

## Richness and density of birds in timber *Nothofagus pumilio* forests and their unproductive associated environments

MARÍA VANESSA LENCINAS<sup>1,\*</sup>, GUILLERMO MARTÍNEZ  
PASTUR<sup>1</sup>, MARLIN MEDINA<sup>2</sup> and CARLOS BUSSO<sup>3,4</sup>

<sup>1</sup>Centro Austral de Investigaciones Científicas (CONICET), CADIC, cc 92 (9410) Ushuaia, Tierra del Fuego, Argentina; <sup>2</sup>Universidad Nacional del Litoral; <sup>3</sup>Centro de Recursos Naturales Renovables de la Zona Semiárida (CONICET); <sup>4</sup>Departamento de Agronomía - Universidad Nacional del Sur, Argentina; \*Author for correspondence (e-mail: cadicforestal@arnet.com.ar)

Received 16 July 2003; accepted in revised form 30 March 2004

**Key words:** Bird sampling, Conservation, Forest management, Patagonia, Sustainability, Tierra del Fuego

**Abstract.** Research on forest management impact focuses mainly on timber stands, and leaves out the unproductive forest environments. These stands are spatially mixed with timber forests. The objective was to evaluate richness and density of birds in timber *Nothofagus pumilio* forests and their unproductive associated environments, and discuss forest management implications. These stands showed significant differences in their forest structure, which generate a great variety of ecological environments. A total of 1881 individuals belonging to 30 bird species were observed during the sampling, in spring and summer seasons. These species were mainly migratory and insectivores, Passeriforms being the most important group. From 12 to 17 birds/ha were found, which varied with the forest environments and seasons. Timber stands of *Nothofagus pumilio* support a low number of bird species. Most of them are opportunistic and a few prefer these woods over other forested or afforested areas. Low bird density and richness characterize these austral forests, which share their diversity with a high variety of ecosystems along Patagonia. Timber *N. pumilio* forests has a marginal value for bird species conservation, considering its richness, density and the percentage of this forest in the total forested landscape of Tierra del Fuego (Argentina).

### Introduction

*Nothofagus pumilio* (Poepp. et Endl.) Krasser (commonly named 'lenga') forests rarely constitute big, continuous huge masses. Usually, the landscape is formed by a mosaic of several forest types, where timber and unproductive forests are mixed. These associated unproductive environments are conformed by forests with low site quality index (Martínez Pastur et al. 1997) due to soil impediments, excess of water or wind exposure. Other unproductive environments are constituted by *N. antarctica* (Forster f.) Oersted (commonly named 'ñire') forests, and may alternate with rangelands and peat-lands. Most of the studies analyzing the forest management impact over timber stands, centered their analysis on a single or group species (Lanfranco 1977; Niemela 1990; Schlatter 1995; Arroyo et al. 1996). These studies did not consider the

unproductive environments, or the interactions between biotic and abiotic components of the forest environment (Deferrari et al. 2001).

Forest structure of old growth stands has been significantly modified through the application of silvicultural treatments, i.e. regeneration cuts and thinning prescriptions (Martínez Pastur et al. 2000, 2002a). The modifications in forest structure have produced a significant impact over the understory, insect and bird communities (Deferrari et al. 2001; Spagarino et al. 2001; Martínez Pastur et al. 2002b). These changes in population structure or losses of species due to forest management are supposed to be analyzed not only at the productive stand but also at the ecosystem level. From this point of view, species with little habitat specialization lose relevance, while those that only occur in a timber stand acquire greater ecological and conservational importance. For these reasons, the aims of this work were to evaluate bird richness and density in timber *N. pumilio* forests and their unproductive associated environments in Tierra del Fuego (Argentina), and to discuss implications of the implemented forest management.

