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Effects of disturbances generated by different management strategies on the vegetation strata of *Nothofagus antarctica* forests of Chubut, Argentina

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Abstract. Nothofagus antarctica is a species of the Andean-Patagonian forest with a wide distribution from the north of Neuquén to Tierra del Fuego. Although the N. antarctica forests are of great economic importance for the region, they are intensely affected nowadays by human activities such as grazing, firewood extraction, conversion into pastures and the replacement by coniferous plantations. These activities produce changes in the N. antarctica forest, mainly by the alteration of its original structure affecting the performance of the ecosystem as a whole, resulting in the loss of biodiversity. Since July 2008 up to May 2010 in the northwest of Chubut, Patagonia, we analyzed the effect of disturbances associated with different management strategies on species composition and structure of N. antarctica forest. The disturbances on N. antarctica forest considered in this study are derived from extraction of firewood by patches and landscapes, conversion of forests into pastures, forest fires occurred 15 and 25 years ago. Pristine forest was considered a control. The structure, composition and species diversity differ between forests affected by different disturbances. The higher arboreal and shrub stratum cover was observed in pristine sites (PR) while the largest herbaceous cover was observed in sites converted into pasture. The diameter at breast height (DAP) and the basal area (BA) of individuals of N. antarctica was larger than in those sites affected by firewood extraction at the landscape scale (FWL) than at the patch scale (FWP), while the density (number of individuals) was higher in the sites burned 25 years ago (B25). The canopy cover was higher in PR and FWL compared with those in the remaining sampling sites. Although some differences were found in the richness among the sampling sites, being higher in firewood extraction by patches and landscaped sites (FWP and FWL), there were no differences of diversity and dominance among sampling sites. Our results are compared with those obtained in previous studies in Patagonia and are of importance in the improvement of the management of N. antarctica forest and its conservation.

[Keywords: impacts of forest management, Patagonia, conservation]

Resumen. Efectos de los disturbios generados por diferentes estrategias de manejo sobre los estratos vegetales de bosques de Nothofagus antarctica de Chubut, Argentina. *Nothofagus antarctica* es una especie de los bosques Andino-Patagónicos, con una amplia distribución que se extiende desde el norte de Neuquén hasta Tierra del Fuego. Si bien los bosques de *N. antartica* son de gran importancia económica para la región, en la actualidad son muy afectados por actividades humanas como el pastoreo, la extracción de leña, la conversión en pastos y el reemplazo por plantaciones de coníferas. Estas actividades alteran la estructura original del bosque de *N. antartica*, lo cual afecta el funcionamiento de los ecosistemas en su conjunto y determina la pérdida de biodiversidad. Desde julio de 2008 a mayo de 2010, en el noroeste de Chubut, Patagonia, analizamos el efecto de las perturbaciones asociadas con distintas estrategias de manejo sobre la composición de especies y la estructura de los bosques de *N. antartica*. Los disturbios de los bosques de *N. antartica* considerados en este estudio se derivan de la extracción de leña por manchones y parquizado, la conversión de bosques en pasturas, los incendios ocurridos hace 15 y 25 años y, a modo de control, también se consideraron los bosques prístinos. La estructura, composición y diversidad de especies se diferenciaron entre bosques afectados por diversos disturbios. La mayor cobertura de los estratos arbóreos y arbustivos se observó en los sitios prístinos (PR), mientras que la mayor cobertura del estrato herbáceo se observó en los sitios convertidos en pasturas. El diámetro a la altura del pecho (DAP) y el área basal (BA) de los individuos de *N. antarctica* fue mayor en los sitios afectados por la extracción de leña por parquizado (FWL) que por parche (FWP), mientras que la densidad (número de individuos) fue mayor en los sitios quemados hace 25 años (B25). La cobertura del dosel fue mayor en PR y FWL, en comparación con los restantes sitios de muestreo. Aunque se encontraron diferencias en riqueza entre los sitios de muestreo (fue mayor en los sitios sometidos a extracción de leña por manchones y parquizado [FWP y FWL]), no se encontraron diferencias de diversidad y dominancia entre sitios de muestreo. Nuestros resultados son comparados con los obtenidos en estudios previos en la Patagonia y resultan de importancia en la mejora en la gestión de los bosques de *N. antarctica* y su conservación.

[Palabras clave: impactos del manejo forestal, Patagonia, conservación]

