks may be to eliminate the subsidy for *Pinus radiata* plantations, as the financial opportunity cost of the *Pinus radiata* plantations include a subsidy (D.L 701). That subsidy paid for *Pinus radiata* plantations could be paid for Maulino coastal forest or ruil plantations (restoration) on the proposed reserve networks. Although currently there is a native forest law (Law No. 20,283), which provides subsidies, these are very low in comparison to those provided for *Pinus radiata* plantations.

If only is considered the current distribution model of ruil as a basis for identifying zones suitable for its preservation and restoration, the ruil would be protected where it no longer is able to exist and the money for its conservation and restoration would be "wasted" for not including climate change as a factor, like in the future scenario. The losses in monetary terms would be between € 1.5 million and € 1.6 million

As seen in the tables and figures presented in the result section, there is almost a 50% decrease in the size and cost of the reserve networks of the future model scenario in comparison with those of the current model scenario, making these reserves networks easier to implement and manage – and most importantly, leaving out areas unsuitable for the existence of the most threatened species of the country in the future model scenario, this being more appropriately to be implemented by decision-makers.

The reason for the decrease in size and cost in the reserve networks of the future model scenario is because in this scenario the species distribution model that was used considered the future climatic conditions of the study area with the aim of forecasts the effect of climate change in ruil forest. The future model clearly illustrates that the influence of climate change will be quite disruptive for the ruil, since the area suitable for the life of the species is reduced by half. Thus, many areas that are suitable for ruil in the current model scenario will not be in the future. On the other hand, the future model scenario only considers those areas that would be suitable, given that the reserve networks generated in this scenario are more cost-effective and feasible to implement than those from the current model scenario.

As the reduction of the reserve networks in terms of area and cost are significant, it is important to consider the climatic change variable in this type of analysis – particularly if we consider that these types of analysis usually are performed for developing countries, like Chile. These countries do not have the resources for the implementation of reserve networks for species in risk – especially when they have to face different land uses that are carried out in the species distribution area.

As is show in the results section (Table 13 and Figure 23 for the current and Table 17 and Figure 31 for the future model scenario), *Pinus radiata* plantations would be the most affected land use in the current and future model scenarios, since a high percentage of the proposed reserve networks in both scenarios have at this moment *Pinus radiata* plantations, representing 34% to 40% of the surface of the reserve networks generated in the current model scenario and 36% to 38% of the surface of the reserve networks generated in the future model scenario.

On the other hand, agriculture land is present in the reserve networks generated in both scenarios but with a very low area (between 0.7% and 1.5% in the current model scenario and 1% to 2 % in the future model scenario). The reason of this is because agricultural land has an opportunity cost greater than that of *Pinus radiata* plantation and grassland. For this reason, Marxan has prioritized during the selection process those places that had a lower value being these places where there are – or have the potential for – *Pinus radiata* planting. Thus, as agricultural lands have a higher opportunity cost, the PUs that have agricultural land were not mostly chosen. Since the purpose of Marxan is to determine cost-effective reserve networks, Marxan focuses on choosing the PUs with the lowest opportunity cost to be part of the reserve network.

It should be noted that 29% to 36% of the area of the reserve networks generated in the current model scenario and 29% to 32% of the area of the reserve networks generated in the future model scenario correspond to grasslands, which are lands used for planting *Pinus radiata*, like for livestock. The opportunity cost that was assumed for grassland use was the same as the one used for *Pinus radiata* planting, since these soils are usually used for forest planting as well. For this reason Marxan also selected it, since the opportunity cost is the same as *Pinus radiata* plantation.