## Materials and methods

### *Location of the study area and sampling of the stands*

A *Nothofagus* forest of the central zone of the Grande islands of Tierra del Fuego was selected. It was located in the Ushuaia ranch (54°27'32"S, 67°30'16"W), 10 km north to Fagnano Lake and 5 km east to Yehuin Lake (Figure 1). This place is characterized by short, cold summers and long winters with snow and frost. Climate belongs to the Southern anti-boreal zone defined by Tuhkanen (1992) and could be included into the domain of sub-polar in the southern hemisphere (Burgos 1985). Mean monthly temperatures vary from about -7 to 14 °C (extremes vary from -17 °C in July to 22 °C in January). There are three months with mean temperatures under 0 °C, a growing season of about five months and precipitation near 400 mm/year. The average wind speed is 8 km/h, reaching up to 100 km/h during storms.

An area of 1000 ha was chosen within the property of the ranch (20% of the total area). Previous forest management history was known. Intensive cattle grazing have not been carried out since the last 10 years, but a natural browsing pressure of *Lama guanicoe* Müller exists (Pulido et al. 2000). The forests were classified according to the tree communities or environmental characteristics that could influence on bird populations. These classifications were made by fieldwork identification, and analysis of aerial photos (*Instituto Geográfico Militar*, February 1989, 1:20,600) or satellite images (SPOT, February 1995). Six forest environment types were determined, that included two timber productive *N. pumilio* forests, one in the plain ground (LF) and one in a middle altitude of a southern hillside (slope of 25°) (MHLF); and four associated unproductive forest environments, an edge between *N. pumilio*

