

Quantitative analysis of forest fragmentation in Patagonia, Argentina

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Abstract

We analyzed the occurrence of forest fires and the substitution by exotic conifer species in one emblematic area of the indigenous forest species 'ciprés' geographical distribution representing 2,5% of the total area covered by this species in the Patagonian Andes of Argentina, to quantify changes in landscape heterogeneity between 1970 and 2001. Our results showed that those places dominated by 'ciprés' forests forming a continuous or interconnected area of more than 4,000 hectares in 1970 had been drastically modified in 2001. A net area reduction of 14% was accompanied by a strong negative change in forest landscape heterogeneity due to fragmentation of 'ciprés' forests -almost 24% in the considered period of time-. A significant decrease was checked in the average patch size -35 hectares in 1970 vs. 10 hectares in 2001-. Major 'ciprés' patch occupied in 1970 an area of almost 500 hectares, whereas in 2001 it was almost 60% smaller -210 hectares-.

Keywords: Patagonia, fragmentation of indigenous forest, landscape change

1. INTRODUCTION

The analysis of landscape changes and their causal factors related to human activities are central issues of landscape ecology and land-use planning. Landscapes are conceived as dynamic entities, resulting from the continuous interactive processes between socially organised humans and the current states of biological and physical forms (Fuentes, 1990, fide Fukamachi *et al.*, 2001). At a landscape level, certain analyses of forest fragmentation include retrospective studies assessing changes occurred through specific time periods (Jenkins and Parker, 2000; Ripple *et al.*, 2000). In Patagonia, two main central issues in the study of forest fragmentation related to human-induced alterations are nowadays of great relevance: changes at landscape level across time and a better understanding of the fragmentation process at a landownership level.

To improve the comprehension of the first problem the indigenous tree species *Austrocedrus chilensis* -ciprés de la cordillera- that most clearly shows human influence, was selected. '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 37° 08' up to the 43° 43' S (Bran *et al.*, 2002). It is preferably located at altitudes that range between 300 and 1,000 m depending on the latitude, 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 (Dezzotti and Sancholuz, 1991), where it usually develops dense mixed forests along with the evergreen *Nothofagus dombeyi* -coihue-.

At present the pure 'ciprés' forests and the mixed 'ciprés-coihue' areas cover 135,400 hectares (Bran *et al.*, 2002). 'Ciprés' has been historically affected by unplanned development of human settlements increasing risk of fires (Rothkugel, 1916; Veblen and Lorenz, 1987; Bondel and Almeida, 1996), irrational use for cattle grazing (Seibert, 1982), substitution by exotic conifer species (Loguercio *et al.*, 1999) and timber exploitation, currently restricted to stands with weakened or dead trees affected by a disease named as mal del ciprés" (Dirección General de Bosques y Parques, 1999).

Thus, our current studies are involving the temporal and spatial analysis of the fragmentation process at different scales, measured on different photographic records as a function of patch variation in size, shape and area of this selected tree species and also a field research to gain precise knowledge about the land use history of representative land ownerships and the relationship with the existing fragmentation situation of 'ciprés' forests.

2. STUDY AREA AND METHODS

The area selected for the study covers approximately 6,000 hectares and it is placed in the NW of Chubut Province, Argentina -area center coordinates: 42°09'06"S 71°22'48"W-. This area is characterized by mountainous topography with altitudes between 300 m.a.s.l. at valley bottoms and 2,000 m.a.s.l. It is dissected by the valley of the river Epuyén, where human presence is very noticeable with numerous settlements, infrastructure and crop areas. Vegetal cover, predominantly forests, corresponds biogeographically to the Andean Region, Sub Antarctic Sub region (Morrone, 2001). Average annual temperature is 9.6 °C and annual precipitation is 1,375 mm. The region presents a conspicuous dry season coinciding with the summer period, when temperatures are higher.

This conjunction of high temperatures and scarce precipitation grants other environmental factors related to the hydric regime (e.g. soil depth, slope steepness, aspect) a supreme importance in the genesis of vegetation patches and their dynamics. This issue favours the occurrence and spread of fires and it is a hindrance for the subsequent recovery of the affected areas.

A detailed analysis of landscape elements on a photo mosaic assembled with 25 infrared aerial photographs (1:20,000) taken in 1970 was carried out. The identification of forest fires and exotic conifer species substituting former indigenous 'ciprés' forests was carried out on an IKONOS multispectral image from 2001. A digital terrain model was specially developed to support the orthorectification of this material. In order to accomplish all these tasks different modules of Erdas Imagine and ArcView computational packages were used. The defined landscape elements were delimited as patches according to different forest types and later distinguished into three classes of density: dense, semi-dense and sparse. Intensity field controls helped adjust the initial classification of forest types. The area calculation for the different classes and the analysis of the landscape changes were carried out with the programs Xtools and Fragstats, both working as extensions of the ArcView software.

