



Changes in *Nothofagus pumilio* forest biodiversity during the forest management cycle. 2. Birds

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Abstract. Human activities, such as logging, modify the forest structure and the microenvironments of the original *Nothofagus* forests. The aims of this work were to evaluate changes in the diversity and relative abundance of birds and to analyze their trophic relationships with insect and plant communities along the *Nothofagus pumilio* forest management cycle. Data was collected using a point sampling method along transects located in different forest structures during the summer season, by direct (sight) and indirect (hearing) recognition following sunrise. Bird diversity and abundance significantly varied along the forest management cycle. Seven new species appeared after harvest, but the total number did not vary by the end of the forest management cycle, and there was no significant loss of species. Bird abundance was directly related to the insect abundance and plant biomass. Relationship between groups (lower plants, monocotyledons and dicotyledonous) is also discussed. Major studies in bird ecology are necessary to develop new silvicultural alternatives based on the more sensitive species to harvest. Forest management strategies and mitigation alternatives must be incorporated into forest planning in order to maintain the original structure of bird communities and the equilibrium with other forest species.

Key words: bird abundance, bird diversity, conservation, shelterwood cut, sustainability, Patagonia, Tierra del Fuego

Introduction

Nothofagus pumilio (Poepp. et Endl.) Krasser (commonly named ‘Lenga’) forests are the dominant ecosystem of Tierra del Fuego; they are used for wood extraction, cattle grazing, tourism and recreation. Forest management is carried out by the silvicultural system described by Schmidt and Urzúa (1982), which produces an important change in forest structure, significantly altering the abundance and diversity of the understory (Fernández et al. 1998), proportional to the disturbance imposed (Holmes 1990; Elliot and Swank 1994; Haight 1995; Lindenmayer 1995; Lusk 1996; Fahrig 1997; Burel et al. 1998). Maintaining the ecological characteristics of the original system should be the main objective in the planning of forest management, and should be based on the sustainability and in agreement with the environment (Burel et al. 1998).

Over-aged trees, high heterogeneity of microenvironments and an irregular structure characterize the original forest (Martínez Pastur et al. 2000). However, managed *N. pumilio* forests are even aged and very homogeneous (Schmidt and Urzúa 1982). Management through a regular system alters habitats of the original forest and fragmentation of the original system occurs (Burel et al. 1998). Forest fragmentation has many problems for the population dynamics of birds (Trine 1998; Cornelius et al. 2000) and may contribute to the extinction of some species (Fahrig 1997).

Nothofagus forests sustain low bird diversity, with few endemic species in Tierra del Fuego (Schlatter 1995) but many species in the Patagonia region (Rozzi et al. 1997). Clark (1986), Narosky and Yzurieta (1987) and Rozzi et al. (1997) cited nearly 60 species in the terrestrial ecosystems of the region with less than 40 of them living exclusively in forest environments. There are few species that occupy all ecological niches, and as such, they have a high capacity for environmental adaptation (Arroyo et al. 1996). A great percentage of the birds of these forests develop in several environments; with less specific requirements for microenvironments or inter-specific relationships for develop. However, some of them have special requirements for water environments, food availability, open places for hunting, or determined conditions for nesting. Within the fuegian species, it is possible to find: several trophic feeding levels (herbivores, omnivores and carnivores), migration levels (resident, partial migratory or migratory) and different environmental uses (*N. pumilio*, *N. antarctica* forests, or preferentially different stratum within the forest structure).

There are few studies of forest birds in Tierra del Fuego and the majority of them are observations and descriptions of species (see Olrog 1948; Humphrey and Bridge 1970; Humphrey et al. 1970; Venegas 1973, 1986; Clark 1984; Navas and Manghi 1991; Rozzi et al. 1997). Schlatter (1995) analyzed bird communities in the first years following a shelter wood cut in a *N. pumilio* forest of Chile, but did not quantify the impact in later stages. Some studies described the impact of *N. pumilio* forest management on forest structure and other related communities (plants, insects, *Lama guanicoe*) in Tierra del Fuego (see the first part of this work; Fernández et al. 1998; Martínez Pastur et al. 1999a, b, 2000). For these reasons, the aims of this work were to evaluate the changes in bird diversity and relative abundance of birds, and analyze the possible trophic inter-relationships with insect and plant communities along the *N. pumilio* forest management cycle.

