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Forest management with variable retention impact over bryophyte communities of *Nothofagus pumilio* understory

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Abstract: Bryophyte communities are an essential component of the understory in temperate forest, but few works analyze their potential as habitat indicators. Bryophytes, as the other plant species and wildlife, were significantly affected after the harvesting. For this, bryophyte cover, richness and biomass were compared in three different types and retention levels, and in unmanaged primary *Nothofagus pumilio* forest. A base line was determined prior to harvesting in a full site quality range and canopy gaps presence. Bryophyte communities were most abundant in low site quality class (13% cover and 844 kg ha^{-1} biomass) than in high site quality class (5% cover and 357 kg ha^{-1}), while biomass differences were found inside the canopy gaps (1,404 kg ha^{-1}). Silvicultural systems with different retention types significantly affect bryophytes after the harvesting. Most of the primary forest species decreased in the harvested sectors, as in the dispersed retention (15 to 30 m² ha^{-1}) and clear-cuts, but the original bryophyte communities survive inside the aggregate retention. However, some life forms as tall turf growing better in the dispersed retention, while lax weft appears after the harvesting in the most open sectors (e.g. clear-cuts). The variable retention treatment, which combines the aggregated and the dispersed retention, appears as the most adequate forest management strategy in order to maintain the bryophyte biodiversity within a high conservation level.

Key words: aggregated retention; dispersed retention; bryophytes; life forms; Patagonian forests

1 Introduction

Biodiversity conservation is the main objective of wild-managers around the world, where human activities are the main cause for the environment and species loss. For this, it is necessary to tend toward the equilibrium with the environment when an economic activity is planned (Carey et al. 1999), minimizing the impacts for the managed ecosystems (DeBell and Curtis 1993, Kohn and Franklin 1997, Mitchell and Beese 2002). Among other anthropogenic activities, forest management is evaluated increasingly by public scrutiny on the basis of their effect on non-timber values of managed forests, including the provision of habitat for forest species. Forest management impacts biodiversity, which could be positive or negative depending on the employed silvicultural system (Willot 1999, Spagarino et al. 2001, Martínez Pastur et al. 2002).

Bryophyte communities are an essential component of the understory in most of the temperate forest around the world (Matteri 1998). However few works exists for Tierra del Fuego, mainly in taxonomy (Matteri and Schiavone 1988, 1991, Buck 2002), and none analyze their potential as good habitat indicators (Rosso et al. 2001). On the other hand, few works include bryophyte communities in forest management impact studies (Martínez Pastur et al. 2002) on middle and long term research. Beside this, these works usually do not include comparisons between forest structure before and after silvicultural practices (Before-After-Control-Impact or *BACI* approach), that are designed for determining the extent of variation in biodiversity in study sites prior to the implementation of treatments (Wardell-Johnson and Williams 2000).

Several regeneration methods have been proposed for Southern Patagonian forests (Schmidt and Urzúa 1982, Martínez Pastur et al. 2000, Martínez Pastur and Lencinas 2005, González et al. 2006) based on natural regeneration of the harvested stands (Martínez Pastur et al. 1999a, Rosenfeld et al. 2006). These forests have been mainly managed through selection cuts or clear-cuts (Gea et al. 2004), or by shelterwood cuts in Chile (Schmidt and Urzúa 1982, Rosenfeld et al. 2006). This last method significantly affects the original diversity of the system under management (plants, birds, insects, fungi and mammals) (Martínez Pastur et al. 1999b, 2002, Pulido et al. 2000, Deferrari et al. 2001, Spagarino et al. 2001, Ducid et al. 2005), including cryptogam plant communities (Gamundi and Matteri 1998). Thus, a new alternative silvicultural method was defined to conserve the original biodiversity affected by the forest management (Martínez Pastur et al. 2005, Vergara and Schlatter 2006). This method proposes to leave 30% of the timber quality forest area as aggregated retention and 15-20% basal area as dispersed retention (Martínez Pastur and Lencinas 2005, González et al. 2006). This method might mitigate the harmful effects of traditional forest management practices (Martínez Pastur and Lencinas 2005, Lencinas et al. 2007). However, little is known about the effects of different retention types and the spatial-temporal changes on bryophyte communities. Therefore, the first aim of this work was to study different retention type effects on bryophyte cover and biomass in *Nothofagus pumilio* forests, compared to an unmanaged primary forest. For more detailed analysis, bryophyte life forms were studied at the fourth year after cuts. The hypothesis was that silvicultural systems with aggregated retention improve the conservation value of bryophyte community structure compared with dispersed retention, maintaining bryophyte diversity levels more similar than those observed in unmanaged primary forests. A base line in the unmanaged primary forests was determined prior to harvesting, where site quality and canopy gaps influence were analyzed. The hypothesis was that bryophyte growth is related to canopy closure and site quality of the stands. The second aim of this work was to assess temporal changes on bryophyte community cover and biomass in three harvested stands and one unmanaged primary stand. The hypothesis was that variable retention differently influence over the bryophyte community along the time.