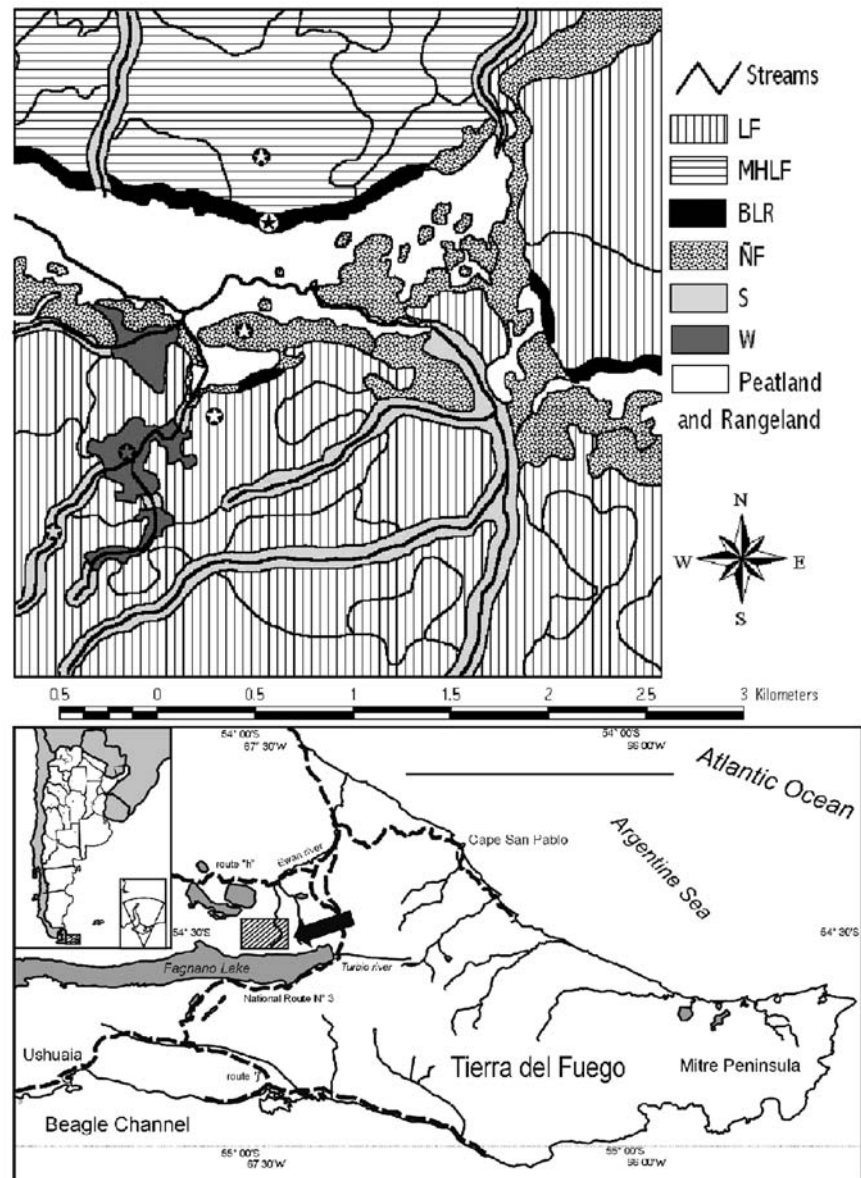


Figure 1. Location of the study area, environments stand classification and treatment location within the study area (star points). LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio*–*N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests.

forest and rangeland (BLR), *N. antarctica* forest (ÑF), *N. pumilio*–*N. antarctica* forest wetland (W) and riparian environments inside of *N. pumilio* forests (S). A timber forest was that which had: (a) at least a site quality V (Martínez Pastur et al. 1997); (b) no timber restrictions established in the forest provincial law no. 145; and (c) commercial volumes up to 40 m<sup>3</sup>/ha (healthy logs up to 30 cm diameter and 3 m long). The remaining forests which constitute the landscape, and where timber activities have not been carried out, were considered in this work as associated unproductive forest environments: ÑF is conformed exclusively by non timber species, W has flooding floors which excludes traffic of heavy machines, and BLR and S have special protection functions against wind and water erosion. All identified stand types were incorporated into a geographic information system. Six zones composed by group of stands representing the described forest environments were selected along a north–south topographic gradient (Figure 1). These stands possessed a good conservation status and had an easy field access.

#### *Forest structure and understory characterization*

Each group of stands was characterized through ten forest plots on two 100 m transects, which were 50 m apart one from another and perpendicular to the slope. Within each forest plot, trees were sampled by the ‘angle count sampling’ method (BAF 8) (Bitterlich 1984). Basal area, DBH (diameter at breast height), number of trees and total volume (Martínez Pastur et al. 2002a) were obtained. In addition, dominant height (average of the three dominant trees closer to the sampling point) was measured, and site quality was defined following Martínez Pastur et al. (1997) for *N. pumilio* and Lencinas et al. (2002) for *N. antarctica*. Crown cover was estimated using a spherical densiometer (Lemmon 1957). Forest floor cover (understory, woody debris and litter floor) was registered by a grid of 100 points/m<sup>2</sup> in every sampling plot. Main components of the understory were classified to characterize each environment. Finally, a herbarium was made with the collected plant material, following the taxonomy classification proposed by Moore (1983).

#### *Bird sampling methodology*

Data were collected by the point sampling method (Blondel et al. 1981) in each treatment in spring (November 1998) and summer (March 1999) during morning and afternoon hours. Daily observations during the winter allowed determination of resident bird species (July 1999). In the morning, samples were taken during a 4-h period following sunrise, and in the afternoon were taken in a 2-h period before sunset (Hagar et al. 1996; Peris 1997; Douglas Robinson et al. 2000). Sampling was carried out under similar climatic conditions, and days with fog, strong winds or rain were discarded (Venegas 2000).

Five sampling plots were established in different stands of each forest type. These were at least 100 m apart, and were visited in different days until sampling was finished. Each sampling plot was visited 14 times (two seasons, 25 times in the morning and 10 times in the afternoon) reaching a total number of counts of 420. A 10-min observation period was used in each count. It consisted of a 2-min period of accustomization (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). A short accustomization period of 2 min was chosen because the forest birds are not evasive. Sampling used a direct (*sight*, by binoculars) recognition method, without limit in the observation range. Jointly, a list of observed species while working in the field was registered, to try to establish the whole assemblage of species, including rare or infrequent ones. The taxonomy, number of individuals and observation distance (m) were recorded at each count. Distance was measured using an IMPULSE laser rangefinder and taxonomy of the birds follows Narosky and Yzurieta (1987).