Materials and methods

Location and sample stands

A group of six stands of *N. pumilio* forest were selected for this study in San Justo ranch – Tierra del Fuego (54°06' SL, 68°37' WL) (VF = virgin forest; H1 = a stand

harvested by a shelterwood cut system one year ago; H6 = a stand harvested six years ago, with abundant regeneration; IGP = a 40 years old stand in initial growth phase with few remaining seed trees; FGP = a 80 years old stand in final growth phase from a clear cut 80 years ago; and M = an even aged stand of 230 years old in mature phase). The description of the forest structure and the ecological characterizations of the stands are introduced in the first part of this work. For details about the silvicultural method see Schmidt and Urzúa (1982) and Martínez Pastur et al. (2000).

Sampling methodology

Data was collected by point sampling method along transects in each treatment during February in the summer season, and were adjacent to the insects capture sites described in the first part of this work. Transects were established on a systematic design covering the area of the selected stands (VF = 8 points; H1 = 9 points; H6 = 6 points; IGP = 3 points; FGP = 5 points; M = 5 points) and were visited twice. Transects were 100 m apart, and samples were taken every 100 m along each transect. This design was used in order to detect all the variability in bird diversity and relative abundance of each stands conditions. Each point sampling was based on a 10-min period, consisting of a 2-min period of accustoming (time in which birds return to their normal activity) and an 8-min period of counting (Reynolds et al. 1980; Scott and Ramsey 1981; Fuller and Langslow 1984; Verner 1988; Hagar et al. 1996). The accustoming period of 2 min was adequate, because the birds of the *N. pumilio* forests are not evasive. Sampling used a direct (sight, by binoculars) and indirect recognition method (through the hearing reconnaissance bird songs) (Schlatter 1995). The observation range (hearing and sighting) was fixed on 50 m according to the first sampling tests, as used as well by Schlatter (1995). The samples were taken in a 4-h period following sunrise (Hagar et al. 1996), which is the time of major social and feeding activity of birds. The samples were carried out under equal climatic conditions, discarding days of fog, strong winds or rain.

Data analysis

Indexes of *constancy-abundance* were calculated from the sampling data, which was described in the first part of this work. Analysis of variance was carried out on diversity and number of sampled birds and means were separated using a Tukey test with a significant difference of $P < 0.05$. Different stands were clustered using a complete linkage amalgamation rule and euclidean distance measurement, based on diversity (presence or absence) and relative abundance of the species (Crisci and Armengol 1983). This was compared through the Shanon diversity index (Peet 1975; May 1975).

Results

Bird diversity changes over the forest management cycle

Species diversity: Fifteen species of six different orders were identified: 60% belonged to Passeriforms, 13% to Falconiforms and 27% to the other four orders (Table 1). The number of species varied during the forest management cycle (Figure 1). A total of seven species were identified in the VF. The number of species in logged stands ranged from 9–11 in H1 and H6 to 4 in the IGP, reaching to the original values at the end of the forest cycle in the M stage (Table 1). The species number in the virgin forest (VF) did not change after logging. However, after harvesting (H1 and H6 treatments), seven new species were detected.

There were no differences in species number between VF and other treatments when an analysis of variance per sampling point was done (Table 2), but there were differences among the logged treatments. There were significantly fewer species in IGP (0.8 species per station) than in H1 and H6 (2.6–3.0 species per station).

Passeriforms were the most important order in the studied *N. pumilio* forest, with a constancy of 100% and a dominance of 91%. Within this order, *Aphrastura spinicauda* had 100% constancy and 45% dominance, and *Zonotrichia capensis* had 100% constancy and 22% dominance. The second most important order was the Psittaciforms, with *Enicognathus ferrugineus* (67% constancy and 6% dominance) as the only representative species in Tierra del Fuego (Table 3).

Table 1. Species and individuals number sampled in each treatment along the *Nothofagus pumilio* forest management cycle.

Species	Order	Treatment					
		VF	H1	H6	IGP	FGP	M
<i>Aphrastura spinicauda</i>	Passeriforms	39	49	26	3	25	28
<i>Zonotrichia capensis</i>	Passeriforms	7	14	57	3	5	2
<i>Elaenia albiceps</i>	Passeriforms	10	12	1	–	6	5
<i>Turdus falcklandii</i>	Passeriforms	5	5	1	–	3	1
<i>Troglodytes aedon</i>	Passeriforms	–	19	5	–	1	2
<i>Scytalopus magellanicus</i>	Passeriforms	–	1	2	2	2	–
<i>Phrygilus patagonicus</i>	Passeriforms	–	–	6	–	–	2
<i>Tachycineta leucopyga</i>	Passeriforms	–	–	2	–	–	–
<i>Carduelis barbata</i>	Passeriforms	–	–	3	–	2	–
<i>Milvago chimango</i>	Falconiforms	1	–	1	–	–	–
<i>Polyborus plancus</i>	Falconiforms	–	1	–	–	–	–
<i>Enicognathus ferrugineus</i>	Psittaciforms	6	5	11	–	–	3
<i>Campephilus magellanicus</i>	Piciforms	–	2	–	–	1	–
<i>Glaucidium nanum</i>	Strigiforms	–	–	–	1	–	–
<i>Theristicus caudatus</i>	Ardeiforms	1	–	–	–	–	–

VF = virgin forest; H1 = stand harvested one year ago; H6 = stand harvested 6 years ago; IGP = initial growth phase stand; FGP = final growth phase stand; M = mature phase stand.