2 Methods

2.1 Studied stands and forest structure characterization

An old-growth *Nothofagus pumilio* pure forest was selected in San Justo ranch – Tierra del Fuego, Argentina (54° 06' S, 68° 37' W) with a full range of site qualities (site index at 60 years old - SI_{60} varied from 9.8 to 23.2 m). Stands growing in a site quality *I* (SI_{60} = 19.85 to 23.20 m) could have more than 1,100 m^3 ha^{-1} and tress reach to 27.5 m height, in a site quality *II* (SI_{60} = 16.50 to 23.20 m) have up to 900 $m^3.ha^{-1}$ and heights up to 24.0 m, in a site quality *III* (SI_{60} = 13.15 to 16.50 m) have up to 700 m^3 ha^{-1} and heights up to 20.5 m, in a site quality *IV* (SI_{60} = 9.80 to 13.15 m) have up to 550 m^3 ha^{-1} and heights up to 17.0 m, while in a site quality *V* (SI_{60} = < 9.80 m) stands have less than 400 m^3 ha^{-1} and trees present a total height less than 17.0 m (Martínez Pastur et al. 1997, 2000, Gea et al. 2004).

Climate is characterized by short, cold summers and long, snowy and frozen winters. In the studied period (2002-2004), mean monthly temperatures varied from about –0.2°C to 10.4°C (extremes from -9.6 °C in July to 24.9°C in February) in the unmanaged primary stands, while in the harvested stands varied from about -1.0 °C to 10.6 °C (extremes from -11.3 °C in July to 25.9 °C in February). Only three months $year^{-1}$ were free of mean temperatures under 0 °C, and the growing season extended for about five months. Soil temperature (30 cm deep) never froze into the unmanaged primary stands, but it was frozen in the harvested stands (-0.2 to -0.6 °C during June-July). Precipitation was 382 mm $year^{-1}$ inside the unmanaged primary stands, while this was 639 $mm.year^{-1}$ in the harvested stands. The average wind speed outside the forest was 8 km h^{-1}, reaching up to 100 km h^{-1} during storms.

The studied stands were old-growth forests, and they had never been disturbed by forest practices in the past. The original forest structure presented 22.9 m total height, 528 trees ha^{-1}, 40.6 cm diameter at breast height, 65.0 m^2 ha^{-1} basal area and 727.8 m^3 ha^{-1} total over bark volume. In 61 ha of the studied forests, three regeneration systems were applied by `*Los Castores*' sawmill during 2001, left out an unmanaged primary stand as a control (*C*). The assayed treatments were: (1) a dispersed retention (*DR*), where 30 m^2 ha^{-1} basal area of the most dominant trees were homogeneously left out as remnants (105 trees ha^{-1}, 54.8 cm diameter at breast height and 353.7 m^3 a^{-1} total over bark volume), which was comparable with a first intervention of a shelterwood cut (Schmidt and Urzúa 1982, Martínez Pastur et al. 2000); (2) an aggregated retention with clear-cuts between them (*AR*), where the aggregates represent 28% retention of the timber stands (one circular island per hectare of original forest with 30 m radius); and (3) a variable retention (*VR*) with aggregated and dispersed retention (15 m^2 ha^{-1} basal area of the most dominant trees were homogeneously distributed between aggregates, representing 40-60% retention) (Martínez Pastur and Lencinas 2005, Martínez Pastur et al. 2005). The *AR* treatment was subdivided into two parts, the aggregates (*AAR*) and clear-cuts among aggregates (*CAR*), while *VR* treatment was subdivided into the aggregates (*AVR*) and the dispersed retention among aggregates (*DVR*).

