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Regeneration of *Fitzroya cupressoides* after indigenous and non-indigenous timber harvesting in southern Chilean forests

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Abstract

Fitzroya cupressoides (Cupressaceae) is an endemic and long-lived conifer of southern Chile and Argentina (40–43° S). This species has been subject to continuous exploitation since the 16th century, causing extensive population decline. Historically, the main labour force for the exploitation of *F. cupressoides* (alerce) was the indigenous Mapuche-Huilliche population, first under the command of the Spanish settlers and later, of non-indigenous Chileans. In coastal forests, timber of alerce has been harvested by Huilliche communities as well as by Chilean and international forestry companies. Records of the regeneration of this pioneer tree after exploitation in the Andean mountains have generally shown limited regeneration depending on the intensity of harvest. Because indigenous exploitation does not use machinery for timber harvesting, and is supposedly less utilitarian than commercial harvest, I propose that areas in the Coastal Range harvested by Huilliche communities should present higher regeneration of alerce than areas harvested by forestry companies. To test this hypothesis, I sampled 10 stands harvested and abandoned by forestry companies and 10 stands harvested by Huilliche communities in the coastal range of the Osorno Province (41° S, 400–800 m). In each stand, I estimated the density of regeneration (sapling stage), number of stumps, number of live adults, and the number of standing and fallen dead alerce. Each stand was characterized by elevation, forest-type, incidence of fire, and vegetation cover. Results showed that forests harvested by Huilliches had higher numbers of live, remnant adult trees with a *dbh* $\geq$ 60 cm than forests harvested by timber companies. The number of stumps with a *dbh* $\geq$60 cm was significantly higher in stands harvested by timber companies than in Huilliche stands. Despite large differences in sapling densities among stands, regeneration density of alerce was unrelated to the type of harvest used by indigenous people or forestry companies.

Keywords: Alerce; Coarse woody debris; Conifers; Logging; Temperate forests

1. Introduction

As a source of timber, temperate rainforests have been of secondary importance to indigenous populations of southern Chile, relative to other values, such as hunting and fishing grounds, a place for collecting and gathering fungi and seeds, and a source of land for farming (Molina et al., 2006). Before the Spanish arrival, timber was rarely used by indigenous populations. However, at the end of the 16th century Spaniards discovered the high timber quality and economic value of the gymnosperm *Fitzroya cupressoides*, ‘‘alerce’’. Given its beautiful grain and strong resistance to rot, the demand for alerce wood grew very quickly.

Through extensive timber harvest, indigenous peoples, Spaniards, and Chileans reduced the populations of alerce, especially in the valley of the Andean foothills of the Chilean Lake District, during the following three centuries (Fraver et al., 1999). At present, logging of live alerce trees is illegal in Chile, and only the harvesting of dead wood is permitted. In the past two centuries, several indigenous communities, collectively referred as *Huilliches* (name given to the inhabitants of the south), have harvested the wood of alerce in their own territories (Molina et al., 2006; Fig. 1). In the mid 20th century several forestry companies became interested in harvesting alerce timber in this indigenous land. This created a sustained territorial conflict with the indigenous peoples. Forestry companies stayed on the lands under exploitation for no more