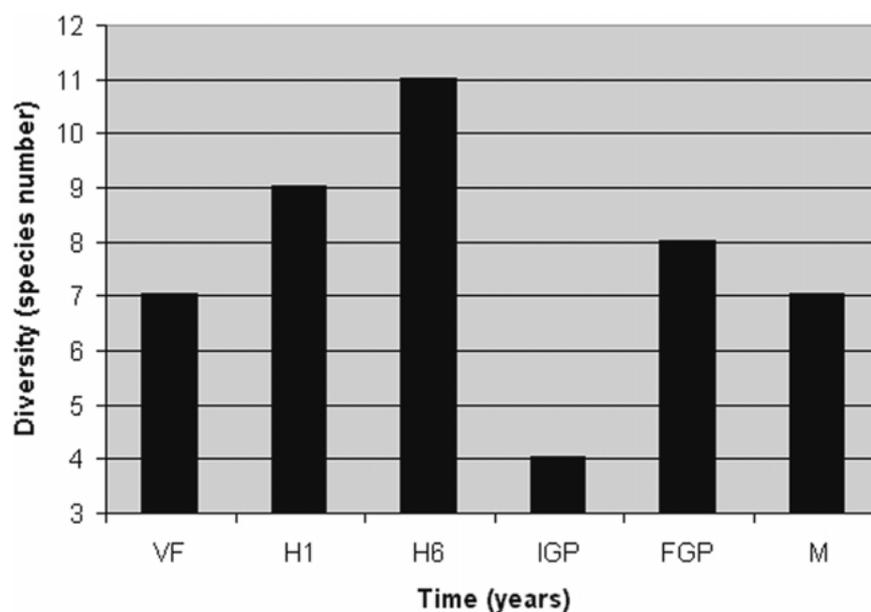


Figure 1. Total species number variation of birds along the *Nothofagus pumilio* forest management. VF = virgin forest, H1 = harvested stand one year ago, H6 = harvested stand six years ago, IGP = initial growth phase, FGP = final growth phase, M = mature stand.

One third of the sampled bird species had a great range distribution and were found in all the stands (Figure 3). There was only one species exclusive to the original forest (7%), two to the harvested stands (13%) and another one species to the secondary forests (13%). The other species are shared within the stands, mainly in the harvested stands and the secondary forests (33%). None of the species are

Table 2. Analysis of variance for the species and individuals number sampled (8 min recognition sample point) in each treatment along the *Nothofagus pumilio* forest management cycle.

Treatment	Species (n)	Individuals (n)
VF	2.00 ^{a,b,c}	3.81 ^{a,b}
H1	3.00 ^c	5.55 ^b
H6	2.58 ^{b,c}	8.50 ^c
IGP	0.83 ^a	1.33 ^a
FGP	2.60 ^{a,b,c}	4.40 ^{a,b}
M	1.8 ^{a,b}	4.00 ^{a,b}

F test (significance) = species: 5.705 (0.000); individuals: 6.933 (0.000).

Different letters means significant differences at $P < 0.05$.

VF = virgin forest; H1 = stand harvested one year ago; H6 = stand harvested six years ago; IGP = initial growth phase stand; FGP = final growth phase stand; M = mature phase stand.