3. RESULTS AND DISCUSSION

The number of indigenous forest patches identified on the photo mosaic from 1970 was 1,191 corresponding 50% to the forest type 'ciprés' in any of the three density classes (table 1). The total area covered by the four vegetation types on the three density classes was 4,166 hectares, corresponding 1,921 hectares -46%- to pure 'ciprés' forests. Thirty-eight percent of indigenous forests of all types on the study area were dense, 22% were semi-dense and 40% were sparse. The average patch area was 3.5 hectares. Major patches corresponded to the sparse density class -averaging 4.6 hectares- and the smallest to the semi-dense class -averaging 2.6 hectares-. The forest type 'ciprés' covered the greatest area and it was distributed on the whole study area (fig. 1).

On the IKONOS image from 2001 we could check that the indigenous forests on the eastern side of the study area suffered the greatest impact owed to the substitution by exotic species of a faster growth rate

(fig. 2). In this sector the stands with greater density of `ciprés`, `ciprés-coihue` and `coihue-ciprés` were more affected. Plantation patches totalized 106, although some patches could be further dissected, considering criteria as species, age, density and the presence of remaining indigenous species. In 2001 the total area of plantations encountered 877 hectares, being the average patch size of 8.2 hectares. The plantation patch of major size had 94 hectares. The number of indigenous forest patches considering all forest types was 1,572 covering an area of 3,580 hectares (table 1). This way, the heterogeneity of the former forest landscape was dramatically intensified because of the fragmentation and the area decrease of the indigenous forest for almost all considered forest types, with the only exception of `ciprés-coihue` and `coihue-ciprés` forest types in the semi-dense and sparse classes (fig. 3).

Table 1. Patch number and area of each forest type in 1970 and 2001 in the study area and the variation between both years.

Forest type	1970						2001						Variation					
	Classes of density																	
	1		2		3		1		2		3		1		2		3	
	N°P	CA	N°P	CA	N°P	CA	N°P	CA	N°P	CA	N°P	CA	N°P	CA	N°P	CA	N°P	CA
Ciprés	163	442	180	427	246	1052	240	373	225	366	318	868	77	69	45	61	72	184
Ciprés-coihue	97	334	61	133	24	119	152	281	65	118	33	112	55	53	4	15	9	7
Coihue-ciprés	140	448	37	79	10	32	188	419	38	74	13	31	48	29	1	5	3	1
Ciprés-shrubs	79	361	68	266	86	473	98	324	95	206	107	408	19	37	27	60	21	65

References: N°P: patch number; CA: class area. In all cases the variation refers to an increase of the patch number and a decrease in the area of each forest type for the considered time period.

