Ciencia e Investigación AGRARIA

Cien. Inv. Agr. 39(3):521-531. 2012
www.rcia.uc.cl
FORESTRY

RESEARCH PAPER

Current and potential distribution areas for *Nothofagus alessandrii*, an endangered tree species from central Chile

Rómulo Santelices[1], Fernando Drake[2], Carlos Mena[3], Rodrigo Ordenes[4], and Rafael M. Navarro-Cerrillo[5]

[1]Facultad de Ciencias Agrarias y Forestales, Universidad Católica del Maule. Casilla 617, Talca, Chile.
[2]Facultad de Ciencias Forestales, Universidad de Concepción. Casilla 160-C, Correo 3, Concepción, Chile.
[3]Facultad de Ciencias Forestales, Universidad de Talca. Calle Dos Norte 685, Talca, Chile.
[4]Departamento Medio Ambiente, Pacific Hydro. Camino Coya s/n, Rancagua, Chile.
[5]Facultad de Agronomía y Montes, Universidad de Córdoba. Carretera Nacional IV, km 396, 14071 Córdoba, España.

Abstract

Santelices, R., F. Drake, C. Mena, R. Ordenes, and R.M. Navarro-Cerrillo. 2012. Current and potential distribution areas for *Nothofagus alessandrii*, an endangered tree species from central Chile. Cien. Inv. Agr. 39(3): 521-531. *Nothofagus alessandrii* ("ruil") is an endangered species native to the Maule Coastal Forest of central Chile. Previous studies have demonstrated that the current distribution of this species and rates of deforestation and fragmentation present a serious threat to the species. To address this threat, spatial and temporal variation in remnant "ruil" forest cover was analyzed for the period from 1991 to 2008. Using aerial photography and geomatic tools, the state of "ruil" forests cover in 1991 was compared to the "ruil" forests cover in 2008 and with this information, the potential distribution area of this species was calculated. The results demonstrate that the current area of "ruil" forest is approximately 314 ha, with a net loss of 42 ha (12% of the forested area) over the 17-year study period. The annual deforestation rate for "ruil" during this period was 0.74%, a value that is significantly lower than that reported just two decades ago. Taken together with the fact that the majority of "ruil" forests belong to large private companies, with an additional 15% protected by the Chilean government, the conservation status of "ruil" forest has become less critical, at least in the short term. In addition, the habitat model from this study showed that there is a large area of 9,841 ha within which "ruil" forests could be greatly expanded through active forest restoration.

Key words: Deforestation, forest tree, *Nothofagus alessandrii,* potential distribution, "ruil", spatial distribution.

Introduction

The central zone of Chile has been subjected to constant anthropogenic pressure, especially during the last two centuries. As a consequence, the region has experienced a drastic reduction in surface forest cover (Donoso and Lara, 1996). One of the most critical examples is what has happened to *Nothofagus alessandrii* Espinosa ("ruil"), an endemic and endangered species of central Chile (Benoit, 1989). Its natural distribution is restricted to shaded slopes in the Coastal Range of the Maule region in central Chile (San Martín *et al.*, 1991;

Received November 3, 2011. Accepted May 9, 2012.
Corresponding author: re.santelices@gmail.com

San Martín *et al*., 2006). More than 10 years ago, "ruil" forest area scarcely covered 350 ha and was highly fragmented (Bustamante and Grez, 1995; Bustamante and Castor, 1998). The fragments were integrated within a forest matrix of *Pinus radiata*, a very aggressive species in ecological terms (Bustamante and Simonetti, 2005), which has successfully invaded *N. alessandrii* forests (Bustamante and Castor, 1998; Bustamante and Simonetti, 2005). "ruil" is not only considered the most endangered tree in Chile (Hechenleitner *et al*., 2005), but its rate of deforestation has also been estimated to be one of the highest on the globe (Bustamante and Castor, 1998).

The decline of *N. alessandrii* forests is one of the clearest examples in Chile of environmental degradation as a result of anthropogenic activity. Habitat fragmentation and loss of biodiversity caused by deforestation are the main threats to this ecosystem (Bustamante and Grez, 1995). Therefore, it is urgent to study and manage the remaining native vegetation in the area where this species is naturally distributed, an area that contains 25 biodiversity hotspots as declared by the conservation community (Myers *et al*., 2000). Conservation of this highly fragmented ecosystem should be considered a priority. In this urgent context, it is important to determine and assess the surface cover and current status of the remaining forest stands. In addition, it is important to estimate the potential distribution area for this species to find ways to increase its current surface cover. Information about species distribution, forest health, and opportunities for restoration is needed to design natural resource management systems that will allow for conservation of natural resources, thereby helping to guarantee the sustainability of communities and their environments.