2.2 Bryophyte sampling methodology

A base line of bryophyte communities was defined prior to harvesting, and their changes were determined during the first four years after the harvesting (2002-2005) resulting in a repeated measures design. To define the base line, two factors were considered in the unmanaged primary stands (C): site quality class and presence of canopy gaps. These factors influence over the availability of light and soil water content at the understory level (Veblen 1989, Bartsch and Rapp 1995, Heinemann et al. 2000, Mariottini et al. 2002). Prior to harvesting, samples were taken in two site quality types (high site quality stands with more than SI60 = 15 m and low site quality stands with less than SI60 = 15 m), and outside or inside of five canopy gaps (average of 23 m diameter). After harvesting, samples were taken in the four treatments described before (C, DR, AR and VR). In the treatments with aggregates (AR, VR), the sampling effort was proportional to the aggregated retention area, distributing the plots inside the aggregates (AAR and AVR) and in the space among them in the harvested sectors (CAR and DVR).

In both studies, bryophyte communities were studied by ten plots in each treatment located through a random polar coordinate system (an angle and a distance were randomly selected from a table proportional to the stand area). For the base line study a total of N = 40 plots (two site qualities with n = 15 per treatment, inside and outside the gaps with n = 5 per treatment). For the comparison of the regeneration treatments after the harvesting a total of N = 160 plots (samplings in 4 stands with n = 10 along 4 years). Each plot was conformed by four 0.25 m^2 subplots orthogonally placed 5 m apart from the centre (Martínez Pastur et al. 2002), while in each canopy gap eight 0.25 m^2 subplots were placed, considering two positions (near and far to the gap centre) and four orientations (north, west, east and south). In each subplot, bryophyte cover was registered by a grid of 100 points m^{-2} by a frequency method. In each subplot, above ground bryophyte material was collected for biomass determination, drying it in an oven at 70 °C until constant weight. During the fourth year after harvesting, a bryophyte floristic inventory and life forms classification were carried out in each subplot. Bryophyte was classified at species level when it was possible (Matteri 1972, 1975, 1985, Zander 1993, Ochyra and Matteri 2001, Buck 2002, Matteri and Schiavone 2002), and life forms followed Matteri and Schiavone (1988) in wefts (lax or dense), rough mats or turf (tall or short) (for more details about life form classification see Magdefrau 1982).

2.3 Data analysis

A repeated measures ANOVA (analysis of variance) and two one-way ANOVA's were used to analyze the data. Significantly different averages were tested for differences by Tukey ($p < 0.05$). When data on biomass were not normal distributed, it was transformed by $W = ln(Y+1)$, where W is the transformed variable and Y is dry biomass in $kg.ha^{-1}$. Statistica (Statsoft) and Statgraphics (Statistical Graphics Corp.) software were used for these analyses.

Different retention types and unmanaged primary forests were clustered using a complete linkage amalgamation rule with euclidean distance measurement and farthest neighbor cluster algorithm (Gauch and Whittaker 1981) based on a matrix of the fourth year after harvesting bryophyte biomass along the studied treatments. Finally, two detrended correspondence analyses (*DCA*) were carried out, using relative (%) and absolute (kg ha^{-1}) biomass of bryophyte life form, without down weight for rare species and with axis rescaling (Hill 1979). *DCA* was selected although the gradient length was minor to 2.5 in both analyses (Jongman et al. 1995), because this is the only ordination technique that simultaneously analyses sampling units and species, allowing the examination of ecological interrelationships between them in a single-step analysis (Ludwig and Reynolds 1988). For more intuitive interpretation, *DCA* axes were rotated in the graphic, using 60º angle and vertical reflect for absolute biomass (kg ha^{-1}), and 5º angle for relative biomass (%). PC-Ord (McCune and Mefford 1999) and Statistica (Statsoft) software were used for these analyses.

