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Changes in *Nothofagus pumilio* forest biodiversity during the forest management cycle. 1. Insects

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Abstract. Human activities, like logging, modify the dynamics and composition of virgin forest, affecting the equilibrium between the natural species. *Nothofagus* forests sustain an entomofauna that is endemic, and includes relict species of significant conservation importance. The aim of this work was to evaluate the changes in insect diversity and abundance of a *Nothofagus pumilio* forest managed by a shelterwood cut system. Insect capture was carried out using a set of traps along a horizontal and vertical gradient. Sampling was taken in day and night conditions, in post-harvesting situations and different phases of stand development. The diversity and abundance of insects varied significantly during the forest cycle (defined as 100–200 years according to site quality). One morphospecies was lost every 11 years until the end of the forest cycle. It may be necessary to modify the current silvicultural system to one that conserves insect diversity through a reduction in disturbance.

Key words: forest management, insect diversity, loss of species, *Nothofagus pumilio*, Patagonia, sustainability

Introduction

Nothofagus pumilio (Poepp. et Endl.) Krasser (commonly named 'Lenga') constitute the most important component within the forests of South Patagonia, with a wide range of natural distribution from 36°50′ to 55°02′ SL. In Tierra del Fuego (Argentina) the forests are used mainly for cattle grazing and harvesting. Forest management is carried out according to the regulation of the Provincial Law n° 145, utilizing as a regeneration method the shelterwood cut system (Schmidt and Urzúa 1982). This silvicultural system mimics the natural forest dynamics through the opening of large canopy gaps, offering better ecological conditions for regeneration (humidity, brightness and protection against the wind). However, these conditions could alter the existing equilibrium between other species that make up the forest ecosystem (Fernández et al. 1998; Martínez Pastur et al. 1999a).

Human activities, such as harvesting, modify the composition and dynamics of the original natural forest (Michaels and McQuillan 1995; Christensen and Emborg

1996; Wigley and Roberts 1997; Liu et al. 1998) and affect biodiversity (Elliot and Swank 1994; Lindenmayer 1995; Lusk 1996; Fahrig 1997). The impacts produced by logging could be: (a) low impact if no modified species richness; (b) intermediate impact if modified slightly (with increases or decreases) species richness; or (c) high impact if the number of present species in the system declines (Reader et al. 1991). The maintenance of forest biodiversity should be the main objective of forest management (Christensen and Emborg 1996), which requires knowledge of the affected species ecology (Elliot and Swank 1994) and the quantification of the risks of change in species composition (Morris et al. 1993).

The *Nothofagus* forests sustain an entomofauna which is endemic and includes relict species of significant conservation importance (Lanfranco 1977; McQuillan 1993; Solarvicens 1995). A limited number of these communities have been studied by the first scientific expeditions at the beginning of the last century (Berg 1895; 1899; Bruch 1925), centering on the current state of the knowledge of species taxonomy (Gentili and Gentili 1988; Welch 1988; Niemela 1990; McQuillan 1993; Stary 1994; Solarvicens 1995; Morrone and Roig 1995), and utilizing some insect groups to define biogeographical regions (Niemela 1990). There are studies that describe the forest management impact on understory communities of the *N. pumilio* forest in Tierra del Fuego (Fernández et al. 1998; Martínez Pastur et al. 1999a, b), and studies that have analyzed the effect of the first years of a shelterwood cut on the insect communities of a *N. pumilio* forest (Lanfranco 1977; Solarvicens 1995). However, there has been no quantification of the impacts in later stages of the forest management cycle. For these reasons, the objective of this work was to evaluate the changes in insect diversity and abundance through the forest management cycle in a *N. pumilio* forest in Tierra del Fuego (Argentina) managed by a shelterwood cut system.

Materials and methods

Study area

A group of stands of *N. pumilio* forest (500 ha) in San Justo ranch – Tierra del Fuego (54°06′ SL, 68°37′ WL) were selected for study, where '*Los Cóndores*' sawmill administers the logging of the area. The use of the forest is exclusively for timber but there is a significant grazing pressure by *Lama guanicoe* ('guanaco') on the forest regeneration (Martínez Pastur et al. 1999b). This study is considered to be focused at the local scale, according to the ecological scales proposed by Niemela (1997).

Study stands

Samples was obtaining in pure *N. pumilio* stands, sampling seven stages of the forest management cycle: post-harvesting situations and different development phases

according to the classification proposed by Schmidt and Urzúa (1982). The treatments were:

1. a virgin forest stand (VF) (year 0 of the forest management cycle);
2. a stand harvested 1 year after logging by a shelterwood cut system (H1) (year 1);
3. a stand harvested 6 years after logging by a shelterwood cut system, with abundant regeneration (H6) (year 6);
4. a stand in initial growth phase (IGP) with few remnant individuals in the superior stratum (year 40);
5. a stand in final growth phase (FGP) originated by a clear cut 80 years ago;
6. a part of FGP stand managed by a commercial low thinning (FGPt);
7. an even aged stand in mature phase (M) (year 200 of the forest management cycle).

