HUMAN-INDUCED CHANGES OF FOREST PATTERNS IN PATAGONIA, ARGENTINA

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ABSTRACT

One of the world's more diverse biomes, the Eco-Region of the Valdivian Temperate Forests, shows a world-wide consensus among scientific organizations and conservationists on the value of their biodiversity and the threats that must confront. The "ciprés de la cordillera", identified as a focal native tree species, has been severely affected by human influence. Our studies were aimed to characterize human-induced changes on "ciprés" landscape patterns over a 30-years period on 15% -20.000 hectares- of the total area covered by these forests in Patagonia. In two of the study areas we measured an area decrease of former "ciprés" forests and an increase of forest isolation, mainly due to forest fires and substitution by exotic conifers. In the third study area, forest fires and further timber exploitation also reduced the original area. However, we demonstrated an increase of the "ciprés" potential area, mainly owed to the growth of young trees, also allowing the connectivity of former isolated patches.

Key words: *Patagonia, native forests, human impacts, multitemporal analysis, remote sensing*

INTRODUCTION

Forest landscapes have natural levels of spatial and temporal heterogeneity. Human- induced disturbances tend to alter the "natural" heterogeneity and spatial patterning of these landscapes. The result is that most forest landscapes exist in various states of structural modifications (Loyn and McAlpine, 2001). Although several studies assessing human-induced changes of spatial and temporal heterogeneity regarding tree species in forest landscapes have been developed worldwide (e.g. Lida and Nakashizuka 1995; Rescia et al. 1997; Silbernagel et al. 1997; Roth 1999; Ripple et al. 2000; Jenkins and Parker 2000; Puric-Mladenovic et al. 2000; Hessburg et al. 2000; Löfman and Kouki 2001; Fukamachi et al. 2001, Lawes et al. 2004; Tucker et al. 2005), such studies are still uncommon in Patagonia.

In the Andes region, strengthening of certain human activities during the last decades is concerned with changes on landscape heterogeneity of native forests. Thus, we considered the native tree species "ciprés de la cordillera" (Austrocedrus chilensis, here on "ciprés") generally allocated in places of favorable microclimatic characteristics and accessible locations that made possible a most unplanned development of human settlements and land uses. "Ciprés" is an endemic forest species in the cold temperate forests of Patagonian Andes region in Argentina and Chile. In Argentina it forms relatively dense pure stands in a west-east precipitation gradient between 1,600 and 500 mm/year, being the conifer with the largest geographical distribution, from 37º08' up to the 43º43'S (Bran et al. 2002).

It is located at altitudes between 300 and 1,000 m, in a 60-to-80 km-wide strip, representing the forest boundary between the Patagonian steppe to the east and the humid forests of *Nothofagus*

to the west, developing dense mixed forests along with the evergreen "coihue" (*Nothofagus dombeyi*). At present the pure and mixed "ciprés" forests cover 135,400 hectares (Bran et al. 2002). We considered three study areas of increasing size located in Province Chubut (Figure 1). The smallest one (Study area A) of around 2,000 hectares is placed in the nearness of Esquel city, the most important Chubut´s population in the Andes cordillera -area coordinates: 42°38'S 71°22'W-. The middle-size area (Study area B) covers approximately 6,000 hectares and it is placed in the NW of Chubut Province -area coordinates: 42°09'S 71°22'W.
The biggest area (Study area C) comprises about 40,000 hectares covering the whole valley of Trevelin –area coordinates: 42°38'-43°34'S, 71°22'-71°51'W) between the Chilean border to the West and the town of Trevelin to the East. These areas are characterized by a mountainous topography with altitudes between 300 m.a.s.l. at valley bottoms and 2,000 m.a.s.l. Climate is temperate with an annual average temperature of 10°C. Precipitations oscillate between 1200 mm/year and 600 mm/year in a West-East gradient of only 30 km. In these areas our major interest was focused on the detection and analysis of human-caused changes in landscape heterogeneity for a 30-years period from 1970 to 2001 on "ciprés" forests at a landscape level. At the same time, we tried to link the more relevant human-caused alterations with "positive" and "negative" changes on landscape heterogeneity, thus considered when the former "ciprés" area had became smaller or bigger in size and connectivity.