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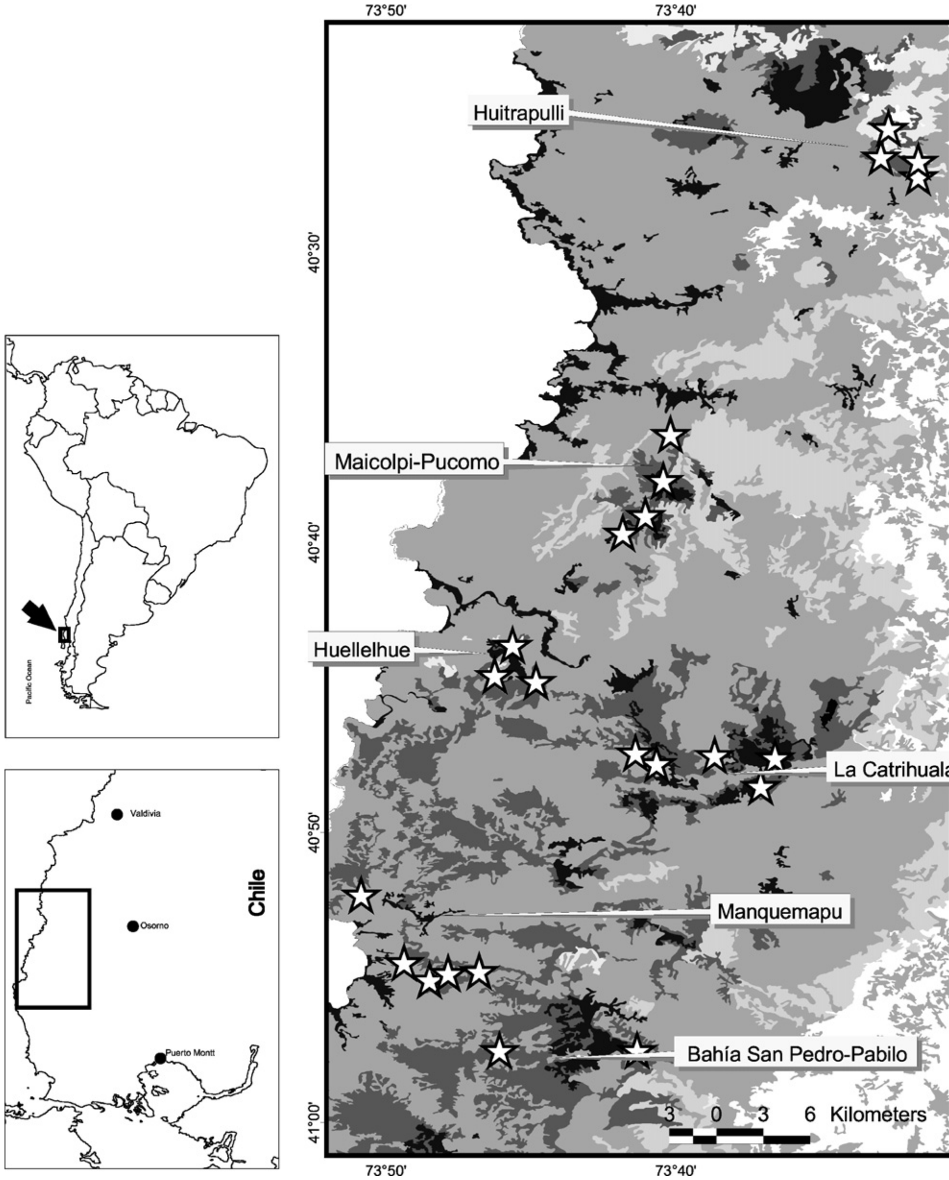

Fig. 1. Distribution of the *Fitzroya cupressoides* forests (darker gray shading) and mixed evergreen forests (lighter gray shading) in Osorno coastal range, Chile. In black non-maped areas. In white agricultural areas. The stars shown the forest stands studied, including both indigenous and forestry companies harvesting.

than 30 years, which is approximately the time that took them to extract the best exploitable timber, and later abandoned the areas. Presently, Huilliches still harvest dead wood left over in these cutover forests as well as dead from other burnt stands in their territories in the Coastal Range. In these areas, we find a mosaic of alerce forests harvested by forestry companies, Huilliches and both. Whether the harvesting of dead wood by the indigenous communities harms the regeneration of alerce or other forest values remains a controversial issue.

Alerce is a pioneer tree species that establishes in the Andes following disturbance by landslides and vulcanism, but it does not grow in tree fall gaps (Lara, 1991; Ramírez de Arellano, 1997; Schlegel, 1997). Some studies have examined the dynamics and regeneration of alerce unlogged stands in Andean forests in the Lake District of southern Chile (Lara, 1991; Donoso et al., 1990; Donoso et al., 1993) and coastal forests in Chiloé Island (Armesto et al., 1995; Armesto et al., 1996). Other studies have addressed forest dynamics, tree regeneration and size structure of harvested stands in coastal (Veblen and Ashton, 1982; Cortés, 1990; Donoso et al., 1993), Andean (Veblen et al., 1976; Schmidt and Burgos, 1977; Donoso et al., 1987; Rodríguez, 1989; Lara, 1991; Donoso et al., 1993) and currently rare, remnants of central valley forests, located between the Andean and coastal mountains (Fraver et al., 1999; Silla et al., 2002). Regeneration of alerce in harvested areas in the Andes is generally low or completely absent (Veblen et al., 1976; Schmidt and Burgos, 1977; Donoso et al., 1993). These results led the authors to conclude that the lack of regeneration in logged Andean stands is largely due to the high intensity of exploitation of this species in the past. In contrast, on coastal mountains at similar latitudes, Cortés (1990) and Donoso et al. (1993) have reported abundant regeneration of alerce in commercially harvested forests. Accordingly, here I propose that differences in alerce regeneration among coastal stands would be indicative of differences in the intensity of timber extraction.