Conservation and landscape restoration are two of the main objectives of forest planning. To achieve these objectives, high-quality spatial information about land cover is necessary (Felicísimo, 2003; Navarro-Cerrillo et al., 2011). Predictive models are important tools that provide information that can be used for species conservation (Pearce and Ferrier, 2000). These models can be used to achieve objectives such as biodiversity conservation and reduced fragmentation of forests by facilitating decision-making for conservation planning and restoration management (Navarro-Cerrillo *et al*., 2006). One example of a predictive model is a map of potential species distributions, which are theoretical zones defined by a hypothetico-deductive process (Navarro-Cerrillo et al., 2011) that are created by combining the use of GIS with multivariate mathematical models. The models can be generated through diverse techniques such as logistic regression, non-parametric classification and regression trees (CART) or multivariate adaptative regression splines (MARS) (Felicísimo, 2003). Currently, one of the most widely used algorithms for developing maps of potential distribution is the Maxent model® (www.maxent.sourceforge.net, Princeton University and AT&T Labs, Princeton, NJ, USA, 2004). The advantage of the algorithm used in this open-source software is that it only requires information about the current distribution of the species, not information about areas outside the current distribution. The model also accepts the use of both qualitative and quantitative variables, provides the response curves of the species for different environmental variables, and incorporates importance values for each variable into the predicted distribution for the species (Phillips et al., 2006).

To date, no studies have been carried out proposing potential distribution maps for *N. alessandrii*. The objectives of this study were to determine the surface cover and rate of deforestation of *N. alessandrii* forests and utilize this information to identify potential distribution areas using the Maxent model®.

Materials and methods

Study area

Nothofagus alessandrii has a very limited natural distribution, restricted to a narrow band that extends less than 100 km in latitude along the Coastal Range of the Maule region, between 100 and 450 m above sea level (San Martín *et al.*, 1991). *N. alessandrii* is part of the Bosque Maulino Costero (Maule's coastal forest) and tends to form stands in shady exposures. The geographic locations and climatic conditions of known stands of *N. alessandrii* are presented in Figure 1 and Table 1.

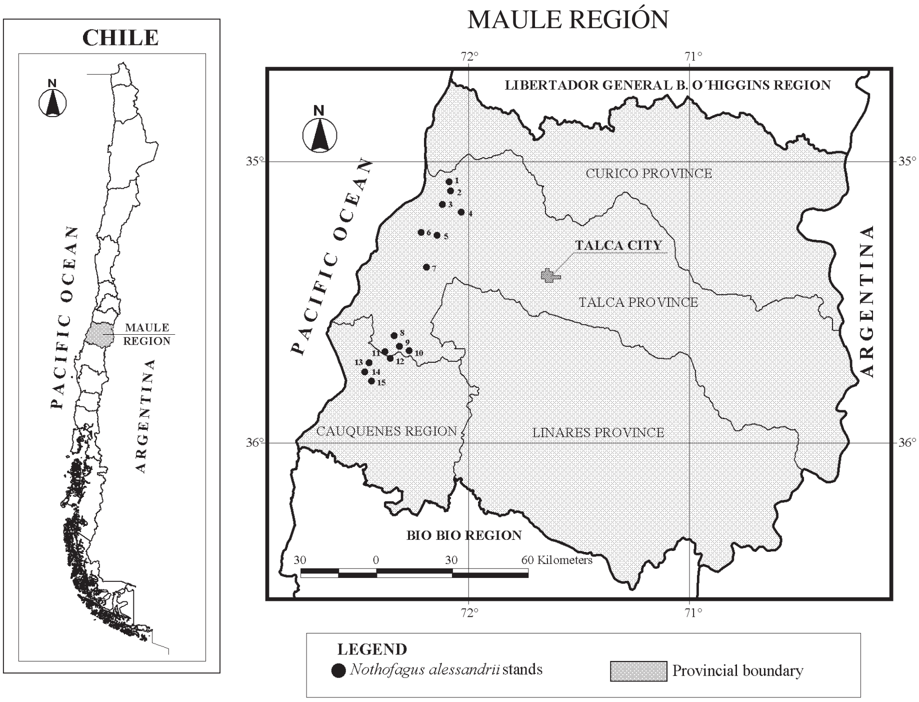

Figure 1. Spatial distribution of *Nothofagus alessandrii* forests in the Maule region of central Chile.

Table 1. Geographic locations and climatic conditions of original *Nothofagus alessandrii* fragments in the Maule region of central Chile (San Martín *et al.,* 1991; Santibáñez and Uribe, 1993).