Another important point to consider is that the land protected under the future model scenario includes land where ruil already exists today. However, not all of the 1,223 hectares of forest with ruil nowadays were included in the reserve networks generated in the future model scenario, because there are 450 hectares located in areas that in the future will be not suitable for ruil survival due to climate change's impact. Just 773 hectares (63%) of the remaining fragments with ruil will exist in the future according to the SDMs used here. Thus, all the efforts that could be made for the protection of ruil should focus on protecting only the 773 hectares that will remain in the future. Figure 38 shows that the northern fragment and those closer to the coast will disappear as a reaction to climate change. Therefore, any measure to preserve the ruil should focus on the fragments that will persist in the future, avoiding wasting valuable time and funds.

In this study, the use of ruil distributions models allowed me to take into acount the effect of climate change in the prioritization process and to identify potential geographic areas with the necessary edaphoclimatic features for preserving and restoring the ruil. For this reason, the use of species distribution models that integrate the climate change variable, such as the one provided by Alarcón & Cavieres (2015) and used here to project cost-effective reserve networks in the future model scenario, are deemed to be more accurate or closer to reality and should always be included in the design of reserves networks in conservation planning. When considering the effect of climate change in my analysis, reserve networks generated in the future have less potential economic impact than those generated in the current model scenario and thus, they can be considered optimal for implementation when compared to the current one. Thus, the identification cost-effective suitable areas help decision-makers know those regions where it is possible to implement restoration programs for ruil and the Maulino coastal forest in the Maule region.

In this study – in addition to the species distribution models – the social-economics aspect of the study area was also considered. I believe that the only way to protect the Maulino coastal forest and the ruil forest is through the implementation of cost-effective reserve networks to preserve them at the lowest possible costs. Because know this make easier to implement and expand reserve networks in the future via the prudent use of conservation resources, and thus easier to support among competing interests.

To generate the cost-effective reserve networks, I identified first the land uses in the study area. Then I calculated the opportunity cost of the more profitability activities (*Pinus radiata* plantations and *Cabernet Sauvignon* vineyards) performed in the study area. A cost-benefit analysis was performed to these two production activities in order to calculate the opportunity cost. I chose these activities since they have the highest profitability in the study area and are developed in the distribution area of the Maulino coastal forest and ruil. The opportunity cost of these two production activities was calculated to include it as an input in the Marxan analysis.

The identification of zones to restore with ruil or Maulino coastal forest in the Maule region is a good measure to ensure their preservation – in addition to controlling threats such as the clearing and destruction of their habitats. Thus, as Santelices (2009) said, restoration programs for these forests are very important to increase their number of individuals in the populations and to establish new populations through additional plantings of their species in suitable sites, if they cannot be displaced naturally due to the fragmentation of their distribution (Santelices, 2009).

When habitats are highly fragmented – like in the Maulino coastal and ruil forest cases – some authors as Bellard *et al*., 2012 propose that conservation planning may require consideration of drastically distinct approaches, such as man-made translocation of both species and their habitats to allow the species to adapt to changing climatological events. For this reason, the reserve networks generated in here, especially from the future model scenario, may be considered as the zones to carry out restoration programs for the Maulino coastal forest and ruil in the Maule region. It is very relevant to take into account artificial translocation as a messure for the Maulino coastal forest and ruil preservation as a better alternative or way to carry out more efficacious and proficient aproaches than just wait for the species to move naturally to more suitable areas for it.

Concerning climate change, no studies on the identification of zones to protect the Maulino coastal forest and ruil have been performed considering its impact. My study is the first one done in the zone that integrates biological, social-economic and climate change aspects in the analysis, as climate change represents a major defiance for traditional conservation planning.

Climate change arguably magnifies other threats to biodiversity conservation as well, like habitat loss, forest fires, contamination, illegal hunting and the propagation of invasive exotic plants (Araújo, 2009) – threats already facing the Maulino coastal and ruil forests, especially since the latter is suffering an invasion of *Pinus radiata* seeds, which is accelerating the fragmentation process of the forest. Furthermore, in recent years (2016, 2017) an upward trend in the rate of forest fires in the zone has been increasing the danger to which both forests are exposed.