It may be argued that timber harvesting practiced by indigenous communities in Chilean coastal forests differs from higher intensity commercial timber harvest practiced by forestry companies. Differences could be due to a lower demand for large timber trees and the absence of harvesting machinery in indigenous lands. If the intensity of timber harvest affects the recovery of alerce populations, it would then be possible to expect differences in regeneration density between stands harvested by indigenous peoples and those harvested by forestry companies. Consequently, I expect a higher regeneration of alerce in coastal forest stands harvested by indigenous people (soft harvest) than in those commercially exploited by forestry companies (hard harvest).

The objective of this study was to quantify and compare the regeneration potential, stem size structure and intensity of harvesting of alerce in stands exploited, largely during the 20th century, by indigenous peoples and by forestry companies. I addressed two questions: (i) Is indigenous cultural idiosyncrasy expressed in lower intensity of timber harvest than logging by forestry companies? (ii) Is the regeneration potential of alerce different in stands subjected to these different forms of harvest? I am not pretending to prove Rousseau's hypothesis about the noble savage (Redford, 1990), but rather to assess whether certain variables of forest dynamics differ as a consequence of different harvesting practices.

2. Methods

This study was carried in the coastal mountains of southern Chile, in the X Region (40° 41′ S, 73° 15′ W, Fig. 1, Table 1). The coastal range is a mountain chain of low altitude and generally gentle slopes that lie parallel and close to the Pacific Ocean. In the study area, the summits are found at around 900 m, and the study sites lay in high, flat areas, usually near mountaintops, where dense stands of the long-lived conifer alerce occur in different states of conservation. In this coastal range, I sampled 20 different stands of alerce; 10 were harvested by indigenous people and 10 harvested by forestry companies. The 20 alerce stands were all located within five indigenous settlements on the Coastal Range (Fig. 1): Trafunco Los Bados – Neipan, Maicolpi, Caleta Huellelhue, Catrihuala, and Manquemapu. During January and February 1996 and 1997, three to five stands within each of these five Huilliche communities were studied.

In general, two other tree species are frequent in the canopy of alerce forests: *Drymis winteri* and *Nothofagus dombeyi*. Dominant species of sub-canopy trees and understory shrubs were *Tepualia stipularis*, *Podocarpus nubigena*, *Baccharis magellanica* and *Desfontainia spinosa*.

2.1. Size structure of stands and intensity of harvest

A survey of regeneration patterns was carried away using line transects. Each stand studied was selected in the field, I selected the stands only in plain areas, with some signals of harvested. The minimal distance between stands was 2 km. Six parallel transects were established separated from one another by an interval of about 30 m (cf. Donoso et al., 1993). Transect lines were 50 m long. On both sides of the transect line, within a 1-m wide strip, I recorded the number and diameter at breast height (*dbh*) of all live individuals of alerce taller than 2 m. Because the presence of stumps and fallen logs is indicative of shingle manufacturing and intensity of use of alerce timber, I recorded the number and basal diameters of all the stumps, the number and *dbh* of fallen logs and the number and *dbh* of standing dead individuals (snags). The number of stumps and fallen logs was indicative of the intensity of exploitation of alerce timber in the stand, as measured by the number of alerce trees cut (stumps) relative to the total number of trees (the sum of all stumps and trees remaining alive, without regeneration) with *dbh* $\geq$5 cm.

The presence of fallen logs is also indicative of shingle manufacturing, which is done at the site leaving a significant portion of the cutover tree on the ground. Other uses (e.g., posts and beams) are revealed by nearly complete log removal from the stand using oxen and tractors, which leaves less woody detritus than shingle manufacturing. These practices may differ between stands harvested by Huilliches and those harvested by forestry companies. The density of alerce regeneration was recorded in 2×2 m^2 quadrats, placed every 10 m along the same transect lines ($n = 5$ per stand). All individuals $\leq$2 m tall were defined as regenerating from seed or occasionally from rootstocks. No distinction was made between these two types of regeneration. Tree-ring counts made at the base on five saplings (1.5 to 2 m tall) showed that these individuals were 26–40 years old. Therefore, most of the regeneration recorded was established in the last 50 years. Because regeneration of alerce is directly and positively related to canopy openness (Veblen et al., 1995), a visual assessment of percent canopy (>5 m height) and understory cover (<1 m height) was made at each stand. For each transect, cover was assigned to a percentage category, in the following intervals: 0, 20, 40, 60, 80 and 100%. Alerce stands in the study area were further classified in two types (*sensu* Donoso et al., 1987), depending on the dominant tree species in the canopy: pure alerce forests – with nearly complete or exclusive dominance of live and dead alerce in the canopy; and mixed alerce forests – with presence of other canopy species, such as *Drimys winteri, Nothofagus dombeyi, N. nitida, Pilgerodendrum uviferum*, *Saxegothea conspicua* and *Podocarpus nubigena*. Further, each stand was characterized using the following descriptive variables: evidence of past fire, such as charcoal and burned stems, elevation (meters above sea level), duration of commercial or indigenous exploitation (in years), year when harvesting ceased, if the stand was abandoned (from personal interviews with Huilliche people and data in Molina et al., 2006), and evidence of operation of portable sawmills (e.g., leftover machinery and sawed timber) (Table 1).