The forest structure was characterized by dominant height (100 tallest trees/ha), basal area, number of trees, total volume, crown cover (measured using a spherical densiometer of Lemmon 1957) and forest floor cover. In each stand, the forest structure was measure at 10 points along two transects of 100 m long each. The total volume was obtained through the model proposed by Peri et al. (1997). The forest floor cover (understory, woody debris and bare ground) was sampling in 50 plots of 1 m^2 each along transects. The main understory plants was collected and identified following the taxonomy of Moore (1983). The cover was estimate using a grid of 100 points in each plot.

Insect sampling

The sampling was carried out collecting adult individuals of the insect class, during the summer season. This could be considered as an intermediate point in the period of thermal activity that goes from November to April (Niemela 1990). A set of traps was utilized to capture epigeal insects, in a horizontal and vertical gradient, during the day and the night. Each set of traps was compound of (Ross 1973; Pastrana 1985): (a) traps with ethanol like attractant, placed in a height gradient along the forest vertical structure (level floor, 1/4, 1/2 and 3/4 of the total height of the dominant trees) to trap lepidoptera (Noctuidae) and coleoptera (Cerambycidae, Scarabaeidae, Staphylinidae, Scolytidae); (b) light traps of universal model (fluorescent black and fluorescent cold white) (Barratt et al. 1972) placed on the forest floor and at 3/4 of the total height, to collect lepidoptera (Noctuidae), diptera and hymenoptera; (c) a set of 10 pit-fall traps distributed in 32 m^2 (each trap was of 13 cm diameter and 10 cm depth) (Lanfranco 1977; Michaels and McQuillan 1995) to collect coleoptera (Scarabeydae), colembola and other walking insects; (d) two trays of white colour and two of yellow colour (38×28 cm^2), with water and commercial detergent to capture diptera and hymenoptera; (e) traps of sticking paper (20×30 cm^2) yellow and light blue, along a height gradient (level floor, 1/3 of the total height and 2/3 of the total height), to capture hymenoptera, psocoptera, diptera and homoptera. This set of traps was installed for

two days for each treatment. After trapping, insects were classified to a level of order, and their number was quantified manually. Comparisons in terms of capture and species richness (Solarvicens 1995) for the sampling stands were done with the number of morphospecies or recognizable taxonomic units (RTUs) (Oliver and Beattie 1993; Lewis and Whitfield 1999) and individual number. An index of constancy–dominance was utilized (Saiz and Zalazar 1982) to characterize and compare the presence of the different insect orders in the treatments. This index take account of the presence of each group on the total sampling sites, relating the individuals percentage within each insect group to the total number of captured insects.

Results

Structure of the stands

The sampled stands belong to middle–high site quality class (III to I) (according to the classification proposed by Martínez Pastur et al. 1997). Although the *N. pumilio* forest structure will vary with site conditions and other related ecological factors (Martínez Pastur et al. 1994), the evolution along the forest management cycle can be characterized as follows (Table 1):

1. an initial pure VF over-aged, over-stocked, with a high crown closure (80–90%), a low number of trees per hectare of large diameter in a stage of decay (according to the classification proposed by Schmidt and Urzúa 1982), a high volume stand and a low cover understory;
2. after the shelterwood cut the forest structure changes dramatically, with a remnant basal area of 40% (H1), which slowly decreases to 20% because of the local windthrow of several trees (H6). These structures have a remnant stratum of few timber individuals with a low crown cover (25%), a high density understory that

Table 1. Characterization of the forest structure, crown closure and floor cover of the sampled stands (mean values).

	Basal area (m^2/ha)	Dominant height (m)	Density (n/ha)	Total volume (m^3/ha)	Crown closure (%)	Understory cover (%)	Debris cover (%)	Bare ground (%)
VF	66.88	25.79	347	924	85.72	8.93	18.60	72.53
H1	24.16	22.91	90	261	25.23	10.20	50.65	36.40
H6	12.19	24.60	53	168	24.89	48.55	29.60	21.70
IGP	16.98	6.50	13025	115	75.85	24.00	4.65	71.40
FGP	62.24	25.50	1466	728	87.65	11.40	33.60	54.50
M	69.88	27.50	575	931	83.20	19.90	26.90	53.00

VF – virgin forest; H1 – shelterwood cut system one year after logging; H6 – shelterwood cut system six years after logging; IGP – a stand in the initial growth phase; FGP – a stand in the final growth phase; M – an even aged stand in the mature phase. The total volume per hectare was obtained through the model proposed by Peri et al. (1997).

competes with *N. pumilio* saplings, and a high percentage cover of woody debris on the floor (Martínez Pastur et al. 1999a);
3. when the *N. pumilio* regeneration reaches to the exponential growth stage (IGP) has a high density and suppresses the understory plants;
4. later, the number of trees decreases by a self-thinning process (Fernández et al. 1997) reaching 80% of their total height (FGP) (Martínez Pastur et al. 1997) maintaining a closed canopy closure, and a sparse understory (forest in final growth phase); and finally,
5. the forest reaches an even-aged stage, very homogeneous, with a high proportion of mature individuals (M), good stocking, with high crown closure and similar characteristics of the VF.

Specificity of capture of the utilized system trap

The utilized system trap set captured a total of 104 RTUs (Oliver and Beattie 1993) of eight different insect orders. A small percentage of the RTUs was taxonomically identified (Table 2) many new species and genus, appearing that had not been described before. The diptera were the best represented order with a constancy of 100% and a dominance of 82%, followed by the hymenoptera that showed a constancy of 100% and a dominance of 11% (Table 3). These two orders were the most dominant groups recorded.

