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HARVESTING ADAPTATION TO BIODIVERSITY CONSERVATION IN SAWMILL INDUSTRY: TECHNOLOGY INNOVATION AND MONITORING PROGRAM

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Abstract

Social demands related to native forest ecosystems are based on an efficient management, with a balance between conservation and timber production. This paper describes the industry adaptation to a biodiversity program with an alternative regeneration method. The proposed method leaves 30% of the timber-quality forest as aggregated retention and 15 m^2 ha^{-1} basal area as dispersed retention. While many costs increased considerably, the incomes also may increase by applying new management strategies and technology innovation. A monitoring program was established in the harvested stands to evaluate the ecological functionality of the applied regeneration system (forest structure, climate change, regeneration dynamics, habitat quality and abiotic cycles). The implementation of an innovated technology and monitoring program in the forest and industry determined a balance between economic values and biodiversity conservation.

Key words: forest management, silviculture, sawmill industry, native forest, certification.

Introduction

Natural forests around the world have been managed following economic criteria as the main variable in the selection of the regeneration method (Franklin, 1989) and design of the sawmill industry. The profitability analysis always implicates to reach the maximum yield according to investment. Recently, ecological and social criteria have been prioritized over economic variables to achieve biodiversity conservation (Mitchell and Beese, 2002). Therfore, an opportunity appears to combine wildlife conservation and wood production through management strategies (Carey et al., 1999). For this, it is neccesary to optimize all the activities along the productive process, maximizing products and minimizing costs.

In Tierra del Fuego (Argentina) from 700 to 1000 $ha.year^{-1}$ are logged (Gea et al., 2004), corresponding to a log harvesting volume of 63.2 thousand $m^3.year^{-1}$. Since the 1960s, main timber demand has been the sawmill industry. Other alternative wood uses (e.g. pulpwood export) are forbidden by provincial regulation law nº 202. A forest management plan before harvesting is compulsory with a validity time of five years, and includes a study of target stands and timber yields to be harvested. Harvested forests represents 21% of timberland, due to it only includes the most accessible stands with the highest site quality. This policy leaves out large timberland areas which could be included into the management. Despite this, most of the regeneration systems had been incorrectly applied, because the prescribed cuts did not follow the theoretical models (Gea et al., 2004). This mismanagement was due to unclear forest policies, local corruption and a lack of the correct applying of forest legislation (Martínez Pastur and Lencinas, 2005). In this context, a project named PIARFON leading by the National Forest Administration was conducted in South Patagonia to develop an alternative of sustainable forest management, through the design of new alternative silviculture methods. This work describe the modification of a sawmill industry by adapting the harvesting methodology through the innovation in the applied technology to the biodiversity conservation aspects, and by incorporating an environmental monitoring program.

The proposed regeneration method

In Southern Patagonian forests the economic criteria was the main variable for forest management decisions since the beginning of silviculture in the region (Gea et al., 2004). Previous methods recommend transforming the original structure to an even-aged managed forest (Schmidt and Urzúa, 1982; Martínez Pastur et al., 2000) via natural regeneration of the harvested stands (Rosenfeld et al., 2006). However, during the past few years alternative silvicultural methods have been proposed, which conserve some of the original heterogeneity of old-growth forest. From those, while the selection group cut method (Bava and López, 2005) affects an small percentage of the forest area, the other propose to leave intact a percentage of the original old-growth forests (Martínez Pastur and Lencinas, 2005; González et al., 2006; Vergara and Schlatter, 2006). This last method was defined to conserve the original biodiversity affected by shelterwood cuts, and proposed to leave 30% of the timber-quality forest as aggregated retention (patches of 30 m radius) and 15 $m^2.ha^{-1}$ basal area as dispersed retention. This variable retention method was assayed in a wide range of forest composition and structures, geographic locations and physical environments, e.g. *Demonstration of Ecosystem Management Options* (Aubry et al., 1999), *Montane Alternative Silvicultural Systems* (Arnott and Beese, 1997), *Date Creek Silvicultural Systems* (Coates et al., 1997), *Sicamous Creek Silvicultural Systems Research Project* (Vyse, 1997), *Tanjil Bren Trial* or *Warra Silvicultural Systems* (Hickey et al., 2001). The variable retention method (aggregated and dispersed retention) maintained a similar yield rate to the first cut of shelterwood cut, decreasing the extraction costs and saw-log prices. As shelterwood cuts, this new proposal allows the harvesting of low site quality stands. However, the main advantage of the variable retention method resides in allowing the logging low degree of tree occupation stands (e.g. stands with less than 40 $m^2.ha^{-1}$), and therefore these stands can be incorporated into the productive system.

"Kareken" sawmill: The study case

The strong limitation of the forest industry in Patagonia, both in Argentina and Chile, was the absence of the sawmill design adapted to the native forest under management. Usually, the installed industry only harvests healthy large logs resulting in a lack of a complete silviculture management. However, it is possible to adapt the forest industry to all the timber products obtained through the applying of theoretical silvicultural models. Furthermore, a percentage of the profit obtained from the implementation of new alternative silviculture proposals can be invested in biodiversity conservation. In this context, a company ("Kareken" sawmill) was installed during 2004 in Los Cerros Ranch (54º20' S, 67º45' W), 87 km south from Rio Grande city in Tierra del Fuego (Argentina).