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Introduction

Human activities are considered the main source of impacts on the vegetation and fauna of the temperate forest of the Andean-Patagonian region (Simonetti et al. 1995). Environmental effects arising from such activities may have consequences that are local or regional, depending on the type and intensity of the impact on the ecosystems (Raffaele et al. 2014). One of the most characteristic ecosystems of Andean Patagonian in Argentina is the *Nothofagus antarctica* ([G. Forst.] Oerst. 1871) deciduous forest (Veblen et al. 1996). *Nothofagus antarctica*, commonly called "ñire", taking up to 751000 ha stretching from the province of Neuquén (33° S) up to Beagle Channel (55° S) (SAyDSN 2005). Historically, *N. antarctica* forest was relegated to forest by being considered of low productivity usage (Peri 2009a). This low productivity is largely attributed to its slow growth (Premoli & Vidal 2004), to the twisted shape of the column shafts and, often, to its poor health (Alvarado Ojeda 2006). In South Patagonia, forestry was historically based on wood processing of *N. pumilio* ("lenga") (Gea et al. 2004), but at present, the availability of these forests is very limited, resulting these heavily forested areas in an unsustainability situation, even though what the forest may sustain or provide (Martínez Pastur et al. 2004). Due to that situation, *N. antarctica* is a species of great economic importance for the region, because of its location and distribution, taking up areas in Southern Patagonia where agriculture is the ordinary activity (Peri et al. 2005). But in most of their distribution *N. antarctica* forest are intensively affected by human activities (Peri 2009a) such as livestock grazing, firewood extraction, conversion into pasture and replacement by conifer plantations (Schlichter & Laclau 1998). These activities produce changes in the *N. antarctica* forest, mainly by the alteration of their original structure and by the invasion of exotic species such as *Taraxacum officinale*, *Holcus lanatus*, *Poa pratensis*, *Rosa eglanteria*, among others (Gallo et al. 2004; Raffaelle et al. 2014), and in the structure and composition of the communities of the associated fauna (Lencinas et al. 2005, 2008, 2010), which usually affect the ecosystem and could result in the loss of biodiversity. Despite of the importance of this problem, few studies focused on the disturbances on *N. antarctica* forest derived from human activities (Gallo et al. 2004; Rusch et al. 2004; Peri et al. 2005; Reque et al. 2007; Carranza & Ledesma 2009; Peri 2009a).

The sustainable systems of native forest management challenges to reconcile the conservation with the needs to meet the requirements of the related population. However, despite the great impact on the regional level of these forest systems, the lack of appropriated information (based on scientific, social and economic livelihoods) limits the possibility to manage sustainably the *N. antarctica* forest, which could maximize the production of the system and promote its conservation (Peri et al. 2006; Peri 2009a). Thus, the aim of this study is to determine how the different types of disturbances, like fire, firewood extraction, pasture conversion, or others, affect the structure, plant species composition and diversity, like richness, diversity, dominance and abundance, of *N. antarctica* forests from West Chubut.

Materials and methods

Study site

To select the *Nothofagus antarctica* forest sectors affected by the different disturbances, we used satellite images shared by the staff of the INTA EEA San Carlos de Bariloche (Province of Río Negro), EEA Esquel (Province of Chubut), and our own field information obtained previous to this study. The selected forest belong to the same basin (Futaleufú), and the ranges of altitude (between 600 and 840 m.a.s.l.) and distance (17 km between the furthest points) among sites were as narrow as possible. In addition, the original structure of the *N. antarctica* forest in all sampling sites was similar

Table 1. Location of the sampling sites (FWP = firewood extraction by patches; FWL = firewood extraction by landscaped; PC = conversion of forest into pasture; B15 = fires occurred 15 years ago; B25 = fires occurred 25 years ago; PR = Pristine forests).

Tabla 1. Ubicación de los sitios de muestreo (FWP = extracción de leña por manchones; FWL = extracción de leña por parquizado; PC = conversión de bosques en pasturas; B15 = incendios ocurridos hace 15 años; B25 = incendios ocurridos hace 25 años; PR = bosques prístinos).

Sampling sites	Latitude	Length
FWP	S 43° 11.513	W 71°24.254
	S 43°11.232	W 71°25.22
FWL	S 43°11.416	W 71°24.179
	S 43°10.447	W 71°24.192
PC	S 43°11.269	W 71°25.239
	S 43°09.41	W 71°24.86
B15	S 43°13.483	W 71°36.207
	S 43°14.231	W 71°36.224
B25	S 43°06.22	W 71°33.57
	S 43°05.247	W 71°32.318
PR	S 43°12.269	W 71°23.89
	S 43°12.477	W 71°24.387

(patches of *N. antarctica* with individuals between 4 and 8 m in height).

The disturbances on *N. antarctica* forest considered in this study were: 1) firewood extraction by patches (FWP), 2) firewood extraction by landscaped (FWL), 3) conversion of forest into pasture (PC), 4) fires occurred 15 years ago (B15), and 5) fires occurred 25 years ago (B25). As a control, we also considered pristine forests (PR). Two replicates were considered for each disturbance type (10 sampling sites) and for the pristine forest (2 sampling sites); and the minimum distance between replicates was 1500 m (Table 1).