The specificity of capture for the several types of trap utilized is presented in Table 4. The pit-fall traps exhibited the least effort of capture (number of captures per trap type) (58% of the individuals), followed by the yellow trays (13%) and the sticking paper traps (10%). The pit-fall traps were designed to capture walking insects, but they were more efficient at capturing diptera attracted to the water mirror. However, the efficiencies of capture of the different trap types varied according to the orders: (a) diptera and colembola were gathered mainly in the pit-fall traps (67 and 72% of the individuals); (b) lepidoptera, in the light traps (black and white) (71% of the individuals); (c) hymenoptera in the yellow traps (of tray or paste) (91% of the individuals); (d) homoptera and psocoptera in the yellow trays (55 and 44% of the individuals); (e) coleoptera in the ethanol traps (35% of the individuals); and (f) hemiptera in the pit-fall traps and the white trays (100% of the individuals).

Variations in capture along a vertical gradient

The capture varied along a vertical gradient from the forest floor up to the tree canopy (Table 5). The highest percentage of individuals captured were at the understory level (87%) (0–1.5 m), while traps at 2/3 of the total height of the dominant trees captured 9% of the individuals (mainly hymenoptera, lepidoptera and coleoptera), and at the canopy level the remaining 4% were captured (mainly psocoptera and hymenoptera). The majority of the orders exhibited high indices of capture in the understory (60–100%), with the exception of the hymenoptera (47% of the individuals at stem level).

Table 2. Taxonomy of insects determined along the sampled stands.

Order	Family	Sub-family	Genera	Species	Identify
Hymenopterae	Colletidae		*Hylaeus*		1
	Cynipidae	Cynipini	*Paraulax*		2
	Figitidae	Figitinae	*Figites*		2
	Braconidae		*Apanteles*		3
			Meteorus		3
			Xynobius		3
			Chelonus		3
			Aleiodes		3
	Ichneumonidae				4
	Diapriidae	Belytinae			5
		Ambositrinae	*Dissoxylabis*		5
			Propsilomma		5
			Exallonyx		5
			Periclista		4
Lepidopterae	Hepialidae		*Callipielus*	*arenosus* Butler	6
	Geometridae		*Coironalia*	*crusiferaria* Berg.	6
	Noctuidae	Hadeninae	*Soriptania*	*syzygia* Hmpe.	6
		Noctuinae	*Pseudoleucania*	*aspersa* Butler	6
				peeroni Gn.	6
				antartica Staudinger	6
			Caphornia	*flavicosta* Wallengreen	6
			Peridroma	*clerica* Butler	6
			Pareuxoa	*koehleri* Olivares	6
	Saturniidae	Cuculliinae			6
			Catocophala	*rufosignata*	6
			Ormiscodes		6
Coleopterae	Tenebrionidae		*Hydromedium*		7
	Scarabeidae	Melolonthinae			7
	Scolitidae				7
	Curculionidae				7
	Carabidae	Migadopini	*Migadops*	*latus* G.M.	7
		Trechini	*Trechisibus*	*antarticus* Dej.	7
	Staphylinidae				7
	Tenebrionidae				7
	Crhysomelidae	Eumolpinae			7
	Nitidulidae				7
	Temnochilidae				7
	Cucujoidea				7
Collembolae	Entomobryidae				8
Hemipterae	Nabidae		*Nabis*	*faminei*	9
	Mixidae		*Stenodema*	*dohmi* Stal.	9
Homopterae	Cicadellidae	Deltocephalinae	*Amplicephalus*	*ornatus* Levinauvori	10
	Psillidae				10

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Table 3. Constancy–dominance index of each insect order.

Orders	Constancy (%)	Dominance (%)
Diptera	100	81.9
Lepidoptera	100	2.5
Hymenoptera	100	10.5
Homoptera	86	0.3
Coleoptera	100	0.9
Colembola	71	3.6
Hemiptera	28	0.1
Psocoptera	57	0.2

Table 4. Specificity and range of capture for the utilized insect traps.

	Types of trap (%)							
Orders	Pit-fall	White tray	Yellow tray	Ethanol	Fluorescent white light	Fluorescent black light	Light blue sticking paper	Yellow sticking paper
Diptera	67	9	13	2	2	2	2	3
Lepidoptera	–	3	2	12	31	40	3	9
Hymenoptera	1	1	16	1	–	–	6	75
Homoptera	21	21	55	3	–	–	–	–
Coleoptera	18	5	4	35	16	22	–	–
Colembola	72	12	10	–	2	4	–	–
Hemiptera	50	50	–	–	–	–	–	–
Psocoptera	6	13	44	13	12	–	12	–

Percentages referred to the total individuals within each order.

Table 5. Specificity and range of capture along a vertical gradient of the forest.

	Vertical gradient (%)		
Orders	Understory level	Stem level	Canopy level
Diptera	95	3	2
Lepidoptera	58	33	9
Hymenoptera	37	47	16
Homoptera	97	3	–
Coleoptera	63	29	8
Colembola	96	4	–
Hemiptera	100	–	–
Psocoptera	69	6	25

Percentages referred to the total individuals within each order.

