14 Identification of Priority Areas for Conservation in South Central Chile

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Temperate rainforest in the island of Chiloé, Southern Chile. This forest area (Senda Darwin) has been degraded by timber extraction, fire and livestock browsing, but is now recovering gradually as the result of a forest restoration initiative. Photo: Adrian Newton.

There is an increasing awareness in Chile of the need to improve the representation of the country's forest types in the national network of protected areas, and to reduce the impacts of the native forest conversion to other land uses. One promising strategy is to use the principles of systematic conservation planning to identify important areas for the conservation of biodiversity. In this chapter we use information on the vulnerability of native forest to threatening processes and information on the distribution of forest types to systematically determine priorities for biodiversity conservation in the temperate forest region of South Central Chile. We find that the existing reserve network covers approximately 12% of the study region, and that only 53% of the area of native forest estimated to be present before European settlement remained in 1997. Temperate forest is now largely restricted to the upper elevations of the Andean and coastal ranges, within a matrix of pasture, agriculture and plantations. We develop a model of the conversion of native forest to plantations and predict conversion to be more likely in warm and low rainfall areas that are close to towns and roads and on red clay and mixed alluvial soils. We argue that the priority areas for conservation should be currently unprotected areas that are vulnerable to plantation conversion and that, if lost or degraded, will result in conservation targets being compromised. We find the Evergreen forest type to be a priority for conservation owing to its lack of representation in the existing reserve network and the degree to which it has been cleared. By focusing our conservation efforts on areas with the greatest conservation value and the highest likelihood of losing significant portions of this value, we will be able to achieve maximum impact for conservation investments in south central Chile.

Introduction

Despite the ecological importance of Chilean temperate forests (Davis *et al.*, 1994–1997; Wilcox, 1995; Olson and Dinerstein, 1998; Stattersfield *et al.*, 1998), they have experienced a long history of degradation and destruction (Veblen, 1983; CODEFF, 1992; Rozzi *et al.*, 2000; Neira *et al.*, 2002; Chapters 2 and 3) and are presently threatened with conversion to other land uses, particularly plantations of exotic species (Neira *et al.*, 2002). Between 1995 and 1998, about 6,700 ha of native forest in the Los Lagos Region were replaced with plantations (CONAF-CONAMA-BIRF, 1999). Despite these threats, temperate rainforests are poorly represented in the existing protected area network (Neira *et al.*, 2002), which is biased towards the high elevation, volcanic areas of the Andes (Armesto *et al.*, 1998).

There is an increasing awareness in Chile of the need to improve the representation of the country's forest types in the reserve network (Armesto *et al.*, 1996b; Neira *et al.*, 2002) and the adequacy of coverage of the current reserve network has been questioned (Contreras *et al.*, 1979; Ormazábal 1986a, b; Armesto *et al.*, 1998; Rozzi *et al.*, 2000; Pauchard and Villarroel, 2002). For example, Armesto *et al.* (1998) illustrated that more than 90% of the reserved land in the temperate forest region is concentrated at high latitudes (greater than 43° S; specifically in regions XI and XII), outside the richest area of biodiversity (which is between 35.6° and 41.3° S), and in regions with low human population densities and few forest-related industrial developments.

Strategies are therefore required to reduce the impacts of the conversion of native forest to plantations and improve the representativeness of the reserve network within the temperate forest region of Chile. One promising strategy is to use the principles of systematic conservation planning to identify important areas for the conservation of biodiversity. Systematic conservation planning is the process of locating and designing conservation areas (ranging from strict reserves to areas that are important for off-reserve management) to promote the persistence of biodiversity *in situ* and has become the international norm for making spatially-explicit decisions about reserve networks (Possingham *et al*., 2006).

Recent advances in the field of systematic conservation planning have seen the development of principles and tools to design efficient reserve networks that meet pre-determined conservation targets for the biodiversity features of interest (Margules and Pressey, 2000). Approaches to systematic conservation planning recognize that, due to constraints on the amount of land that can be set aside for biodiversity conservation, there is a need to conserve biodiversity in the most efficient manner possible (Pressey *et al*., 1993). It is also recognized that conservation areas must also able to mitigate at least some of the processes that threaten biodiversity. However, while much attention is directed towards understanding the patterns of biodiversity, much less has been given to determining the areas of the landscape most vulnerable to threats. In this context, it is useful to assess the vulnerability of the remaining areas of native forest in south central Chile to help identify their relative urgency for protection (Wilson *et al*., 2005a,b).

When developing a conservation plan, vulnerable areas might be avoided so that objectives are achieved, as far as possible, in areas without liabilities for implementation and management. Considerations of defensibility, or avoiding vulnerable areas, can be especially important if resources are likely to be insufficient for effective management. When implementation of new conservation areas commences, an important consideration in scheduling their implementation will often be their relative vulnerability (Wilson *et al*., 2005a). The more vulnerable areas might receive higher priority, especially if there are few or no alternative areas available to protect the biodiversity features they contain. This strategy can minimize the extent to which conservation objectives are compromised by threatening processes during the frequently protracted process of establishing conservation areas on the ground.

There are a variety of possible approaches available to assess the relative vulnerability of areas to threatening processes. Wilson *et al*. (2005a) reviewed methods that have been used to assess vulnerability and categorized them into four groups based mainly on the types of data employed. The first method uses information on permitted or projected land uses. The second method identifies the extent of past impacts on features and uses these data to predict future impacts on the same features. In some circumstances, the underlying spatial (e.g. proximity to cities and roads) and environmental characteristics (e.g. soil type, slope, climate) believed to have predisposed areas to threatening processes in the past are determined, and areas that are presently unaffected and share these characteristics are then identified. The third method identifies vulnerable areas as those with high concentrations of taxa with high probabilities of extinction, and the final method is based on expert knowledge. All four methods have been employed at a variety of spatial scales and resolutions in countries with differing levels of development, even in those typically regarded as data-poor. The data underpinning many of the methods are globally available and so most methods are applicable anywhere, at least at a coarse scale.