I carried out a model I (fixed-effects) nested ANOVA where type of harvesting was a factor with two levels (indigenous and forestry companies harvesting) and the subgroups were defined by the stands. Residuals of ANOVA and fitted regression

Table 1
Characteristics of 20 logged *Fitzroya cupressoides* stands, ordered by indigenous community and from north to south in the Chilean Coastal Range

Indigenous community or locality	Name of logged stand	Years of timber extraction	Year of abandonment	% present Canopy cover	% present Understory cover	Elevation (m)	Burned stand	Forest type	Presence of sawmill
Trafunco Los Bados and Neipán									
	Casa Redonda	?		51	35	795	Yes	Mixt	Yes
	Lof Lom	7	1968	10	25	890	No	Mixt	No
	Pichipiutril	27	In use	21	32	882	No	Mixt	No
Pucomo-Maicolpi									
	Cancha O'Higgins	2	1950	28	46.7	450	Yes (1915)	Mixt	Yes
	El Solar	6	1952	23	38.3	720	Yes (1915)	Pure	No[a]
	La Romaza	16	In use	37	54	500	No	Mixt	No
Huellelhue									
	El Banco	4	1970	20	67	450	Yes	Mixt	Yes
	Ñirehue	>100	In use	10	63	346	Yes	Mixt	No
	El Jote	>100	In use	43	36	326	Yes	Mixt	No
La Catrihuala									
	El alambrado	7	1957	40	26	850	Yes (1960)	Mixt	Yes
	Pampa Bonita	7	1957	3	63	876	Yes (1960)	Mixt	Yes
	La Plaza	7	1957	5	57	763	Yes (1960)	Mixt	Yes
	El Envaralado	7	1957	45	38.3	820	Yes (1960)	Mixt	Yes
Manquemapu									
	El Cordonal	6	In use	50	37.5	620	Yes (1880?)	Mixt	No
	De Miguel	50	In use	43	55	550	Yes (1880?)	Pure	No
	Pollo Flaco	20	In use	63	45	700	Yes (1880?)	Pure	No
	Palihue	50	In use	43	38.3	500	Yes (1880?)	Mixt	No
	Los Canelitos	60	1970	10	60	430	Yes (1880?)	Mixt	No
Pabilo[b]									
	Casa Armá	20	1965	40	45	786	Yes	Pure	Yes
	Pabilo	20	1960	0	67	780	Yes	Pure	Yes

The date of the main fire is indicated in blancket. In blancket is shown the years with sawmill.
[a] The wood was cut in the Cancha ÓHiggins Sawmill.
[b] Pabilo is not an indigenous community.

models for dependent variables were tested for normality. When it was not possible to normalize the data, a Mann-Whitney non parametric test was used for the comparisons of the two types of harvesting practices. I used Spearman's rank correlation to assess the relationships between canopy and understory cover and alerce regeneration. I considered probabilities between 0.051 and 0.1 marginally significant. Analyses were performed using Statistica version 6.0.

3. Results

3.1. Number and size structure of stumps

The average number of alerce stumps was lower in stands harvested by Huilliches (23.9 ± 28.2) than in those harvested by forestry companies (61.5 ± 74.6; Tables 2–4, Fig. 2). However, this difference was not statistically significant ($U = 38.00$, $P = 0.147$; Table 2). The number of small and medium diameter stumps (5–59 cm *dbh*) versus large stumps ≥60 cm DAP was higher ($U = 30.00$, $P = 0.06$) in stands harvested by forestry companies (49.2%, $N = 395$ stumps in all transects) than in those harvested by Huilliches (32.5%, $N = 126$ stumps). Because the forest at Los Canelitos, harvested by Huilliches, concentrated nearly all of the small and medium stumps in indigenous-harvested sites (110 out of 126) I excluded this stand from the analysis. This lowers the proportion of small diameter alerce in Huilliche land to 8.5%, indicating that logging by Huilliche tends to concentrate on higher diameter of alerce leaving the younger trees ($U = 24.00$, $P = 0.03$). I found a significant effect of the local stand nested within type of harvesting in all the sizes categories of stumps, including Los Canelitos forest ($F_{1,8} = 23.15$, $P < 0.01$).