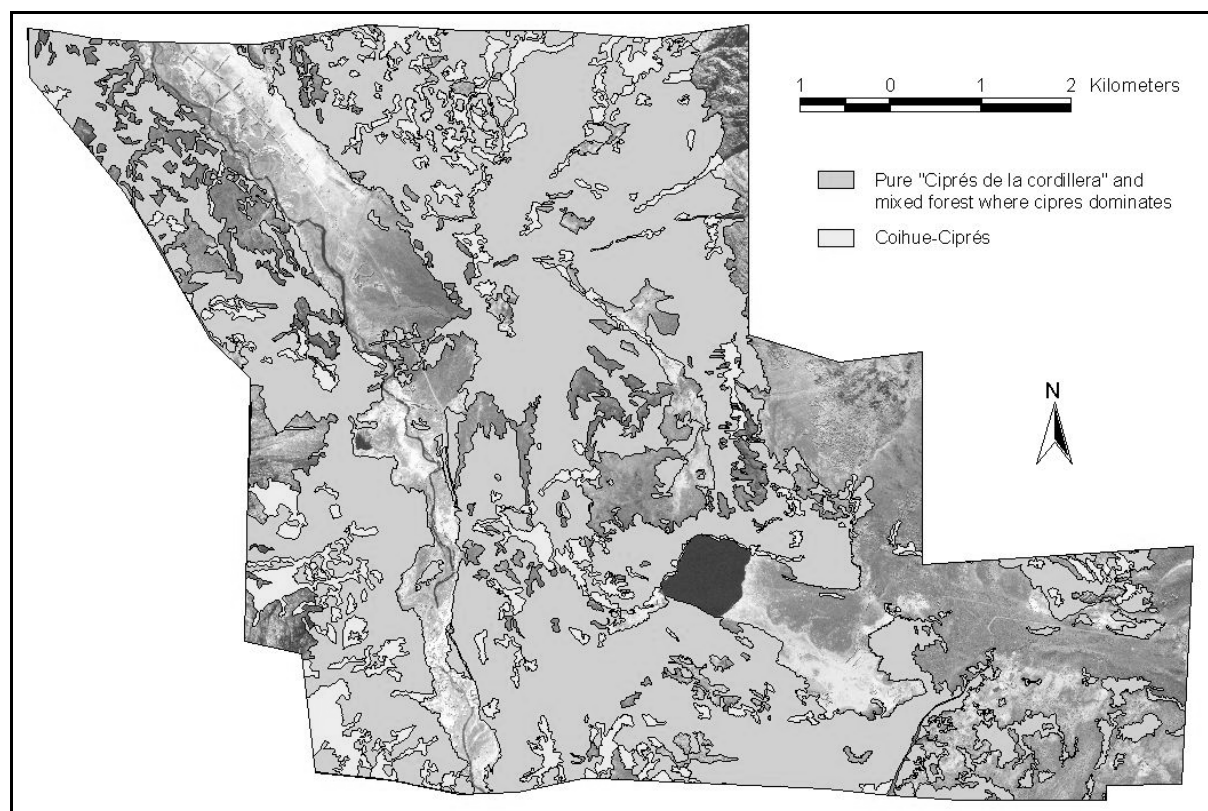


Figure 1: Distribution of indigenous forests in the study area in 1970.

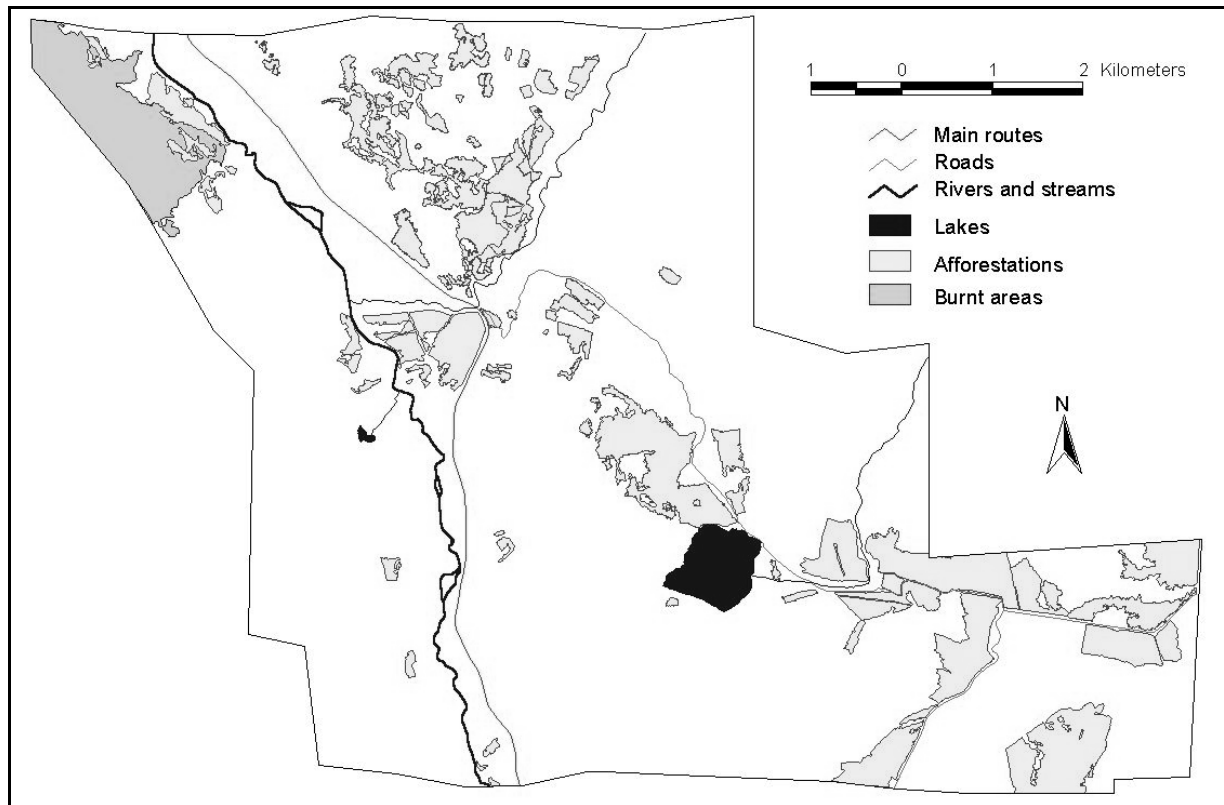


Figure 2: Main changes on landscape heterogeneity occurred between 1970 and 2001 due to substitution of indigenous forests by exotic conifer species and forest fires

Considering only the forest types 'ciprés' and 'ciprés-coihue' into the density classes dense and semi-dense, the patch number increased from 191 to 303 and the forest area was reduced from 1,336 hectares to 1,138 hectares. In this case, the level of fragmentation was more intense since the increase in the patch number was almost 60%, whereas the percentage of area reduction was similar to the general one - i.e.14%.