A measure of vulnerability alone is likely to be an insufficient criterion for identifying priority areas for conservation. This is because biodiversity features, such as forest types, are likely to have different spatial options available to achieve their conservation targets. The differences in the relative irreplaceability of areas can be crucial in determining the most urgent areas for conservation. Although some areas might be irreplaceable and therefore require protection in order to meet our conservation targets, a measure of conservation value alone will rarely be sufficient to define conservation priorities. This is because areas of high irreplaceability may not be threatened. Areas of the landscape that are priorities for conservation should be those that are both vulnerable to threatening processes and that, if lost or degraded, will result in targets being compromised (Margules and Pressey, 2000; Pressey and Taffs, 2001).

The objective of this chapter is to use information on vulnerability of native forest to threatening processes and information on the distribution of forest types to systematically determine priorities for biodiversity conservation. As part of this process, areas of native forest that are both highly vulnerable and irreplaceable are identified. These areas (land costs and cultural and societal values being equal) should be the priorities for biodiversity conservation.

The study region for these analyses is located within south central Chile and extends from approximately latitude 39.5°S to 43°S (Valdivia, Osorno and Llanquihue Provinces of Region X), and from the coastal mountain range to the Andes. This region covers approximately 4.2 million ha and contains a large proportion of the remaining temperate forest in southern Chile. The area is presently experiencing high rates of conversion to plantations (Neira *et al*., 2002).

Historical and Current Extent of Native Forest

Prior to European settlement, native forest was estimated to cover 3.7 million ha, which corresponds to 88% of the study region (Lara *et al*., 1999). The remainder was comprised largely of areas devoid of vegetation, such as those subject to volcanic activity. The area of native forest has subsequently been reduced and in 1997 was estimated to occupy 2 million ha (CONAF-CONAMA-BIRF, 1997). Only 53% of the area of native forest estimated to be present before European settlement remained in 1997, with 38% having been converted to pasture and agriculture and 6% converted to plantations.

Temperate forest is now largely restricted to the upper elevations of the Andean and coastal ranges. Extensive areas of native forest in the Central Valley between the coastal and Andes ranges have been converted to other land cover types (Fig. 14.1).

Prior to European settlement, the native forest in the study region was comprised of seven types (following the classification scheme of Neira *et al.*, 2002; see Appendix). Small areas of Guaitecas Cypress (52 ha) and sclerophyllous forest (1,726 ha) have since established in the study region. Many of the forest types have been reduced in extent (Fig. 14.2). Prior to European settlement, the forest types that had the greatest coverage were Evergreen, Coigue–Raulí–Tepa/Roble–Raulí–Coigue and Alerce. These three types accounted for 3.25 million ha, or 87% of the native forest cover. Proportionally,

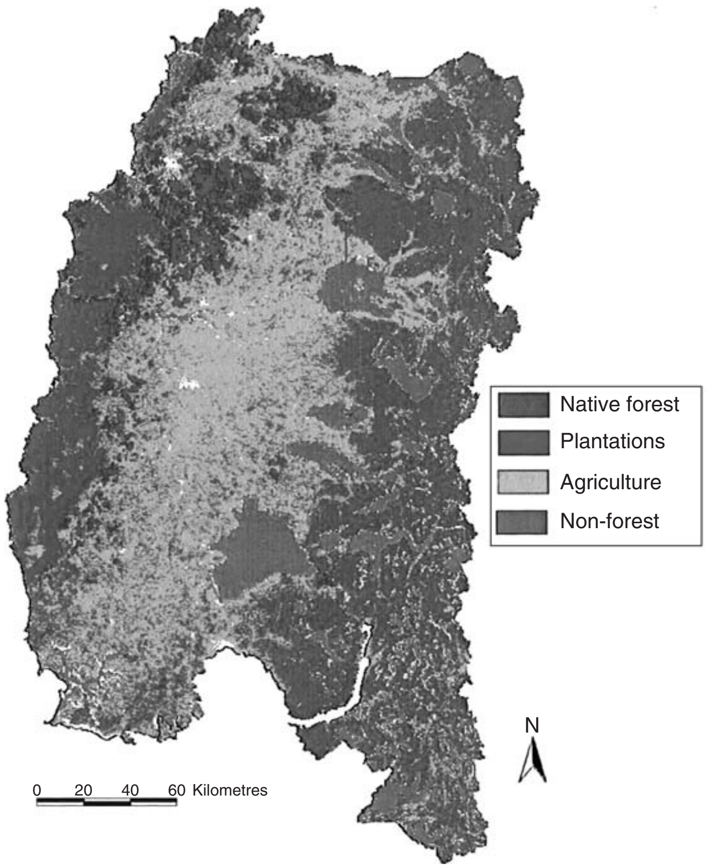

Fig. 14.1. The spatial extent of the major land cover types in 1997. Native forest is restricted to the coastal range (western portion of study region) and the Andes range (eastern portion of study region). Much of the native forest in the Central Valley between these two ranges has been converted to agriculture and plantations.