3.2. Density of individuals remaining alive

The number of adult alerce that remained alive in each stand varied between zero in Casa Redonda to 38750 trees/ha in El Solar (Tables 2 and 3). The average number of green trees remaining in forests harvested by Huilliches (153.1 ± 121.9) was similar to forests logged by forestry companies (138.7 ± 133.0, Table 4) ($U = 57.50$, $P = 0.87$). The effect of stand nested within type of harvesting was statistically significant ($F_{1,18} = 19.95$, $P < 0.01$).

The size distribution of alerce trees remaining alive in each stand (Tables 3 and 4) shows that most green trees in the harvested areas had *dbh* <10 cm. These stands were La Romaza, where most individuals had 10 to 30 cm *dbh* and El

Table 2
Numbers of live and dead adult trees, stumps and intensity of use (% stems logged) by transect and stand, and estimated regeneration of *Fitzroya cupressoides* by hectare in 20 logged stands in the Costal Range of Osorno Province, in the Chilean Lake District

Type of explotaition	*F. cupressoides* stand name	No. of trees remaining alive (>5 cm *dbh*)/ha	No. of logs/ha	No. of snags/ha	No. of stumps/ha	Percent of stems removed	Regeneration (No. of saplings/ha)
Forestry companies	Cancha ÓHiggins	2533	233	267	1383	35.8	32583
Forestry companies	Casa redonda	0	150	33	83	100	167
Forestry companies	El solar	7650	100	200	783	9.4	59083
Forestry companies	El envaralado	2617	67	117	833	24.8	83
Forestry companies	El alambrado	2383	117	100	117	4.8	8333
Forestry companies	La plaza	933	33	550	883	52.1	3792
Forestry companies	Pampa bonita	1217	33	33	417	75	1000
Forestry companies	El banco	583	50	33	117	25.0	19167
Forestry companies	Casa armá	3500	950	1200	297	45.9	4250
Forestry companies	Banco Pabilo	200	1367	17	3617	95.2	167
Indigenous	Lof Lom	1750	100	167	250	4.5	583
Indigenous	Pichipiutril	1933	33	17	17	3.7	3667
Indigenous	La romaza	1683	67	100	950	34.6	0
Indigenous	Ñirehue	100	17	67	383	75.0	4500
Indigenous	El Jote	183	17	33	333	57.5	2417
Indigenous	Cordonal	49667	233	267	450	9.4	13083
Indigenous	De Miguel	2367	250	367	167	8.1	21000
Indigenous	Palihue	1933	217	250	67	3.3	26833
Indigenous	Pollo flaco	6833	200	400	0	0	19833
Indigenous	Los canelitos	1400	1133	1317	183	30	11167

It is shown the stand re-sample in La Catrihuala (El alambrado 1 and 2, La Plaza 1 and 2, Pampa bonita 1 and 2). The stand are show in north-south order. Pabilo-San Pedro there is not in indigenous land.

Envaralado with most *dbh*s between 20 and 30 cm. Individuals of alerce with diameters between 2 and 10 cm predominated in Pucomo-Maicolpi alerce forests (except La Romaza), El Alambrado, El Banco and Casa Armá, representing a large pulse of recruitment. The forests of Manquemapu community showed a large recruitment peak in the size range from 5 to 25 cm *dbh*, presumably a fire known to have occurred 120 years ago (according to Huilliche testimony). Pichipiutril and Lof Lom were nearly the only stands with remnant alive individuals >50 cm *dbh*. Regarding the number of green alerce trees ≥60 cm *dbh* in each stand (Tables 2–4), I found a statistically significant difference between stands harvested by Huilliche people and by forestry companies ($U = 29.00$, $P = 0.041$).

3.3. Snags and logs

Most dead alerce still standing showed evident signs of fire and have holes, making them useless as timber. Los Canelitos stands out among all sites compared, as it had the highest number of logs and snags of (Table 2). Considering all stands, the average number of snags in different states of decay was 1649 ± 3093 per hectare. In both types of timber exploitation, the predominant diameters of alerce snags varied between 20 and 80 cm *dbh*. There were no significant differences in the number of snags and logs between stands harvested by Huilliches and those harvested by forestry companies (logs: $U = 59.00$, $P = 0.947$; snags: $U = 48.50$, $P = 0.45$). The effect of local stand nested within type of harvesting was statistically significant on the number of logs ($F_{1,18} = 24.43$, $P < 0.01$) and snags ($F_{1,18} = 45.69$, $P < 0.01$). In the stands La Catrihuala and Huellelhue communities, there were less fallen trees, probably because in these forests there has been continuous scavenging of dead wood by Huilliches through the years following the end of commercial exploitation.