The saw-timber of *Nothofagus pumilio* (lenga) processed by "Kareken" sawmill are mainly commercialized to the secondary industry (furniture factories), the local building industry and pallet components. The actual industry includes the harvesting, the processing of 6200 $m^3.year^{-1}$ saw-timber products, and their commercialization. The industry was designed to process a wide range of log qualities (including "C" quality according to Cordone and Bava, 1997) and sizes (longer than 2 m and up to 18 cm).

Roads construction (3 km.year^{-1}) was carried out with a Caterpillar hydraulic excavator 320, while the maintenance was done with a John Deere 670D. The tree-cutting was conducted by two chain-saw (Husqvarna 281) operators, carrying out directed cuts and producing 210 m^3.labour-day^{-1} of complete stems (a cut at stem-base and another at 18 cm stem diameter). Log extraction was done using one cable skidder Caterpillar 525 (one machine operator and one assistant), reaching a stem volume extraction of 150 m^3.labour-day^{-1} with an average extraction distance of 200 m. Transport was done with a Mercedes Benz 2423B tipper-truck, while the loading and log movement was carried out by two Caterpillar telehandler TH62.

Sawmill was mounted in a 680 m^2 galvanic construction, located 1 km away from forests, with an independent sharpening room and personnel dependences in campus of 2.2 ha. The layout of sawmill includes: i) a principal Premonorte vertical log band saw with a flywheel diameter of 1200 mm and a Premonorte log carriage with 4 head-blocks, commanded at distance by one machine operator; ii) a Premonorte band re-saw machine with a flywheel diameter of 1200 mm (1 operators and 2 assistants); iii) a Premonorte multiple cutting head machine with 2 axes and 5 circular blades (1 operator and 1 assistant); iv) a saw blunt machine (2 operators); and v) a Polonyi classification table (3 operators) composed by 3 lines of 12 m length where saw-timber is classified and prepared to be commercialized according to their qualities and sizes. The sharpening room (1 operator) is equipped with a Wollmer chain saw sharpening machine, a saw grinding machine, a tig/mig welder and tooth-setter/gauge maintenance implements.

Technology innovation

Sawmill "Kareken" production process was designed together with the forest management plan for a medium-term of 15 years (Vukasovic et al., 2004), while forest local legislation demands a short-term planning of 5 years. This additional invest in forest inventories and planning, as one of the innovations, allowed to the company to elaborate a medium-term invest policy and cost analysis. Also, this forest management plan included a harvesting planning at landscape level, which alternate stands of different site qualities into the annual harvesting, and a balanced road design according to the extracted timber in harvested areas. Road design was done with a geographical information system with high-resolution QuickBird (pixel 0.3-0.6 m) and digital terrain model images (pixel 90 m), and a strict field control. Also, forest management plan included the development of biometric models adapted to the products processed by sawmill. This biometry allowed to the prediction of future yield through the analysis of different silviculture alternatives, as well as the control of the production process and the economical feasibility of different invest alternatives (García, 1988). It is necessary precise stand models for the silviculture planning within the forest management and ordination, as well as for economical future evaluations. Timber production model considered the regeneration method to be applied and the losses generated during the harvesting. The difference obtained during the two first years between the predicted and the harvested volumes was 2.7%.

The aggregated retention distribution at landscape level defined the road design with a secondary roads distanced of 100 m outside the aggregated retentions (Vukasovic et al., 2004). Other innovation for road construction was the use of hydraulic excavators instead of bulldozer, which usually has been employed in South Patagonia. When hydraulic excavator was used, the superficial horizon of the forest floor was extracted and deposited at both sides of the road, minimizing the damage of the root overstory systems. Although the road construction costs were higher (47%), there was low damage in the base stem of the remnant trees, improving the aesthetic of the harvested forest and reducing the wind-throw. Also, the pilling-zones construction (*canchones*) that usually occupy 2-3% of the harvested area has been eliminated by placing the harvested logs at the primary road borders which were periodically removed. The absence of pilling-zones reduced areas of incomplete regeneration due to the increase of soil density caused by heavy machine traffic. The maintenance of the primary roads with the use of motor-graders reduced the time of road useless due to thaw during the spring (during 2005-2006 the roads were not used during 21 days.year^{-1}) (Vukasovic et al., 2004).

During the harvesting, trees must fall outside of the aggregated retention, which reduces the damage of the remnant trees in the aggregates. Furthermore, the stem cutting instead log production inside the forest diminished the chain-saw operations in 30%. Both, the secondary road design between the aggregates and the directed stem cuttings enhanced skidder performance, and diminished in 45% the cost when it was compared to the traditional harvesting operations (log extraction under a shelterwood cut). Stem cuts were done at the border of the roads, discarding 3-5% of harvested material, which were used as firewood for the ranch and sawmill. Log stockpiled was located near sawmill with a dimension to supply the industry during 5 months to avoid any lack of logs due to climatic constrains or broken machines. The use of telehandler facilitates the stockpiled and log movement in sawmill, minimizing the cost and dead-times during operations.