3 Results

Significant differences were detected among different site quality stands during the base line characterization. Bryophyte cover ($F = 7.62$, $p = 0.002$) and biomass ($F = 3.54$, $p = 0.043$) presented greater values in low quality sites (13% and 844 kg ha^{-1}, respectively) than sites with medium-high quality classes (5% and 357 kg ha^{-1}, respectively). Beside this, there were no differences between bryophyte cover in

Table 1. Repeated measures ANOVA for treatments (comparison among unmanaged primary forests, dispersed retention, variable retention and aggregated retention) on bryophyte cover (%) and biomass (kg ha^{-1}) along the four first years after harvesting in *Nothofagus pumilio* forests.

Source	df	Cover		Biomass	
		MS	*F (p)*	MS	*F (p)*
Between subject effects					
Treatments	3	26.43	*3.99 (0.015)*	2.74	*8.36 (0.000)*
Within subject effects					
Years	3	7.98	*1.07 (0.365)*	0.47	*1.93 (0.129)*
Interaction					
Treatments x Years	9	4.62	*0.62 (0.778)*	0.29	*1.22 (0.290)*

df = degrees of freedom; MS = median square; F (p) = Fisher test and probability between brackets

Table 2. One-way ANOVA for treatments (comparison among unmanaged primary forests, dispersed retention, variable retention and aggregated retention) on biomass (%) of each bryophyte life form, at the fourth year after harvesting in *Nothofagus pumilio* forests.

Treatment	Rough mat	Tall turf	Short turf	Dense weft	Lax weft
C	57.5 a	29.9 a	5.2 a	7.3 a	0.0 a
DR	21.4 a	77.8 b	0.3 a	0.5 a	0.0 a
VR	48.1 a	25.2 a	6.2 a	0.5 a	10.0 a
AR	62.6 a	28.8 a	0.3 a	4.3 a	7.0 a
F (p)	2.29 (0.095)	6.10 (0.002)	1.07 (0.374)	1.28 (0.297)	1.00 (0.405)

C = unmanaged primary forest; DR = dispersed retention; VR = variable retention; AR = aggregated retention. F (p) = Fisher test and probability between brackets (N = 40). Different letters indicate differences by Tukey at P < 0.05

closed forests and inside the gaps (F = 2.16, p = 0.166), but significant differences were detected in biomass (F = 8.70, p = 0.011), which was higher inside the gaps (1404 kg ha^{-1}). Positions (near and far to the gap centre) and orientations (north, west, east and south) not significantly influenced in bryophyte cover (F = 0.01, p = 0.973 and F = 1.61, p = 0.206, respectively) and biomass (F = 0.02, p = 0.885 and F = 1.32, p = 0.285, respectively). However, lowest values where observed in south orientation plots (4% cover and 424 kg ha^{-1}), medium values in east and west orientation plots (9% and 564 kg ha^{-1}) and highest values in north orientation plots (18% and 1256 kg ha^{-1}).

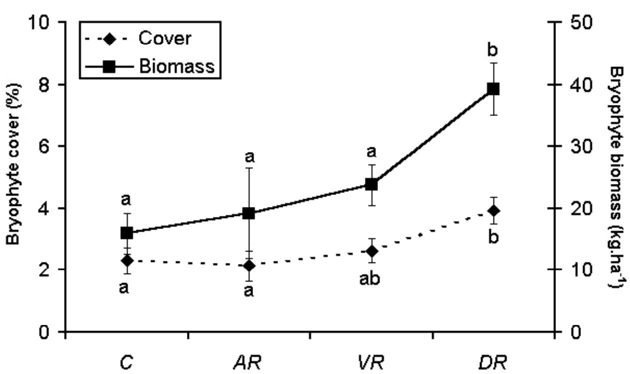

Figure 1. Average bryophyte cover (%) and biomass (kg ha^{-1}) for the four first years after harvesting in *Nothofagus pumilio* forests. Error bars indicate standard error. C = unmanaged primary forest; AR = aggregated retention; VR = variable retention; DR = dispersed retention. Different letters for each variable indicate differences by Tukey at P < 0.05.

Results of repeated measures ANOVA indicate that treatments significantly affect bryophyte cover and biomass, while effects of years after harvesting are non-significant (Table 1). The interaction between treatments and years was also non-significant; this indicates that mean cover or biomass on each treatment did not significantly changed along the years. Bryophyte biomass did not significantly differ among unmanaged primary forests (*C*), aggregated retention (*AR*) and variable retention (*VR*) treatments (159-238 kg ha^{-1}), but significantly increased in the dispersed retention (*DR*) (392 kg ha^{-1}) (Figure 1). Similarly, bryophyte cover did not significantly differ among unmanaged primary forests and aggregated retention treatment (2%), while significantly increased in the dispersed retention (4%). In variable retention treatment, cover presented intermediate values (3%) between unmanaged primary forests and dispersed retention.