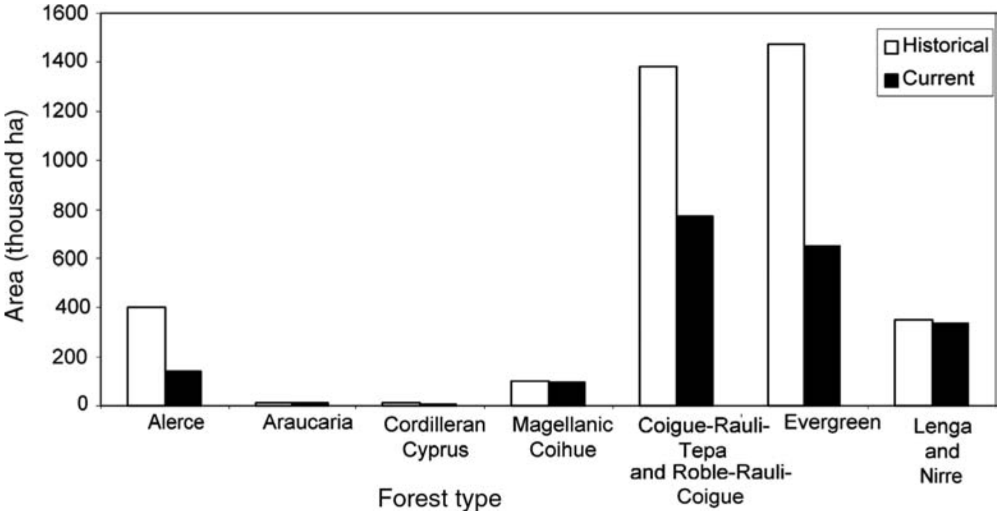

Fig. 14.2. Historical and current extent of each forest type.

these forest types remain dominant, but their area has since substantially diminished. For example, the cover of Alerce forest has been reduced by approximately 65% (Fig. 14.2).

Large proportions of the Coigue–Raulí–Tepa/Roble–Raulí–Coigue, Cordilleran Cypress, Evergreen and Alerce forest types have been converted to pasture and agriculture (Table 14.1). The Coigue–Raulí–Tepa/Roble–Raulí–Coigue and Evergreen forest types have also been converted to plantations (Table 14.1).

Table 14.1. The proportion of the original extent of each forest type that remains as native forest (of some type) or that has been converted to another type of land cover. For details of the forest types, see Appendix.

	Current land cover type					
Original forest type	Native forest	Pasture and agriculture	Wetlands	Urban areas	Plantations	Other
Alerce	81	15	1	0	0	3
Araucaria	90	4	0	0	0	6
Cordilleran Cypress	71	22	0	0	0	7
Magellanic Coihue	93	4	0	0	0	3
Coigue–Raulí–Tepa/ Roble–Raulí–Coigue	34	57	0	1	7	1
Evergreen	53	36	1	0	8	2
Lenga	85	7	0	0	0	8
Ñirre	93	2	0	0	1	4

The Existing Reserve Network

The existing reserve network covers approximately 12% of the study region and is represented by six national parks, ten private reserves, one national monument and three national reserves (Table 14.2). Using overlay analysis in geographic information systems software, it is apparent that national parks, which account for 86% of the total extent of conservation areas, are located in the Andes range, generally at elevations greater than 600 metres, and on large volcanic cones (Table 14.2). Seventy per cent (359,167 ha) of the reserve network is forested. The remaining is comprised of volcanic areas and other areas devoid of vegetation (CONAF-CONAMA-BIRF, 1997).

Our goal is to identify priority areas to protect (either through strict reserves or off-reserve management) 15% of the extent of each forest type that existed prior to European settlement. Information on the pre-European extent of each forest type was obtained from a historical land cover dataset (Lara *et al.*, 1999). Basing the target on the historical extent of each forest type ensured that larger targets were allocated to forest types that have been most reduced in extent (Pressey, 1998; Pressey *et al.*, 2003; RACAC, 1996). The conservation target allocated each forest type to vary according to the proportion of the pre-European extent remaining (Table 14.3).

The representativeness of the existing reserve network was assessed by determining the number of forest types represented at the target level and the number represented above the target level. The conservation targets for the Araucaria, Magellanic Coigue and Lenga forest types are met in the existing reserve network (Table 14.4). A large proportion of the target allocated to the Alerce forest type is met in the existing reserve network (Table 14.4). In

Table 14.2. The historical and current extent of the native forest types in the study region, the % change in the extent of the forest types since European settlement and the conservation target allocated to each forest type.

Native forest type	Historical extent (ha)	Current extent (ha)	% Change in area	Target area (ha)	% of Remaining extent requiring protection to meet target
Alerce	400,214	140,305	–65	60,032	42.8
Araucaria	10,292	9,587	–7	1,544	16.1
Cordilleran Cypress	10,281	6,512	–37	1,542	23.7
Magellanic Coihue	99,741	95,372	–4	14,961	15.7
Coigue–Raulí–Tepa/ Roble–Raulí–Coigue	1,381,725	770,928[a]	–44	207,259	26.9
Evergreen	1,470,945	647,277	–56	220,642	34.1
Lenga and Ñirre	353,688	338,478,	–4	53,053	15.7
TOTAL	3,726,886	2,008,895		559,033	

[a]Comprising 400,748 ha of Coigue–Raulí–Tepa and 370,180 ha of Roble–Raulí–Coigue.

Table 14.3. Characteristics of the existing reserve network in the study region. The reserve network consists of National Parks, a National Monument, three National Reserves and Private Reserves. Characteristics concerning the elevation range, rainfall range and soil type of the conservation areas are provided.