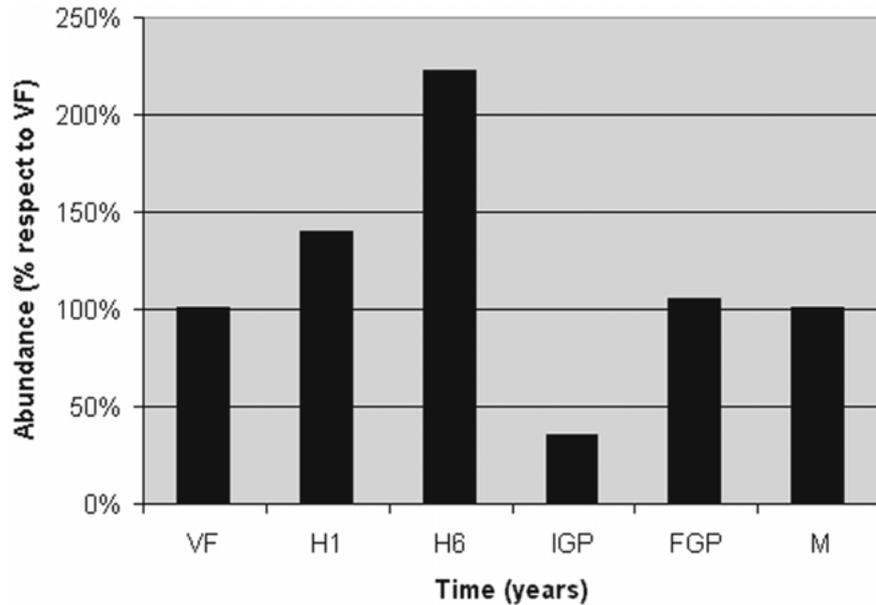


Figure 2. Relative total abundance variation of birds along the *Nothofagus pumilio* forest management. The bird number data were standardized and expressed as a percentage of the virgin forest sampled individuals. VF = virgin forest, H1 = harvested stand one year ago, H6 = harvested stand six years ago, IGP = initial growth phase, FGP = final growth phase, M = mature stand.

endemic of Tierra del Fuego, but four are endemic for Patagonia (*Apharstura spinicauda*, *Phrygilus patagonicus*, *Enicognathus ferrugineus* and *Campephilus magellanicus*). They live in a wide spectrum of environments well represented in several protected areas of Argentina and Chile throughout Patagonia region. The sampled

Table 3. Constancy – Dominance Index for the sampled species.

Species	Order	Constancy (%)	Dominance (%)
<i>Aphrastura spinicauda</i>	Passeriforms	100.0	44.9
<i>Zonotrichia capensis</i>	Passeriforms	100.0	21.9
<i>Elaenia albiceps</i>	Passeriforms	83.3	8.9
<i>Turdus falcklandii</i>	Passeriforms	83.3	3.8
<i>Troglodytes aedon</i>	Passeriforms	66.7	6.9
<i>Scytalopus magellanicus</i>	Passeriforms	66.7	1.8
<i>Phrygilus patagonicus</i>	Passeriforms	33.3	2.0
<i>Tachycineta leucopyga</i>	Passeriforms	16.7	0.5
<i>Carduelis barbata</i>	Passeriforms	16.7	0.5
<i>Milvago chimango</i>	Falconiforms	33.3	0.8
<i>Polyborus plancus</i>	Falconiforms	16.7	0.3
<i>Enicognathus ferrugineus</i>	Psittaciforms	66.7	6.4
<i>Campephilus magellanicus</i>	Piciforms	33.3	0.8
<i>Glaucidium nanum</i>	Strigiforms	16.7	0.3
<i>Theristicus caudatus</i>	Ardeiforms	16.7	0.3

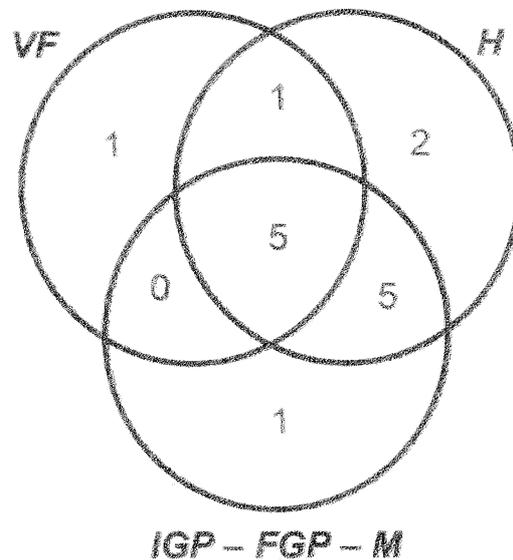


Figure 3. Number of bird species overlap among the sampled stands. VF = virgin forest, H = harvested stands, IGP = initial growth phase, FGP = final growth phase, M = mature stand.

bird diversity represents the number of species that can easily be found within the closed canopy *N. pumilio* forests, and could increase greatly in borders or near rivers (Schlatter 1995).

The main food resource is the great diversity and abundance of insect, which can be found in the *N. pumilio* forests. Most of the birds (87%) were mainly insectivores or occasional consumers, but only two species eat insects exclusively (*Campephilus magellanicus* and *Trachycineta leucopyga*). Twenty-seven percent of the species were pure carnivores, but they also used other food resources. The majority of the species take advantage of the supply of fruits, flowers, nectar and grains during the summer season (80% of the species are pure or occasional consumers of vegetal food). By the way, near half of the species are resident (54%) and stay in Tierra del Fuego during the winter in the forest environments. The other species are partial migrants, choosing more favorable environments (13%) during low temperatures or the food availability decreases; or are full migrants (33%) that come back to Tierra del Fuego during the breeding season (Table 4).