Locality	Latitude (S)	Longitude (W)	Altitude (m)	Average annual rainfall (mm)	Average annual temperature (°C)
1. Huelón	35º 05'	72º 04'	230	708	13.1
2. Catorce vueltas	35º 06'	72º 04'	100	709	13.9
3. Lo Ramírez	35° 10'	72° 06'	385	708	13.1
4. Macal	35º 09'	72º 08'	150	708	13.1
5. Coipué	35° 16'	72° 08'	412	708	13.1
6. Agua Buena	35º 16'	72º 09	300	708	13.2
7. Quivolgo	35° 23'	72° 12'	262	709	13.9
8. El Fin	35º 37'	72º 21'	250	926	13.3
9. Porvenir	35º 40'	72º 19'	300	926	13.3
10. La Montaña	35º 40'	72º 18'	350	926	13.3
11. El Desprecio	35° 40'	72° 20'	344	926	13.3
12. Suc. Espinoza	35º 39'	72º 20'	380	926	13.3
13. Bellavista	35° 40'	72° 21'	400	926	13.3
14. La Bodega	35º 47'	72º 28'	200	837	11.7
15. El Corte	35° 50'	72° 30'	280	837	11.7

Estimation of the surface cover and distribution of Nothofagus alessandrii

Topographic maps (1:50,000) produced by Chile's Instituto Geográfico Militar (IGM) were used as cartographic base maps for Curepto, Pichamán, Empedrado, and Cauquenes. Information from an agro-climatic map prepared by Santibáñez and Uribe (1993) was also utilized. For stand delimitation, non-metric aerial photographs (1:10,000) were used. The aerial photographs were provided by the Corporación Nacional Forestal (CONAF) from local flights carried out in March of 2008 and in 1991. ArcGIS version 9.1 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA, 1997) and ArcView version 3.2 (Environmental Systems Research Institute (ESRI), Redlands, CA, USA, 2005) were used for geographic referencing and analysis of the photographs. Vector mapping used the Provisional South American Datum of 1956, Zone 19 and incorporated the following features: i) a road network of existing roads including highways, secondary roads, tracks, etc., represented by solid lines; ii) a hydrographic network of existing waterways including rivers, canals, and estuaries, etc., represented by differing solid lines; iii) populated centers, including areas inhabited by small rural communities that make a living from various activities in the study area; iv) soil use capacity, a soil classification based on land use and vegetation development; v) slope; vi) topographic exposure (aspect); and vii) agro-climatic districts, a classification of the land according to climatic parameters such as rainfall, temperature, and humidity.

Using photo interpretation, stands of *N. alessandrii* were identified based on shape, color, shading, and texture of foliage. According to López and García (1968), tonal characteristics, rather than absolute colors, are useful for species differentiation. The species in this study was a deciduous tree that had started the process of leaf abscission a few weeks before other tree species present in the area (San Martín *et al.*, 2006). At the time that aerial photographs were taken in March 2008, its foliage had already turned a yellowish color. In terms of accuracy, the average scale at which polygons were interpreted and digitalized was 1:2,500. In stands where there was uncertainty about species identification, photo interpretation was verified in the field using a Garmin GPS system. Once the current surface cover and cover in 1991 had been determined (by means of photo interpretation), the rate of deforestation was estimated according to the algorithm given by Puyravaud (2003):

$$r = \frac{100}{t2 - t1} * \mathrm{Ln}\left(\frac{A2}{A1}\right)$$

where r is the annual deforestation rate (%) and A1 and A2 represent the forest area (ha) at time t1 and t2 (years), respectively.

Estimation of the potential distribution area of Nothofagus alessandrii

N. alessandrii is only distributed in a restricted area of the Coastal Range in the Maule region. Therefore, to estimate the potential distribution area, a specific study area was selected within the region. A digital topographic map (DTM) was developed using slope distribution covering, and aspect was obtained from the map and recorded as eight cardinal points. Subsequently, the topographic map and digital maps of other areas of surface cover were cropped to the boundaries of the study area and converted to raster format. The cell size used was 50 m due to the distance between the contours on the IGM maps. Using these data and the Maxent® algorithm (Maxent 3.1.0, Maximum Entropy, http://www.maxent.sourceforge.net), maps were developed estimating the potential cultivation area for *N. alessandrii* within its natural range.