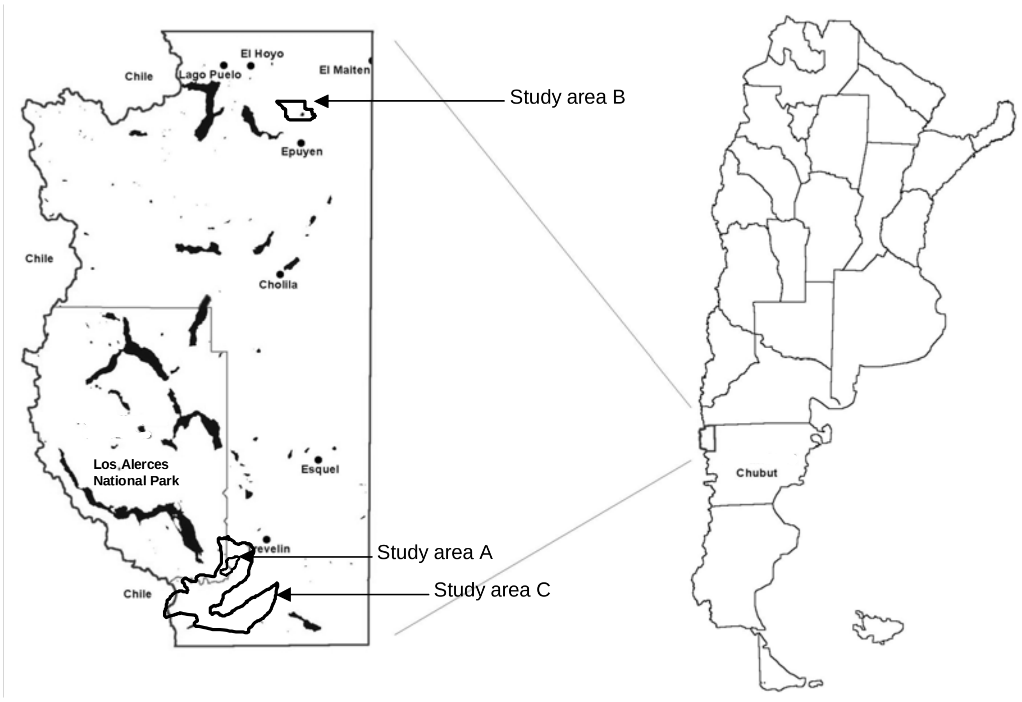

Figure 1. Study areas in Province Chubut, Patagonia, Argentina

METHODOLOGY

A detailed analysis of landscape elements on photo mosaics assembled with 23 (study area A) 25 (study area B) and 44 (study area C) infrared aerial photographs (1:20,000) taken in 1970 was carried out. The identification of burnt areas and timber exploitation was performed on an SPOT XS-PAN satellite image from March 2001 -4 bands, spatial resolution of 10x10m- for study areas A and C, whereas burnt areas and plantations with exotic species were identified on an IKONOS satellite image from January 2001 -4 bands, spatial resolution of 4x4 m- for the study area B. Two digital terrain models were specially developed to support the orthorectification of this material. On photo mosaics of the year 1970 the defined landscape elements were delimited as forest patches according to a classification on forest types. In addition, tree patches were distinguished according to three density classes: dense (average distance between dominant trees less than 5 m), semi-dense (average distance between dominant trees among 5 and 10 m) and sparse (average distance between dominant trees more than 10 m). The area calculation for the different classes and the analysis of the considered landscape changes were carried out with Xtools and Patch Analyst programs, both working as extensions of the ArcView software. Alternatively, following landscape indices were used: patch number per class (N), class area (A) (area of all polygons belonging to the same class, expressed in hectares), percentage of class area (A%) regarding the total landscape area, mean patch size (MPS), representing the arithmetic average size of every patch of a given class type, area-weighted mean patch size (MPS2) to rectify the effect of small patches on the patch size (McGarigal and Marks, 1995), and maximum patch size (MaxPS), to get an idea of the connectivity degree of the class of interest.