When climate change is a serious agent of risk for the existence of the species, the election of sites to protecting the present species range does not always indicate that the species is adequately safeguarded (Araújo, 2009). Because with climate change the distribution areas of species may change and it can move out of their current habitats. For this reason, the current preservation zones could be deprived of their species in the years to come. Since these areas designated as reserves may be located in zones where they are not suitable for some species anymore, as was shown in the case of ruil, in which its surface is reduced in the future model scenario. Climate change therefore poses a serious threat to traditional approaches to conservation planning, as it is very possible that the species and their natural environments will move from their current ranges.

With respect to the national reserve “Los Ruiles” located in the Maule region’s coastal range, that strive to protect the Maulino coastal and ruil forests, it is well situated, given that its location coincides with the ruil’s future distribution. “Los Ruiles” is part of the area that covers the 773 hectares of the Maulino coastal forest with ruil that will survive in the future. As some authors have recommend (Bellard *et al*., 2012), existing reserve should be revisited factoring in climate change via climate and species distribution modeling for the purpose of reassess current protected zones, their size, layout, etc., as we did here.

As can be seen in the results section, the comparison between the reserve networks of the current model scenario and the reserve networks of the future model scenario, convey a coherent lesson: we can either preserve the nature at half of the price or reach even greater preservation aims for the same price if costs and climate change are formally considered from the beginning in the process of designing the reserve network.

It should be noted that my study works on issues that are relevant today, such as are the preservation and restoration of the enviroment, the biological diversity and also was considered the global warming or climate change. Since there are a lot of international efforts and flagship programs that invite governments to preserve and restore their forests. Some of them are the “Strategic Plan for Biodiversity 2011–2020 of the Convention on Biological Diversity”, “the Bonn Challenge”, “the New York Declaration on Forests”, “the initiative 20x20”, “the Global Partnership on Forest and Landscape Restoration (GPFLR)”, “the IUCN Restoration Initiative”, “SUSTAIN”, and the “Global Mangrove Alliance”, to name a few.

In addition, recently on March 1, 2019, the UN General Assembly officially announced the “Decade on Ecosystem Restoration (2021-2030)” to elevate ecosystem restoration (GPFLR, 2019; IUNC, 2019; UNEP, 2019), endeavoring to massively escalate the rehabilitation of deteriorated and damaged environments as a demonstrated action to fight against climate change, as a way of boosting restoration efforts to millions of hectares based on successful pilot initiatives (GPFLR, 2019; IUNC, 2019; UNEP, 2019).

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7. Appendices

7.1. Appendix 1: Gestion Forestal

The Gestion Forestal program is an initiative developed by the "Instituto Forestal de Chile INFOR" (Forest Institute) since 2001. It is sponsored by the Development and Innovation Fund of the Corporation for the Promotion of Production (FDI-CORFO) (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019). The main mission or goal of this program is to increase the research generated in Chile on the forest sector. And disseminate the information that it produces on the forestry sector in Chile, with focus in technology, business and forest management approaches for small and medium farmers (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

This program allows the access of small and medium Farmers and public in general, to information on technology and management approaches for different profitable productive forest species, that could be considered as an alternative for the small and medium farmers to be incorporated into their production systems (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

This program offers many tools to strengthen forestry activities in rural areas of Chile. It has identified areas for forest development (plantations) in Chile and has created technology packages that are linked to forest types that have the promise of being developed in the country, among other topics related to forestry (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

The specific information provided by Gestion Forestal consists of: technological packages, basic aspects of negotiation and commercialization and marketing, bibliographic material, information on non-timber forest products, business tools and agroforestry management patterns for different forest species that are planted in Chile or that have the potential to be developed in the country and that can be managed by small and medium farmers (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

Within the technology packages there are information on the establishment and management of different species (exotics and native) to perform forest plantations in Chile. The information is provided for each species and refers to general aspects of the species, such as suitable distribution maps for the species, ecological requirements, locations of nurseries, growth areas according to site indices, information about cost income and profitability for the establishment and management for the plantations of each species (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

