POLICY FORUM: ECOLOGY

Conservation Targets in South American Temperate Forests

J. J. Armesto,* R. Rozzi, C. Smith-Ramírez, M. T. K. Arroyo

Latin American countries presently rely on the expansion and strengthening of their National Parks and Reserves (NPR) systems as the "safest" investment in conservation (*1*). Consistent with this view, nature conservation organizations are seeking to double the land area protected in each nation from the current average of 5% (*2*). This high-priority effort aims to prevent the massive loss of biodiversity that is anticipated as a result of global trends in land use (*3*, *4*). Here we assess whether an initiative of this kind will lead to more effective biodiversity preservation in the confined and endangered temperate forests of southern South America (*5*, *6*).

South American temperate forests occur along a narrow but latitudinally extensive strip of land between 35° and 55°S, centered in south-central Chile (see the figure). The strong biogeographic isolation of southern temperate forests eliminates the possibility that forests outside the region may act as sources of recolonization after habitat destruction or sudden climate change. Therefore, the NPR system is the only long-term reservoir of temperate forest biodiversity in South America. Our analysis provides new evidence for current discussions about the role of biological reserves in forests. Such discussions are predominantly based on case studies in tropical or Northern Hemisphere forests (*7*).

First established in the early 1900s, the Chilean NPR system was one of the pioneers in Latin America (*8*). In the temperate forest region of south-central Chile, there are 59 parks and reserves protecting 13 million hectares out of a total of 40.5, which represents 29% of the land in this region (*9*). Among Latin American countries, only Costa Rica, which protects 21% of its territory, comes close to this large proportion of protected area (*10*). We compared the area of NPR in each administrative region (AR) of Chile within the range of southern temperate forests (see the figure, inset) with the numbers of native vertebrate and tree species, endemic woody genera, and forest types (*11*). We contrasted these patterns with land covered by plantation forestry and agricultural crops, and with human population density, as indicators of the intensity of land use in south-central Chile (*11*). Species distributions were obtained from the literature (*11*), areas classified by land-cover type are from the recently completed survey of Chilean forests (*9*), and human population data are from the 1992 census (*12*).

Map of the southern cone of South America. The map shows the distribution of temperate forests (dark red) along the western margin of the continent. The sharp eastern boundary of the temperate forests is determined by the presence of the Andes Range, with maximum elevations from 1000 to 5000 m. Semiarid land barriers (brown) to the north (matorral) and east (steppe) and the location of the nearest wet forests (dark blue patches in upper part of figure) are also shown. (**Inset**) Map of Chile, showing the six administrative regions (*22*).

There is a large disparity between the distribution of NPR and regional biodiversity within the latitudinal range of temperate forests. More than 90% of the protected land is concentrated at high latitudes (>43°) outside the richest area of biodiversity. Paradoxically, the amount of land in parks and reserves per AR is inversely correlated with the species richness and endemism for the woody flora and vertebrate fauna, which are considered to be indicator groups (*13*). Half of the land is under protection in the two most austral ARs, which have the lowest richness of biodiversity indicator groups (see the figure). In contrast, much lower proportions of land (<10% on average) are protected in the biologically richer northern regions. Most dramatically, the areas of highest diversity of forest types and tree species richness, maximum concentration of endemic woody genera, and maximum species richness of native mammals, amphibians, and freshwater fishes (35.6° to 41.3°S) remain largely outside the extensive NPR system.

Another critical threat to biodiversity in the southern temperate forest region is that areas of high endemism and species richness correspond with areas of high human density and intense land use for plantation forestry, farming, and the raising of livestock (*11*). Consequently, in the biologically richer ARs, biodiversity is at risk not only because protected areas are lacking but also because of their isolation within an intensely managed mosaic of plantations and urban areas. To quantify the potential impact on protected forest remnants of anthropogenic effects that originate in the matrix, such as the invasion of exotic species, fire, agroindustrial pollution, illegal hunting, and uncontrolled logging, we defined an index of matrix influence (IMI). The IMI was calculated for each AR, based on the proportion of land covered by exotic tree plantations, crops and pastures, and urban areas relative to the remaining cover of native forest (*14*).

We describe two scenarios: An optimistic one, which assumes that all forest outside reserves will be preserved, and a pessimistic one, in which all forests outside reserves will be cleared and converted to other land uses. Under the pessimistic scenario, the IMI is close to 1 (maximum matrix influence and isolation) in the four northern ARs that are richest in vertebrate species, woody taxa, and endemism, whereas it drops to <0.5 in the two biologically less rich southernmost ARs. The conservation status does improve substantially if all forest remnants in ARs between 35.6° and 41.3°S were preserved (the optimistic scenario), but the IMI remains high (>0.6) in three biologically rich ARs. Only in region

J. J. Armesto, C. Smith-Ramírez, and M. T. K. Arroyo are at the Laboratorio de Sistemática & Ecología Vegetal, Facultad de Ciencias, Universidad de Chile, Casilla 653, Santiago, Chile. R. Rozzi is in the Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT, 06269–3042 USA.