RESULTS

CHANGES ON LANDSCAPE HETEROGENEITY IN THE STUDY AREA A

On this 2,000 ha landscape unit we identified several qualitative changes of the landscape heterogeneity (Figures 2a-b). These changes are mainly harmful due to forest fires, timber cutting followed by grazing and substitution of “ciprés” forests with pine plantations (table 1).

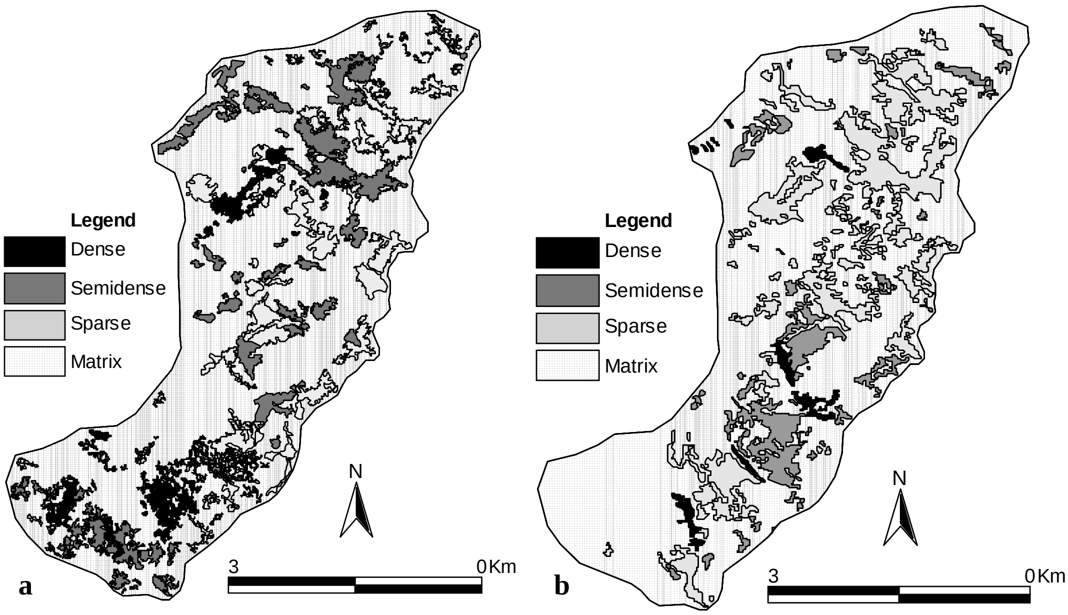

Figure 2. Distribution of “ciprés” patches in study area A in 1970 (a) and in 2001 (b).

On the other hand, the growth of young “ciprés” forests probably not present or indiscernible in 1970 was considered a positive change of the heterogeneity (table 1).

Table 1**.** Changes of the “ciprés” (Ci) forest landscape heterogeneity in the study area A

Causes of changes on heterogeneity	GPS CP	Area (ha)	% of total Ci area (ha)
Forest fires (N)	39	107	23
Timber cutting and grazing (N)	26	70	15
Substitution of “ciprés” forests with exotic pine (N)	5	14	3
Growth of young “ciprés” forests (P)	15	42	9
Total	85	233	50

N: negative change; **P**: positive change. The indicated GPS control points (CP) are those linked to landscape changes.