Conservation area	Area (ha)	Type of reserve	Elevation range (m)	Maximum rainfall range (mm)	Soil type
PN Villarica	17,359	National Park	600–2,000	2,500–4,000	Sandy Volcanic Soils, Recent Volcanic Soils (Volcanic cone)
PN Hornopirén	12,141	National Park	400–1,800	5,000	Not available
PN Hornopirén	6,479	National Park	400–1,800	5,000	Not available
PN Puyehue	112,377	National Park	200–1,800	3,000–4,000	Sandy Volcanic Soils, Recent Volcanic Soils (Volcanic cone)
PN Vicente Pérez Rosales	249,804	National Park	0–1,800	2,500–3,500	Volcanic Alluvial Sands, Sandy Volcanic Soils (Volcanic cone)
PN Alerce Andino	39,882	National Park	0–1,400	2,500–4,000	Sandy Volcanic Soils
Subtotal National Parks	***438,042***				
San Pablo de Tregua	2,189	Private Reserve	200–1,400	2,500	Recent Volcanic Soils
Fundo San Julian	326	Private Reserve	200–600	2,500–3,000	Recent Volcanic Soils
Rodeo Grande	34	Private Reserve	0–400	2,500	Red Clay
Parque Pumalin	17,200	Private Reserve	600–2,000		Not available
Campo Escuela Polincay	16	Private Reserve	0–200	2,500–4,000	Sandy Volcanic Soils
Parcela Lipingüe	229	Private Reserve	0–200	3,000	Recent Volcanic Soils
Santa Elvira	75	Private Reserve	0–200	2,500	Recent Volcanic Soils
Cuinco	4	Private Reserve	0–200	1,500	Red Clay
Santa Anita/El Mirador	153	Private Reserve	0–200	2,000	Recent Volcanic Soils
Parcela Altamira – CEA	3	Private Reserve	0–200	4,000	Metamorphics
Subtotal Private Reserves	***20,229***				
Alerce Costero National Monument	2,248	National Monument	400–1,000	4,000	Metamorphics
Subtotal National Monuments	***2,248***				
RN Llanquihue	34,147	National Reserve	0–1,600	2,500	Sandy Volcanic (Volcanic cone)
RN Valdivia	9,789	National Reserve	0–800	4,000	Metamorphics
RN Mocho-Choshuenco	7,518	National Reserve	1,200–1,600	4,000	Sandy Volcanic (Volcanic cone)
Subtotal National Reserves	***51,454***				
Total extent of protected areas	*511,973*				

Table 14.4. Contribution of the existing reserve network to meeting the conservation targets for the forest types.

Native forest type	Area in existing reserve network (ha)	% of Target satisfied in existing reserve network	Area of unprotected extent requiring protection to meet target (ha)	% of Unprotected extent requiring protection to meet target
Alerce	34,356	57.2	25,676	18.3
Araucaria	1,702	110.2	0	0
Coigue–Raulí–Tepa/Roble–Raulí–Coigue	92,956	44.9	114,303	14.8
Cordilleran Cypress	862	55.9	680	10.4
Magellanic Coihue	54,843	366.6	0	0
Lenga and Ñirre	138,903	261.8	0	0
Evergreen	35,545	16.1	185,097	28.6
Total	*359,167*			

comparison, the Evergreen forest type is under-represented in the existing reserve network (Table 14.4).

Obtaining a Representative Reserve Network

The conservation planning decision-support tool, Marxan (Ball and Possingham, 2000), was used to determine the areas of native forest with the highest irreplaceability, or likelihood that they will require protection in order for the conservation targets to be met. The planning units employed in this analysis were the extant remnants of native forest. The following input tables for Marxan were constructed:

- Information on each planning unit, including its area and land use.
- Information on the distribution of each forest type in each planning unit.
- Information on each forest type, including its conservation target.

The simulated annealing algorithm in Marxan was used to perform the analysis. The adaptive simulated annealing schedule followed by iterative improvement was used and was configured so that the number of simulated annealing iterations was 10 million and the number of temperature decreases was 10,000. The conservation feature penalty factor was set to 1000, which ensured that all conservation targets were met. Marxan was run 100 times to produce 100 near-optimal solutions. Irreplaceable planning units were identified as those that were included in each of the 100 reserve network solutions.

Marxan is one of several tools available to perform systematic conservation planning analyses and can find good solutions to a mathematically defined optimization problem (Possingham *et al.*, 2000). Marxan underpinned the rezoning of the Great Barrier Reef and is used by over 1,000 users in over 80 countries world-wide (http://www.ecology.uq.edu.au/marxan.htm). It is the primary spatial planning tool used by The Nature Conservancy (USA). While Marxan was employed in this analysis, it is recognized that many other tools have been developed, including C-Plan (NSW NPWS, 1999), ALDO (Groves, 2003), CODA (Bedward *et al.*, 1992), Diversity-ED (Faith and Walker, 1994; Margules and Redhead, 1995), ResNet/ResNet-GUI (Sarakinos *et al.*, 2001; Kelley *et al.*, 2002), Sites (Andelman and Willig, 2003; Noss *et al.*, 2002), TAMARIN (Stoms *et al.*, 2007), TARGET (Faith *et al.*, 2003) and WORLDMAP (Williams *et al.*, 2003). In addition, various commercial optimizing packages (such as LINDO, CPlex and XPRESS) have been used for conservation planning (Rodrigues *et al.*, 1999). Each tool has its relative advantages and disadvantages – we employed Marxan since we have found it to deliver efficient solutions to large and complex conservation planning problems in a timely manner.

Our analysis indicates that 12 planning units are irreplaceable (i.e. were included in each of the reserve network solutions) and will require protection in order for the conservation targets allocated to the Alerce, Cordilleran Cyprus, Coigue–Raulí–Tepa/Roble–Raulí–Coigue and Evergreen forest types to be met (Table 14.5; Fig. 14.3). These planning units cover 344,499 ha. The forest occurring within the existing reserve network (359,167 ha) and the additional planning units account for approximately 35% of the remaining forested area in the study region. A large proportion of the forest in the coastal range requires protection in order for the target allocated to the Evergreen forest type to be met (Fig. 14.3).