A statistically significant and positive correlation was found ($r_s = 0.86$ Spearman, $P = 0.003$, $n = 20$) between the number of stumps in each stand and the number of logs of alerce, indicating that most trees felled were used for shingle manufacturing.

3.4. Intensity and duration of harvesting

The intensity of exploitation measured as the number of trees of alerce cut (stumps) relative to the total number of trees (the sum of all stumps and alive trees remaining in each stand) varied between <1% in Pollo Flaco to 95% in Pabilo communities (Table 2). Huilliches harvested on the average 27% of the original stems, compared to 43% harvested by forestry companies. This difference was not statistically significant ($U = 38.50$, $P = 0.10$). But, if I considered the only trees with *dbh* ≥20 cm the difference between indigenous and industrial harvest was marginally significant ($U = 32.00$, $P = 0.07$), and it became statistically significant for trees with *dbh* ≥60 cm ($U = 30.00$, $P = 0.05$), indicating more intensive harvest by forestry companies.

Alerce forests harvested by Huilliches have a long history of exploitation, from 10 up to >100 years, with an average of 56 years (Table 1). In contrast, forests harvested by forestry companies had shorter histories of exploitation, from 4 to 20 years, with an average of 8.4 years. The differences in the duration of exploitation between indigenous and forestry companies stands was statistically significant ($U = 15.50$, $P = 0.003$).

Table 3
Diameter classes of live *Fizroya cupressoides* trees and stumps (cutover trees) in stands harvested by indigenous people

Diameter class	Lof Lom		Pichipiutril		La romaza		Ñirehue		El jote		Cordonal		De Miguel		Palihue		Pollo flaco		Los canelitos	
	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump
<10–19.9	1	8	27	0	63	1	3	0	8	0	288	0	129	0	82	0	236	0	77	44
20–39.9	5	0	44	0	33	1	0	0	0	0	9	0	13	0	19	0	107	0	7	59
40–59.9	13	0	11	0	3	12	2	3	0	5	1	0	0	0	8	0	45	0	0	44
60–79.9	23	1	5	0	0	12	0	4	0	6	0	0	0	0	4	0	12	0	0	18
80–99.9	20	1	3	0	0	15	0	6	0	4	0	0	0	2	1	0	5	1	0	48
100–119.9	18	3	6	0	1	8	0	7	1	4	0	6	0	1	1	3	3	0	0	2
120–139.9	12	2	6	1	1	7	0	2	2	0	0	5	0	2	0	1	2	2	0	0
140–159.9	5	0	8	0	0	1	0	0	0	0	0	5	0	2	1	0	1	1	0	0
160–179.9	2	0	2	0	0	7	1	0	0	0	0	6	0	2	0	0	0	0	0	0
180–199.9	0	0	1	0	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0
>200	5	0	3	0	0	2	0	1	0	1	0	3	0	0	0	0	1	0	0	2

Table 4
Diameter classes of live *Fitzroya cupressoides* trees and stumps (cutover trees) in stands harvested by forestry companies

Diameter class	Cancha O'Higgins		Casa redonda		El solar		El envaralado		El alambrado		La plaza		Pampa bonita		El banco		Casa armá		Banco Pabilo	
	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump	Alive	Stump
<10–19.9	141	0	0	0	393	0	143	0	19	0	22	0	1	0	28	0	192	12	12	44
20–39.9	11	0	0	0	64	0	6	1	27	3	1	0	0	3	9	0	12	99	0	69
40–59.9	0	2	0	0	2	0	0	5	14	2	0	2	0	10	0	0	5	40	0	64
60–79.9	0	9	0	0	0	2	0	12	5	0	0	2	0	3	0	1	0	13	0	25
80–99.9	0	15	0	4	0	4	0	15	5	0	0	0	0	8	0	2	0	1	0	12
100–119.9	0	17	0	0	0	9	0	12	4	0	0	0	0	12	0	2	1	2	0	2
120–139.9	0	18	0	0	0	6	0	4	8	0	0	0	0	1	0	0	0	1	0	0
140–159.9	0	10	0	0	0	12	0	1	2	0	0	0	0	3	0	0	0	0	0	1
160–179.9	0	5	0	1	0	6	0	0	4	0	0	0	0	1	0	1	0	0	0	0
180–199.9	0	2	0	0	0	2	0	0	0	0	0	0	0	3	0	0	0	0	0	0
>200	0	5	0	0	0	6	0	0	1	2	0	0	0	0	0	1	0	0	0	0