Saw of the logs was designed to obtain the maximum saw-wood products, giving priority to board and plank productions (up to 7.5 cm width, 2.5 cm thick and 1.5 m long). For this, the production strategies were modified to the wood markets in order to quickly locate the saw-wood production of high and low quality. Sawmill includes a meticulous control of the daily production (quantity and quality of saw-wood products) which gives the chance to analyze the yield evolution according to different sawmill out-lines. When 1078 m^3 saw-wood production was analyzed, board represented 53% and short length pieces (less than 1.5 m long) represented 15% of total products, where most of the saw-pieces presented 2-4 m length. This sawmill production design was adequate, due to the production was not forced to saw one special product (e.g. high quality boards).

Sawmill yield is the most important tool for the economic evaluations. One of the main premises that the company must include in their planning, should be "adapt the company to the products that native forest could offer," and not "only take the products from the forests which adapts to the company." The aim of this premise is the entirely use of the native forest products, allow to diminishing the landscape impacts concentrating the harvesting activities, minimizing the forest value costs and maximizing the incomes per unit area. In this context, sawmill yield varies with quality and log sizes. Most of the logs (93%) were of medium qualities (B and C), while few of them are of the extreme classes (4% for A and 3% for D qualities). Larger size logs (up to 30 cm) represented 60%, which was expectable for a good management of medium site quality native forests, but this percentage decreased in low site quality stands (Martínez Pastur et al., 2000). The mean log volume was 0.44 m^3, which was higher than the mean harvested logs in Tierra del Fuego (0.38 m^3) (Martínez Pastur, 1999) due to the processed logs were longer (4 m).

The yield of big healthy logs (up to 30 cm with A and B qualities) presented the higher values, reaching to 30% of the log volume without bark estimated through Smalian formula. Small logs (18 to 30 cm) and middle-low quality (C) also had an acceptable yield (up to 20%), while low quality logs (D) presented yield less than 10% (Figure 1). The innovative inclusion of small logs of high and middle-low qualities did not influenced the sawmill yield, but significantly increased the harvesting yield. Thereby, the costs of raw material and fixed costs of the company significantly decreased, while the incomes of the entire process were improved. The inclusion of this low quality logs increased the short length pieces in 10%-25%, but board pieces production did not change. Beside this, plank production diminished, which only could be obtained in the high healthy logs. The over-sizes of each saw-wood piece were not included in the yield estimations, which represented a variable percentage between 4% and 20%. Finally, another innovation in the saw production was the inclusion of thickness pieces (½ and ¾ inches) with up to 1.2 m long, which were destined to pallet industry market. The inclusions of these products allowed to increase sawmill daily production in 2.1 m^3, which represents an improvement of 7% in the company incomes.

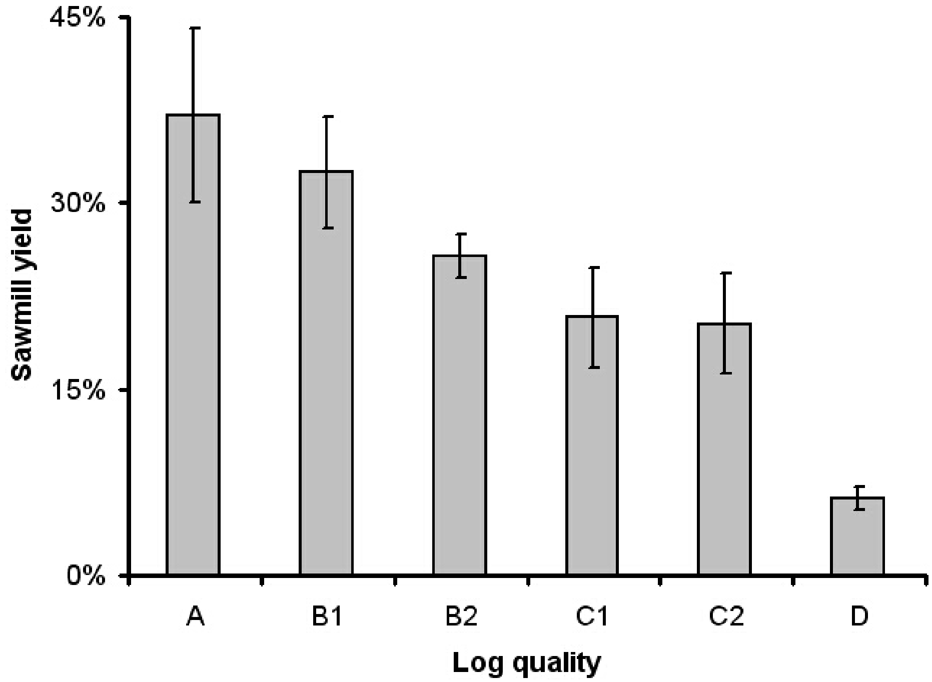

Figure 1. Saw log yield in "Kareken" sawmill. 1 = logs up to 30 cm diameter, 2 = logs under 30 cm diameter. Log classification is based on Cordone and Bava (1997).

At the beginning of the sawmill project, the work-days was designed in simple weekly journals. According to daily sawmill yield data it was observed a decrease in production during the first days after each weekend. After three work days, the sawmill yield was stabilized within the average expected limits. This yield loss varied between 5% and 7% for a six-month analyzed period. Operators accustoming after the weekend significantly impact over the monthly sawmill incomes. Therefore, a longer work-period was proposed to minimize the accustoming period between non-working days. The work-day was modified to working periods of 20 days by 10 days off, with labors journeys of 8 h.