Environmental and vegetation variables

The information was obtained in two consecutive seasons: spring-summer 2008 and 2009. We randomly selected 3 sampling points at each sampling site where the following information was obtained in a radius of 5 m from such points:

a) Full cover by strata according to the scale described by Braun-Blanquet (1932) and Mueller-Dombois & Ellenberg (1974) (herbaceous strata below 0.6 m, shrub strata between 0.6 and 3 m, and arboreal strata above 3 m). Where the main strata were composed by sub-stratums, these were also considered.

b) Species composition: we identified the species represented in each stratum with the help of the information of Dimitri & Orfila (1985) and Zuloaga et al. (2008). Due to morphological similarities between species, *Poa ligularis* and *P. pratensis*, *Senecio filaginoides* and *S. neaei*, and *Bromus setifolius* and *B. stamineus*, they were grouped by gender. Species were also classified according to their origin: native or exotic.

c) To characterize the *N. antarctica* forest structure at each sampling site, the basal area (BA), diameter at breast height (DAP), number of individuals (absolute density) and canopy cover were estimated. By definition, the basal area (BA) is the area of a cross section of the stem or trunk of a tree at a certain height from the ground (Matteucci & Colma 1982). In *N. antarctica*, this parameter was measured by diameter or height of the chest perimeter (DAP) and then it was calculated as:

$$BA = \pi*(DAP2/4)$$

The DAP of trees was measured at a height of 1.3 m from the surface of the ground using a diameter tape. The number of individuals (absolute density) was estimated by counting the number of individuals of *N. antarctica* in the sampling area. Canopy cover was estimated using the area of circle formula as:

$$C = \pi * r^2/\text{sample area}$$

being r = DAP/2.

Data analyses

Comparisons of relative cover among the sampling sites, the three strata (arboreal, herbaceous and shrub) and the 2 origins (exotic and native), were done with a three-way analysis of variance (ANOVA). Means were separated by the Tukey honestly significant difference test ($P<0.05$). Complementary, detrended correspondence analyses (DCA) and cluster analysis were done, without down-weighting rare species and rescaling the axis (Lencinas et al. 2008), to emphasize ecological interrelationships between them, using species coverage (relative vegetation cover). The cluster analysis was conducted at sites affected by different disturbances and in pristine forest using a complete linkage amalgamation rule and the Euclidean distance measurement (Hill 1979; Greenacre 1984; Manly 1994). These analyses allowed the identification of sites affected by different disturbances, with cover and species identities alike, which were used to detect differences in species cover composition cover in their habitats (Ludwing & Reynolds 1988).

The sampling sites were characterized and compared with species richness, dominance and diversity (Moreno 2001). The species richness (S) was calculated as the number of species present in the sampling sites (S=number of species/total number of individuals) (Magurran 1988). The dominance was calculated using the Simpson index, taking into account the representativeness of the species with the highest importance value, and according to □=□ p_i^2, where p_i=proportional was abundance of the species i, (Peet 1975; Magurran 1988). Diversity was calculated using the index of Shannon-Wiener, expressed through uniformity of values of importance across all species in the sample, assuming that individuals are selected randomly, that all species are represented in the sample, and according to the equation $H'=-p_i \ln p_i$, were p_i=proportional abundance of the species i (Peet 1975; Magurran 1988).

Comparisons of richness, diversity and dominance among sampling sites were done with a one-way analysis of variance (ANOVA). The means were separated by the Tukey honestly significant difference test ($P<0.05$).

Nothofagus antarctica variables (BA, DAP, absolute density and canopy cover) accomplished the assumptions of parametric ANOVA. Therefore, this analysis was preferred, while means comparison were done by Tukey honestly significant difference test ($P<0.05$). For statistical analysis Infostat Proffesional v.2014 was used (Di Rienzo et al. 2014).

RESULTS

A total of 39 species belonging to 21 families were represented in the sampling points (Table 2). The dominant families in cover were Poaceae (21.41%), Nothofagaceae (14.46%) and Asteraceae (13.07%). Most of the species represented in the samplings belonged to the shrub stratum (44.92%), followed in abundance by the herbaceous (35.04%) and the arboreal (20.02%) strata. Regarding the origin, 86.50% of the species were natives whereas the remaining species were exotic.

The herbaceous stratum of the PR sites was dominated by the native *Bromus* sp., while at FWP sites the herbaceous stratum was dominated by the natives *Stipa* sp., *Bromus* sp., and by the exotics *Taraxacum officinale* and *Madia sativa*. At FWL, B15 and B25 sites the herbaceous stratum were dominated by the native *Stipa* sp., and by the exotics *Trisetum* sp., *T. officinale*, *M. sativa* and *Poa* sp. At PC sites the natives *Poa ligularis* and *Stipa* sp. dominated the herbaceous stratum, being *M. sativa* and *T. officinale* the most abundant exotic species. The shrub stratum of PR and FWP sites was dominated by native *Schinus patagonicus* and *Chacaya trinervis*, whereas the arboreal stratum was dominated by *N. antarctica*. While at FWL sites the shrub stratum was dominated by the natives *S. patagonicus* and *Maytenus chubutensis*, and by *Berberis parodii* and *Chusquea culeou* at B15 sites; and at both types of sites, the arboreal stratum was dominated by *N. antarctica*. At B25 sites the shrub stratum was dominated by the natives *M. chubutensis* and *Mutisia decurrens* and by the exotic *Rosa eglanteria* while the arboreal stratum was dominated by the natives' *N. antarctica* and *Lomatia hirsuta*, whereas *Pinus* sp. was the most abundant exotic species. At PC sites, only native species were represented in the shrub strata, being *Escallonia rubra* and *Mulinum spinosum* the most abundant among them, while arboreal species were absent there.