When a cluster analysis was done, considering the presence or absence of the species and the relative abundance of the sampled individuals, the following linkage was observed: (a) the final stages stands (FGP and M) were the most closely related, and were very similar to the virgin forest (VF) (b) the stand harvested one year ago (H1) and the initial growth phase stand (IGP) were related with the previous group; and finally (c) the stand least related with the other stands was the one harvested six years prior (H6) (Figure 4).

Table 4. Trophic role and migration type for the sampled species.

Species	Trophic level	Stay
<i>Aphrastura spinicauda</i>	Insectivore, Frugivore ^{*,c}	Resident
<i>Zonotrichia capensis</i>	Insectivore, Granivore, Frugivore, Herbivore	Migratory
<i>Elaenia albiceps</i>	Insectivore, Frugivore, Nectivore ^{*,d}	Migratory
<i>Turdus falcklandii</i>	Insectivore, Frugivore, Granivore, Herbivore ^{*,b}	Resident
<i>Troglodytes aedon</i>	Insectivore, Granivore ^{*,c}	Migratory
<i>Scytalopus magellanicus</i>	Insectivore, Frugivore, Granivore	Resident
<i>Phrygilus patagonicus</i>	Granivore, Frugivore, Insectivore, Herbivore ^{*,a,b} , Nectivore ^{*,f}	Partial migratory
<i>Tachycineta leucopyga</i>	Insectivore	Migratory
<i>Carduelis barbata</i>	Granivore, Herbivore, Insectivore ^{*,a}	Partial migratory
<i>Mitrago chimango</i>	Carnivore, Insectivore, Frugivore ^{*,c}	Resident
<i>Polyborus plancus</i>	Carnivore, Frugivore ^{*,c}	Resident
<i>Enicognathus ferrugineus</i>	Herbivore, Granivore, Frugivore	Resident
<i>Campephilus magellanicus</i>	Insectivore	Resident
<i>Glaucidium nanum</i>	Carnivore, Insectivore	Resident or Partial migratory ^c
<i>Theristicus caudatus</i>	Insectivore, Carnivore, Frugivore ^{*,c}	Migratory or Partial migratory

Based on ^a Humphrey et al. (1970); ^b Schlatter (1995); ^c Rozzi et al. (1997); ^d Smith Ramírez and Armesto (1998); ^e Clark (1986); ^f Traveset et al. (1998).

* Occasional = when a number follows the classification, the cited authors add another trophic level.

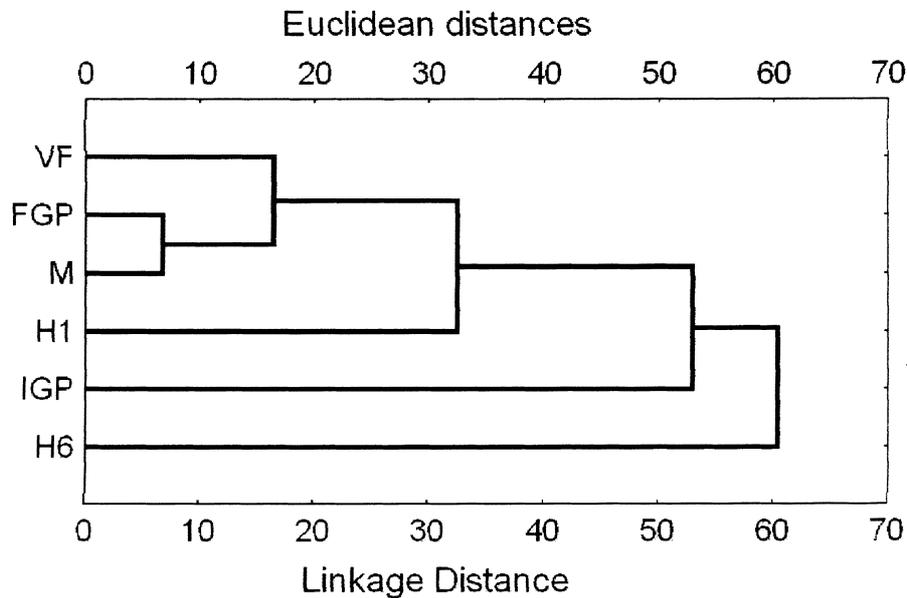


Figure 4. Cluster analysis using bird diversity presence and relative abundance of the species data with a complete linkage amalgamation rule and euclidean distance measure. VF = virgin forest, H1 = harvested stand one year ago, H6 = harvested stand six years ago, IGP = initial growth phase, FGP = final growth phase, M = mature stand.