Monitoring Program

It became common to use easily measurable surrogates, or indicators for unmeasured biological values or environmental conditions of conservational interest (Margules and Pressey, 2000). A suitable indicator should have several qualities, including being easy to identify and monitor, be sufficiently sensitive to changes in the unmeasured value it is indicating, and distributed over the whole area of interest (Noss, 1990). McGeoch (1998) define a biological indicator as something (species, object, process) that readily reflects the abiotic or biotic state of an environment or quality habitat; represents the impact of environmental change on that habitat, community or ecosystem; or is indicative of the diversity of a subset of taxa, or wholesale diversity within the study area. Thus, it can be possible separate the indicators in three categories: environmental, ecological and biodiversity indicators. The following monitoring program was designed to include all these indicators.

Forest structure

Remnant overstory stability is one of the main concerns when the regeneration treatment was applied, due to the need for canopy protection to maintain regeneration and biodiversity, as well as economic loss incurred by blow-down trees. For this, a set of 54 permanent sampling plots was defined to analyze the forest structure dynamics after harvesting (aggregated and dispersed retention) and in unmanaged forests. In each forest plot, trees were sampled by the angle count sampling method (basal area factor 6) (Bitterlich, 1984). Basal area, diameter, number of trees, total over-bark volume, dominant height (average of the three dominant trees closer to the sampling point) and site quality were obtained following methodologies proposed by Martínez Pastur et al. (1997) and Martínez Pastur et al. (2002a).

Forest site corresponded to stands of middle-high qualities with a dominant height of 22-24 m. Diameter was

54-56 cm before harvesting and reached 73-80 cm in the remnant overstory, while the tree number diminished from 540 to 70-76 trees.ha^{-1}. Total over-bark volume was 790-950 m^3.ha^{-1} before harvesting and 135-240 m^3.ha^{-1} in remnant overstory. Basal area presented a full occupancy in the unmanaged forests and in the aggregated retention (69-79 m².ha^{-1}), while the dispersed retention varied between 14% and 27% of the original stand (18.5 m².ha^{-1} close to aggregated and 10.5 m².ha^{-1} far away from aggregates) (Figure 2). The average remnant basal area in the harvested forests (including aggregated and dispersed retention) reached to 34.9 m².ha^{-1}, representing 50% of the original one.

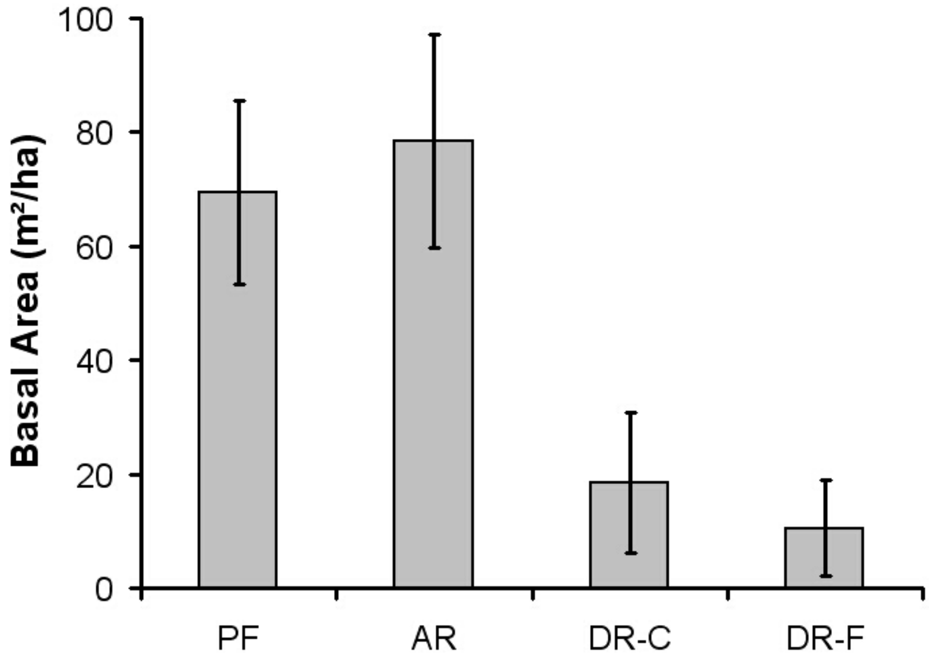

Figure 2. Basal area of the overstory in the unmanaged primary forests (*PF*), aggregated retention (*AR*) and in the dispersed retention (*DR-C* = close to aggregates, *DR-F* = far away to aggregates) after two years of harvesting.