CHANGES ON LANDSCAPE HETEROGENEITY IN THE STUDY AREA B

Fragmentation of “ciprés” forests was more intense in semi-dense and sparse classes on the eastern side (Figure 3a) whereas the decline of the “ciprés” area was variable within these two sectors, being superior in dense and sparse classes in the western sector (Figure 3b). The “coihue” area came down in the western sector whereas this class area increased in the eastern sector. The matrix enlarged its area in the burnt sector and decreased in the afforested one. In both cases there was a reduction in the number of patches.

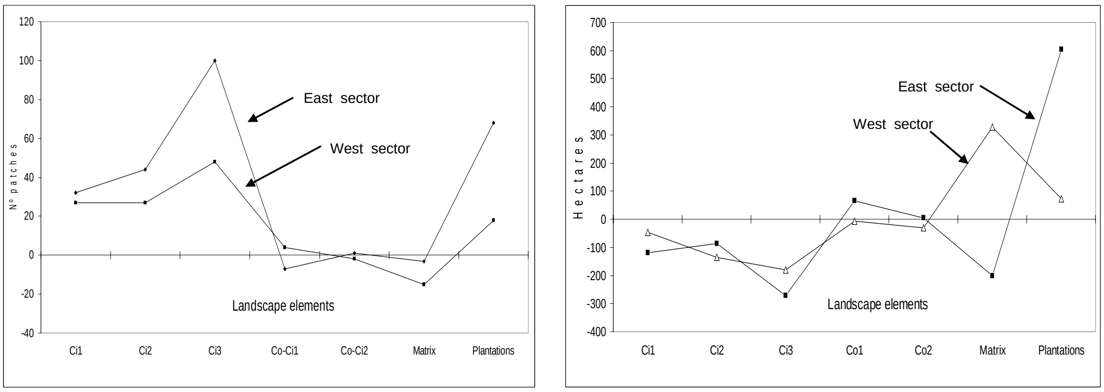

Figure 2. a) Net patch number variation for the considered landscape elements between 1970 and 2001 in western and eastern sectors, b) Net area variation for the considered landscape elements between 1970 and 2001 in western and eastern sectors (References: Ci1: dense “ciprés”; Ci2: semi-dense “Ciprés”; Ci3: sparse “ciprés”, Co-Ci1: “coihue”-dense “ciprés”; Co-Ci2: “coihue”-semi-dense “ciprés”; Co1: dense “coihue”; Co2: semi-dense “coihue”)

The net 24%-decrease in area -835 hectares (table 2)- was accompanied by a strong negative change in the heterogeneity of the forest landscape due to the fragmentation of the “ciprés” area almost 34% in the considered time period. In 1970 the zones dominated by “ciprés” forests constituted a predominantly continuous or interconnected area and occupied almost 3,400 hectares (Figures 4a-b). This situation was drastically modified being 360 hectares affected by forest fires, exclusively in the western sector (Figure 4c) and 475 hectares replaced by plantations, mainly on the eastern side of the study area (Figure 4d).

Table 2. Quantification of changes of "ciprés" forests due to forest fires and substitution by afforestations

	Landscape element	N	A	$A_{\%}$	MSP	MSP^2	MaxSP
1970	"Ciprés"	551	3,375	56	19.5	35.5	486
	"Coihue"	164	484	8	5.2	0.8	51
	Plantations	0	0	0	0	0	0
	Matrix	176	2,153	36	12,2	200	801
	Total	891	6,013	100	-	-	-
2001	"Ciprés"	831	2,540	42	9.8	9.9	209
	"Coihue"	160	517	9	5.1	1.5	63
	Plantations	86	677	11	7.9	5.1	101
	Matrix	158	2,280	38	14.4	332.9	1,212
	Total	1,235	6,013	100	-	-	-