Bryophyte richness at the fourth year after harvesting was higher in the harvested stands than in the unmanaged primary forests (Appendix). There were found 11 species and morphospecies in the aggregated retention, 10 in the variable retention and 9 in the dispersed retention, while in the unmanaged primary forests 7 species and morphospecies were found. Richness inside the aggregates of both treatments (*AAR* and *AVR*) (8 species and morphospecies) was similar to those found in the unmanaged primary forests, while in the harvested sectors there were identified 10 species and morphospecies. Bryophyte biomass in most of the life forms, expressed as relative abundance, did not significantly change after the harvesting (rough mat, short turf, dense and lax weft) (Table 2). However, significant differences were found in tall turf in the dispersed retention, being the dominant bryophyte life form. Beside this, lax weft appeared after the harvesting in treatments with aggregates (*AR* and *VR*), but with higher spatial variation levels.

Likewise, bryophyte biomass of the species and morphospecies, expressed as relative abundance, did not significantly change after the harvesting (Table 3). However, significant differences were found

Treatment	ACAU	LELA	SAUN	PLPR	POTT	BRSP	Others
C	25.5 a	31.2 a	0.8 a	29.9 a	4.8 a	7.3 a	0.4 a
DR	11.6 a	8.2 a	1.2 a	77.8 b	0.3 a	0.4 a	0.6 a
VR	19.6 a	12.1 a	5.1 a	25.8 a	4.6 a	0.1 a	23.2 a
AR	31.7 a	3.9 a	9.3 a	25.8 a	0.1 a	1.7 a	27.4 a
F (p)	1.01 (0.399)	2.46 (0.078)	2.59 (0.068)	6.08 (0.002)	0.83 (0.488)	1.60 (0.206)	3.12 (0.038)

*A*CAU = Acrocladium auriculatum; LELA = Lepyrodon lagurs; SAUN = Sanionia uncinata; *PLPR = Platyneuron p*raealtum; POTT = Pottiaceae family; BRSP = Brachythecium genus; Others = unidentified morphospecies. C = unmanaged primary forest; DR = dispersed retention; VR = variable retention; AR = aggregated retention. F (p) = Fisher test and probability between brackets (N = 40). Different letters indicate differences by Tukey at P < 0.05.

Table 3. One-way ANOVA for treatments (comparison among unmanaged primary forests, dispersed retention, variable retention and aggregated retention) on biomass (%) of each bryophyte species, genus or family, at the fourth year after harvesting in *Nothofagus pumilio* forests.

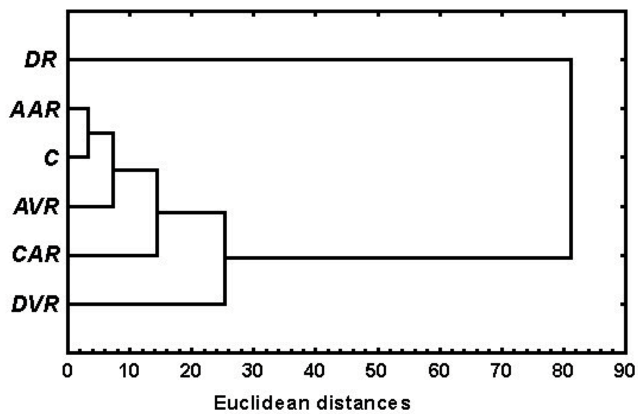

Figure 2. Classification of unmanaged and managed *Nothofagus pumilio* forest at the fourth year after harvesting based in bryophyte life form biomass (kg ha-1). DR = dispersed retention; AAR = aggregates in aggregated retention; C = unmanaged primary forest; AVR = aggregates in variable retention; CAR = clear-cuts among aggregates in aggregated retention; DVR = dispersed retention among aggregates in variable retention.

in *Platyneuron praealtum* in the dispersed retention, being the dominant species which only grows in tall turf life form. Rough mats were mainly composed by *Acrocladium auriculatum*, *Lepyrodon lagurus* and *Sanionia uncinata*, which were equally distributed in all treatments. *Pottiaceae* family was the most representative in the short turf life form, while *Brachythecium* sp. was the most abundant genus in the dense weft life forms.