Climate change

Climate is characterized by short, cool summers and long, snowy and frozen winters. To quantify the impact of the forest management over the main climatic variables, three Davis Weather Monitor II stations where installed in the unmanaged forests, inside the aggregated retention and in the dispersed retention (40 m apart from the aggregates edge). Mean monthly temperatures (years 2005-2007) varied from –2.6°C to 9.3°C (extreme temperatures from –10.1°C in July to 19.2°C in February) in the old-growth forests, while in the harvested stands varied from –2.5°C to 9.3°C (extremes temperatures from –8.8°C in July to 20.3°C in February) inside the aggregates, and from –2.5°C to 9.4°C (extremes temperatures from –10.8°C in July to 21.1°C in February) in the dispersed retention (Table 1). Only three months per year were free of mean temperatures under 0°C, and the growing season extended for approximately five months. Soil temperature (30 cm deep) never froze in the old-growth forests and into the aggregates, but soil freezing was observed in the dispersed retention during July (extremes reached to -3.0°C). Rainfall reaching to the forest floor was 440 $mm.yr^{-1}$ inside the old-growth forests, while in the harvested stands was observed 444 $mm.yr^{-1}$ into the aggregates and 559 $mm.yr^{-1}$ in the dispersed retention. The average wind speed outside the forest was 8 $km.h^{-1}$, reaching up to 100 $km.h^{-1}$ during storms. Wind speed increased from the primary unmanaged forests to the dispersed retention.

Table 1. Climate characterization in the primary forests (*PF*) and in the harvested stands (aggregated - *AR* and the dispersed retention - *DR*) through the air temperature (T°C), soil temperature at 30 cm depth (S°C), average high wind speed into the forests (m/s) and rainfall (mm).

Station		JUL	AGO	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN
PF	*T°C*	-1.2	0.5	2.7	5.2	7.1	8.1	9.3	8.8	7.5	4.3	1.6	-2.6
	S°C	0.3	0.5	1.4	4.0	5.6	6.6	8.0	8.0	7.3	5.3	3.3	1.0
	Wind	0.0	0.1	0.3	0.4	0.4	0.4	0.3	0.3	0.6	0.8	0.2	0.2
	Rain	33.0	37.4	36.8	30.9	36.9	25.8	33.8	40.6	13.9	50.9	38.0	62.3
AR	*T°C*	-1.0	0.8	2.7	5.9	7.2	8.2	9.3	9.2	7.7	4.3	1.7	-2.5
	S°C	0.1	0.4	1.3	3.9	5.6	7.0	8.2	8.5	7.8	5.6	3.5	0.8
	Wind	0.5	0.8	0.9	2.0	1.9	1.7	1.1	1.1	1.7	1.6	0.7	0.4
	Rain	30.8	36.8	37.2	31.8	36.5	27.2	32.7	39.5	16.1	48.9	42.0	64.3
DR	*T°C*	-1.0	0.9	2.7	6.1	7.5	8.7	9.4	9.3	7.9	4.2	1.8	-2.5
	S°C	-0.1	0.2	1.3	3.9	5.6	7.4	8.4	10.4	9.0	6.0	3.6	0.4
	Wind	1.9	2.2	2.3	3.4	3.2	2.2	1.5	1.6	1.9	2.2	1.7	2.0
	Rain	46.1	39.0	43.1	37.8	49.6	30.2	48.2	60.6	30.8	52.0	48.4	73.6

The changes in the studied variables modified water balances in the forest floor, as well as water availability in the litter and organic layer, being the main adverse factor for regeneration establishment during November when bud sprouting occurs. Average temperature was higher in winter and lower in summer inside the unmanaged forests, while extreme values were founded in the harvested stands. These conditions generated adverse environments for many species (mainly insects) which seek protection inside the forest floor.

Regeneration dynamics

Natural forests in Tierra del Fuego are characterized by a permanent seedling bank in the understory and the lack of a seed bank in the forest floor (Cuevas and Arroyo, 1999). The seedling bank, however, can survive for long periods of time (Cuevas, 2002), awaiting a canopy opening to occur in a natural dynamic process (Rebertus and Veblen, 1993) or due to human harvesting (Rosenfeld et al., 2006). Regeneration dynamics was studied in the same 54 forest structure plots, with one regeneration permanent sub-plot (5 m x 0.2 m) and traps for flower and seed studies. Two years after the harvesting, it was found 109 $thousand.ha^{-1}$ seedlings inside the aggregates, while in the dispersed retention were found 77 and 82 $thousand.ha^{-1}$ seedlings near and far-away to aggregates. In the unmanaged forests, the seedling bank was lower with 20 $thousand.ha^{-1}$ seedlings. During the seeding of 2006 a high seed production was detected with 12.2 $millions.ha^{-1}$ seeds in the unmanaged forests, 7.9 $millions.ha^{-1}$ seeds inside the aggregates, and 4.4 and 1.2 $millions.ha^{-1}$ seeds in close and far sectors of the dispersed retention. These seeds production allowed to the establishment of a large number of seedlings in 2007, with 986 $thousand.ha^{-1}$ seedlings in the unmanaged forests and 863, 184 and 124 thousand.ha^{-1} seedlings inside the aggregates, and close and far sectors of the dispersed retention, respectively. The average seedling ages were 1-2 years in the unmanaged forests, 2-3 inside the aggregates, and 3-4 in the dispersed retention.