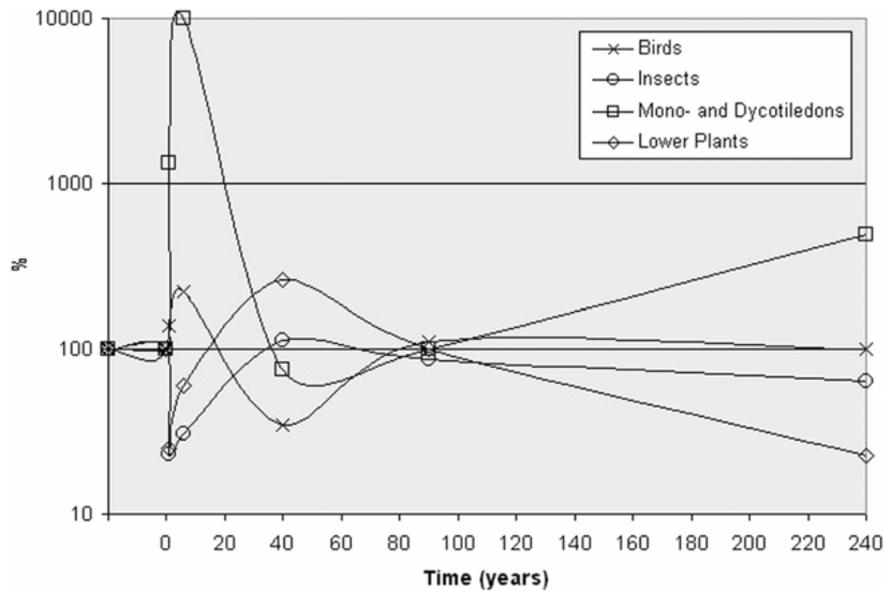


Figure 5. Comparison between relative biomass of Plants (lower plants, monocotyledons and dicotyledonous) (Fernández et al. 1998), and abundance of Insects (see the first part of this work) and birds along the *Nothofagus pumilio* forest management. The biomass and the abundance were expressed as a percentage of the virgin forest values.

Finally, the sampled stands were compared using the Shannon diversity index, which relates the proportional abundance of species. The lowest values were found in the initial growth phase stand (0.57), followed by the mature stand (0.77) and virgin forest (0.81). The highest value was found in the stand harvested six years prior (H6) with 1.26, while recently harvested stand (H1) and the final growth phase stand showed intermediate values (0.86 and 0.91, respectively).

Changes in abundance: A total of 389 birds were detected at the 72 sampling points. Passeriforms were the most abundant species (91%), followed by Psittaciforms and Falconiforms (Table 1). The abundance of birds for each phase along the forest management cycle presents greater variations (Figure 2). At the beginning of the silvicultural cycle (H1 and H6) the bird population was 222% greater than the VF. After that, the number of individuals decreased to a minimum in the IGP (35% compared to VF), and returned to the same level as VF at the final stage (M). The pattern of variation described was most notable in some Passeriforms species, such as *Zonotrichia capensis* populations, which increased 800% after the shelterwood cut. In addition, *Enicognathus ferrugineus* and some Falconiforms were not observed in forests with closed structure and high crown cover (IGP and FGP) but they were present at open stages (Table 1). Analysis of variance (Table 2) showed that birds were less abundant in VF (3.8 birds per point) than in H6 (8.5 birds per point), fact also displayed in the previous population pattern.

As described for diversity, the bird abundance was mainly represented by carnivores (insectivore species) followed by a lesser number of omnivores, herbivores, predators and carrion species (Table 4). This species balance is expected to be found in ecosystems with low vertebrate diversity, such as in *N. pumilio* forests.

Discussion

Analysis of the sampling method

The most common techniques in bird census are: (1) the mapping of territories based on determining the territorial boundaries (2) transects and (3) sampling with point counts (Jiménez 2000). This last method provides several advantages and was chosen for sampling, because it is the most efficient for censusing birds in structurally complex habitats such as forests (Reynolds et al. 1980).

Jiménez (2000) found that the bird diversity did not change significantly beyond a radius of 50 m, or a time observation more than 6 min. In preliminary assays, this study reached similar results, sampling a radius of 50 m for 8 min observation period at the point counts plots. This radius plot and time counting are in agreement with those reported by Rozzi et al. (1997) and Schlatter (1995).