Cluster analysis showed a major similarity between unmanaged primary forests (*C*) and inside the aggregates (*AAR* and *AVR*) of both harvested treatments with aggregates (7.5 Euclidean distance) (Figure 2). This group was jointed to the harvested sectors of these treatments (*CAR* and *DVR*) (25.5 Euclidean distance). Finally, dispersed retention (*DR*) was the most different treatment, related with others in a far distance (80.5 Euclidean distance).

Three groups were defined according to the canopy closure for the *DCA* analyses: a first group (*C-A*) conformed by unmanaged primary forest and inside aggregate plots, a second one (*DR-DVR*) conformed by the dispersed retention treatment and the harvested sectors of the variable retention treatment, and a third group (*CAR*) composed by clear-cut plots of the harvested sector in the aggregated retention treatment (Figure 3). In absolute biomass as well as in relative biomass analysis, most of the species and morphospecies were related to the first group, with *Brachythecium* sp. as the most related one. *Pottiaceae* family and *Lepyrodon lagurus* were also related to this group. Tall turf species (*Platyneuron praealtum*) and morphospecies were more related to the dispersed retention, as were described in Table 2 and 3. Some morphospecies (rough mat and dense or lax wefts) were more related to clear-cuts. Finally, few species as *Acrocladium auriculatum* and *Sanionia uncinata* appeared as generalists when the relative biomass analysis was considered.

4 Discussion

Forest management significantly affects the horizontal and vertical structure of the primary *Nothofagus pumilio* forest (Martínez Pastur et al. 2000). The canopy opening allows a rapid growth of the forest regeneration (Rosenfeld et al. 2006) due to the increase of light intensity at understory level and soil water availability (Martínez Pastur et al. 2007). However, these microclimatic changes (Caldentey et al. 1999-2000) produce a large impact over the natural cycles (Richter and Frangi 1992, Caldentey et al. 2001) and the original biodiversity including mammals (Martínez Pastur et al. 1999b, Pulido et al. 2000), birds (Deferrari et al. 2001, Vergara and Schlatter 2006), insects (Lanfranco 1977, Spagarino et al. 2002), fungi (Ducid et al. 2005), and plants including bryophytes (Martínez Pastur et al. 2000).

Bryophyte communities growing in the understory showed a high variability due to the different micro-environments which might be found into the forest along the stands with different site quality classes. Contrary to the hypothesis, bryophyte communities were more abundant in low site quality classes due to the greater proportion of bare soil than in the medium-high quality classes (70% and 15% respectively) (Mariottini et al. 2002). In this research, small to medium size canopy gaps significantly influenced over bryophyte biomass. Many works describes the influence of gaps in tree regeneration dynamics and understory communities too (Veblen 1989, Bartsch and Rapp 1995, Heinemann et al. 2000). Greater values of cover and biomass of bryophyte communities were found in the northern sector of the gaps, as was cited for tree regeneration in northern Patagonia (Heinemann et al. 2000).

Nothofagus is a classic Gondwanan genus and is quantitatively important in many southern forested landscapes (Monks and Kelly 2006), being the last unmanaged primary forests in the southern hemisphere. Since the 1990s, even-age management with shelterwood cuts has been the dominant silvicultural system used in Southern Patagonia (Schmidt and Urzúa 1982, Gea et al. 2004). However,