With respect to the basic aspects of negotiation, commercialization and marketing for forestall business, the program offers the basic marketing and commercialization aspects that should be considered by every small and medium farmers if they decide to start a business in the foresty sector; in order they could have the basic knowledge to run their forest business independently and profitably (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

With respect to the Bibliographic material provided by Gestion Forestal, it is mainly focus on establishment of forest plantations in the Chile. Also, it offers information on the management, extraction and commercialization of non-timber forest products as their export statistics as well. Furthermore, there is a lot of information on marketing and potential markets (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; Gestion INFOR, 2019).

A further aspect to highlight is that Gestion Forestal has a forest profitability simulator. It is a web module for the economic and financial analysis of forest management for the different species presented for Gestion Forestal as alternatives for the small and medium farmers. It is present as a tool to support forest business management. It also has an Agroforestry section, which provides information on the various agroforestry models that can be developed in Chile, such as the forest-cattle model, agriculture-forest model and agriculture-forest-cattle model (Gestion Forestal, 2011; Silva-Muñoz, 2012).

The information that this program offers is oriented to all the small and medium farmers of Chile but mainly those who are located between the Maule Region (VII Region) and Los Lagos Region (X Region) of Chile. This information has been systematized in the web site, of quick and easy access, which gathers information of great relevance for the rural sector (Gestion Forestal, 2011; Silva-Muñoz, 2012; Gestion Forestal, 2018; INFOR, 2019).

As the study area is part of the Maule region in this thesis, I used as source of data the information generated by Gestion Forestal.

7.2. Appendix 2: Characterization of the production chain and marketing of the Chilean wine industry

The “Oficina de estudios y políticas Agrarias (ODEPA) del Ministerio de agricultura de Chile (Office of Agrarian Studies and Policies (ODEPA) of the Ministry of Agriculture of Chile)” in 2015 published a study whose purpose was to investigate and characterize the production and marketing of wine produced by the wine industry in Chile (ODEPA, 2015).

The purpose of the study was to research and disseminate information about the wine industry in Chile. This study generated information on costs, income and profitability of *Cabernet Sauvignon* vineyards from the Maule region among other information (ODEPA, 2015).

The general objective of the study was to carry out a characterization of the production and commercialization chain of the wine agroindustry from the perspective of its structure, agents and practices, with sufficient information to enable the assessment of the conditions of competition and symmetry of bargaining power in their markets (ODEPA, 2015).

And the specific aims of the research were to (i) Identify and describe the characteristics and structure of the relevant market(s). (ii) Characterize common business practices in identified relevant markets, considering differences in geographical and/or product coverage, as well as magnitude of agents or production involved. (iii) Identify commercial practices and conditions of the structure of the value chain, in each one of the relevant markets identified. And (iv) Identify opportunities to improve asymmetry in bargaining power, recommending actions, policies or instruments that could be addressed from the perspective of the public sector (ODEPA, 2015).

The study begins with a description of the winemaking process in Chile, starting with a more in depth description of the production of wine grapes in the various categories of production modes, vines, yields, and harvest. And continues, in a detailed manner, with the entire process of winemaking until bottling.

In addition, this study presented a detailed analysis of the wine production and markets trends the wine industry market. General and economic aspects are presented here as well, such as the surface of existing vineyards, wine production (legal and economic aspects). Here many factors involve the wine productions are analyzing such as the quantity of wine produced, production costs, main producers of the country, commercialization value chain in national and international wine markets and their respective sale prices in Chile and abroad.

The study also presents a section of the Industrial Organization of the wine production chain in Chile, specifically, production chain and marketing of grapes and wine, production (yields), commercialization, costs and prices of wine grapes in Chile for region, based on variety (species of vine), irrigation and other yield variables. In this section is where I found the information (on costs, income and profitability of *Cabernet Sauvignon* vineyards from the Maule region) used in my thesis to perform economics the analysis.