A total of 305 data points representing species presence were used as the dependent variable, corresponding to the number of polygons identified in the spatial distribution of *N. alessandrii* forests. The independent variables initially used in the model were: i) Climatic variables: temperature (maximum, minimum, and mean annual), mean annual precipitation, mean annual relative humidity, annual water deficit, and annual potential evaporation; ii) Edaphic variables: drainage, surface texture, soil depth, permeability, soil acidity (pH), and soil stoniness; and iii) Topographic variables: slope and aspect.

As a first step, values were determined for all of the above variables for the "ruil"'s natural range. Variables that had at least two levels were incorporated into the model and the Maxent® algorithm (Phillips *et al.*, 2006) was tested. Next, using an iterative process, the most significant variables for estimating the potential distribution area for "ruil" cultivation were selected, using a probability of occurrence greater than 70%. Model performance was evaluated using the Maxent® software by analyzing the contribution of each variable in addition to sensitivity and specificity rates.

Results

Current distribution of Nothofagus alessandrii

The current area of "ruil" forest is just over 314 ha (Table 2), with forest stands occurring in four communities in 15 locations, for a total of 305 stands with an average stand size of 1.03 ha. The largest forest remnant is in the community of Empedrado in the province of Talca. The fragmented distribution of "ruil" forests is clear: most of the stands have no spatial connectivity to other stands and are surrounded by plantations of *P. radiata*, especially near the towns of Empedrado (35°35'27" S, 72°16'39" W) and Constitución (35°19'54" S, 72°24'42" W). The forest area protected by the Chilean government in the Reserva Nacional Los "ruil"es measures 49.3 ha and is surrounded by plantations of *P. radiata* in the two adjacent sectors, El Fin and El Corte. The change in "ruil" forest cover from 1991 to 2008 was 42 ha, meaning that there was an annual deforestation rate of 0.74% during that period.

Table 2. Distribution of *Nothofagus alessandrii* forests in the Maule region of central Chile in 1991 and 2008.

Commune	Locality	Surface (ha) 1991	Surface (ha) 2008
Curepto	Huelón	10.6	7.6
	Catorce Vueltas	4.0	3.6
	Lo Ramírez	47.0	46.3
Constitución	Macal	14.8	15.1
	Coipué	2.5	2.6
	Agua Buena	1.4	1.5
	Quivolgo	5.9	5.2
	El Fin	9.4	10.2
Empedrado	El Porvenir	52.0	43.2
	La Montaña	62.7	62.8
	El Desprecio	64.8	39.2
	Suc. Espinoza	0.4	0.7
	Bellavista	9.9	7.0
Chanco	La Bodega	2.7	2.7
	El Corte	68.2	66.6
Total		356.3	314.3

Potential distribution of Nothofagus alessandrii in the Coastal Range of the Maule region

The potential distribution of *N. alessandrii* is 9,841 ha (Table 3 and Figure 2). However, the current land use in the deforested area is mainly tree plantations on privately owned land. The most important variables in the potential distribution model are maximum annual mean temperature, altitude, and mean annual precipitation. Together, these variables explain 87% of the model results (Figure 3). Analysis of the contribution of individual variables shows that slope as a single variable is not useful for predicting the potential distribution of *N. alessandrii* (Figure 4). Furthermore, when any given variable is omitted from the model, the strength of the model does not significantly decrease. In other words, the addition of a single variable provides little information not contained in the other variables (Figure 4).

The developed model explains the potential distribution of "ruil" with three basic variables: maximum annual temperature (58%), altitude (16%), and mean annual precipitation (12%) (Figure 3). According

Table 3. Current and potential distribution of *Nothofagus alessandrii* forests in the Coastal Range of central Chile.

	Surface (ha)	
Commune	Current	Potential
Curepto	72.6	-
Constitución	9.3	2,015
Empedrado	163.1	5,365
Chanco	69.4	1,363
San Javier	-	865
Pelluhue	-	233
Total	314.3	9,841

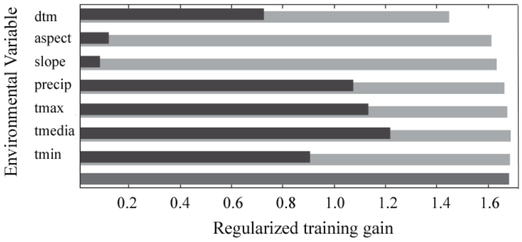

Figure 4. Jackknife test of variable importance in the potential distribution model of *Nothofagus alessandrii* in the Coastal Range of the Maule region, Chile (dtm= digital topographic map, aspect= aspect, slope= slope, precip= precipitation, tmax= annual maximal temperature, tmedia= annual average temperature, tmin= annual minimal temperature). Without variable ■, with only variable ■, with all variables ■.