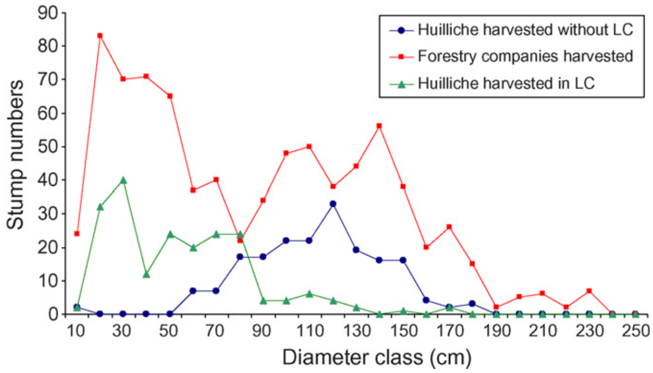

Fig. 2. Diameter distributions at breast height (*dbh*) of standing dead stems and stumps in *Fitzroya cupressoides* forests harvested by Huilliches and forestry companies in the coastal range of Osorno, showing separately the contribution of Los Canelitos stand (=LC).

3.5. Canopy and understory cover

Canopy cover per stand ranged from 0 to 63%, with an average of 24.9% ± 19. Understory cover was relatively higher than canopy cover, ranging between 33 and 75%, with an average of 52.1 ± 13.0. For all stands compared, the relationship between regeneration of alerce and percent canopy cover was positive and statistically significant ($r_s = 0.28$; $P = 0.03$, $N = 20$), but the relationship with understory cover was not statistically significant ($r_s = 0.27$; $P = 0.15$, $N = 20$).

Alerce forests logged by Huilliche communities presented higher average tree canopy cover than alerce stands logged by forestry companies, with averages of 33.0 ± 18.9% and 16.4 ± 17.2%, respectively (Table 2), but this differences was not statistically significant ($U = 38.00$, $P = 0.36$). Understory shrub cover was similar in both situations, with an average of 51.3 ± 13.1 and 57.3 ± 12.9% in forests harvested by Huilliche and forestry companies, respectively ($U = 40.00$, $P = 0.45$).

3.6. Regeneration of alerce forests

Regeneration, estimated as the number of individuals ≤2 m tall, was abundant in most alerce stands studied, despite different logging impacts (Table 2). The highest density of regeneration was found in the forest El Solar, with 59,083 individuals per ha. Only the stands at La Romaza and El Envaralado lacked regeneration (Table 2). The median of current alerce regeneration for all alerce forests studied was 4500 saplings per ha.

The density of alerce regeneration was the slightly lower in stands harvested by Huilliche communities compared to those harvested by forestry companies (10308 ± 9589 vs. 12933 ± 19322 individuals/ha, respectively; Table 2), a difference that was not statistically significant ($U = 57.50$, $P = 0.87$) due to the large variance of the data. The effect of stands nested within type of harvesting was statistically significant ($F_{1,18} = 22.18$, $P < 0.01$). When unburnt stands are removed from the analysis, (Lof Lom, Pichipiutril and La Romaza, all harvested by Huilliches), regeneration in forests harvested by Huilliches was 11453 ± 8878 individuals/ha, still not significantly different from the regeneration density in stands harvested by forestry companies ($U = 22.00$, $P = 0.21$).

The only variable that presented a statistically significant and positive correlation with the density of alerce regeneration in all stands was the number of alerce trees remaining alive after logging ($r_s = 0.60$; $P = 0.001$, $n = 20$). When I removed from this analysis the number of alive individuals with <30 *dbh*, to make these two variables independent, the correlation was marginally significant ($r_s = 0.32$; $P = 0.08$, $n = 20$). On the other hand, regeneration density was unrelated to the type of forest (pure or mixed alerce) ($U = 23.50$, $P = 0.22$).

4. Discussion

The fact that the fraction of original trees harvested from stands and the number of adult trees ≥60 cm *dbh* remaining alive were statistically different between stands harvested by Huilliche people and those logged commercially, reflects important contrasts in Huilliche and industrial idiosyncrasies of harvesting alerce timber (objective 1). However, these differences in the post-harvest condition of these two types of stands did not result in differences in the density of alerce regeneration (objective 2).