7.3. Appendix 3: Chilean Forestry Laws Subsidies

Since the beginning of the last century the Chilean government has recognized the importance of forest plantations for the country's economic growth. This is why, the government has created several programs which provide incentives for forest plantations, many of which have transcended the administration of several Governments (Silva-Muñoz, 2012)

In 1931 the Chilean government enacted the Forest Act, where the main objective was to promote forest plantations by not taxing the companies that carried out this work. During the sixties and early seventies, the national government of Chile began to incentivize forest plantations in a more aggressive way through the delivery of economic aid through CORFO (Silva-Muñoz, 2012).

In Chile, currently there are two laws that directly affect the protection and restoration of native forests, one that provides bonuses to encourage the planting of forests for industry (Decree Law 701) and another that provides bonuses to encourage native forest protection and restoration (Law 20.283).

Decree Law 701

Decree Law 701 was created 1974 for the Chilean government, whose objective was to promote plantations of exotic forest, mainly *Pinus radiata* and *Eucaliptus globulus*, in suitable lands and regulate all the forestry activity in the country (CONAF, 2011; Silva-Muñoz, 2012)

The aim of the Decree Law 701 was to promote forestry and industrial development, mainly through paper mills, and to combat soil erosion, especially on the slopes of hills and riverbanks (CONAF, 2011; Silva-Muñoz, 2012).

The initiative implied a 75% bonus for pine and eucalyptus plantations, a benefit that was skillfully taken advantage of by the large companies such as the Paper and Cardboard Manufacturing Company - better known as "CMPC" - of the powerful Matte Group; and Grupo Arauco, which is in the hands of the Angelini (CONAF, 2011).

Between 1974 and 1995 to promote forestry development in Chile two components were established (i) A subsidy for the afforestation or stabilization of dunes in soils suitable for forestry, which provided a subsidy equivalent to 75% of the net costs of establishing the plantation on suitable for forestry land. (ii) A subsidy on for all the forestry activities such as management, pruning and thinning activities (CONAF, 2011; Silva-Muñoz, 2012).

In 1998 the law 19.561 was created to modify the Decree Law 701. The objective of this change in the Decree Law 701, was to encourage small and medium farmers to take advantage of the benefits of this law and plant pine or eucalyptus forests on their lands, specifically the lands that face degradation problems, as a measure for the recovery of these kind lands. This law took effect in 1998 but it is retroactive to 1996, and considers two components: (i) A subsidy for smallholders to cover forestry plantations and forest management activities on the plantations, the subsidy was equivalent to 90% of the net costs of planting the first 15 hectares of the total area of the plantation, then the subsidy was equivalent 75% to cover the cost of the remaining hectares of the plantation. (ii) A subsidy for afforestation, soil recovery and dune consolidation activities, in frail soils and degraded soils that are in the course of becoming desertified. The objective is to provide a subsidy equivalent to 75% of the net costs of each activity (CONAF, 2011; Silva-Muñoz, 2012).

In 2011, new modifications to Decree Law 701 were implemented through the Law 20.488. With this modifications two new land owners categories were implemented into the Decree Law 701, (i) the category of medium forest owner, which will have a subsidy of 75% and (ii) a third category "others" which are those who do not qualify for the two previous categories (small and medium forest owners), who will receive a bonus of 50% of the costs. This modification also provides special benefits to indigenous communities and the individuals who belong to them and create a public register of forest operators, which will be administered by CONAF (CONAF, 2011; Silva-Muñoz, 2012).

After the implementation of the Decree Law 701, the native forest gradually began to disappear amid accusations of illegal logging and suspicious fires. According to farmers, the main damage to tree plantations has been drought and the irreparable condemnation of soils, which cannot be reused for agricultural work (Silva-Muñoz, 2012).

Law 20.283 Native forest recovery and forest development

The objective of Law 20.283 is to is to promote the protection and concervation of native forest through the provision of subsidies to those who sustainably obtain products from them (BCN, 2011; Silva-Muñoz, 2012).