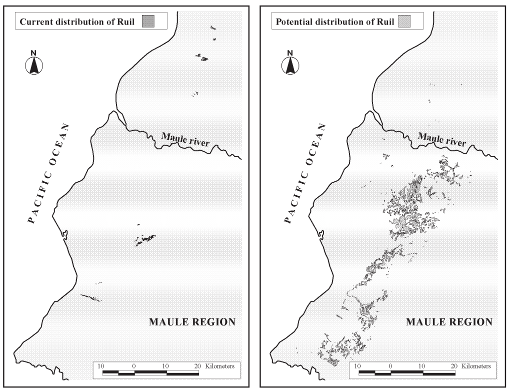

Figure 2. Current and potential spatial distributions of *Nothofagus alessandrii* forests in the Coastal Range of the Maule region, Chile.

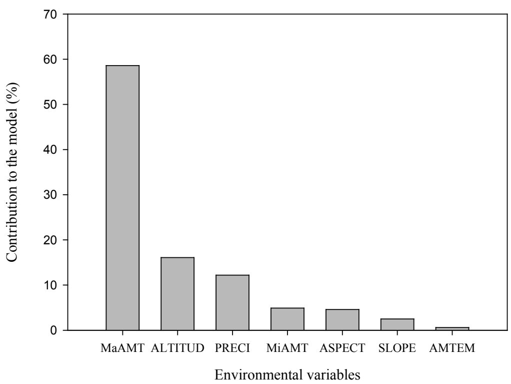

Figure 3. Relative contributions of the variables to the potential distribution model of *Nothofagus alessandrii* in the Coastal Range in the Maule region-Chile (MaAMT= maximum annual mean temperature, ALTITUD= altitude, PRECI= mean annual precipitation, MiAMT= minimum annual mean temperature, ASPEC= aspect, SLOPE= slope, AMTEM= annual mean temperature).

to the index of sensitivity generated by Maxent®, which refers to the proportion of presence data points correctly predicted, the model has a low omission error rate (Figure 5). Similarly, and more importantly, the level of specificity (also produced by the program) shows a low error rate in the proportion of correctly predicted absence data points. The high proportion of correctly classified events (0.954 out of a maximum of 1) indicates that the model has good predictive value.

Discussion

In 17 years, the area of *Nothofagus alessandrii* forest declined by 42 ha, and forest cover decreased by 11.8% with respect to the area of "ruil" forest cover in 1991. This decrease is due to anthropogenic causes, and in some cases, the disappearance of whole polygons was observed. However, in certain sectors, the amount of "ruil" surface cover increased not because the number of trees had increased through reforestation but because of the ability of *N. alessandrii* to regenerate by sprouting from the base (Donoso, 1993; San Martín *et al.*, 2006). In 1991, there was no evidence of "ruil" in these sectors, which was certainly due to logging, but over time, the trees recovered as a result of natural regeneration processes. The annual deforestation rate of "ruil" between 2008 and 1991 was 0.74%, which

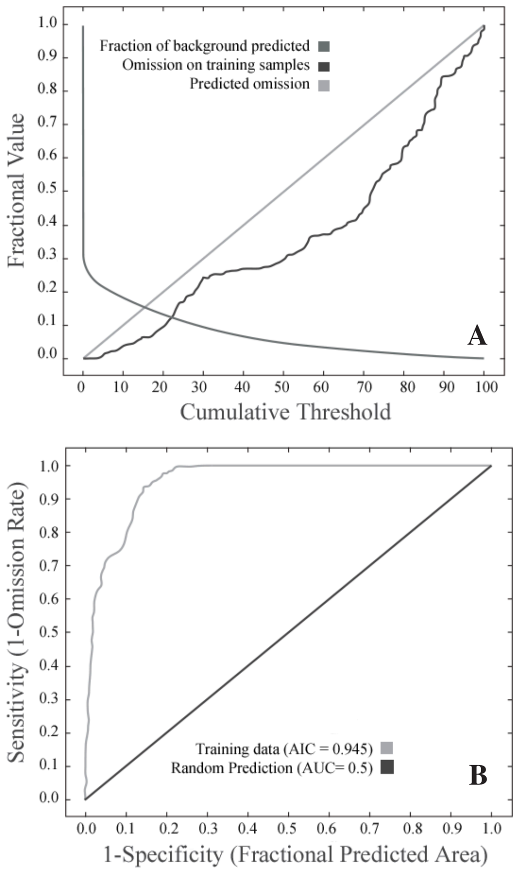

Figure 5. A: Analysis of the omission rate and predicted area as a function of the cumulative threshold, by mean Maxent®. B: Analysis of the predictive capacity of the potential model of *Nothofagus alessandrii* by the mean of the sensitivity index given by Maxent® (AUC= area under curve).

is significantly lower than the 8.15% reported by Bustamante and Castor (1998), who evaluated the status of these forests in the early 1980s. According to information provided by the FAO, the highest deforestation rate worldwide (4.5%) is found in certain African countries, and the global rate is 0.04% (FAO, 2009). Based on the results of this study, the current rate of deforestation of *N. alessandrii* forests is not one of the highest reported globally, as it was at the time of the Bustamante and Castor (1998) study.