Table 14.5. The degree to which conservation targets are met in the proposed reserve network.

Native forest type	% of Target satisfied by proposed reserve network
Alerce	103
Araucaria	110
Coigue–Raulí–Tepa/ Roble–Raulí–Coigue	101
Cordilleran Cypress	116
Magellanic Coihue	367
Lenga and Ñirre	262
Evergreen	107

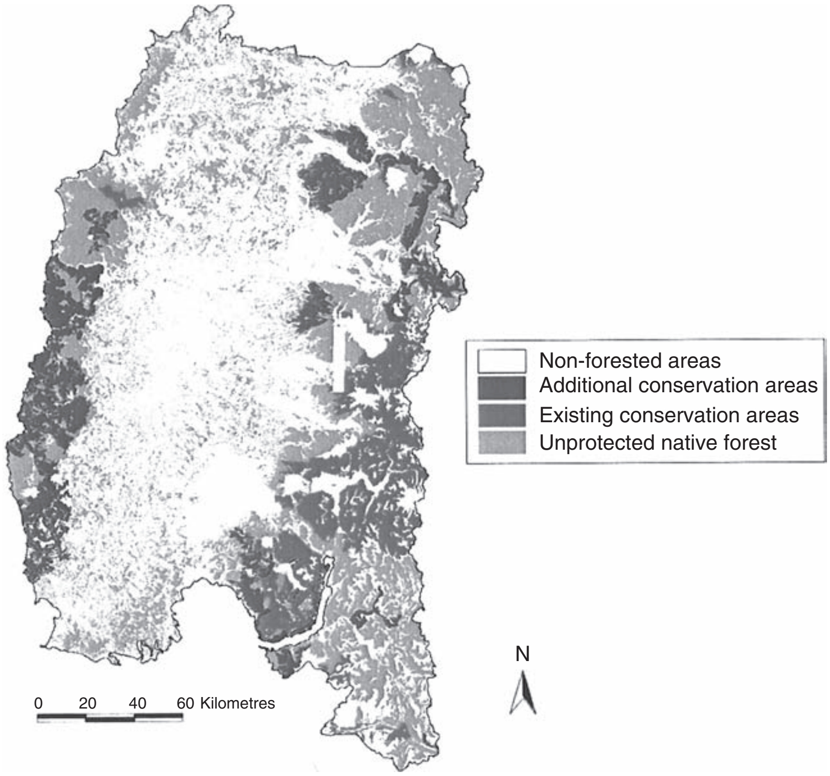

Fig. 14.3. Additional conservation areas required to meet the targets allocated to each forest type.

Vulnerability of Remaining Native Forest to Plantation Conversion

Wilson *et al*. (2005a) describe an assessment of the relative vulnerability of remaining areas of native forest to conversion to plantations. The probability of exposure of native forest to this threatening process was assessed using a quantitative method based on spatial and statistical modelling (Method 2 from the review of Wilson *et al*., 2005a). First, a classification tree was used to identify environmental variables that may explain the spatial distribution of native forest conversion. The variables considered for inclusion in the model of native forest conversion to plantations after correlated variables were excluded were annual precipitation, latitude, soil type, slope, altitude, distance to towns and distance to roads. These variables were then further analysed using a multivariate, spatially explicit statistical model, using the statistical technique of logistic regression. The model was used to identify the variables that explain the spatial distribution of native forest conversion. The best-fit statistical model proposed that the presence of native forest conversion to plantations is a function of soil type, slope, altitude, annual precipitation, distance to roads, distance to towns and latitude (Table 14.6).

The model predicted conversion to plantations to be more likely in areas of low elevation and gentle slope. The probability of conversion was negatively related to distance to towns, distance to roads, rainfall, high altitude, steep slopes and latitude. The conversion of native forest to plantations is predicted to be more likely in relatively warm and low rainfall areas that are close to towns and roads and on red clay and mixed alluvial soils (Table 14.6). Areas of native forest with a high probability of conversion were identified in order to delineate areas of native forest highly vulnerable to plantation conversion (Fig. 14.4).

Table 14.6. The coefficients for the explanatory variables included in the model that describes the conversion of native forest to plantations.

Variable	Coefficient	SE	T-statistic	Wald statistic	*P*-value
Intercept	55.77	0.87	64.10	4,108.28	
Soil type (Marine sediments –Soil type 1)					
Sandy volcanic soils – Soil type 7	–2.18	0.16	–13.65	186.25	***
Volcanic alluvial sands – Soil type 8	–0.43	0.17	–2.53	6.40	*
Mixed alluvial – Soil type 2	0.61	0.22	2.78	7.73	**
Red clay – Soil type 3	0.62	0.14	4.50	20.21	***
Metamorphic – Soil type 4	–0.65	0.14	–4.81	23.17	***
Recent volcanic soils – Soil type 5	–0.96	0.14	–7.03	49.45	***
Salt pan – Soil type 6	–1.51	0.15	–10.31	106.20	***
Annual precipitation (mm)	–0.0002	0.00	–12.56	157.84	***
Latitude (degrees south)	–1.37	0.02	–63.40	4,019.79	***
Distance to towns (km)	–0.00003	0.00	–30.33	920.06	***
Distance to roads (km)	–0.0006	0.00	–43.30	1,874.83	***
Slope (baseline is 0–15%)					
Slope 15–30	0.09	0.02	4.41	19.48	***
Slope 30–45	–0.27	0.03	–7.92	62.71	***
Slope 45–60	–1.56	0.12	–13.10	171.67	***
Slope 60–100	–1.76	0.19	–9.49	90.11	***
Altitude (baseline is 0–200 masl)					
Altitude 200–400	0.28	0.02	13.75	189.06	***
Altitude 400–600	–0.18	0.03	–6.16	37.93	***
Altitude 600–800	–1.46	0.06	–25.02	626.01	***
Altitude 800–1000	–3.43	0.22	–15.58	242.76	***
Altitude 1000–1200	–2.96	0.27	–10.82	116.99	***
Altitude 1200–1400	–1.04	0.18	–5.74	32.92	***
Altitude 1400–1600	–3.38	0.86	–3.92	15.34	***
Altitude 1600–1800	–2.35	2.39	–0.98	0.96	0.33
Altitude 1800–2000	–5.58	34.83	–0.16	0.03	0.86