Insect diversity changes through the forest management cycle

Species richness

The number of insect RTUs declined through the cycle (Figure 1), from the VF to the final stage of forest management (M). When the tree felling and logging were carried

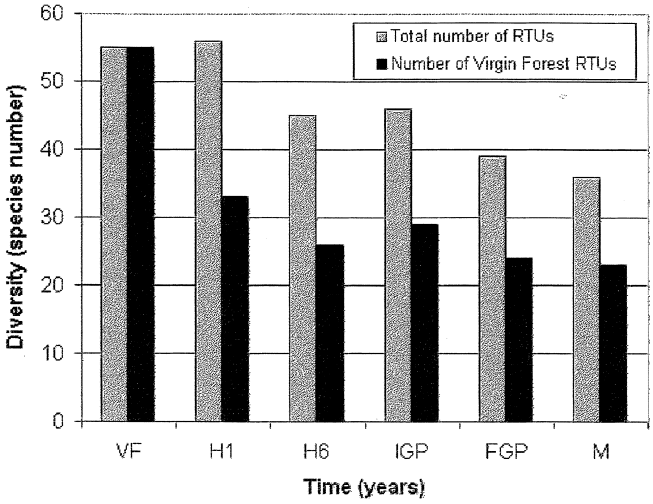

Figure 1. Total number and VF RTUs insect variation during the *N. pumilio* forest management cycle. VF (year 0), harvested stands (years 1–6), IGP stand (year 40), FGP stand (year 80) and M stand (year 200).

out (H1 and H6), an abrupt decrease in the number of RTUs occurred (18%). Overall there was a loss of 1 RTU every 11 years along the forest management cycle (from the original stand at year 0 to 220) approximating a 36% decline. Coleoptera had the highest percentage RTUs loss (56%). The remaining orders show losses of 20–30% (Table 6). Lepidoptera was the only order that showed an increase in species diversity after logging (143% with respect to the VF), but that returned to its original level in the succeeding stages and then fell in the final phases. The application of the thinning treatments (FGPt) improved the insect richness (8%) compared to a stand without intervention (FGP) (Table 6). Increases in coleoptera and hymenoptera richness, and decreases in diptera and lepidoptera richness occurred.

Fifty-five RTUs was recorded in the VF stand, 20% of them disappeared just after the shelterwood cut and another 11% disappeared 6 years after the cut. These RTUs (31%) represent the loss of specific insect diversity of the original system. The loss of RTUs was: 29% of lepidoptera (36% of the captured RTUs in the VF), 24% of coleoptera (44% of the RTUs of the VF), 24% of diptera (20% of the RTUs of the VF), 18% of hymenoptera (38% of the RTUs of the VF) and 6% of hemiptera (the only one captured in the VF).

A third part of the sampled RTUs (31%) had a wide range distribution and were founded in all the stands (Figure 2). Only 11 RTUs are exclusive to VF (11%) and 7 are shared with the harvested forests (7%), which disappear within the years. On the other hand, 18 new RTUs (17%) appeared in harvested stands and another 17 RTUs (16%) were shared with the IGP, FGP and M stands (Figure 2). These last RTUs could have colonized the ecosystem after the logging and remained in subsequent successional stages.

Table 6. RTUs per insect order (RTUs of the VF + new RTUs captured) and total number of insects (values in parenthesis) captured in each sampling.

Orders	BF	H1	H6	IGP	FGP	FGPt	M
Diptera	20(4123)	13 + 6(733)	11 + 7(1055)	12 + 9(3851)	10 + 7(3359)	10 + 5(568)	9 + 6(2357)
Lepidoptera	14(107)	10 + 10(117)	5 + 8(45)	7 + 5(52)	7 + 6(48)	6 + 3(20)	7 + 3(80)
Hymenoptera	8(115)	3 + 4(81)	5 + 0(223)	4 + 2(1026)	4 + 1(279)	4 + 5(142)	3 + 2(282)
Homoptera	2(6)	2 + 0(12)	2 + 0(12)	1 + 0(1)	0 + 0(0)	1 + 0(1)	1 + 0(1)
Coleoptera	9(62)	4 + 2(26)	3 + 2(11)	4 + 0(25)	3 + 0(14)	4 + 2(10)	3 + 1(30)
Colembola	0(0)	0 + 1(45)	0 + 1(6)	0 + 1(1)	0 + 1(127)	0 + 1(474)	0 + 1(54)
Hemiptera	1(1)	0 + 0(0)	0 + 1(1)	0 + 0(0)	0 + 0(0)	0 + 0(0)	0 + 0(0)
Psocoptera	1(1)	1 + 0(1)	0 + 0(0)	1 + 0(2)	0 + 0(0)	1 + 0(7)	0 + 0(0)

VF – virgin forest; H1 – shelterwood cut system one year after logging; H6 – shelterwood cut system six years after logging; IGP – a stand in initial growth phase; FGP – a stand in final growth phase; FGPt – a stand in final growth phase thinning at 25% of the original basal area; M – an even-aged stand in mature phase.