There are five sectors where "ruil" surface cover is greater than 39 ha (a total of 258.2 ha across the five sectors, representing 82.2% of the total "ruil" forests cover), and most of these forests are in the hands of the private sector, which could be considered an advantage because private ownership reduces the pressure on forest resource use. For example, there was a recent acquisition of a property in Lo Ramirez by an electric power company. As part of an environmental mitigation program, the company has made a commitment to the Chilean environmental authorities to carry out conservation and restoration activities in 46.3 ha of "ruil" forest. The stand with the largest area (35.6 ha) can be found in this sector, which will allow for future evaluation of the outcomes of this initiative.

Of the 15 localities where "ruil" forests are present, eight localities have less than 10 ha each (a total of 30.8 ha, equivalent to 9.8% of the total forest cover in the study area). The situation is extreme in areas such as Catorce Vueltas, Coipué, Agua Buena, Sucesión Espinoza, and La Bodega, where there are fewer than 4 ha per locality, and the size of the fragments making up the forest cover is less than 1 ha. Another risk factor that should be taken into account is that these forests are located within a matrix of plantations of *P. radiata*, a species that successfully invades "ruil" forests (Bustamante and Castor, 1998; Bustamante and Grez, 1995). In addition to the risk that the small size of these forests will affect the future status of the species, a fragmented distribution of isolated forest patches due to geographic diversity was observed. From a genetic standpoint, the isolation and spatial separation of forest fragments could limit pollen mobility among populations of trees from different stands. This could result in the pollination or crossing of mature individuals within the same population, which carries the risk of endogamy and reduced genetic variability within populations. If low seed viability (Olivares *et al.*, 2005; Santelices *et al.*, 2009) is interpreted as the result of endogamy, this process may already be happening. Most of these forests belong to smallholders, which could be disadvantageous because pressure on forest resources still exists despite legal protections that prohibit cutting the forest. In this case, Chilean governmental institutions must ensure that the goals outlined in the policy for the conservation of natural resources and their international commitments are met. The government should take action to acquire the forest patches or to compensate the forest owners, many of whom are poor, for the environmental services generated by *N. alessandrii* forests. According to Olivares *et al*. (2005) and public information about the acquisition of property in Lo Ramírez by a private company, nearly 40% of the forest resource remains in the hands of smallholders.

"ruil" forests protected by the state are located in the Reserva Nacional Los "ruil"es in the sectors of El Corte and El Fin. The forest fragments are spatially separated and total 49.3 ha, representing more than 15% of the forest resource. Therefore, the efforts made by state institutions, mainly CONAF, to increase the protected area of forests of this species should be appreciated. An evaluation of the forest area that is under the administration of the Chilean government (Sistema Nacional de Areas Silvestres Protegidas del Estado, SNASPE) shows that the status of the forest is not critical. However, the forest property (38.9 ha) located in the southernmost provenance of El Corte may represent a different tree population than the rest of the forest (Santelices *et al*., 2009). Therefore, there is an urgent need to incorporate other sectors into the system of areas protected by the State, especially those sectors where the forest patches cover a very small surface area.

In the model developed using Maxent®, mean annual maximum temperature was the most significant contributing variable to the model (over 58%), followed by altitude and mean annual precipitation. These results indicate that *N. alessandrii* does not tolerate high temperatures and that its potential distribution is restricted to the coastal lands of the Coastal Range in the Maule Region, characterized by higher levels of precipitation, and mild temperatures due to the moderating effect of the Pacific Ocean. In contrast, the areas eliminated by the model from the potential distribution of the species were the eastern lands of the Coastal Range, which are characterized by higher temperatures and lower rainfall, factors that together limit crop cultivation. Although "ruil" is only found on shaded slopes (San Martín *et al*., 2006), aspect was not one of the more significant variables in the model and was of little use in explaining the distribution of *N. alessandrii* forest.