#### *Bird density and richness estimation*

A new method to estimate density and richness is proposed. Previous sampling methods in Tierra del Fuego forests have used plots with a fixed observation range of 50 m (Schlatter 1995; Deferrari et al. 2001). These samplings only recorded birds found within the plot boundaries, while those that were observed outside the plot were ignored. This methodology has the following weaknesses: (a) the small size and behavior of some birds significantly reduces the detection probability at a distance of 50 m, while others of great size usually could be observed at larger distances; (b) the method did not consider forest structure, which can underestimate density and richness in closed stands; and (c) the rigidity of the sampling avoid its adaptation to different forest types. The analysis was carried out individually for each environment. Within each treatment the maximum observation distance was divided in two portions. Half of the maximum observation distance of each treatment represented the radius of an internal circle (inner circle), which was utilized for bird density estimations. Maximum observation distance represented the radius of an external circle (outer circle) and data recorded were used for richness estimation. Thereafter, all bird observations were included in the analysis.

#### *Data analysis*

Comparisons of treatments were carried out by non-parametric Kruskal–Wallis test, and means were separated using confidence intervals for the median test ( $p < 0.05$ ). Homogeneity of the sighting numbers of each species between seasons, observation times and treatments were analyzed through frequencies

and abundances compared by a  $\chi^2$  test ( $p < 0.05$ ). Different stands were clustered using a complete linkage amalgamation rule and euclidean distance measurement based on a matrix of bird species occurrence along the studied treatments. A relationship between treatments was done through this analysis, and groups were defined according to their similarity. After that, a DCA (Detrended Correspondence Analysis) was carried out with bird richness and abundance data, without weighting for rare species. Through this analysis the sampling units and species ordination are obtained simultaneously allow to examine the ecological interrelationships between them in a single analysis (Ludwig and Reynolds 1988).

## Results

### *Ecological characterization of the stands*

The sampled stands showed significant differences in the forest structure (Table 1), which differ mainly in the dominant forest species and stand height. Timber *N. pumilio* stands (LF and MHLF) are characterized by large trees (up to 23 m height), with a closed canopy (up to 96%), high accumulation tree volume (600–700 m<sup>3</sup>/ha), a great proportion of bare floor (50–70%) and a poor understory cover (11–25%). These stands represent 64% of the study area (71% of this percentage corresponds to LF and 29% to MHLF) (Figure 1). Understory is sparse and homogeneous distributed, increasing their richness and density in presence of a forest canopy gap. In all the stands *Osmorhiza*

Table 1. Forest structure, crown closure and floor cover in timber *Nothofagus pumilio* forests and its unproductive associated stands.

Stands	Sp	DH (m)	SI (1–5)	DBH (cm)	BA (m <sup>2</sup> /ha)	TOBV (m <sup>3</sup> /ha)	CC (%)	UC (%)	BFC (%)	DC (%)
Kruskal–Wallis statistic:		42.531 (0.000)	38.397 (0.000)	6.362 (0.272)	2.486 (0.778)	17.132 (0.004)	42.775 (0.000)	43.222 (0.000)	28.225 (0.000)	12.232 (0.031)
LF	L	24.2bc	2.6bc	36.5a	56.4a	682.0c	95.7b	24.7bc	50.9a	24.4a
MHLF	L	22.7b	2.9c	49.5a	49.2a	584.8bc	98.0c	11.2a	71.1c	17.7a
BLR	L	27.2c	1.7ab	41.5a	43.2a	543.1b	95.1bc	15.4ab	66.5bc	18.2a
ÑF	Ñ	13.5a	1.4a	40.0a	48.0a	335.7a	92.1ab	30.4c	54.3ab	15.3a
W	L-Ñ	17.6a	4.25d	38.5a	45.4a	364.1ab	76.7a	41.9c	44.2a	13.9a
S	L	21.4b	3.1bc	46.6a	53.1a	573.2bc	90.7ab	36.0c	48.8a	15.2a

Variables. Sp – forest species, DH – dominant height, SI – site index, DBH – diameter at breast height, BA – basal area, TOBV – total over bark volume, CC – crown cover, UC – understory cover, BFC – bare floor cover, DC – debris cover, L – *N. pumilio*, Ñ – *N. antarctica*. Stands. LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio* – *N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests. Values in parentheses represent significance levels. Different letters within columns represent significant differences at  $p < 0.05$  by confidence interval for the medians.