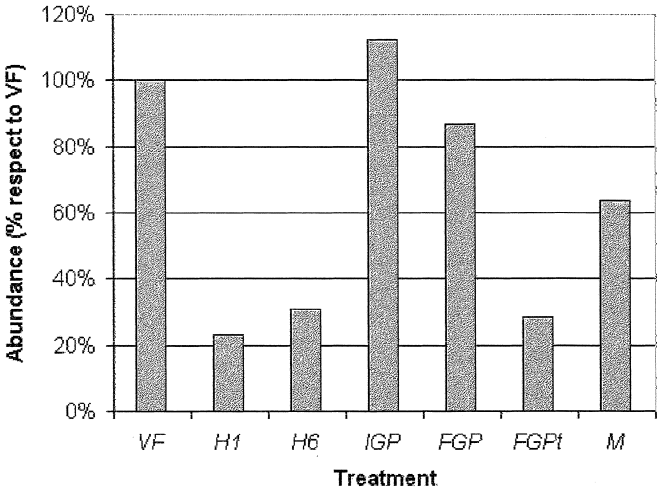

Figure 2. Number of RTUs overlap among the sampled stands. VF – virgin forest, H – harvested stands, IGP – initial growth phase, FGP – final growth phase, M – mature stand.

Insect abundance

The total number of insects captured in each phase of the forest management cycle varied greatly (Figure 3). At the beginning of the silvicultural treatment (H1) a loss of 77% of individuals occurred, followed by a population explosion, which reached a maximum during the IGP phase (112% of the VF population). After this stage, insect numbers decreased until the final stage of the cycle (M) (64% of the original number of insects). This decrease is most notable in diptera and hymenoptera, while in other orders a gradual loss is observed (coleoptera) or a small population increase (lepidoptera, homoptera and colembola), both after logging (Table 6). Furthermore, a significant increase in the number of hymenoptera captured in the IGP (nine times more than in the VF) and colembola in the FGP (not captured in the VF) was observed. The application of intermediate treatments (FGPt) drastically diminished the number of individuals (32.6%) in comparison to the unthinned stand (FGP) (Table 5).

Discussion

Ecological characterization of the stands

The VF possessed an irregular structure, consisting of many overlapping even-aged patches. This overlap generated stands with several different crown strata and a high diversity of microenvironments. The canopy is closed (86% of crown closure) (Table 1), but it is common to find natural openings created by the mortality of one or more trees. Individuals of all ages, some healthy, some in decline and a few dead stand-

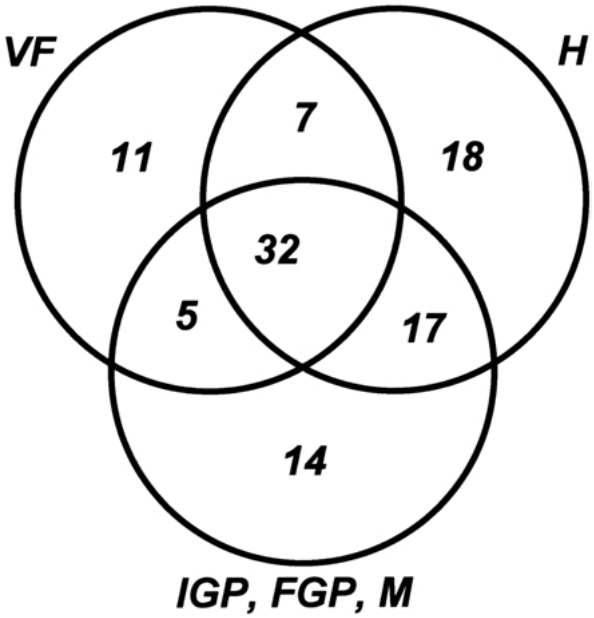

Figure 3. Relative abundance variation of the captured individuals of insects in the sampled stands of *N. pumilio* forest. VF – virgin forest, H1 – harvested stand one year ago, H6 – harvested stand six years ago, IGP – initial growth phase, FGP – final growth phase, FGPt – final growth phase thinning stand, M – mature stand.

ing trees represent the tree strata. The understory is sparse (<10% of floor cover), with very little biomass, and comprised of numerous species of herbaceous plants (*Galium aparine*, *G. antarticum*, *Cardamine glacialis*, *Osmorhiza chilensis*, *Schizeilema ranunculus*, *Viola magellanica*, *Puccinella magellanica*, *Festuca magellanica* and *Uncinia macrolepis*), few shrubs (*Berberis buxifolia*), and many mosses, liverworts and lichens, as well as cited by Fernández et al. (1998).

When a shelterwood cut was made (H1 and H6), the environmental and ecological characteristics changed significantly. The heterogeneity of environments disappears, resulting in a very homogeneous canopy (25% of crown cover). The woody debris on the floor increases considerably (30% at 50% of forest floor cover) compared to the VF (<20%) (Table 1). The temperature rises because of the increase in solar radiation and the environmental humidity declines because of the wind effect, which is reflected in the sapling mortality and mosses growing on the stems. On the other hand, the brightness and forest humidity of the floor increases (for the higher proportion of precipitation that reaches the forest floor) which permits the establishment of new understory species (reaching up to 50% of the floor cover), with rise up to 600% of the original biomass. This understory was comprised of plants of the VF, and other native species that were not previously present in the forest (*Acaena magellanica*, *Geum magellanicum*, *Stellaria debilis*, *Colobanthus quitensis*, *Gentianella*

magellanica, *Senecio acanthifolius*, *P. parviflora*, *Phleum alpinum*, *Agrostis flavidula*, *Bromus unioloides*, *Deschampsia kingii*, *Carex macloviana*, *Cystopteris fragilis* and *Blechnum penna-marina*), a great affluence of exotic species (*Rumex acetosella*, *Taraxacum officinale*, *Veronica serpylifolia*, *Capsella bursa-pastoris*, *Cerastium fontanum* and *Poligonum aviculare*) and a diversity of mosses, liverworts and lichens.