N. alessandrii tends to occur in specific areas, which is reflected in both its current and potential distribution. The distribution pattern of "ruil" is conditioned by environmental variables. According to the potential distribution model, maximum temperature plays a fundamental role. In addition, "ruil" is known for its tendency to take refuge in shady spots (San Martín *et al*., 2006), which is consistent with maximum temperature being the main limiting factor. According to the developed model and the autoecology of the species (San Martín *et al*., 2006), the remaining "ruil" stands tend to be concentrated in the area between the rivers Maule and Curanilahue, which is only one of the two areas that characterize their natural spatial distribution.

In general, the entire Coastal Range of the Maule region has been subjected to strong anthropogenic pressure that has negatively impacted natural resources, especially native forests (Donoso and Lara, 1996). According to Donoso and Landaeta (1983), in the early nineteenth century some *N. alessandrii* forests were cut to make way for crops and after abandonment of the land, the forests were regenerated through coppicing. From an evolutionary standpoint, *N. alessandrii* is an ancient species (San Martín *et al*., 2006) that originally developed under more favorable environmental conditions, such that its current niche is very limited and fragmented. Thus, forests that might have developed on sunny slopes may not have regenerated under the local conditions. There is no doubt that the distribution of *N. alessandrii* has been shaped not only by environmental variables but also by historical human forces which limited the spread of the species to other sites. Interactions among environmental variables, especially climatic ones, and anthropogenic influences have conditioned the spread of "ruil", relegating the forest to specific areas and resulting in a high degree of forest fragmentation.

Species distribution models created with GIS are useful tools for predicting the potential distribution of a species and helping to make tentative decisions about conservation (Naoki *et al.*, 2006). Limiting factors in the development of the model in this study included environmental homogeneity in the study area (only a few climatic, edaphic, and topographic variables showed enough variation to be selected for the model) and the quality of the information available (cell size was limited to 50 m due to the distance between topographic contours). Nonetheless, the model can be used as a tool to increase forest cover and improve the conservation status of *N. alessandrii*.

Depending on the selected algorithm, it is possible to build significantly different predictive models for the same situation (Naoki *et al.*, 2006). Therefore, it is advisable to compare the efficiency and accuracy of the proposed model with others (*e.g.,* MARS or CART models) (Navarro-Cerrillo *et al.*, 2011). These models should be evaluated using more detailed information about *N. alessandrii* habitat.

Acknowledgments

Funding for this study was provided by the Universidad Católica of Maule. In addition, we want to thank Ing. Alexis Villa (Corporación Nacional Forestal, Ministerio de Agricultura de Chile), and we give additional thanks to the “Diversidad funcional y resiliencia del bosque mediterráneo” (DIVERBOS) project.

Resumen

Santelices, R., F. Drake, C. Mena, R. Ordenes, y R.M. Navarro-Cerrillo. 2012. Distribución espacial y áreas potenciales de cultivo para *Nothofagus alessandrii*, una especie en peligro de extinción de Chile Central. Cien. Inv. Agr. 39(3): 521-531. *Nothofagus alessandrii* Espinosa ("ruil"), es una de las especies características del Bosque Maulino costero de la zona central de Chile, que se encuentra en peligro de extinción. Se ha descrito que su patrón de distribución, deforestación y fragmentación la podrían llevar a la desaparición. Por ello, se realizó un análisis comparativo de la variación temporal y espacial de estos bosques entre los años 1991 y 2008. Por medio de fotografías aéreas y herramientas de geomática, se determinó el área boscosa en esos dos periodos y, a partir de esa información, se estimó la superficie potencial de la especie. Los resultados muestran que el área actual cubierta por bosques de "ruil" es de ~314 ha, lo que ha significado una disminución de 42 ha en 17 años (12% de la superficie boscosa). La tasa de deforestación anual en este periodo fue de 0,74%, significativamente menor a la reportada hace dos décadas, lo que junto a la concentración de los bosques de mayor superficie en grandes empresas privadas y al 15% protegido por el Estado de Chile, permiten visualizar, al menos en el corto plazo, una situación menos crítica para la conservación de la especie. Existe una superficie potencial, de acuerdo al modelo desarrollado, de 9.841 ha con las que se podría incrementar el recurso a través de la restauración forestal.

Palabras clave: Deforestación, distribución espacial, especie forestal, distribución potencial, *Nothofagus alessandrii,* "ruil".

References

Benoit, I. 1989. Libro rojo de la flora terrestre de Chile (Primera parte). Editorial de la Corporación Nacional Forestal (CONAF). Santiago, Chile. 157 pp.

Bustamante, R.O., and O. Grez. 1995. Consecuencias ecológicas de la fragmentación de los bosques nativos. Ambiente y Desarrollo 11:58-63.