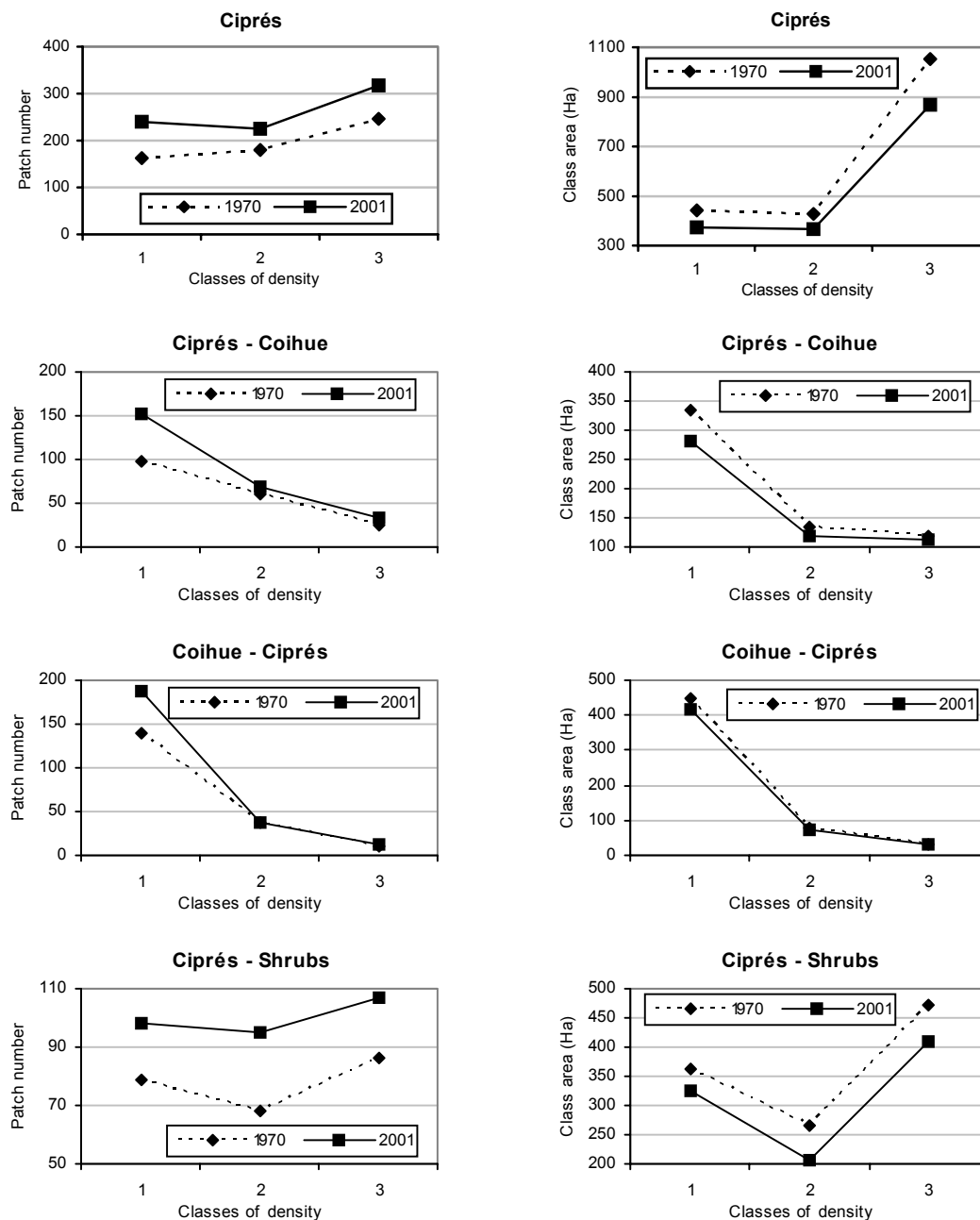


Figure 3. Main changes of indigenous forest types related to forest area reduction and increase of fragmentation levels between 1970 and 2001.

The substitution 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 "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. On the other hand there still remains the question of the incidence of forest fires. Recent statistics of 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 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.

These results become relevant if we consider that this multifaceted fragmentation process has an increasing influence on the degradation of environments and biodiversity decline. These assessments are also especially worrisome because `ciprés` covers the smallest area among those indigenous forest species traditionally used with diverse purposes, whereas also some other concurrent human-related processes are threatening these singular forest ecosystems. Hence, quantitative evaluation of forest fragmentation has become essential to support a decision-making practice leading to a more efficient protection of these unique ecosystems.

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