Further along the forest management cycle (IGP and FGP), the forest recovers some of its natural ecological conditions. The canopy closes again (76% at 87%), humidity increases, the understory returns to normal levels of floor cover and biomass, the brightness falls considerably and the wind diminishes in intensity. These forest stages are characterized by canopy homogeneity (even-aged forest) and high proportion of dead trees due to self-thinning, which decreases through the time (Fernández et al. 1997). Few understory plants survive this high crown closure (*G. aparine*, *C. glacialis*, *O. chilensis*, *V. magellanica*, *A. magellanica* and *S. debilis*), but because of the increase in shade and high humidity, the growth of mosses and mushrooms was favored.

At the final stage of forest management cycle (M), self-thinning has stopped. The forest system originated by this silvicultural treatment is even-aged and mature, with few individuals of ill health, scarce dead wood on the forest floor and few openings in the canopy. These last phases of the forest management cycle have lost the diverse microenvironments, the presence of multiple strata and the uneven-aged structure that could found in the VF. The understory is sparse again, with similar biodiversity to the VF, where few exotic species were survived (*Veronica serpylifolia* and *Cerastium fontanum*).

One of the main objectives of the forest management is the regularization of the stands; transforming uneven age stands to even age stands (Schmidt and Urzúa 1982). In this way, desirable characteristics of the original virgin structure are lost. These original forests have a tree strata represented by individuals of all ages, some healthy, some in decline and a few dead standing trees, of great ecological importance for insect development (Stewart and Burrows 1994). Another characteristic of enormous ecological importance for the entomofauna is the thick leaf mould that is found on the forest floor of the virgin stand (Lanfranco 1977; Niemela 1997). This provides ideal conditions for the development of many of the insect species associated with epiphytic plants and fungi (McQuillan 1993). By the way, there are highly specialized insects microhabitats, like some drills of the boreal forests (Niemela 1997). These species are extremely vulnerable to forest management, because they do not survive to the changes in the environmental conditions when are exposed during the forest management subjected to a shelterwood cut.

Insect sampling system design

This system was design to capture a large spectrum of epigean insects living in productive pure stands of *N. pumilio* forests, but it must be keep in mind that capturing of

certain individuals in a particular environment, does not mean that the same could survive or reproduce there (Niemela 1997). On the other hand, several sampling designs will give different relatives values. For example, Lanfranco (1977) and Solervicens (1995) utilized only two types of traps and manually gathered insects. The number of captured RTUs in this work was lower than those insect species sampled by Solarvicens (1995) who captured 188–225 species in different *Nothofagus* forests of Tierra del Fuego (Chile). However, the dominance of diptera within the *N. pumilio* forest agrees with results from Solervicens (1995) from the Condor River (Tierra del Fuego-Chile) (73–77% of the captured individuals were diptera, 10–15% were coleoptera and 6–9% were hymenoptera) and by Lanfranco (1977) in Monte Alto (Magallanes-Chile) (97% of the captured individuals were diptera and 2% were coleoptera). The majority of these species are associated with the forest floor (Solarvicens 1995), as was found in this current work. This is mainly due to the decomposing leaf material of the forest offering ideal conditions for the development of larvae and pupae, as well as parasites and predators (McQuillan 1993; Niemela 1997).

Changes in insect diversity through the forest management cycle

The variation of richness and abundance in *N. pumilio* forests is attributable to the forest management. Similar results have been recorded in Finnish and US forests (Niemela 1997; Lewis and Whitfield 1999), where several insect species are considered in danger of extinction. The virgin stand had a high number of species, consistent with results obtained by Lanfranco (1977), who detected more diversity in a virgin *N. pumilio* stand (Monte Alto–Magallanes–Chile) compared with a harvested one. However, Solarvicens (1995) did not arrive at the same conclusions, finding greater species richness in a harvested forest 8 years after logging than a VF. The main species losses are attributable to the insect specialization for particular microenvironments (Niemela 1997) and the adaptation to specific kind of food (Kitching et al. 2000) found in the VF. In this work, 11% of the sampled RTUs were only found in the VF, and had disappeared from the other stands. These is in strong agreement with Niemela (1997) and Willott (1999), whose cite that nearly 10% of VF species are highly specialized and disappear in the managed stands. On the other hand, an increase in the number of non-VF insect species was observed after management intervention. These species could be: (1) good colonizers of near by environments, like forest edges, peats, bogs or *N. antarctica* (ñire, ñirre) forests, as cited by Solarvicens (1995) and Niemela (1997); or (2) species very poorly represented in virgin stand such that they were few recorded, but that had increased in number due to a favorable change in the environmental conditions due to changes in the structure through the *N. pumilio* forest management cycle. However, the open canopies of the harvested stands could cause this increase in the number of captured RTUs, where light traps were visible from a long way away.