Bustamante, R.O., and C. Castor. 1998. The decline of an endangered temperate ecosystem: the "ruil" (*Nothofagus alessandrii*) forest in central Chile. Biodiversity and Conservation 7:1607-1626.

Bustamante, R.O., and J. Simonetti. 2005. Is *Pinus radiata* invading the native vegetation in Central Chile? Demographic responses in a fragmented forest. Biological Invasions 7:243-249.

Donoso, C. 1993. Bosques templados de Chile y Argentina. Variación, estructura y dinámica. Editorial Universitaria. Santiago, Chile. 484 pp.

Donoso, C., and E. Landaeta. 1983. "ruil" (*Nothofagus alessandrii*), a threatened Chilean tree species. Environmental Conservation 10:159-162.

Donoso, C., and A. Lara. 1996. Utilización de los bosques nativos en Chile: pasado, presente y futuro. *In*: J. Armesto, C. Villagrán, M.K. Arroyo (eds.). Ecología de los bosques nativos de Chile. Editorial Universitaria. Santiago, Chile. p. 363-388.

Felicísimo, A. 2003. Uses of spatial predictive models in forested areas territorial planning. CIOT 2003, IV International Conference on Spatial Planning. Zaragoza, Spain. 15 pp.

FAO. 2009. Situación de los bosques del Mundo 2009. Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO). Roma. 158 pp.

Hechenleitner, P., M. Gardner, P. Thomas, C. Echeverría, B. Escobar, P. Brownless, and C. Martínez. 2005. Plantas amenazadas del centro-sur de Chile. Distribución, conservación y propagación. Universidad Austral de Chile y Real Jardín Botánico de Edimburgo. Valdivia, Chile. 188 pp.

López, F., and García V. 1968. Aplicación de la fotografía a los proyectos de restauración hidrológico-forestal. Ministerio de Agricultura, Dirección General de Montes, Caza y Pesca Fluvial, Instituto Forestal de Investigación y Experiencias. Madrid, España. 163 pp.

Myers, N., M. Mittermeier, C. Mittermeier, G. Da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Naoki, K., M. Gómez, R. López, M. RI, and J. Vargas. 2006. Comparación de modelos de distribución de especies para predecir la distribución potencial de vida silvestre en Bolivia. Ecología en Bolivia 41:65-78.

Navarro-Cerrillo, R.M., A. Lara-Fernández, P. Blanco-Oyonarte, C. Calzado-Martínez, J. López-Quintanilla, A. Fernández-Cancio, J.R. Guzmán-Alvarez, and R. Sánchez-Salguero. 2006. Aproximación a la definición del hábitat fisiográfico del *Abies pinsapo* Boiss. en Andalucía. Investigación Agraria Sistemas y Recursos Forestales, Fuera de serie: 137-152.

Navarro-Cerrillo, R.M., J.E. Hernández-Bermejo, and R. Hernández-Clemente. 2011. Evaluating models to assess the distribution of *Buxus balearica* in southern Spain. Applied Vegetation Science 14:256-267.

Olivares, P., J. San Martín., and R. Santelices. 2005. "ruil" (*Nothofagus alessandrii*): Estado del conocimiento y desafíos para su conservación. Comisión Nacional del Medioambiente (CONAMA). Talca, Chile. 55 pp.

Pearce, J., and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133:225-245.

Phillips, S., R. Anderson, and R. Schapired. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

Puyravaud, J. 2003. Standardizing the calculation of the annual rate of deforestation. Forest Ecology and Management 177:593-596.

San Martín, J., R. Santelices, and R. Henríquez. 2006. *Nothofagus alessandrii* Espinosa, "ruil". Familia: *Fagaceae*. *In*: C. Donoso (ed.). Las especies arbóreas de los bosques templados de Chile y Argentina: Autoecología. Marisa Cuneo Ediciones. Valdivia, Chile. p. 390-400.

San Martín, J., V. Mourgues, A. Villa, and C. Carreño. 1991. Catastro actualizado de la distribución y estado de conservación de los bosques de "ruil" en la VII Región. Informe Proyecto Investigación y Desarrollo Forestal CHI/89/003. Editorial de la Corporación Nacional Forestal (CONAF). Talca, Chile. 30 pp.

Santelices, R., R.M. Navarro-Cerrillo, and F. Drake. 2009. Caracterización del material forestal de reproducción de cinco procedencias de *Nothofagus alessandrii* Espinosa una especie en peligro de extinción. Interciencia 34:113-119.

Santibáñez, F., and J. Uribe. 1993. Atlas agroclimático de Chile, regiones VI, VII, VIII y IX. Ediciones de la Universidad de Chile. Santiago, Chile. 99 pp.