CHANGES ON LANDSCAPE HETEROGENEITY IN THE STUDY AREA C

The changes in the considered time period (1970-2001) affected an area of 4,400 hectares of "ciprés" forests, being 1,500 hectares (34%) damaged by forest fires or flooded when the so called "Futaleufú" dam was filled (Figure 5). On the other hand, 2,900 hectares appeared as new "ciprés" forest, although this result must be carefully considered in its accuracy, because the poor quality of the aerial photos over some sectors encompassing 2,000 hectares (table 3) cannot allow to demonstrate if the occurrence of young "ciprés" forests, rigorous tested by field controls in all accessible places, is only noticeable in the recent satellite images**.**

DISCUSSION

The substitution of "ciprés" with exotic species is currently a practice not legally allowed nor so extended, yet it is still carried out on burnt "ciprés" stands as well as on sectors affected by the so called "mal del ciprés" disease. Nevertheless, the habitat alterations that these procedures have brought along and indeed keep acting differentially in distinct spatial and temporal scales must not be underestimated (Carabelli 2004).

On the other hand there still remains the question of the incidence of forest fires. Statistics of the Chubut forest service (Dirección General de Bosques y Parques, 2002) reveals that between May 2001 and March 2002 about 700 hectares of "ciprés" forests in the study area B were damaged by fire -25% of the total "ciprés" forests affected by fires in the distribution range of the species in the provincial territory that season- and 630 hectares of "coihue" forests -28% of the total "coihue" forests affected by fire in Chubut in this time period. Policy of native forest substitution by plantations had been not sustained by a program capable to guarantee the monitoring of management activities in the new plantations.

Currently, this situation has produced a chain of legal and jurisdictional problems, where land is illegally occupied and confrontations are permanently present. A good-quality forest has been substituted by an unmanaged one that will provide raw material of bad quality, laying the basis for a wide discussion on even the financial convenience of the actions carried out.

Lack of management in the plantations threatens their persistence because the risk of fires increases. Huge timber masses representing a high quantity of fuel with vertical and horizontal continuity could be consumed just in a single event without any possibilities of controlling it, risking the adjacent native forests. Finally, these areas with high proportion of weakened and diseased trees constitute a focus for the development and propagation of plagues, as it had been recently demonstrated (Gomez et al. 2006). Besides forest fires, substitution with exotic species and timber exploitation, other processes are affecting the integrity of "ciprés" forests such as the relatively recent but intense landownership subdivision, the unplanned use for grazing and an intensive farming (Carabelli et al. 2006).

This context plays an own role by intensifying a complex of alterations that notoriously has more negative-than-positive effects on these native forests. Such circumstances highlight the need for an integral insight of landscapes and for developing management actions with sound technical and scientific bases and acceptance in the different community sectors, so that land use practices on forest environments in our region contribute to mitigate the deterioration processes of our forest ecosystems.

Nevertheless, the increase of the "ciprés" forest area in the study area C cannot be underestimated, because it is also linked to a greater connectivity of "ciprés" patches. This positive change occurred mainly for two reasons: the first one was the growth of the "ciprés" regeneration and the second one was the presence of very isolated adult trees that were not classified in the sparse class on the photo mosaic because they didn't satisfy the distance requirement. These trees, however, made possible the regeneration that has currently re-connected sectors that formerly had more dense "ciprés" forests.

Table 3. Origin and quantification of the changes in the "ciprés" forests between 1970 and 2001.

Causes of changes on heterogeneity	Area (ha)
Young trees / Masking by the matrix	900
Young trees / Masking by the matrix / Poor quality of aerial photos	2,000
Forest fires	1,350
Flooded forest	150
Total	4,400

REFERENCES

Bran D., Pérez A., Barrios D., Pastorino M., and Ayesa J., 2002. Eco-región valdiviana: distribución actual de los bosques de "ciprés de la cordillera" (Austrocedrus chilensis) - escala 1:250.000. Informe Preliminar. INTA-APN-FVSA. 12 p.