The diptera and the hymenoptera were the more affected orders, while the colembola increased their presence and number. The increase of colembola could be

explained through their preference for closed canopy areas of high humidity, with epiphytes and bryophytes (McQuillan 1993). These results are similar to those in the shelterwood cut and could mean that the application of silvicultural treatments negatively affects the insect populations.

Impact of forest management on insect class diversity: analysis of new silvicultural alternatives

The proposed silvicultural management for *N. pumilio* in Tierra del Fuego affects the structure and composition of the forests. The aim of this management regime is stand regularization, removing the heterogeneity of VF stands. This heterogeneity allows the forest to sustain an enormous insect diversity. Tierra del Fuego has large areas (privates owners and Government lands) of VF that still have not been exploited, but will be soon subjected to forest management (500–1000 ha/year change from VF to harvested forest). To develop *ecologically sound silvicultural practices* (Niemela 1997), firstly it is necessary to: (1) quantify the insect diversity, (2) define their taxonomy, (3) determine the vulnerable species, (4) study their ecology and environment relationships, (5) design silvicultural practices to favor the conservation of vulnerable species, (6) validate the effectiveness and the practicability of the new methodologies, and (7) apply it to the productive areas. Variations to the forest structure (Table 1) modify significantly the ecological conditions within the forest, affecting the sustainable species number and altering the trophic relationships between predators and preys. Therefore, it is very important to enlarge the analysis to other associate groups (e.g. birds, mice, foxes) (Hollifield and Dimmick 1995) and relate them to the changes observed in the Insect classes. Maintaining biodiversity in the stands under forest management should be a priority within the objectives of the forest policies (in the forest companies and in the Forest Service of the Government). Usually management for insects is not considered in strategic conservation plans (Niemela 1997), because there are no basic studies on the conservation status of many insect species (Solervicens 1995). However, the insect populations comprise the majority of the biodiversity of our forests, and a system that maintains their biodiversity is more stable to the change factors or disturbance which could put it in danger (Morris et al. 1993).

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References

Barratt JR, Harwood FW and Deary HO (1972) Functional association of light trap catches to emission of blacklight fluorescent lamps. Environmental Entomology 1(3): 285–290

Berg C (1895) Hemípteros de la Tierra del Fuego, coleccionados por el Sr. Carlos Backhausen. Anales del Museo Nacional de Buenos Aires 4: 195–206

Berg C (1899) Coleópteros de la Tierra del Fuego, coleccionados por el Sr. Carlos Backhausen. Comunicaciones del Museo Nacional de Buenos Aires 3: 57–65

Bruch C (1925) Algunos coleópteros de la Tierra del Fuego. Resultados de la primera expedición a Tierra del Fuego (1921). Universidad Nacional de Buenos Aires. 15 pp

Christensen M and Emborg J (1996) Biodiversity in natural versus managed forest in Danemark. Forest Ecology and Management 85: 47–51

Elliot K and Swank W (1994) Changes in tree species diversity after successive clearcuts in the Southern Appalachians. Vegetatio 115: 11–18

Fahrig L (1997) Relative effects of habitat loss and fragmentation on population extinction. Journal of Wildlife Management 61(3): 603–610

Fernández C, Martínez Pastur G, Peri P and Vukasovic R (1997) Thinning schedules for *Nothofagus pumilio* forest in Patagonia, Argentina. Proceedings XI Word Forest Congress. Vol 3: D. Función productiva de los bosques (CD). Antalya (Turquía), 13–22 October

Fernández C, Staffieri G, Martínez Pastur G and Peri P (1998) Cambios en la biodiversidad del sotobosque a lo largo del ciclo del manejo forestal de la Lenga. Proceedings Primer Congreso Latinoamericano de IUFRO (CD). Valdivia (Chile), 22–28 November

Gentili M and Gentili P (1988) Lista comentada de los insectos asociados a las especies sudamericanas del género *Nothofagus*. Monografías de la Academia Nacional de Ciencias Exactas, Físicas y Naturales de Buenos Aires 4: 85–106

Hollifield B and Dimmick R (1995) Arthropod abundance relative to forest management practices benefiting ruffed grouse in the southern Appalachians. Wildlife Society Bulletin 23(4): 756–764

Kitching R, Orr AG, Thalib L, Mitchell H, Hopkins MS and Graham AW (2000) Moth assemblages as indicators of environmental quality in remnants of upland Australian rain forest. Journal of Applied Ecology 37: 284–297

Lanfranco D (1977) Entomofauna asociada a los bosques de *Nothofagus pumilio* en la región de Magallanes: I parte: Monte Alto (Río Rubens, Ultima Esperanza). Annales del Instituto de la Patagonia (Punta Arenas-Chile) 8: 319–346

Lemmon P (1957) A new instrument for measuring forest overstory density. Journal of Forestry 55(9): 667–668

Lewis CN and Whitfield JB (1999) Braconid Wasp (Hymenoptera: Braconidae) diversity in forest plots under different silvicultural methods. Community and Ecosystem Ecology 28(6): 986–997

Lindenmayer D (1995) Forest disturbance, forest wildlife conservation and the conservative basis for forest management in the mountain ash forests of Victoria – Comment. Forest Ecology and Management 74: 223–231