Table 2. ANOVA results for relative vegetation cover comparing disturbances types (FWP: firewood extraction by patches; FWL: firewood extraction by landscaped; PC: conversion of forest into pasture; B15: fires occurred 15 years ago; B25: fires occurred 25 years ago; PR: pristine forests), origin (exotic and native) and stratum (shrub, herbaceous and arboreal). Significance levels are presented in parenthesis, as *P*. Different letters within columns represent significant differences at *P<0.05*, according to Tukey test.

Tabla 1. Resultados del ANOVA para la cobertura de vegetación relativa comparando los tipos de disturbio (FWP: extracción de leña por manchones; FWL: extracción de leña por parquizado; PC: conversión de bosques en pasturas; B15: incendios ocurridos hace 15 años; B25: incendios ocurridos hace 25 años; PR: bosques prístinos), origen (nativos y exóticos) y estrato (arbusto, herbáceos y arbóreo). Los niveles de significancia se presentan entre paréntesis, como *P*. Letras diferentes dentro de las columnas representan diferencias significativas a un *P<0.05* según la prueba de Tukey

Source of Variation		Relative Cover
A: Disturbance type	F (*p*)	12.88 (<0.0001)
	B25	10.12 a
	B15	10.8 ab
	FWP	14.1 abc
	PR	16.3 bc
	FWL	16.92 c
	PC	17.86 c
B: Origin	F (*p*)	3.96 (0.047)
	Exotic	10.13 a
	Native	13.66 b
C: Stratum	F (*p*)	29.68 (<0.0001)
	Shrub	6.36 a
	Herbaceous	15.58 b
	Arboreal	21.38 c
F Interaction AB (*p*)		3.74 (0.0024)
F Interaction AC (*p*)		6.77 (<0.0001)
F Interaction BC (*p*)		0.17 (0.8468)
F Interaction ABC (*p*)		5.05 (0.0249)

Significant differences among sampling sites were observed both in the vegetal stratum coverage and in the origin of the species (Table 2). In this sense, PR sites (38.91±2.59) presented the highest arborous (36.35 ± 30. 4; $p < 0.05$) and shrub (12.31 ±16.34; $p < 0.05$) cover, compared with the remaining sites, whereas the highest native herbaceous cover was observed at PC sites (22.94 ±16.08; $p < 0.05$; Figure 1; Annex).

In the first DCA ordination analysis, the whole sampling data set was analyzed and only one and two axes were retained for interpretation (eigenvalue axis 1= 0.54 and eigenvalue axis 2= 0.34). These two axes explained the 70.72% of the variance in species and sampling sites relationships (axis 1: 52.82%, axis 2: 20.98%). Axis 1 mainly influenced by low forest disturbance and high arboreal cover, located PC and PR sites in the farthest positions, leaving the FWL and FWP sites in the intermediate space (Figure 2). The axis 2, mainly influenced by high herbaceous and shrub cover, located B25 (on the right) and B15 (to the left) sites in the farthest positions. Complementary, cluster analysis resulted in three main clusters based on specie's

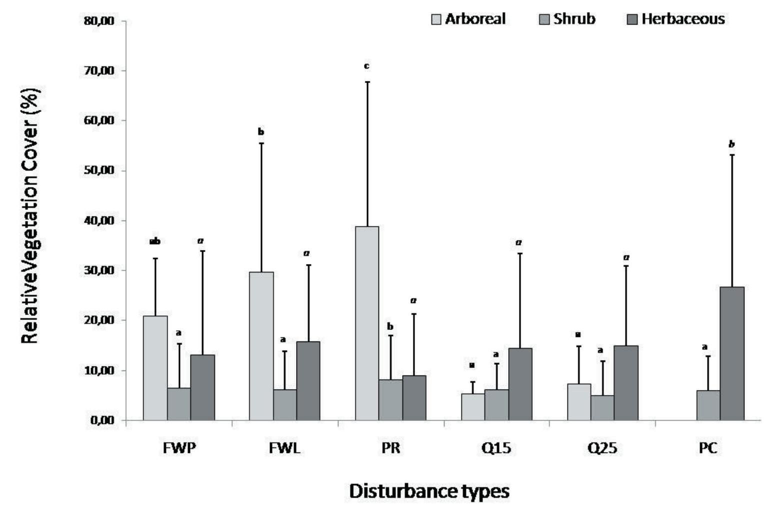

Figure 1. Relative vegetation cover (%) of each stratum at the different disturbance types (FWP = firewood extraction by patches; FWL = firewood extraction by landscaped; PC = conversion of forest into pasture; B15 = fires occurred 15 years ago; B25 = fires occurred 25 years ago; PR = Pristine forests). The different letters in bold indicate the existence of significant differences in the relative cover of the arboreal stratum between disturbance types (Tukey test, $p < 0.05$). The different letters in italics indicate the existence of significant differences in the relative cover of the herbaceous stratum between disturbance types (Tukey test, $p < 0.05$). Different letters indicate significant differences in the relative cover of the shrub stratum between disturbance types (Tukey test, $p < 0.05$).