Rozzi et al. (1997) recommend 6–10 point counts per site in order to capture a representative bird sample, as was cited by Willson et al. (1994) and Morrison et al. (1981), according to the stand conditions. In the present study 6 plots in the IGP stand, 10 in the FGP and M stands, 12 in the H6 stand, 16 in the VF and 18 in the H1 stand were used. However, Reynolds et al. (1980) and Jiménez (2000) also highlighted the sensitivity for detecting rare species, which needed large number of point counts. In this study, the number of plots was defined according the area of each stand. By the way, after the analysis of the relative abundance, the data were standardized.

Bird diversity changes during the forest management cycle

Many studies have been made on the influence of logging and forest management on bird communities, but many few are on austral temperate forests as this one. The results presented here are consistent with those reported by Schlatter (1995), where the Passeriforms order and the carnivorous species (mainly insectivorous) were the most important groups of Tierra del Fuego forests in Chile. Schlatter (1995) also identified more species in harvested forests (29 species) than in un-logged *N. pumilio* forest (25 species), with less species number in second growth (IGP) compared with the original forests. Jiménez (2000) cited 24 species in close *Nothofagus* evergreen

forest of Chile, where the bird diversity was greater than in the southern broadleaved *Nothofagus* forests.

In this study, there was no significant loss in the specific bird diversity of the *N. pumilio* forest managed by a shelterwood cut system, but the species were not the same at the end of the cycle (stand of 230 years old) compared with the original forest. Tierra del Fuego forests have low bird diversity (Schlatter 1995). However, there are no highly specialized species in microenvironments of the virgin forest, as cited by Arroyo et al. (1996) and consequently they are able to colonize new environments generated by the forest management. By the way, new species were detected in the harvested stands, which usually occur in other environments, such as forest borders, river margins, open areas, bogs or *N. antarctica* forests. Therefore, they can colonize logged areas, when a favorable change in the environmental or nutritional conditions occurs. Schlatter (1995) identified 13 new species in harvested stands, which were not identified in un-cut *N. pumilio* forests. In an unevenly aged forest of *Fagus grandifolia*, *Acer saccharum* and *Betula alleghaniensis* (New Hampshire, USA), changes in the horizontal and vertical structure (due to wind-throws or harvesting) caused increases in the bird diversity by improving the environmental conditions or food availability (Holmes 1990). The same changes were observed in *Nothofagus* forests in New Zealand (Wardle 1984) around openings in the canopy, due to natural tree fall or human activity (harvesting, road construction or silvicultural practices). Spurr (1987) reported a loss of native species and an increase in exotic bird species after the harvesting of a pure *Nothofagus menziesii* forest (Rowallan, New Zealand).

Even aged forest structures in initial growth phase of evergreen *Nothofagus* (Chile) have lower diversity than primary forest structures (Rozzi et al. 1997). These diversity losses are due to nesting requirements, as for *Campephilus magellanicus* or *Glaucidium nanum* (Willson et al. 1994), or for food specialization and the need of an open canopy for hunting (Rozzi et al. 1997). Arroyo et al. (1996) cited six species of *N. pumilio* forests in Tierra del Fuego as sensitive to harvesting. Two of these species was found in this study (*Campephilus magellanicus* and *Scytalopus magellanicus*). The first of these species has special requirements for food and nesting, which are abundant in the primary forests, but the second one was not found in our old growth forests, suggesting a preference for open or closed areas with high humidity or near little streams under the forest canopy.

The observed changes in bird abundance were cited for many forests. Lilieholm et al. (1993) found a smaller bird population in closed forests of *Pseudotsuga menziesii*, than in managed stands or harvested forests. The same behavior was observed in a *Nothofagus menziesii* forest (Rowallan, New Zealand) where bird abundance fell significantly due to the loss of the nesting habitat in second growth stands (Spurr 1987). However variations in bird abundance were observed in a *Dacrydium cupressinum* forest over the forest cycle, mainly due to changes in food on offer and loss of environment (Spurr et al. 1992).

Trophic relationships and use of environments by birds related to understory biomass and insect abundance over the forest management cycle

There were correlations between bird abundance and the pattern of variation in the understory biomass reported by Fernández et al. (1998) (lower plants, monocotyledons and dicotyledonous). Insect abundance and variations in environmental conditions were also correlated with bird abundance. Bird abundance was directly related to the Gramineae species and dicotyledonous biomass of the understory (Figure 4). When the forests were open (H1 and H6), a great variety of plants and biomass were recorded (1074 kg dry weight/ha of biomass compared with 11 kg/ha in virgin forest) (Fernández et al. 1998). This represented a substantial food resource for granivore and herbivore bird species during flowering, fruiting and grain production (Smith Ramírez and Armesto 1998; Holmes 1990; Schlatter 1995). This was reflected in the increase in use of the forest environment by the Passeriforms species. However, when the forest closed again (IGP) and the number of plants in the understory falls (8 kg/ha) (Fernández et al. 1998), the number of birds also declined. Similarly, the understory of *Nothofagus* forests of New Zealand provides a high percentage of food supply, because the trees are a poor food resource. When the ecological conditions favor the development of the understory, it could permit an increase in the diversity and abundance of birds (Wardle 1984).