This law establishes a scheme of incentives for the preservation of native forests and xerophytic formations (adapted to aridity), forestry activities for the extraction of wood and other products intended for the management and restoration of these forests. It prohibits the logging of native species in the vicinity of natural watercourses and in areas with excessive slopes, and of those species in any of the categories with conservation problems. At the same time, it promotes research, the improvement of species and the maintenance of their ecosystems, as a way to strengthen the native forest them (BCN, 2011; Silva-Muñoz, 2012).

This law grants allowances to small, mid-sized and big landlords, who have the appearance of indigenous forest on their lands. In order to have access to the subsidies, they must submit a management plan focused on the preservation of biological diversity; logging and non-timber activities (tourism, fruits, seeds, fungi, natural medicine, carbon sequestration, etc). This bonus is pay to cover the cost of activities that help the regeneration, recovery or protection of xerophytes formations of high ecological value or to cover activities to preserve the native forests (BCN, 2011; Silva-Muñoz, 2012).

The main activities that the bonus covers are: (i) Activities to promote regeneration, recovery or protection of xerophytes formations of high ecological value or native forests preservation. For this activity the subsidies can reach up to 5 monthly tax units per hectare. (ii) Forestry activities for the production, recollection and management of non-timber products, such as mushrooms, wild fruits, medicinal plants, vegetable fibers or tourism services will have a bonus. This bonus will reach up to 5 monthly tax units per hectare. (iii) Forestry activities designed to manage and restore native forests for timber production purposes. This bonus can reach up to 10 monthly tax units per hectare. For small forest owners, the amount of the subcidies listed above will be increased to 15% (BCN, 2011; Silva-Muñoz, 2012).

This law also contemplates the provision of subsidies for research, in order to attract the academy to generate studies to increase the knowledge on issues related to indigenous forestlands environments, their governance, maintenance, safeguarding, enhancement and restoration (BCN, 2011; Silva-Muñoz, 2012).

The Law 20.283 about the subsidies to encourage and support for research stated: (i) Academic and tech-related research concerning indigenous forestry and the stewardship of its rich biological diversity. (ii) Research and technological development of projects aimed at safeguarding soils, hydrological services, plants, fauna and native environments linked to indigenous forests. (iii) Development and implementation of training programs, as well as teaching and knowledge sharing and technologies diffusion in remote rural areas dedicated to the education and training of individuals and peasant villages. Mainly dedicated to the use of existing sources of environmental assets. (iv) The assessing of the impacts of human activities on the native forests according to this law. (v) The implementation of additional activities to those indicated above, to provide background information, information dissemination, knowledge or resources aimed at the implementation of the objective of this Law recovery (BCN, 2011; Silva-Muñoz, 2012).

In general, this law establishes the management plan for preservation of the native forest, to protect biological richness and ensure the continuation of existing natural forest conditions for the evolution of species and ecosystems. It promulgates standard rules of environmental protection by regulating the cutting of trees around streams, wetlands, on steep slopes and in the vicinity of glaciers (BCN, 2011; Silva-Muñoz, 2012).

7.4. Appendix 4: Organization mission statements considered for the targets

As mentioned before in the previous chapters of my thesis I follow the guidance of Ardron *et al*. (2010) to define the conservation targets used in my analysis, who said they could be set using a country mandate, organization mission statement or an existing legal framework.

In the Maulino coastal forest scenario, I used two conservation targets, a 17% target for the Maulino coastal forest in general and a 90% target for the ruil forest. But in the case of the ruil forest scenarios (Current and Future Models Scenarios) I only used one conservation targets and this was a 17% target.

The 90% target set for ruil forest in the Maulino coastal forest scenario, was set following the recommendation of San Martin (2011, personal communication), who postulated that in order to preserve the ruil, at least 90% of its total area must be protected or conserved. Another reason to choose this target was the critical conservation status of the ruil according to CBD.