Figura 1. Cobertura de vegetación relativa (%) para cada estrato en los diferentes tipos de perturbación (FWP = extracción de leña por manchones; FWL = extracción de leña por parquizado; PC = conversión de bosques en pasturas; B15 = incendios ocurridos hace 15 años; B25 = incendios ocurridos hace 25 años; PR = bosques prístinos). Las letras diferentes en negrita indican la existencia de diferencias significativas en la cobertura relativa del estrato arbóreo entre los tipos de disturbio (Tukey test, $p < 0.05$). Las diferentes letras en cursiva indican la existencia de diferencias significativas en la cobertura relativa del estrato herbáceo entre los tipos de disturbio (Tukey test, $p < 0.05$). Letras diferentes indican diferencias significativas en la cobertura relativa del estrato arbustivo entre los tipos de disturbio (Tukey test, $p < 0.05$).

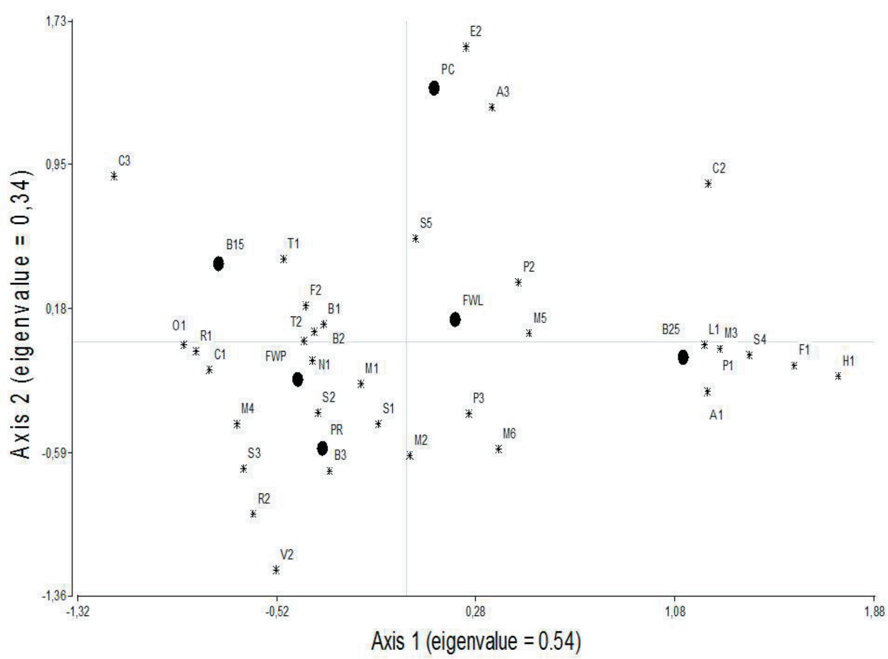

Figure 3. Ordering of disturbance types using vegetation cover data (FWP: firewood extraction by patches; FWL: firewood extraction by landscaped; PC: conversion of forest into pasture; B15: fires occurred 15 years ago; B25: fires occurred 25 years ago; PR: pristine forests).

Figure 3. Ordenamiento de los tipos de disturbio utilizando datos de cobertura de vegetación (FWP: extracción de leña por manchones; FWL: extracción de leña por parquizado; PC: conversión de bosques en pasturas; B15: incendios ocurridos hace 15 años; B25: incendios ocurridos hace 25 años; PR: bosques prístinos).

composition. The pairs of sites B15-B25 and PR-FWL showed the highest similarity, whereas PC and FWP sites were markedly different to the remaining sites (Figure 3).

The species richness (S) varied among sampling sites ($F_{5;197}$=6.35; *P*<0.0001), being the highest values observed at FWL and FWP sites (*P*<0.0001) (Table 3). The diversity (Shannon index) and dominance (Simpson index) of species did not differ among sampling sites ($F_{5;193}$=2.43, *P*>0.05 and $F_{5;193}$=1.51, *P*>0.05, respectively).

The DAP, BA, canopy cover and density of *N. antarctica* individuals differed among sampling sites ($F_{4;284}$=53.10; *P*<0.0001). The highest values of DAP were observed at FWL sites, whereas the lowest ones were observed at the burned sites (B15 and B25) (Tukey, *P*<0.05; Table 4). The highest values of BA and canopy cover were observed at PR, FWP and FWL sites (Tukey, *P*<0.05), whereas the lowest ones were also observed at burned sites (Tukey, *P*<0.05; Table 3). The highest values of density were observed at B25 sites and the

Table 3. Richness, dominance and diversity of the species observed in the sampling sites. Values are expressed as mean±standard deviation (SD). Different letters indicate significant differences between types of disturbance for richness, and indices of dominance and diversity (P<0.05).

Tabla 3. Riqueza, dominancia y diversidad de las especies observadas en los sitios de muestreo. Los valores se expresan como media±desviación estándar (SD). Letras diferentes indican diferencias significativas entre los tipos de perturbación para la riqueza e índices de dominancia y diversidad (P<0.05).