Male flowering occurred before bud sprouting during October and November in late spring, while female flowering occurred in November and December in all the stands. Immature fruits were collected between January and March, while mature seeds were founded during March and April. Natural abscission was the main reason to explain the loose of female flowers, immature fruits and seeds. In the unmanaged forests herbivory by insects affected 2.8% of the production, mainly in fruits, while inside the aggregates and in the dispersed retention were observed 1.2% and 1.9%. Birds fed more seeds in the unmanaged forests (4% of the production), while in the aggregates and in the dispersed retention the foraging was lower (3.2% and 1.5%). Flowering was related to the masting seeds observed during 2006-2007. In the unmanaged stands 38.8 millions.ha^{-1} male flowers were detected while in the aggregates and in the dispersed retention the production was lower (8.0 and 1.8 millions.ha^{-1}). Male to female flower production ratio was 2.1, 1.4 and 0.7 for primary unmanaged forests, inside the aggregates and in the dispersed retention, respectively. In the unmanaged forests was detected a seed masting with 18.4 millions.ha^{-1}, while in the aggregates and in the dispersed retention the production was lower (5.8 and 2.6 millions.ha^{-1}). The efficiency in the seed production compared to the female flower production was higher, reaching values up to 74%. On the other hand, it was possible to detected different quality seed production between stands. Primary unmanaged forests presented 33% empty seeds and 56% viable seeds. Less empty seeds (22%-25%) and higher viable seeds (71%-73%) were observed in harvested forests, where seed production was lower.

The applied regeneration treatment with variable retention has intermediate characteristic for regeneration compared to traditional treatments. The observed regeneration was enough to recuperate the harvested sectors. The seedling dynamics inside the aggregates was comparable to those described for primary forest, maintaining the heterogeneity of micro-environments. Seedling growth of the dispersed retention presented a similar response of shelterwood cuts, which homogenize the landscape and induced higher individual growths.

Habitat quality (coleopteron indicators)

The use of indicators for biodiversity has emerged only during the last decade and the idea is to use taxa that are well known, easily monitored, and that represent the whole diversity. Most studies have used species (Fleishman et al., 2005) or higher taxon richness (Prendergast and Eversham, 1997) as indicator of biodiversity. Many studies have found that statistically strong correlations between taxa are rare (e.g. Kati et al., 2004), although there are a few exceptions (Fleishman et al., 2005). However, indicators within groups had better correlations. In Finnish forests, saproxilic coleopteron species are sensitive to forest management alterations (Martikainen et al., 2000) mainly due to the changes in dead wood.

Forest management significantly affects the habitat quality and therefore modifies the biodiversity in *Nothofagus pumilio* forests (Deferrari et al., 2001; Spagarino et al., 2001; Martínez Pastur et al., 2002b; Ducid et al., 2005). As was observed in the boreal forests (Martikainen et al., 2000) a large percentage of coleopteron species is associated to the timber-quality forests (Lencinas et al., 2007). For this, in order to measure the habitat quality loss, forest floor coleopterons were used as key group or forest disturbance indicator, because they are characteristic of particular environment and host specialists.

Adult mobile epigean individuals were collected during the middle summer (January-February). Sampling was done using 24 tracks of 5 pit-fall traps each (14 cm diameter) during 7 days, including a wide spectrum of environments at landscape level. Water was used as a retention agent and formaldehyde as a preservative, while commercial detergent was employed to diminish surface tension. Because Patagonian insect systematic is still incomplete, either the recognizable taxonomic unit (RTU) concept was used (Oliver and Beattie, 1993) to classify the individuals at family level (Richards and Davies, 1984; Romoser and Stoffolano, 1998). RTUs have been demonstrated to be a good tool for insect diversity studies in *Nothofagus* forests (Spagarino et al., 2001; Lencinas et al., 2007). Cluster analysis, using a complete linkage amalgamation rule and Euclidean distance measurement based on a matrix of individual abundance and RTUs were done, as well as a detrended correspondence analysis with RTU abundance and occurrence data, weighting for rare species.

A total of 365 captures corresponded to 29 RTU was analyzed. Primary unmanaged forest presented 4 RTU with an abundance of 14 captures per pit-fall track, where prevailed the Carabidae (*Trechisibus antarcticus*) over Brenthidae (*Apion* sp.), Tenebrionidae and Scaphidiidae. After harvesting three of these species were founded in the aggregated retention with lower captures per pit-fall track (7.3) compared to primary forests. In the dispersed retention more RTUs were sampled (6 including 3 Carabidae, 2 Curculionidae and 1 Saphylinidae) with an abundance of 9.8 captures per pit-fall track. The other environments (primary *N. antarctica* unmanaged forest, peat-lands and grasslands) presented 25 RTUs with the higher captures per pit-fall track (20) corresponding to 10 different families. DCA allowed assembling the sampled coleopteron species according to an environment classification at landscape level (Figure 3). Axis one (eigenvalue of 0.855) and two (eigenvalue of 0.577) were used in the analysis. Axis one was related to canopy closure as well as the closeness or presence of open areas, while axis two indicates the plant species richness of the environment. Primary unmanaged forest assembled with aggregated retention, and close to primary *N. antarctica* unmanaged forest. Peat-lands of *Sphagnum magellanicum* and grasslands dominated by *Poa pratensis*, *Carex decidua* and *Deschampsia antarctica* were the most dissimilar environments compared to the primary forests, while the dispersed retention occupies an intermediate position. A cluster analysis allowed determining the linkage among the *N. pumilio* timber-quality stands: (a) a first group was conformed by the unmanaged forests and the aggregated retention (7.5 of euclidean distance) and (b) a second group of dispersed retention harvested forests (10.0 of euclidean distance) were far joined to the first group (Figure 3).