With respect to the 17% target, this target was chosen on the basis of two international conservation agreements or frameworks and two local mission statement (Strategic Plans) of the Maule regional government.

The organization mission statement that I considered to define the targets of my research are presented in detail below.

1. Strategic Plan for Biodiversity 2011–2020

This initiative was conducted by the Convention on Biological Diversity (UNEP/CBD 2011). It is a decade long plan for the deployment of actions which aims to stop the disappearance of biodiversity to guarantee that, by 2020, the world' s ecosystems will survive negative influences (climate change and human activities) and that they will sustain the delivery of vital services, thus ensuring the diversity of global life and helping human welfare and the elimination of misery in the world. As part of the Strategic Plan, twenty challenging but achievable targets, also known to as the Aichi Biodiversity Targets, have been adopted (UNEP/CBD 2011).

The Aichi Targets transcend the mere protection of biological diversity and deal with issues of sustainable growth as well. They cover a variety of aspects, from the reduction of the pressures on biological diversity and the integration of nature in several areas, to the promotion of sustainable use and the participation of all in the gains obtained from the utilization of environment, including the biological diversity and ecosystem services. These targets have been decided by the 193 members of the CBD and might support the elaboration of Sustainable Development Goals SDG (UNEP/CBD 2011).

Aichi's biodiversity targets have been clustered into five key goals, to be accomplished no later than 2020 but in my thesis, I considering just two of them. The two objectives were the strategic objectives C and D:

- Objective C: "Enhancing the state of biological diversity by ensuring that the environment, wildlife and genetic diversity are properly managed and protected". Point 11 stresses:

    - "In 2020, not fewer than 17% of land and interior areas and 10% of marine and coastal zones (i.e., those in particular important for biodiversity and ecosystems), must be conserved through protected area systems administered in an effective and equitable manner, environmentally meaningful, have a good connection and effective and well-managed safeguarding zones systems and use other conservation measures that are integrable with the wider lands and seascapes" (UNEP/CBD 2011).

- Objective D: "Increase the benefits of biodiversity and ecosystem services for all", as the following points stress:

    - Point 14: "Ecosystems that deliver critical amenities such as water, health, well being and livelihood services and that take in consideration all the requirements of the female population, native peoples, grassroots actors and institutions and the impoverished of vulnerable people must be restored and safeguarded by 2020" (UNEP/CBD 2011).

- Point 15: "By 2020, using conservation and restoring at least 15% of degraded lands will contribute to alleviate and respond to climate change while warding off desertification, increasing ecosystem resilience to carbon stocks, and contributing to biodiversity" (UNEP/CBD 2011).

2. Initiative 20x20

"Initiative 20x20" is a Latin-American initiative that supports the Bonn challenge, which is a worldwide endeavor to bring about the rehabilitation of 150 million hectares of cleared and damaged forests by 2020, and 350 million hectares by 2030 (WRI, 2014).

The "Initiative 20x20" is part of the Bonn challenge but this is an agreement that only involves Latin American countries. Chile and the Caribbean strive to change the course of land degradation, restoring 20 million hectares by 2020, of which Chile commits to restore 0.5 million hectares by then (WRI, 2014).

The initiative will provide assistance for natural and assisted replanting of forest as well as the preservation of existing forests and prevented logging as part of a comprehensive restoration effort. Aware of the varying levels of soil deterioration in the area, the initiative will also provide additional assistance to the efforts for restore soil performance through agroforestry, silviculture and other sustainable land use plans (WRI, 2014).

The main purpose of the initiative is to turn South and Center America into a growing green economy while at the same time, preserve the environmental assets located in the region (WRI, 2014). The initiative emphasizes the safeguarding of rare types of flora and fauna, and the enforcement of measures that contribute to the development of local communities (WRI, 2014)

In my study in order to contributed to the restoration of the natives forest propose in this initiative, the reserve networks generated in the climate change scenarios (current and future models scenarios of ruil) can be considered as potential restoration areas for ruil and Maulino coastal forest and in this way contribute to the “Initiative 20x20” (WRI, 2014).