Indices	Site type perturbation	Mean ± SD	Rank	Signification level
Richness (S)	Pristine (PR)	0.19±0.15	0.04-0.61	a
	Pasture conversion (PC)	.87±2.73	0.43-9.57	a
	Burnt 15 years (B15)	2.48±3.33	0-11.61	a
	Burnt 25 years (B25)	2.94±3.3	0.32-12.68	a
	Firewood extraction landscape (FWL)	3.28±3.55	0.32-15.62	b
	Firewood extraction patches (FWP)	3.62±3.71	0.35-12.65	b
Dominance (Simpson index)	Burnt 25 years (B25)	0.04±0.07	0.00-0.32	a
	Pristine (PR)	0.06±0.10	0.001-0.37	a
	Firewood extraction landscape (FWL)	0.08±0.22	0.00-1.31	a
	Firewood extraction patches (FWP)	0.11±0.19	0.00-0.77	a
	Burnt 15 years (B15)	0.16±0.27	0.01-0.86	a
	Pasture conversion (PC)	0.17±0.30	0.01-1.00	a
Diversity (Shannon index)	Burnt 25 years (B25)	0.21±0.13	0.00-0.37	a
	Firewood extraction landscape (FWL)	0.23±0.12	0.15-0.37	a
	Firewood extraction patches (FWP)	0.24±0.11	0.00-0.37	a
	Burnt 15 years (B15)	0.25±0.10	0.07-0.37	a
	Pasture conversion (PC)	0.26±0.10	0.00-0.37	a
	Pristine (PR)	0.27±0.07	0.14-0.37	a

Table 4. ANOVA results for DAP (diameter at the breast height), basal area (BA), density (number of individuals) and canopy cover (%) of the *Nothofagus antarctica* individuals present in the disturbances types. The values of mean ± standard deviation (SD) and range are presented. Different letters indicate significant differences among the types of disturbance associated with the sites (Tukey test, *P*<0.05).

Tabla 4. Resultados del ANOVA para DAP (diámetro a la altura del pecho), área basal (BA), densidad (número de individuos) y cobertura del dosel (%) de los individuos de *Nothofagus antarctica* presentes en los tipos de disturbios. Los valores se presentan como media ± desviación estándar (SD). Letras diferentes indican diferencias significativas entre los tipos de disturbios asociados a los sitios (prueba de Tukey, *P*<0.05).

Variables	Types of perturbation					Tukey test
	PR	FWL	FWP	Q15	Q25	
Diameter at breast height (cm)	19.85±9.27b	30.68±19.72c	15.17±7.28b	4.45±3.63a	9.06±5.26a	*P*<0.0001
Basal area (m^2/ha)	48.97±22.86b	75.67±48.65b	37.42±17.97b	10.99±8.95a	22.36±12.97a	*P* <0.0001
Density (n/ha)	2.95±2.19 a	18.71±16.55a	33.7±55.33b	13.08±10.58a	77.21±61.95c	*P*<0.0001
Canopy cover (%)	22.04±10.76b	35.6±22.89b	17.6±8.45b	5.17±4.21a	10.52±6.1a	*P*<0.0001
n	50	60	60	60	60	

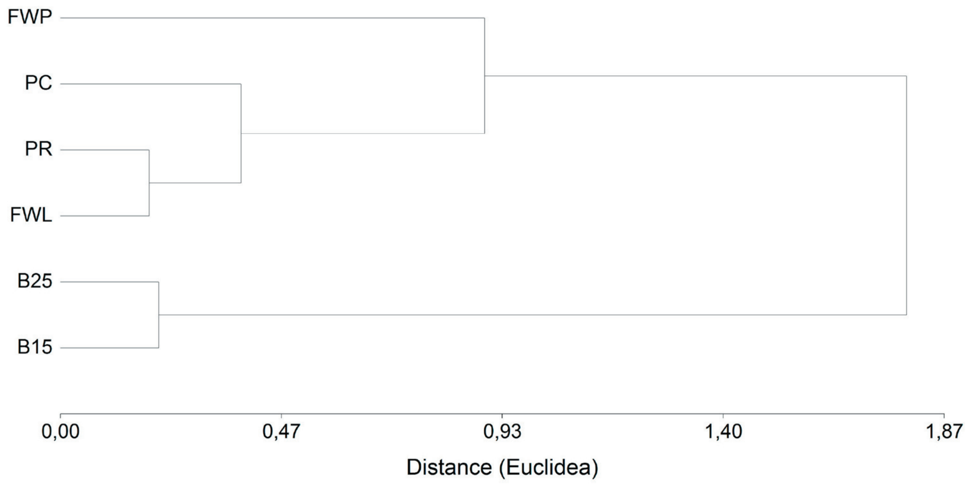

Figure 3. Classification of disturbance type based on vegetation cover sampling data (FWP: firewood extraction by patches; FWL: firewood extraction by landscaped; PC: conversion of forest into pasture; B15: fires occurred 15 years ago; B25: fires occurred 25 years ago; PR: pristine forest).

Figure 3. Clasificación de los tipos de disturbio basado en datos de cobertura de vegetación (FWP: extracción de leña por manchones; FWL: extracción de leña por parquizado; PC: conversión de bosques en pasturas; B15: incendios ocurridos hace 15 años; B25: incendios ocurridos hace 25 años; PR: bosques prístinos).

lowest ones were observed at B15, FWL and PR sites (Tukey, $P<0.05$; Table 4).