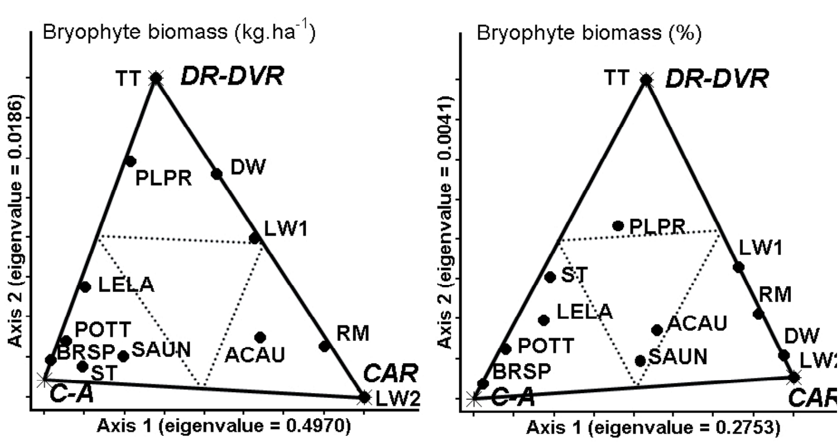

Figure 3. DCA ordination of unmanaged and managed *Nothofagus pumilio* forests at the fourth year after harvesting based in bryophyte life form biomass, in kg ha-1 (gradient length = 1.861) and percentage (gradient length = 2.136). ACAU = *Acrocladium auriculatum*; LELA = *Lepyrodon lagurs*; SAUN = *Sanionia uncinata*; PLPR = *Platyneuron praealtum*; POTT = *Pottiaceae* family; BRSP = *Brachythecium* genus; RM = unidentified rough mat morphospecies; TT = unidentified tall turf morphospecies; ST = unidentified short turf morphospecies; DW = unidentified dense weft morphospecies; LW1 and LW2 = unidentified lax weft morphospecies. C-A = unmanaged primary forests and aggregates in variable and aggregated retention; DR-DVR = dispersed retention in pure treatment and among aggregates in variable retention; CAR = clear-cut among aggregates in aggregated retention. Solid lines indicate location of species shared between two treatments; dotted lines enclose common species for all treatments.

even-age management has been criticized, due to the effects on other forest values. Critics of conventional harvest practices assert that shelterwood cuts of old-growth forests create secondary forests that are poor habitat for many important wildlife and understory plant species (Martínez Pastur et al. 2002). One alternative is including a variable retention in the forest management planning (González et al. 2006), which considers multiple vegetation layers and structurally intact forest habitat retaining the original biodiversity (Franklin et al. 1997). Many studies were carried out in a wide range of forest composition and structures, geographic locations and physical environments to study the feasibility and effectiveness of these methods, e.g. Demonstration of Ecosystem Management Options (Aubry et al. 1999, Halpern 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) studies.

The different treatments affect quantity and quality of bryophyte communities after the harvesting, according to the suggested hypotheses. In this study, changes are not significant among years, but bryophyte community biomass decrease along the four years after harvesting, coincidently with Martínez Pastur et al. (2002) who found 318 kg ha^{-1} in primary forests and 79 kg ha^{-1} after one year of harvesting, and with Jalonen and Vanha-Majamaa (2001) in several felling methods in southern Finland. The overall species composition of the dispersed retention was closer to the clear-cuts than the unmanaged forest, as was cited by North et al. (1996). Beside this, Vanha-Majamaa and Jalonen (2001) determine a linear decrease in biomass and richness of bryophytes when decrease the level of retention in Norway Spruce Finnish forests. These bryophyte losses could be due to the increase of solar radiation, air and soil temperatures, and air wind speed which produces a drastically diminishing of the air humidity during the summer months (Caldentey et al. 1999-2000). On the other hand, these changes in bryophyte community biomass were associated to the decline in insect populations after harvesting (Spagarino et al. 2001) mainly in Collembola order (McQuillan 1993).

The dispersed retention allows developing larger biomass than those found in unmanaged primary forest. However, these biomass increases corresponded to a few species, mainly growing in the tall turf life form, e.g. *Platyneuron praealtum* develop over the forest floor in closed turfs which retains soil water (Matteri and Schiavone 1988). Beside this, in the clear-cuts appeared some species which are not found in unmanaged primary forest. Ruokolainen and Salo (2006) also found bryophyte species which quickly established after a slash-burning in a Finnish forest, and disappeared after ten succession years.

Most of the primary forest bryophyte species decreased in the harvested sectors, but some silvicultural proposals could maintain the original community structure inside the aggregates. The variable retention treatment appears as the most adequate forest management strategy in order to maintain bryophyte diversity within a high conservation level program. This method combines the effectiveness of the dispersed retention for bryophyte biomass production, and maintains the unmanaged primary forest bryophyte diversity inside the aggregates.

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