In this context, it is interesting to analyse the case of Los Canelitos stand. The stand at Los Canelitos, was different from other indigenous stands in that it showed a very high fraction of trees harvested and the highest numbers of small *dbh* stumps. Los Canelitos also showed the highest quantity of litter and detritus in the soil (approximately 100 m^3/ha, C. Smith, unpublished data). This stand occurs at a lower elevation than the other alerce forests in the Manquemapu community (430 m), it is accessible even in winter when other alerce forests are unreachable due to river flooding, and was the oldest stand continuously being harvested by >60 years. The wood from this stand was used for building houses in the Manquemapu community, in addition to the production of shingles and poles for sale outside the community. Consequently, under certain circumstances, such as easily accessible stands, the harvest pressure on stands used by Huilliche people can lead to depletion of timber resources to a level undistinguishable from forestry companies. Despite this high intensity of use, alerce regeneration in Los Canelitos was high (11,167 plants per ha), but lower than other stands in the same Manquemapu community.

This study also documents that the potential for post-harvest alerce regeneration in Chilean Coastal Range forests is highly dependent on the particular characteristics of each stand, as shown by the significant stand effects in the nested anovas. The relationship between the density of alerce regeneration and the number of remaining adult live trees reported here can be consequence of the lack of independence between these two variables, as the regeneration of adult trees <20 cm) *dbh* can be a product of the same regeneration pulse following fire. Lara (1991) reported differences of 300 years among alerces established after a single catastrophic disturbance in Andean forests. Other studies have shown abundant regeneration of alerce in burnt stands in the coastal range of the mainland

(Cortés, 1990; Veblen and Ashton, 1982; Páez & Armesto, unpublished data) and in Chiloé Island (southern coastal forest). Information from three fire-free, old-growth alerce forests in this study showed limited or no regeneration of alerce (0, 583, 3667 individuals/ha, with an average of 1417 individuals/ha), despite their low canopy cover (37%, 10% and 21%, respectively). In contrast, burned forests had an average regeneration of 13,422 individuals/ha (17 stands). Possibly, I did not find a relationship between percent canopy cover and density of alerce regeneration, because all alerce stands have a relatively open cover. Based on these results, I suggest that the occurrence of fire and possibly a high level of canopy opening (as found in the Andes) are more important to alerce regeneration than direct logging impact, at least at the scale of this study. Other studies in burned alerce forests have found high and variable vegetative regeneration of alerce (Cortés, 1990; Silla et al., 2002, Vega unpublished data), my observations in unburned coastal range stands showed all the regeneration was by seeds.

The history of each alerce stand is strongly linked to the history of the indigenous communities that inhabit the study area. For example, regeneration of alerce in harvested stands from La Catrihuala community (Fig. 1) was low in all the transects, which can be explained by the rigorous climate, shallow soils and the intense exploitation exerted by the Hacienda Cameros, which operated in the area around 1950–1960. In contrast, in the Manquemapu community, regeneration was higher and relatively similar among all the alerce forests. The alerce forests of Manquemapu have the same history of use as La Catrihuala, marked by a large fire which took place about 120 years ago, and subsequent gradual harvest by the Huilliches, using hand axes and recently mechanical saw. The forests of Huellelhue (Ñirrehue and El Jote) were harvested gradually by a small local community of Huilliches (Molina et al., 2006). Ñirehue in particular had a long period of harvest, albeit intermittent, since the mid 19th century. The alerce forests of Trafunco Los Bados – Neipan had a more heterogeneous history of exploitation, Lof Lom and Pichipiutril have not been subjected to fire or intensive exploitation, in contrast to what happened to the stands of Casa Redonda where there has been a long and intensive harvest. The Pucomo-Maicolpi forests showed contrasting patterns of regeneration density (with two stands harvested by forestry companies), and differences were more noticeable in La Romaza, which remained unburnt and harvested by Huilliches.

The larger number of small stumps found in stands harvested by forestry companies are probably related to the massive extraction of firewood (stems of all types and sizes) to feed the ovens of mobile sawmills. In some places, such as La Catrihuala, forestry companies hosted a local resident population of approximately 100 people, including families, during their operation, and even kept a small school near the forests. High volumes of firewood were collected by these families during the long and severe winters. In contrast to this social arrangement, Huilliche families often live at lower altitudes, closer to the rivers, and men travel to live temporarily in the forests for five to seven days, moving between their homes and montane forests during the end of spring and summers each year.

Regeneration of alerce in coastal range forests (Veblen and Ashton, 1982; Cortés, 1990 and this study) is generally higher than that reported for Andean stands. It seems that distinctive characteristics of coastal stands, such as reduced competition in less productive soils (Keddy et al., 1997), may have favored a higher regeneration, despite the intense disturbances to these stands by logging and fire. From these results I conclude that the population of this long-lived tree species can recover in these harvested stands through natural regeneration. The large amounts of woody debris left after extractive activities, and the careless practices of burning firewood in sawmills, and cooking stoves in shacks of the Huilliches that harvest the dead wood of alerce, enhance the probability of forest fires.

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