DISCUSSION

The disturbance of natural systems is an event that may alter, depending on its frequency and magnitude, the ecosystem dynamic and the structure of the communities or populations by altering the availability of resources or modifying the physical environment (Relva et al. 2014). The management of the *Nothofagus* forests impact mainly on plant, insects and birds diversity (Defferari et al. 2001; Lencinas et al. 2008; Raffale et al. 2014). In this sense, Spagarino et al. (2001) reported for managed forest at *N. pumilio* at Tierra del Fuego, a loss rate of one insect species every 11 years, which allows the invasion of species from adjacent environments. The pristine forests considered in this study were dominated by native species such as *N. antarctica* in the arboreal, *Schinus patagonicus*, *Ribes* sp. and *Berberis parodii* in the shrub, and *Stipa* sp., *Bromus* sp. and *Viola maculata* in the herbaceous strata. According to the parameters observed in the *N. antarctica* individuals, such as DAP, BA, density and canopy cover, these forests presented a condition suitable for optimal arboreal stratum regeneration, which allows the preservation of their spatial and seasonal variability (Gallo et al. 2004; Peri 2009a).

Fire is one of the most extensive disturbances which produces the most evident short term consequences such as reduction of vegetation cover and changes in vegetation structure and composition (Veblen et al. 2003; Sackmann & Farji-Brener 2006). After fire events *N. antarctica* forests are susceptible to invasion by fast growing exotic species such as *Rosa eglanteria* (Rosa Mosqueta), as it was mainly observed at the B25 sites (see also Varela et al. 2006; Relva et al. 2014). In this study the burned sites showed a replacement of native species by exotic ones, either by forestation with *Pinus* sp. in B15 sites or naturally in the shrub and herbaceous strata of B15 and B25 sites. Usually, under natural conditions the native forest may present a fast restoration (Nuñez & Raffaele 2014; Rovere et al. 2014), but implantation of pines alter this process, given that negatively affect the bushes that regenerate by sprouting, an efficient strategy that allows many species re-colonize after fire events (Nuñez & Raffaele 2014). The diameter and basal area of the *N. antarctica* individuals at B15 and B25 sites were low, which correspond to the state of regeneration of the forest, and at B25 sites this tree characteristic was accompanied by a high density of individuals. At both sites the herbaceous was the dominant stratum, and the shrub and arboreal strata presented a low cover. Despite of the time elapsed between the events at B15 and B25 sites, both type of sites showed similarities in the species composition, cover, richness, dominance and diversity, and in the diameter of the *N. antarctica* individuals, and all of these similarities reflected differences between sites in the regeneration times. Forest fires affect not only vegetation but also soil conditions by reducing the availability of nutrients, organic matter and moisture, thus negatively affecting the regeneration capacity (Veblen et al. 2003). Post fire vegetation recovery times depends largely on the regime of shocks to which has been exposed the community throughout their evolutionary history, the size and composition of the seed bank, the capacity of plant species to regrowth and the environmental conditions (Kozlowski 2002), factors that might explain the differences in the recovery times between B15 and B25 sites. In these environments, post disturbance regeneration of some native species is very slow and is characterized by a successional process dominated in its early stages by opportunistic exotic herbaceous species (Gobbi 1994; Kitzberger et al. 2005).

Natural environments have been changing due to land use. Farming is practiced in Patagonia since the end of the 19^{th} century (Laclau 1997; Gallo et al. 2004; Hansen et al. 2005). Additionally, some areas were transformed into pasture, were replaced by exotic forests, suffered intensive firewood extraction or were fragmented due to human settlement (Rusch & Sarasola 1999; Peri et al. 2005). Despite of being of relatively low suitability for the livestock (Peri 2009a), 70% of the *N. antarctica* forests are used as silvopasture systems (Peri 2009b) given that in the understory of *N. antartica* forest species of good forage value such as *Holcus lanatus*, *Poa pratensis*, *Elymus* sp., *Carex* sp. and *Trifolium repens*, among others, are present and abundant (Gargaglione et al. 2015). In this study the sites converted into pasture presented the greatest cover of herbaceous species of native origin, such as *Stipa* sp., *Azorella trifoliolata*, *Poa ligularis*, *Madia sativa*, among others, and there were no differences among them and the remaining sites in species richness, dominance and diversity. The absence of the arboreal stratum in sites converted into pasture evidence that this practice avoid the *N. antarctica* regeneration.

In addition to the conversion of forest in pastures, the opening of light in the forest through the extraction of firewood can produce changes on the majority of the native species present in the *N. antarctica* forest (Relva et al. 2014). At FWP and FWL the arboreal, almost exclusively composed by *N. antarctica*, was the dominant stratum and the shrub and herbaceous strata presented a low cover. The diameter, basal area and canopy cover of the *N. antarctica* individuals at FWL sites were higher than at FWP sites, whereas the density of individuals was higher at FWP sites, which could be indicating that on these sites would be taking place the regeneration of the arboreal stratum. The dominance and diversity of species at FWP and FWL sites were similar to the observed at the remaining sites under study. Otherwise, the richness of species at FWP and FWL sites was higher than the observed at the other study sites considered, which could be related to the fact that the opening of the canopy results in microclimatic conditions that favors the establishment of vegetation species (Lencinas et al. 2003; Quinteros et al. 2010).