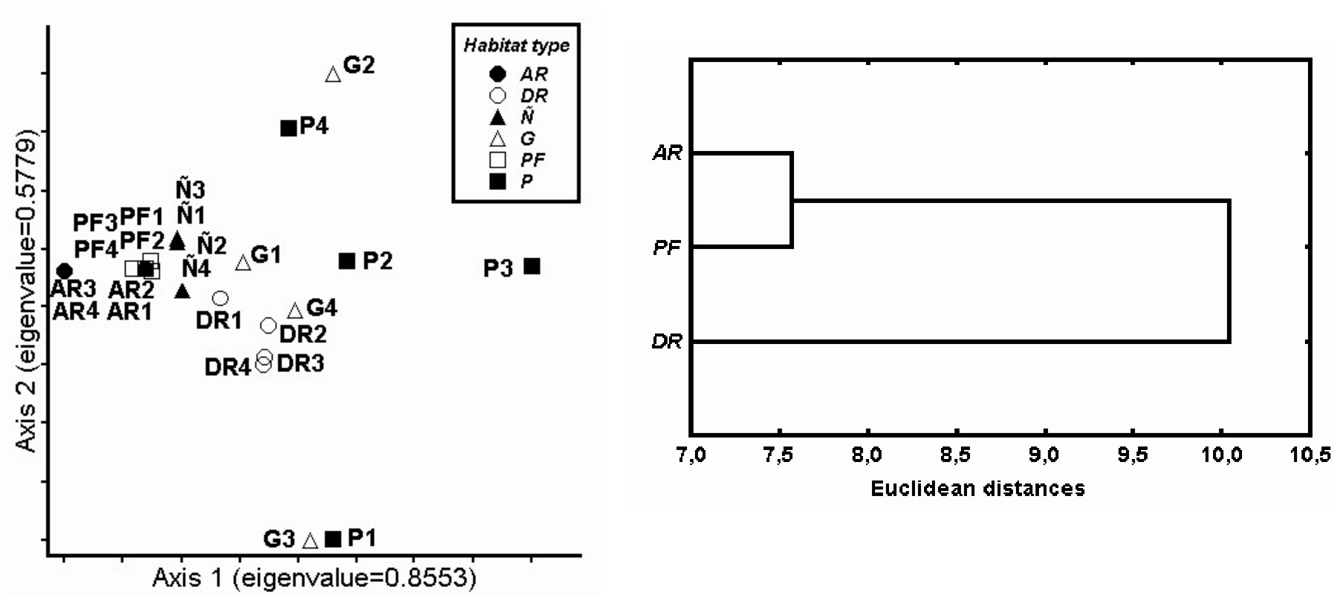

Figure 3. DCA ordination and cluster analysis based on coleopteron abundance data for environment classification at landscape level (*PF* = primary unmanaged forests, *AR* = aggregated retention, *DR* = dispersed retention, *Ñ* = *Nothofagus antarctica* forests, *G* = grasslands, *P* = peat-bogs).

Soil properties and decomposition

Biogeochemical cycle of organic matter and mineral elements plays a key-role in the relationships between soil, vegetation and surrounding environment. The most important contribution to humus occurs through aboveground deposition (Gosz et al., 1976). This litter plays a fundamental role in the turnover and transfer of energy between plants and soil, as source of nutrient accumulated in the uppermost soil layers. This is particularly important when a massive fall of leaf litter occurs annually, leading to a large accumulation of organic material on the surface. Nutrient release from decomposition litter is an important internal pathway form nutrient flux, through leaching or mineralization (Swift et al., 1979). It could affect the productivity of the entire ecosystems, since such nutrients became available from plant uptake. Decomposition rate are regulated by edaphoclimatic factors, litter quality, and the characteristics of decomposer organisms (Coté et al., 2000). Forest management can affect input and removal of nutrients as well as influencing the processes of the internal nutrient cyles. The disturbance and compaction that often accompanies harvesting operations can influence the availability of nitrogen, soil density and decomposition rates (Barg and Edmonds, 1999).

Nitrogen availability into the forest floor material was measured during the middle summer (January-February). Nine samples were randomly collected from managed and unmanaged stands, where inorganic N by steam distillation technique was measured (Bremner and Keeney, 1965). Concentrations were expressed on the basis of oven-dried (105ºC) soil weight. The soil density was measured with metal tubes (5 cm long and 5 cm diameter).

Rates of weight litter loss were measured using the litter-bag technique, in which known-weight sample are enclosed in fiberglass mesh bags and incubated on site. Nine replicate leaf litter-bags were collected for each type of site after 2 to 6 months incubation. In laboratory, leaf litter were removed from the bags, cleaned to quit any extraneous material, and weighed after drying at 60°C for 48 h.

Soil density increased in the dispersed retention compared with primary forest and aggregated retention (Figure 4). Soil N availability under both retentions was similar to soil N availability under primary forestry. In all stands there was more available nitrogen as NH_4 than in NO_3. In harvested areas it was observed an increase of NO_3 with regard to the available total N (47% into aggregates and 48% in dispersed retention vs. 22% in primary forests). During the evaluation time, mass loss of leaf litter did not show significant differences among stands. After six months of incubation the percentage mass remaining of leaf litter was 90%, 88%, and 86%, for primary forest, aggregated retention, and dispersed retention, respectively. The decomposition rate does not present differences between the stands.