Carabelli F. A., 2004. Quantitative analysis of forest fragmentation in Patagonia, Argentina. In: Proceedings of the IUFRO 2004 International Workshop on Landscape Ecology: Conservation and Management of Fragmented Forest Landscapes, Tsukuba, Ibaraki, Japan, 83-87.

Carabelli F., Scoz R., Claverie H., Jaramillo M., and Gómez M., 2006. Changes on landscape heterogeneity and spatial patterning of native forests in Patagonia, Argentina. Investigación Agraria. Sistemas y Recursos Forestales (Madrid), 15(2). In press.

Dirección General de Bosques y Parques, 2004. Estadísticas de extracciones forestales. Informe Técnico. 15 p.

Fukamachi K., Oku H., and Nakashizuka T., 2001. The change of a satoyama landscape and its causality in Kamiseya, Kyoto Prefecture, Japan between 1970 and 1995. Landscape Ecology, 16:703-717.

Gomez C., Greslebin A., Jovanosvski A., and Rajchenberg M., 2006. Enfermedades y plagas en plantaciones de coníferas exóticas en Patagonia. Informe Final, Proyecto PIA 1104. Secretaría de Agricultura, Ganadería, pesca y Alimentación. 71 p.

Hessburg P.F., Smith B.G., Salter R.B., Ottmar R.D., and Alvarado E., 2000. Recent changes (1930s-1990s) in spatial patterns of interior northwest forests, USA. Forest Ecology and Management, 136:53-83.

Jenkins M.A., and Parker G.P., 2000. Changes in the Forest Landscape of the Charles C. Deam Wilderness, Southern Indiana, 1939-1990. Natural Areas Journal, 20:46-55.

Lawes M.J., MacFarlane D.M., and Eeley H.A.C., 2004. Forest landscape pattern in the KwaZulu–Natal midlands, South Africa: 50 years of change or stasis?. Austral Ecology, 29(6):613-623.

Lida S., and Nakashizuka T., 1995. Forest fragmentation and its effect on species diversity in sub-urban coppice forests in Japan. Forest Ecology and Management, 73:197-210.

Loyn R.H., and McAlpine C., 2001. Spatial Patterns and Fragmentation: Indicators for Conserving Biodiversity in Forest Landscapes. In: Raison R.J., Brown A.G., and Flinn D.N. (Eds.). Criteria and Indicators for Sustainable Forest Management. CAB International. Chapter 19, 391-422.

Löfman S., and Kouki J., 2001. Fifty years of Landscape Transformation in Managed Forests of Southern Finland. Scand. J. For. Res., 16:44-53.

McGarigal, and Marks B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Report PNW-GTR-351, USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Puric-Mladenovic D., Kenney W.A., and Csillag F., 2000. Land Development Pressure on peri-urban forests: A Case Study in the Regional Municipality of York. The Forestry Chronicle, 76:247-250.

Rescia A.J., Schmitz M.F., Martin de Agar P., de Pablo C.L., and Pineda F.D., 1997. A fragmented landscape in northern Spain analyzed at different spatial scales: Implications for management. Journal of Vegetation Science, 8:343-352.

Ripple W.J., Hershey K.T., and Anthony R.G., 2000. Historical forest patterns of Oregon´s central Coast Range. Biological Conservation, 93:127-133.

Roth L.C., 1999. Anthropogenic change in subtropical dry forest during a century of settlement in Jaiqui Picado, santiago Province, Dominican Republic. Journal of Biogeography, 26: 739-759.

Silbernagel J., Chen J., Gale M.R., Pregitzer K.S., and Probst J., 1997. An Interpretation of Landscape Structure from Historic and Present Land Cover data in the Eastern Upper Peninsula of Michigan. United States Department of Agriculture, Forest Service, North Central Forest Experiment Station, General Technical Report, NC, 192, 30 p.

Tucker C.M., Munroe D.K., Nagendra H., and Southworth J., 2005. Comparative spatial analyses of forest conservation and change in Honduras and Guatemala. Conservation and Society, 3(1):174-200.