Conclusion

Protecting biodiversity is a central objective in conservation which aims to care for all forms of life, at all levels of organization and ecological roles they perform. Forestry practices alter forest biodiversity and can cause the loss of species (Wigle & Roberts 1997; Deferrari et al. 2001; Spagarino et al. 2001; Martinez Pastur et al. 2002) due to changes in the forest structure and plant cover, the introduction of exotic species, and the modification of micro-climate or nutrients cycles (Reader & Bricker 1992). In this sense, *Nothofagus* forests sustain rich and diverse arthropods' (Lanfranco 1977; McQuillan 1993; Solarvicens 1995) and birds' (Deferrari et al. 2001; Lencinas et al. 2005) communities with a relatively high number of endemic species, and these communities can be altered due to the forestry practices, as in fact was observed by (Niemelä 2001; Spagarino et al. 2001; Lencinas et al. 2005, 2008a,b, 2010; Casaux & Tartara 2012; Gönc et al. 2012; Gönc 2013).

The results presented here full agree with those reported by other authors (Spagarino et al. 2001; Martinez Pastur et al. 2002; Lencinas et al. 2008) in relation to the impacts generated by the wood extraction on the structure and composition of the forests of *Nothofagus* species. Even the selective extraction of a relatively low number of trees creates a number of effects on the forest, including the decrease in the density of trees which might affect the potential for regeneration of forests (Hutchinson 1987; Gentry & Terborgh 1990; Rankin et al. 1992; Johnson & Cabarle 1993). In areas where the forest of *N. antarctica* is mostly degraded due to fires, with short and joint use of excessive grazing, it tested the deterioration of the system, with little regeneration of the tree component, and the consequent invasion of exotic species, which impede the development of weeds and vegetation. It is considered that these areas should be the first to develop the restoration actions.

In order to reach the economic and ecological sustainability of management planning of non-timber quality forests, like *N. antarctica* forests, it should be considered the information derived from studies aimed to develop adequate forest management strategies that increase the protection of associated species, and at the same time, that minimize the impacts on the forest. This practice will help to minimize the impacts on exploited forests, and to improve plant species of understory conservation at landscape and ecosystem level.

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ANNEX

List of species ordered by family, including the origin (N=native; E=exotic), and stratum (H=herbaceous; S=shrub; A=arboreal). Refers to the abbreviation used for the detrended correspondence analyses (DCA).

Lista de especies ordenadas por familia, incluyendo el origen (n=nativas; e=exóticas), y el estrato (H=herbáceas; S=arbustivas; A=arbóreas). Se señala la abreviatura utilizada para el análisis de ordenamiento (DCA)

Family	Species	Species Code	Origin	Stratum
Alstromeriaceae	*Alstroemeria aurea*	A1	N	H
Anacardiaceae	*Schinus patagonicus*	S1	N	A
Apiaceae	*Mulinum spinosum*	M5	N	S
	Azorella trifoliolata	A3	N	H
	Mulinum echinus	M4	E	H
Asteraceae	*Madia sativa*	M1	E	H
	Mutisia decurrens	M6	N	S
	Senecio filaginoides	S3	N	S
	Senecio neaei	S3	N	S
	Taraxacum officinale	T1	E	H
Berberidaceae	*Berberis parodii*	B1	N	S
Celastraceae	*Maytenus boaria*	M2	N	A
	Maytenus chubutensis	M3	N	S
Cupressaceae	*Astrocedrus chilensis*	A2	N	A
Ericaceae	*Gaultharia macronatta*	G1	N	S
Escalloniaceae	*Chacaya trinervis*	C1	N	S
	Escalloria rubra	E2	N	S
Fabaceae	*Sthaeroca rethama*	S4	N	S
Geraniaceae	*Geranium sessili orum*	G2	N	H
Nothofagaceae	*Nothofagus antartica*	N1	N	A
Orchidaceae	*Chloraea magellanica*	C2	N	H
Pinaceae	*Pinus sp.*	P1	E	A
Poaceae	*Bromus setifolius*	B2	N	H
	Bromus stamineus	B3	N	H
	Chusquea culeou	C3	N	S
	Holcus lanatus	H1	E	H
	Poa ligularis	P2	E	H
	Poa pratensis	P3	E	H
	Stipa sp.	S5	N	H
	Trisetum sp.	T2	E	H
Proteaceae	*Lomatia hirsuta*	L1	N	A
Rosaceae	*Elanterea rosa*	E1	E	S
Rosaceae	*Fragaria chiloensis*	F2	N	S
Saxifragaceae	*Ribes cucullatum*	R1	N	S
Solanaceae	*Fabiana imbricata*	F1	N	S
Thymelaeaceae	*Ovidia andina*	O1	N	S
Valerianaceae	*Valeriana carnosa*	V1	N	H
Violaceae	*Viola maculata*	V2	N	H