Liu QJ, Kondoh A and Takeuchi N (1998) The forest vegetation and its differentiation under disturbance in a temperate mountain, China. Journal of Forest Research 3: 111–117

Lusk C (1996) Gradient analysis and disturbance history of temperate rain forests of the coast range summit plateau, Valdivia, Chile. Revista Chilena de Historia Natural 69: 401–411

Martínez Pastur G, Fernández C and Peri P (1994) Variación de parámetros estructurales y de composición del sotobosque para bosques de *Nothofagus pumilio* en relación a gradientes ambientales indirectos. Ciencias Forestales 9(1–2): 11–22

Martínez Pastur G, Peri P, Vukasovic R, Vaccaro S and Piriz Carrillo V (1997) Site index equation for *Nothofagus pumilio* Patagonian forest. Phyton 61(1/2): 55–60

Martínez Pastur G, Peri P, Fernández C and Staffieri G (1999a). Desarrollo de la regeneración a lo largo del ciclo del manejo forestal de un bosque de *Nothofagus pumilio*: 1. Incidencia de la cobertura y el aprovechamiento o cosecha. Bosque 20(2): 39–46

Martínez Pastur G, Peri P, Fernández C, Staffieri G and Rodriguez D (1999b) Desarrollo de la regeneración a lo largo del ciclo del manejo forestal de un bosque de *Nothofagus pumilio*: 2. Incidencia del ramoneo de *Lama guanicoe*. Bosque 20(2): 47–53

McQuillan P (1993) *Nothofagus* (Fagaceae) and its invertebrate fauna – an overview and preliminary synthesis. Biological Journal of the Linnean Society 49: 317–354

Michaels K and McQuillan P (1995) Impact of commercial forest management on geophilous carabid beetles (Coleoptera: Carabidae) in tall, wet *Eucalyptus obliqua* forest in southern Tasmania. Australian Journal of Ecology 20: 316–323

Moore D (1983) Flora of Tierra del Fuego. Anthony Nelson – Missouri Botanical Garden, 395 pp

Morris LA, Bush P and Clark J (1993) Ecological im pacts and risks associated with forest management. Chapter 10. In: Predicting ecosystem risk Cairns J, Niederlehner B and Orvos D (eds) Advances in Modern Environmental Toxicology, Vol XX, pp 153–213. Princeton Scientific Publishing, Princeton, New Jersey

Morrone JJ and Roig S (1995) The diversity of Patagonian weevils. Buenos Aires, Ediciones LOLA, 189 pp

Niemela J (1990) Habitat distribution of carabid beetles in Tierra del Fuego, South America. Entomologica Fennica 29(VI): 3–16

Niemela J (1997) Invertebrates and boreal forest management. Conservation Biology 11(3): 601–610

Oliver I and Beattie AJ (1993) A possible method for the rapid assessment of biodiversity. Conservation Biology 7(3): 562–568

Pastrana JA (1985) Caza, preparación y conservción de insectos. Ed El Ateneo. ISBN 950-02-9823-6, 234 pp

Peri P, Martínez Pastur G, Díaz B and Fucaraccio F (1997) Uso del Índice de Sitio para la construcción de ecuaciones estándar de volumen total de fuste para lenga (*Nothofagus pumilio*) en Patagonia Austral. Proceedings II° Congreso Forestal Argentino y Latinoamericano, 13–15 August, pp 123–132. Posadas, Argentina

Reader RJ, Taylor K and Larson D (1991) Does intermediate disturbance increase species richness within deciduous forest understory? Chapter 17. In: Esser G and Overdieck D (eds) Modern Ecology: Basic and Applied Aspects, pp 363–373. Elsevier, Amsterdam

Ross H (1973) Introducción a la entomología general y aplicada. Ed Omega, Barcelona, 536 pp

Saiz F and Zalazar A (1982) Efecto de las plantaciones de *Pinus radiata* sobre la entomofauna de biomas nativos. I. Coleopteros epigeos. Anales del Museo de Historia Natural de Valparaíso 14: 155–174

Schmidt H and Urzúa A (1982) Transformación y Man ejo de los Bosques de Lenga en Magallanes. Universidad de Chile. Ciencias Agrícolas no. 11, 62 pp

Solarvicens J (1995) Enthomology. Informe del Subproyecto 94–14. Estudios de linea base: Proyecto Río Condor, 79 pp

Stary P (1994) Aphid parasitoid fauna (Hymenoptera, Aphidiidae) of the southern beech (*Nothofagus*) forest. Studies on Neotropical Fauna and Environment 29(2): 87–98

Stewart G and Burrows L (1994) Coarse woody debris in old-growth temperate beech (*Nothofagus*) forests of New Zealand. Canadian Journal of Forest Research 24: 1989–1996

Welch R (1988) Phytophagous insects on deciduous *Nothofagus* in Chile and Argentina. Monografías de la Academia Nacional de Ciencias Exactas, Físicas y Naturales de Buenos Aires 4: 107–114

Wigley TB and Roberts T (1997) Landscape-level effects of forest management on faunal diversity in bottomland hardwoods. Forest Ecology and Management 90: 141–154

Willott SJ (1999) The effects of selective logging on the distribution of moths in a Bornean rainforest. Philosophical Transactions of the Royal Society of London B 354: 1783–1790