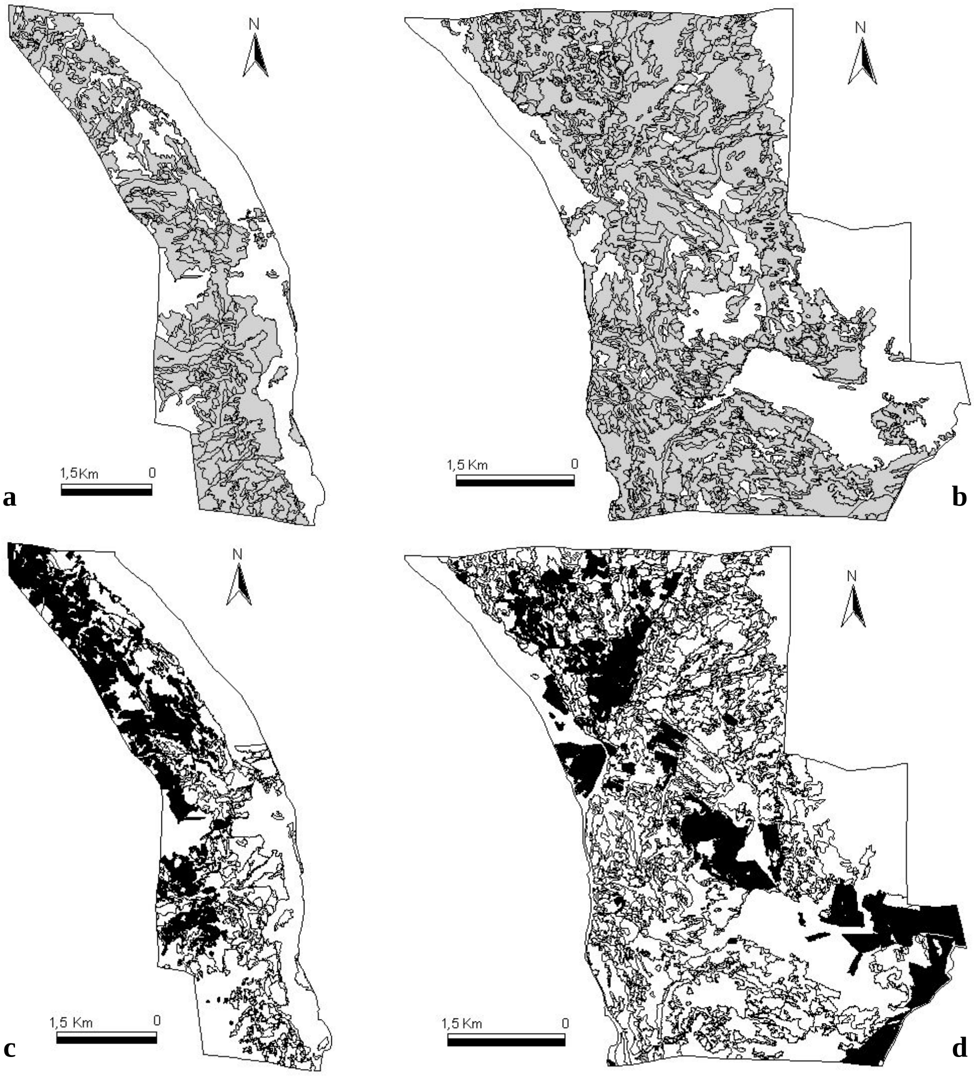

Figure 4. a-b) Western and eastern sector with “ciprés” and “coihue” forest types (grey) and other landscape elements included as matrix (white) in 1970, c) Burnt areas in western sector (black) and other landscape elements including “ciprés” and “coihue” forest types (white) in 2001, d) Plantations of exotic species in eastern sector (black) and other landscape elements including “ciprés” and “coihue” forest types (white) in 2001