SE sftands for the standard error of the estimated coefficient value. ***$P < 0.001$, **$P < 0.05$, *$P < 0.1$.

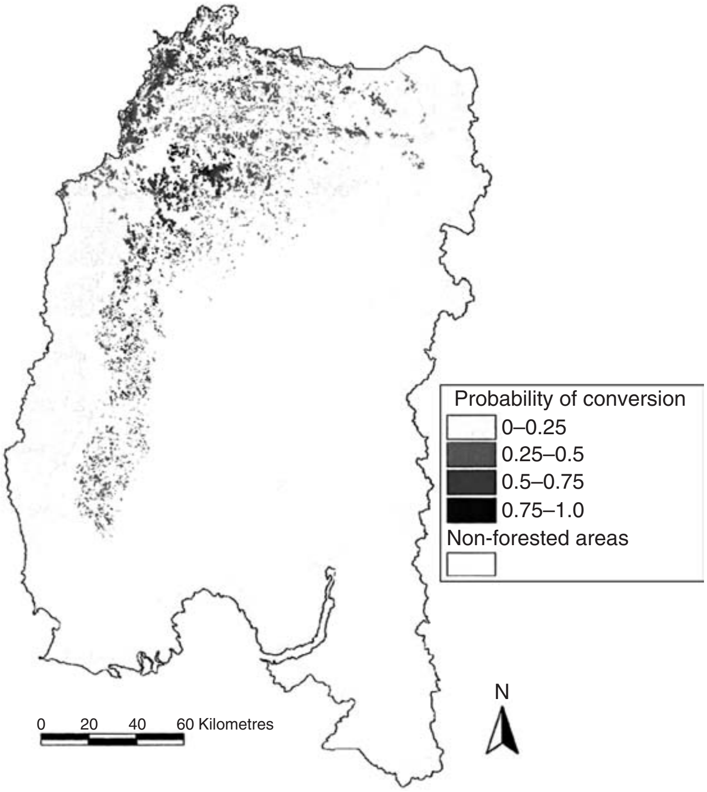

Fig. 14.4. The probability of native forest conversion to plantations. The darker areas have a higher probability of conversion (and are therefore the more vulnerable areas).

The predicted probabilities of conversion do not provide an indication of the imminence of conversion; rather they provide an estimate of how likely it is that conversion will occur in an area at some stage in the future. An exact timeframe for the event is not provided. Therefore, a relative, rather than an absolute, vulnerability is predicted. Areas of native forest identified to be vulnerable to conversion are concentrated in the Central Valley region, east of the coastal range. These areas have moderate slope and elevation, mild climatic conditions and soils with minimal limitations for plant growth. Areas of low probability of conversion are concentrated in the Andes and coastal ranges: areas of steep slope, high elevation, low temperatures and high rainfall. There are some sections of the coastal range with high probabilities of conversion. These areas are situated in lower elevation areas north of the city of Valdivia and surrounding the township of Punta Falsa (south of Valdivia) (Fig. 14.4). Between 1995 and 1998, approximately 16,000 ha of native forest in the study region was degraded or converted to other land uses (Meneses, 2001). Approximately 42% (6,700 ha) was converted to plantations and the majority of this conversion was in the Central Valley region (Meneses, 2001). Therefore, the areas predicted by the model to be at risk of conversion are largely associated with the location of recent activity to convert native forests.

Priority Areas for Biodiversity Conservation

Two-dimensional scatter plots (referred to henceforth as priority plots) were generated to display the irreplaceability and vulnerability values of each unreserved planning unit (Margules and Pressey, 2000). Priority plots allow the planning units that are priorities for conservation action to be visualized. Those planning units in the upper right-hand corner of the priority plots are likely to lose their conservation values and have fewest replacements. Protection of these planning units is urgent if targets are not to be compromised. The lower right-hand section of the priority plots contain planning units that are vulnerable but have more replacements, either because the forest types that occur within them are relatively common or because their targets have been partly met in existing conservation areas. These planning units could move into the upper right-hand corner, if those that are more vulnerable and have higher irreplaceability are lost. In the upper left-hand corner lie planning units with lower vulnerability but with high irreplaceability. Protection of these planning units is less urgent, but they may be used as replacements for planning units that have high irreplaceability and that are more vulnerable. In the lower left-hand corner lie planning units that do not require urgent protection, according to this analysis.

The 12 irreplaceable planning units, required to meet the conservation targets, are highlighted on the priority plot (Fig. 14.5). Eight of these are also vulnerable (have a vulnerability value of 1), with vulnerability calculated as the probability that there is conversion somewhere within each planning unit.