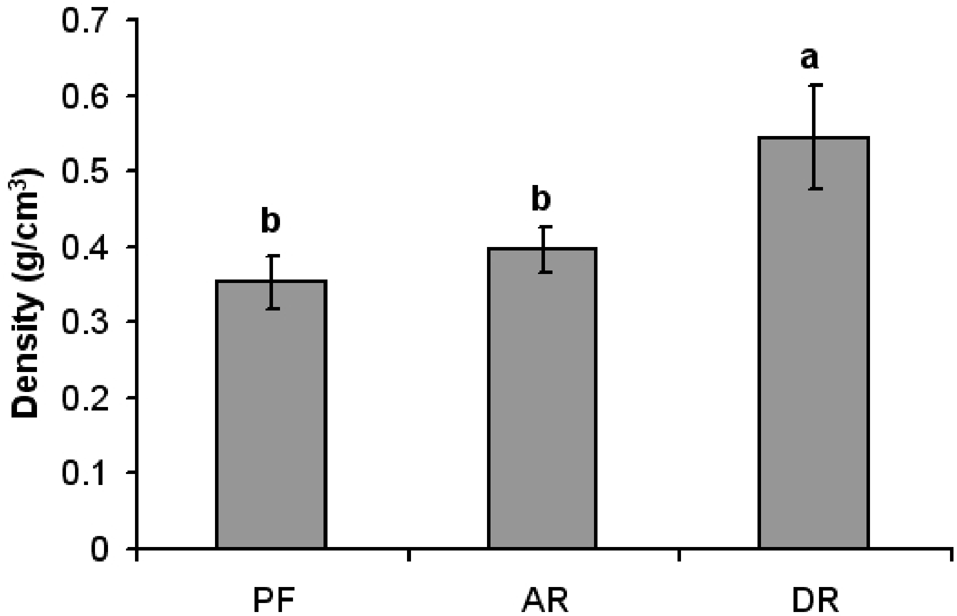

Figure 4. Soil density for primary forest (*PF*), aggregated retention (*AR*) and dispersed retention (*DR*). Error bars represent standard deviation-SD, while means for treatments with different letters are significantly different at P<0.05.

Final comments

The best silvicultural system is that which offers equilibrium between timber yield from the forests to sawmills, a favourable relationship between investments and returns, adequate stand regeneration, conservation of original biodiversity and wide social acceptance (Martínez Pastur and Lencinas, 2005). Several regeneration systems have been used in Tierra del Fuego, at both to experimental and industrial scales (Schmidt and Urzúa, 1982; Martínez Pastur and Lencinas, 2005; Bava and López, 2005). However, few silvicultural systems have been demonstrated to be feasible at industrial scale according to the theoretical models in *Nothofagus pumilio* forests (e.g. shelterwood cuts in XII Region-Chile, or regeneration systems with variable retention in Tierra del Fuego-Argentina). The variable retention system proposed in the present work for Southern Patagonia satisfies the need for a new silvicultural system in Tierra del Fuego, which clearly take into account the maintenance of biological diversity, as well as economic feasibility (Mitchell and Beese, 2002). The performance of a sustainable forest management plan in Tierra del Fuego have advantages compared with other forests around the world, due to: (a) the stands are mostly mono-specific with a more simple predictable dynamics (Rebertus and Veblen, 1993); (b) the successful establishment of regeneration to guarantee forest recruitment, with the exclusion of cattle and control of native *Lama guanicoe* populations; (c) the low human population density in forested areas; (d) the availability of management and biometric tools (e.g. Martínez Pastur et al., 2002a); and (e) the inherent ecological characteristics of these ecosystems, that makes compatible management and biodiversity conservation

(Spagarino et al., 2001; Deferrari et al., 2001; Martínez Pastur et al., 2002b).

To apply a new method at landscape and industrial scale was necessary to analyzed: (a) the economic feasibility in a full site quality range, (b) the yield losses and cost increases derived from the implementation of the new alternative method compared with the traditional practices, (c) the feasibility of the new method along the forest rotation length with the current industry technology, (d) the successful establishment of natural regeneration to recover the harvested stands, and (e) the capacity of the new alternative method to conserve the original biodiversity. In "Kareken" sawmill was possible to determine the feasibility of these points in a short-term period. Through this applied regeneration method, all the site quality forest stands could be possible to include into the harvesting. While many costs considerably increased (e.g. retention areas, road construction and production schemes implemented in the sawmill design), the incomes also increased by applying management strategies and technology innovation, based on scientific research and experimental data. Thus, it was possible to increase the yield in harvesting and sawmill processing using the current industry technology. It was possible to adapt the company to the products that native forest could offer, including the low quality and size logs, minimizing the forest value costs and maximizing the incomes per unit area. The monitoring programs established in the harvested stands allowed to the evaluation of the ecological functionality of the applied regeneration system. The remnant forest structures were according to the proposed method, and short-term response of the regeneration dynamics seems largely enough to satisfactorily regenerate the harvested areas. The abiotic cycles significantly changed in the harvested sectors, but they are maintained inside the aggregate retention. For this, through the implementation of an innovated technology and monitoring programs in the forest and industry it was possible to found equilibrium between economic, ecological and social variables, adapting the harvesting of the native forests to improve the biodiversity conservation.

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