*To whom correspondence should be addressed. E-mail: jarmesto@abello.dic.uchile.cl

X is there a substantial decrease in matrix influence under the optimistic scenario. We conclude from this analysis that, even in the most optimistic scenario, protected areas of high biodiversity will continue to be threatened because of their isolation and the pervasive influence of the anthropogenic matrix.

An additional concern about the NPR system in south-central Chile (35.6° to 41.3°S) is that the great majority of NPRs are located above 600 m altitude, so that >90% of the protected forest occurs at high Andean locations, often on large active volcanoes (*15*). Much of the land in these Andean parks comprises ice and unvegetated terrain (up to 40%) (*9*). Aside from missing the more productive and biologically richer coast range and lowland forests, this distribution of NPRs leaves most of the protected forest vulnerable to volcanic eruptions. Historical documents and extensive deposits of volcanic ash and debris overlying fossil and glacial soils indicate that southern forests have been repeatedly devastated by volcanic eruptions during the Holocene at intervals varying from every 20 to 100 years (*16*).

The analysis presented here emphasizes the weakness of conservation targets defined primarily or exclusively as percentages of regional land in national parks and reserves (*17*). The conservation value of doubling the land in NPRs at the regional or national level will clearly depend on an adequate representation of areas of high diversity and endemism. In South American temperate forests, the first priority should be to rescue forest remnants for conservation in high biodiversity areas and intensely managed areas. As has been shown for the United States (*18*), in Chile and other Latin American countries this poses a complex social and economic challenge, given that areas requiring urgent protection are generally more accessible, hold more promise for commercial use, are privately owned, and highly priced. The question is whether the governments in Latin America, Chile included, are able to assume the large investments and social costs that will be necessary to change the tenure of high-priority conservation areas in heavily managed landscapes (*19*). The strong historical trend of allocating reserves in the less desired, remotest, and cheapest land and the traditional conservationist's appeal for extensive wild landscapes should be better balanced by a focus on small, but biologically valuable, forest remnants in heavily managed areas.

Assuming that the protection of much biodiversity in southern temperate forests and other biologically rich regions in Latin America will have to be accomplished in landscapes that continue to be intensely managed and occupied by people, conservation targets cannot be limited to placing new reserves so as to maximize the number of species preserved at a minimum cost (*20*). Conservation strategies that encourage the careful planning and regulation of land use in the matrix surrounding existing and new protected areas should become a priority. To achieve this goal, a greater investment in environmental education and the development of working partnerships among conservationists, managers, scientists, and private landowners will be essential (*21*).