Low vulnerability replacements for the eight vulnerable and irreplaceable planning units were sought. Fifteen areas with high irreplaceability and low vulnerability were added to the existing reserve network instead of the eight irreplaceable and vulnerable planning units (therefore, a total of 19 planning units were added). With the less vulnerable replacements, the Coigue–Raulí–Tepa/Roble–Raulí–Coigue and Evergreen forest types could not meet their targets (Table 14.7). Therefore, whilst there is some flexibility in the reserve network solution, some of the vulnerable areas will need to be included to meet the targets for these two forest types. The planning units requiring protection to meet the targets for the Evergreen forest type are both irreplaceable and vulnerable and are largely confined to the coastal range.

The position of planning units within the priority plots is not static. Some of the vulnerable planning units are likely to be converted to plantations. As this happens, the irreplaceability of some of the remaining planning units will increase as they become more important for achieving targets for forest types that are now less extensive. Conversely, as planning units are progressively reserved, the irreplaceability of others will decrease as the features they contain approach or reach their conservation targets. The vulnerability of planning

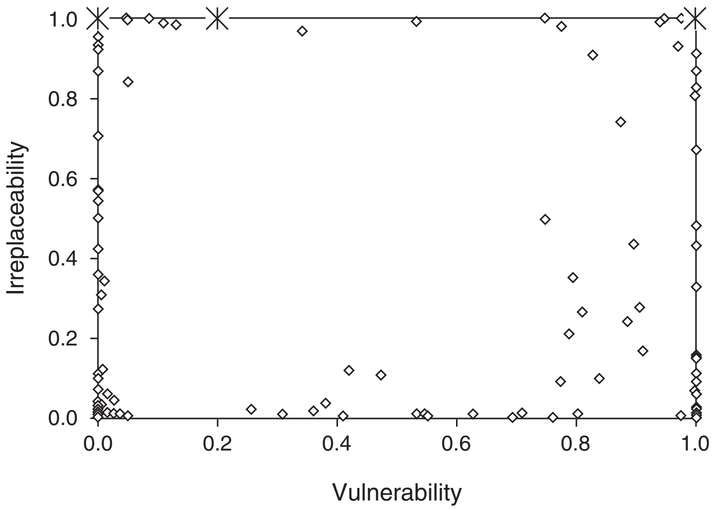

Fig. 14.5. The irreplaceability and vulnerability of the unprotected planning units. Vulnerability is measured as the probability that there is conversion somewhere within the extent of each planning unit. The planning units required to form a representative reserve network are depicted by (*), based on their contribution to meeting the conservation targets for the forest types occurring in the region. Possible replacement planning units are depicted by (◊).

units is also likely to change with time, most likely by increasing, but may also decline if, for example, there is a downturn in the world woodchip or paper pulp market and the rate of conversion of native forest to plantations declines.

Discussion

The analysis of land cover change has shown that, since European settlement, a large proportion of native forest has been converted to other land

Table 14.7. The degree to which targets are met when low vulnerability replacements for the irreplaceable and highly vulnerable planning units are employed.

Forest type	% of Target satisfied in the proposed reserve network
Alerce	132.2
Araucaria	110.2
Coigue–Raulí–Tepa/ Roble–Raulí–Coigue	71.4
Cordilleran Cypress	249.6
Magellanic Coihue	366.6
Lenga	261.8
Evergreen	16.1

uses. Large areas of the Coigue–Raulí–Tepa/Roble–Raulí–Coigue, Cordilleran Cyprus, Evergreen and Alerce forest types have been converted to pasture and agriculture. Additionally, the Coigue–Raulí–Tepa/Roble–Raulí–Coigue and Evergreen forest types have been converted to plantations.

The national parks in the study region, which account for 86% of the total extent of the reserve network, are at high elevations and are situated on large volcanic cones. Much of the land in these Andean parks comprises ice and unvegetated terrain (CONAF-CONAMA-BIRF, 1997). Many of these conservation areas were reportedly chosen for their scenic or recreational value (Pauchard and Villarroel, 2002). The existing reserve network represents some forest types well above their targets (for example, Magellanic Coigue and Lenga and Ñirre) at the expense of others (for example, the Evergreen forest type). According to the forest type classification found in Gajardo (1983), Chile has a total of 85 ecosystems and vegetative subregions, of which 19 are not represented in the reserve network. Approximately 33% of ecosystems have less than 5% of their area protected (Neira *et al.*, 2002).

The vulnerability of extant areas of native forest was predicted according to variables that limit plant growth (such as rainfall and soil type) and variables that determine the suitability of sites for the establishment of plantations (such as slope, elevation and distance to infrastructure (roads and towns)). Areas of native forest predicted to be vulnerable to conversion are concentrated in the Central Valley and western portion of the study region. These are areas of moderate slope and elevation, with mild climatic conditions, and soils with minimal limitations for plant growth. The forests are also accessible by the existing road network and are in close proximity to major towns. These vulnerable areas have been identified by others to have minimal climatic and edaphic limitations for plantation establishment (Schlatter and Gerding, 1995; Schlatter *et al.*, 1995).

In generating the vulnerability model it was assumed that the past pattern of impacts is indicative of future patterns. A consequence of violating this assumption is that the model will erroneously identify areas as vulnerable. For example, much of the remaining forest in the Central Valley region is predicted to be vulnerable. Given that these forests have been highly accessible for much of the recent past, their persistence suggests that their vulnerability might have been overestimated. Conversely, the vulnerability of forest in the coastal range may have been underestimated, as recent conversions of native forest postdate the existing land cover map (on which the vulnerability assessment is based).