3. Maule Biodiversity Strategy

The Maule Biodiversity Strategy is a Plan of Action created in 2002 by The Chilean National Commission of the Environment, CONAMA, for the Maule region of Chile, which main focus was the protection and preservation of the local Biodiversity (CONAMA, 2002). This strategy plan search for implement and establish an adequate level of official safety for all the relevant ecosystems present in the Maule region (CONAMA, 2002). And it stands out that: "With the elaboration of the strategy and the plan of action presented in the The Maule Biodiversity Strategy, the community, the private companies and the public administration will be able to decide together what they want to protect and the reasons for it, and actively cooperate in that objective” (CONAMA, 2002).

The specific objectives and priorities considered by this strategy plan were (i) Conserve the native regional biodiversity through the maintenance of the sustainability of the ecosystems and their species. (ii) Preserve and recover species threatened with extinction. (iii) Protect areas of greatest ecological value. (iv) Preserve intraspecific variability. (v) Improve the level of knowledge about regional Biodiversity. (Vi) Sensitize and educate the community regarding the importance of the region's biodiversity and its threats. (vii) Maintain an information system with up-to-date databases that can be accessed by all the stakeholders involved in the conservation of the Maules’s Region biodiversity (CONAMA, 2002).

With respect to the areas of action that cover this strategy in order to meet the previous mentioned specific objectives, The Maule Biodiversity Strategy cover nine areas of action. (i) On-site protection and preservation of biodiversity. (ii) Ex situ preservation of biodiversity. (iii) Conservation and fair use of endemic genetic resources. (iv) Control of exotic invaders species. (v) Promotion of research into the preservation and sustained utilization of biodiversity. (Vi) Recovery of ecosystems and endangered species. (vii) Education and public sensitization creation about the maintenance, fair and a more efficient utilization of the environment. (viii) Access to information for the protection and fair employed of the environment. The development of biosecurity capabilities. (ix) Sustainable use of environmental assets in the agrarian, forestry, aquaculture, fishing and tourism sectors of the Maule region (CONAMA, 2002).

4. Regional Development Strategy Maule 2020

The regional development strategy Maule 2020 was the fourth document considered to define the conservation targets used in may study (Regional Government of Maule, 2008).

Specifically, here I have considered the pillar 3 of the regional development strategy Maule 2020, wich stated: “Territory, Infrastructure and the Environment: Towards sustainable land use planning with human settlements that improve the quality of life of their inhabitants”. I concider this point as guidance because it is the only Pillar that consider the environmental aspect in this strategic plan, since this regional development strategy has five pillars for the development of the Maule region in general: (i) Social Dimension, (ii) Regional Economy, (iii) Territory, Infrastructure and Environment, (iv) Identity and Culture and (v) Governance and Regional Governance (Regional Government of Maule, 2008).

The main idea behind pillar 3 of the Regional Development Strategy Maule 2020, was to “Contribute to the environmental sustainability of Maule region, positioning itself as a clean Region with respect for nature” and that involve the safeguarding and restoration of the existing biological resources, ecosystems and biological diversity that are present in the Maule region (Regional Government of Maule, 2008).

In addition, the strategy plan stresses in this pillar the importance of generate and implement a plan to evaluate and correct the main environmental damages of the Maule region. With special emphasis on the recovery of soil fertility, native reforestation, erosion control, urban air cleaning and protection and recovery of species with conservation problems or with a critical concervation status (as is the case for the Maulino coastal forest and for the ruil) (Regional Government of Maule, 2008). Furthermore, this plan is seeking to generate a policy that makes possible the recognition and maintenance of the biodiversity present in the ecosystems of the Maule Region by law (Regional Government of Maule, 2008).