Insect abundance and variations in environmental conditions were also correlated with bird abundance. Insect abundance (mainly Dipterons) followed a pattern of variation related to the lower plant biomass, and it is inversely proportional to the bird abundance. The maximum bird abundance (139–222% compared with the VF) was when the forests were open (H1 and H6) which also coincided with a minimum insect abundance (23–31% compared with the VF) and lower plant biomass (25–60% compared to the VF). In New Zealand forests, insects are the principal food supply for birds (21 of the 24 species are insectivores, 9 of them exclusively dependent on insects) (Wardle 1984). However, changes in the environmental conditions (air and floor humidity, temperature and brightness), and the forest structure and the wood debris on the forest floor, have a bearing on bird preference for these habitats (Holmes 1990). For example, *Enicognathus ferrugineus* prefer open forests, as do the Falconiforms species, which need space to hunt their prey. *Glaucidium nanum*, species is nocturnal and utilizes the closed forests for protection during the day. *Troglodytes aedon* lives on the forest floor, and demonstrates a preference for post-harvesting environments (high percentage of wood debris and branches over the floor) which simulates a high density shrub understory, as described by Belles Isles and Picman (1986) in Ontario, Canada.

Another factor that affects the variation in the bird abundance that was not possible to quantify in this study is the trophic relationships with mammal predators (*Pseudalopex culpaeus*, *P. griseus* or *Mustela vison*) and competing mammals (*Akodon* sp., *Euneomys* sp. and *Oligoryzomys* sp.). A combination of the described factors and

the relationships between them, explain the presence and abundance of sampled bird species in measurement sites.

Forest management impact over forest bird diversity and mitigation alternatives

The silvicultural management proposed for *N. pumilio* in Tierra del Fuego affected the horizontal and vertical structure of the forest system, as well as the principal food components utilized by birds. The silvicultural systems aimed to create regular stands and maintain a productive system in early growth stages (30–40 cm of *DBH* in IGP–FGP stages of development) (Schmidt and Urzúa 1982). The second growth forests, formed after the harvesting of virgin forest, generated adverse conditions for the maintenance of diversity and abundance of the majority of bird species of Tierra del Fuego (especially for birds that need space to fly or hunt). This could be mitigated with silvicultural practices such as thinning, which open the canopy enough, to allow the development of the understory. This would offer better ecological conditions for those species that need more space to live (Liliehalm et al. 1993).

However, to define forest management and conservation strategies, first it is necessary to:

- (1) determine the auto ecology of the birds species of the forest;
- (2) determine the species most vulnerable to forest management practices;
- (3) determine the relationship of such species with the environment;
- (4) define the minimal area for the support of an stable population of such species, and the response to the habitat fragmentation;
- (5) modify silvicultural practices to reach an equilibrium between economical and conservation parameters;
- (6) validate the effectiveness and the practicality of new methodologies, and
- (7) make the new alternatives of forest management available to the productive sector (mainly sawmills and farmers).

A silviculture method that proposes dispersed or aggregated retention areas (Franklin and Forman 1987; Franklin 1993; North et al. 1996; Franklin et al. 1997) could maintain bird abundance and diversity. Another important point is the importance of the hollow-bearing trees (Gibbons and Linder Mayer 1996; Pattanavibool and Edge 1996; Rozzi et al. 1997) and the habitat fragmentation (Cornelius et al. 2000). There is no information in Tierra del Fuego for species associated with the needing hollows for nesting and the effect of stocking, or dynamic hollow production over rotation length, nor for habitat fragmentation in *N. pumilio* forests. This would be a good point to begin research to finally define forest management and the proposed conservation strategies (a good summary of issues to take into account could be found in Gibbons and Linder Mayer 1996).

The management of native forest in New Zealand, design for sustained wood production, seems to be incompatible with the maintenance of the biodiversity and abundance of birds (Spurr 1987). Although, this did not occur in the sampling scale carried

out in this study, it could happen when considering a major number of species in a wider zone (regional sampling). The planning of a silvicultural system that can be adapted to the affected species ecology (Rozzi et al. 1997) and the preservation of certain marginal environments (*N. antarctica* forests, humid zones, forest borders and river banks) could mitigate the changes in biodiversity and abundance of species within the managed *N. pumilio* forests.

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