The priority areas for conservation should be the currently unprotected areas that are vulnerable to plantation conversion and that, if lost or degraded, will result in targets being compromised. Given our pre-specified targets for each forest type, we use the simulated annealing algorithm in the decision-support tool, Marxan, to identify areas that are irreplaceable and therefore in need of conservation action. Simulated annealing will not always find the best solution to a complex problem, but will usually find a solution that is near to optimal and do so quickly (Possingham *et al.*, 1993, 2000). It can also provide many good solutions to large and complex problems and therefore has the additional benefit of offering flexible solutions. Alternative approaches for conservation planning, such as scoring areas on the basis of their biodiversity values, have repeatedly been shown to provide inefficient assessments of conservation priorities as they do not account for the complementarity of areas in terms of their biological composition (Pressey and Nicholls, 1989). Furthermore, scoring approaches do not provide a transparent assessment of conservation priorities as a similar score for an area can be obtained by a variety of different means (Possingham *et al.*, 2006).

Eight of the 12 additional planning units identified to be required to meet the conservation targets are both irreplaceable and vulnerable to conversion (fall within the top right-hand corner of the priority plot). The remainder are irreplaceable but not vulnerable (fall within the top left-hand corner of the priority plot). Lower vulnerability replacements for the irreplaceable and vulnerable planning units were sought. However, in order to meet the targets for the Evergreen and Coigue–Raulí–Tepa/Roble–Raulí–Coigue forest types, some of the vulnerable areas will need to be included in the reserve network.

The Evergreen forest type is a priority for conservation owing to its lack of representation in the existing reserve network and the degree to which it has been cleared. The biggest impediment to obtaining a representative reserve network in the study region is being able to meet the conservation target for the Evergreen forest type. The most critical areas for meeting the conservation target for this forest type are located in the coastal range. The coastal evergreen forests are known as the Valdivian evergreen forests and they extend for 250 km from the Toltén River (39°S) to south of the Llico River (41.4°S). In the coastal range, a total of 621 native plant species have been recorded (61 pteridophytes, 8 gymnosperms and 552 angiosperms) as have many rare species of reptiles and amphibians, together with bird species that are restricted to the coastal forests (Smith-Ramírez, 2004).

These results concur with Armesto *et al.* (1992, 1996a), who found that the most critical areas in the temperate rainforest region of southern South America, in terms of species richness, endemism and direct or indirect threat by humans, occur in the Chilean coastal range. Our results also confirm the conclusions of Smith-Ramírez (2004), who stated that 'the establishment of new conservation areas in the coastal evergreen forest region, where the largest areas of continuous old-growth forest still remain, is required for the long-term protection of biodiversity in the coastal range'.

It may be infeasible to add all the high-priority areas identified in the coastal range to the reserve network, owing to the social and financial difficulties of acquiring and managing these areas. Where flexibility is required, high-priority areas could be allocated to a variety of land tenure types, varying from strict protected areas to areas with off-reserve management arrangements with private land holders (Pauchard and Villarroel, 2002). A large majority of the remaining forested areas in Chile are on private property (Neira *et al.*, 2002), including approximately 50% of the vegetation associations that are under-represented in the existing reserve network (Calcagni *et al.*, 1999). Further, the government has limited resources to purchase land and landowners are placing ever higher monetary values on their properties

(Neira *et al.*, 2002). Therefore, the long-term conservation and protection of native forest in Chile will likely require inclusion of areas in both the public and private reserve network.

Focusing conservation efforts on areas with the greatest conservation value and the highest likelihood of losing significant portions of this value should achieve maximum impact for conservation investment, and maximize the extent to which conservation goals are achieved (Pressey, 1997). However, the conservation value and vulnerability of an area is only part of the information needed for prioritizing areas for conservation. Other factors, such as land cost and cultural and societal values, will also be important and private conservation areas are likely to play an important role in achieving conservation goals in Chile. These additional factors could also be incorporated into the framework for systematic conservation planning.

Acknowledgements

The assistance of colleagues in the Universidad Austral de Chile is gratefully acknowledged with respect to accessing relevant data for southern Chile.

Appendix

Table A14.1. Definition of forest types included in the analysis (following Neira *et al*., 2002).

Forest type	Dominant and key associated tree species
Alerce	*Fitzroya cupressoides* (alerce), *Nothofagus betuloides* (Magellanic coigue), *Nothofagus nitida* (Chiloé coigue), *Podocarpus nubigena* (prickly leaved mañio), *Pilgerodendron uviferum* (ciprés de las Guaitecas)
Araucaria	*Araucaria araucana* (Monkey puzzle, pehuen), *Nothofagus dombeyi* (coigue), *Nothofagus alpina* (roble), *Nothofagus antarctica* (ñirre), *Drimys winteri* (canelo), *Nothofagus pumilio* (lenga)
Cordilleran Cypress	*Austrocedrus chilensis* (ciprés de la cordillera), *Cryptocarya alba* (peumo), *Peumus boldo* (boldo), *Maytenus boaria* (maitén), *Quillaja saponaria* (quillay)
Magellanic Coigue	*Nothofagus betuloides* (Magellanic coigue), *Nothofagus pumilio*, *Weinmannia trichosperma* (tineo), *Podocarpus nubigena*, *Pilgerodendron uviferum*
Coigue–Raulí–Tepa/ Roble–Raulí–Coigue	*Nothofagus dombeyi*, *Nothofagus alpina* (raulí), *Laureliopsis philippiana* (tepa), *Aextoxicon punctatum* (olivillo)
Evergreen	*Laureliopsis philippiana*, *Amomyrtus luma* (luma), *Drimys winteri*, *Weinmannia trichosperma*
Lenga	*Nothofagus pumilio*, *Nothofagus dombeyi*, *Nothofagus alpina*, *Araucaria araucana*, *Nothofagus antarctica*, *Nothofagus betuloides*
Ñirre	*Nothofagus antarctica*

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