References and Notes

1. Food and Agriculture Organization (FAO), *Informe del Taller Internacional sobre Políticas de los Sistemas de Areas Protegidas en la Conservación y Uso Sostenible de la Biodiversidad en América Latina* (Oficina Regional de la FAO para América Latina y el Caribe, Santiago, Chile, 1994).
2. World Conservation Monitoring Centre, *Global Biodiversity: Status of Earth Living Resources* (Chapman & Hall, London, 1992); World Wildlife Fund (WWF), *World Bank and WWF Join Forces to Conserve Earth's Forests* (WWF, Washington, DC, 1997); International Union for Conservation of Nature and Natural Resources (IUCN), *Caring for the Earth: A Strategy for Sustainable Living* (IUCN-UNEP-WWF, Gland, Switzerland, 1989).
3. R. A. Houghton, *BioScience* **44**, 305 (1994); J. H. Lawton and R. M. May, Eds., *Extinction Rates* (Oxford Univ. Press, Oxford, 1995); S. L. Pimm, G. J. Russel, J. L. Gittleman, T. M. Brooks, *Science* **269**, 347 (1995).
4. V. H. Heywood, Ed., *Global Biodiversity Assessment* (Cambridge Univ. Press, Cambridge, 1995).
5. J. J. Armesto, C. Villagrán, M. T. K. Arroyo, Eds., *Ecología de los Bosques Nativos de Chile* (Editorial Universitaria, Santiago, Chile, 1996).
6. D. M. Olson and E. Dinerstein [*Cons. Biol.* **12**, 502 (1998)] place Valdivian rain forests (a major temperate forest type in Chile) in the critical and endangered category.
7. G. K. Meffe and C. R. Carroll, Eds., *Principles of Conservation Biology* (Sinauer, Sunderland, MA, ed. 2, 1997); P. L. Fiedler and P. M. Kareiva, Eds., *Conservation Biology* (Chapman & Hall, New York, ed. 2, 1998).
8. The first biological reserves established in Latin America are the Reserva Forestal Desierto de los Leones in Mexico (1876), Perito Moreno (1903; later National Park Nahuel Huapi), and Reserva Forestal Malleco in Chile (1907) [C. Ormazábal, *Sistemas Nacionales de Areas Silvestres Protegidas en América Latina* (Oficina Regional de la FAO para América Latina y el Caribe, Santiago, Chile, 1988)].
9. Proyecto CONAF-CONAMA-BIRF, *Catastro y Evaluación de los Recursos Vegetacionales Nativos de Chile* [Chilean Forest Service (CONAF), Santiago, Chile, 1997].
10. R. García, *Flora, Fauna Areas Silvestres* **6**, 14 (1992). For IUCN categories I and II (strict natural reserves and national parks), protected land areas are 3.5% for South America, 7.2% for Central America, and 3.2% for the temperate broad-leaved forest biome globally (*4*).
11. We computed the number and distribution of species restricted to the phytogeographic region of South American temperate forests (Fig. 1) from the following sources: mammals from lists and references cited in appendix 21.1 of (*5*); amphibians from R. Formas, in *Diversidad Biológica de Chile*, J. A. Simonetti *et al.*, Eds. (Conicyt, Santiago, Chile, 1995), pp. 314–325; freshwater fishes from D. Soto, personal communication; tree species and woody genera from M. T. K. Arroyo, *et al.*, in *High Latitude Rain Forest and Associated Ecosystems of the Coast of the Americas: Climate, Hydrology, Ecology and Conservation*, R. G. Lawford, P. Alaback, E. R. Fuentes, Eds. (Springer, Berlin, 1996), pp. 134–172; from R. Rodríguez, O. Matthei, M. Quezada, *Flora Arbórea de Chile* (Universidad de Concepción, Concepción, Chile, 1983), and from the Flora of Chile Database (Universidad de Concepción, 1998). Plots of the data are available from the authors on request and at www.sciencemag.org
12. For the human population data from the 1992 census, see [Instituto Geográfico Militar, *Atlas Geográfico de Chile para la Educación* (Instituto Geográfico Militar, Santiago, Chile, 1994)].
13. Spearman rank correlations between the protected land area per AR (*9*) and the numbers of species per latitude (*11*) were as follows: $rs = -0.93$, $P < 0.05$ for trees; $rs = -0.74$, $0.05 < P < 0.1$ for amphibians; $rs = -0.59$, NS for fish; and $rs = -0.20$, NS for mammals. For endemic woody genera, $rs = -0.43$, NS; for forest types, $rs = -0.43$, NS (NS: $P > 0.1$).
14. The IMI was calculated per AR as 1 – [native forest area/(forest area + agricultural land + tree plantations + urban area)]. It ranges from 0 (low isolation and minimum matrix influence) to 1 (high isolation and maximum matrix influence). Areas are from (*9*).
15. M. Finckh, *Dissertationes Botanicae* **259**, 1 (1996).
16. T. T. Veblen and D. H. Ashton, *Vegetatio* **36**, 149 (1978); T. T. Veblen, in *The Ecology of Natural Disturbance and Patch Dynamics*, S. T. A. Pickett and P. S. White, Eds. (Academic Press, NY, 1985), pp. 35–51.
17. M. E. Soulé and M. A. Sanjayan, *Science* **279**, 2060 (1998).
18. A. Ando, J. Camm, S. Polasky, A. Solow, *ibid.*, p. 2126.
19. Of 12 high-priority areas for biodiversity conservation in Chilean temperate forests defined by a panel of experts in 1993, 11 are entirely or partly on privately owned land. Three of these have become protected since 1993 [M. Muñoz, H. Nunez, J. Yanez, Eds., *Libro Rojo para la Conservación de la Diversidad Biológica en Chile* (CONAF, Santiago, Chile, 1996)].
20. S. L. Pimm and J. H. Lawton, *Science* **279**, 2068 (1998); A. S. van Jaarsveld *et al.*, *ibid.*, p. 2106.
21. For examples, see J. J. Armesto, R. Rozzi, M. F. Willson, *Bull. Ecol. Soc. Am.* **77**, 120 (1996); M. T. K. Arroyo *et al.*, *Toward an Ecologically Sustainable Forestry Project* (Universidad de Chile, Santiago, 1996); C. Sepúlveda and D. García, *Ambiente y Desarrollo (Chile)* **13**, 59 (1997).
22. The geographic region of the Chilean temperate forests is divided into six ARs (Fig. 1, inset). From north to south, these ARs and their respective areas (in thousands of hectares) are as follows: region VII (Maule), 3032; region VIII (Bio-Bio), 3708; region IX (Araucania), 3182, region X (Los Lagos), 6684; region XI (Aisén), 10714; and region XII (Magallanes), 13171. We referred the data to ARs because sources generally follow these divisions and because the Chilean NPR system is administered regionally.

23. Support from the Darwin Initiative for the Survival of Species (UK); the Research Foundation and Department of Ecology and Evolutionary Biology, University of Connecticut; Fondecyt grant 1980705; and INCO-DC is appreciated. We thank C. Marticorena for information from the Flora of Chile Database (Universidad de Concepción); CONAF for access to the unpublished survey of Chilean native forests; A. Veloso, D. Soto, F. Massardo, and K. Wells for help and advice; R. Chazdon, C. G. Jones, S. T. A. Pickett, and J. Silander for valuable comments. This is a contribution to the Programs of the Institute of Ecological Research Chiloé and Native Forest Studies of the Universidad de Chile. Work was conducted on a J. S. Guggenheim fellowship (J.J.A.) and an endowed Presidential Science chair (M.T.K.A.).