*depauperata* Phil. and *Cardamine glacialis* (Forster f.) DC. appear as the most frequented species. In timber stand other dominant species were: *Galium aparine* L., *Dysopsis glechomoides* (A. Richard) Müller Arg. and *Viola magellanica* Forster f. Average biomass of the understory was 15.2 ton/ha. The *N. antarctica* forests (ÑF) are characterized by lesser height than lenga forests (13.5 m). This site represents the best quality according to the classification proposed by Lencinas et al. (2002). Ñire stand represented 11% of the study area. The proportion of understory cover (30%) was higher than that in lenga forests. Other main species were *Festuca magellanica* Lam., *G. aparine* and *Schizeilema ranunculus* (D'Urv) Domin. Understory biomass was 23 ton/ha. Edge environments (BLR) had very similar forest structure and understory than lenga timber stands, but they represented a little percentage of the total lenga forest (2% of the study area). It had some rangeland species (i.e. *Chilolotrichum diffusum* (Forster f.) O. Kuntze or *Ranunculus peduncularis* Sm.), *Acaena magellanica* (Lam.) Vahl and *Taraxacum officinale* Weber. Total biomass was of 15.5 ton/ha. Stands at the riparian borders (S) presented a similar forest structure and understory than timber forests, but they allowed regeneration of other high variety plant species. This environment occupied 8% of the study area. It was easy to find species such as *A. magellanica*, *V. magellanica*, *Blechnum penna-marina* (Poiret) Kuhn and *Cerastium fontanum* Baumg. The high water availability allowed a 36% higher understory biomass (32.5 ton/ha) than timber forests. In the forest wetland (W), *N. pumilio* and *N. antarctica* coexist and grew in a soil completely saturated of water. This environment represents 2% of the study area, which alternates with beaver (*Castor canadensis* Kuhl) dams. High water availability allowed the development of a high variety of understory species which showed up to 40% cover. Main species were *Senecio smithii* DC., *A. magellanica*, *S. ranunculus*, *C. glacialis* and *C. fontanum*. The biomass in this environment (75.4 ton/ha) was five times greater than that in the timber forests. In the study area, open places were scarce (13%). These were conformed by rangelands and peat lands (93 and 7% of the open areas, respectively). *Hordeum comosum* C. Presl, *Phleum alpinum* L., *Agrostis uliginosa* Phil., *Bolax gummifera* (Lam.) Sprengel, *Ch. diffusum* and *A. magellanica* were major rangeland species. Peat lands were dominated by *Sphagnum magellanicum* Brid., with an important presence of *Marsippospermum grandiflorum* (L. f.) Hooker f., *Empetrum rubrum* Vahl ex Willd. and *Pernettya pumila* (L. f.) Hooker.

#### *Bird sampling methodology*

A total of 1881 individuals belonging to 30 different species were observed (Tables 2 and 3). No increment in species number was obtained when sampling effort exceeded 20 plots, except for W treatment (Figure 2). However, six bird species were not observed during sampling, and only could be detected outside of the observation periods. These species live in the forest with a low frequency,

Table 2. Taxonomy, trophic level, migration type and code names for the observed bird species in the study area.

Species	Order	Trophic level	Migration type	Code
<i>Aphrastura spinicauda</i> Gmelin	Passeriforms	I, F <sup>(3)</sup>	R	APSP
<i>Zonotrichia capensis</i> Statius Müller	Passeriforms	I, G, F, H	M	ZOCA
<i>Elaenia albiceps</i> Hellmayr.	Passeriforms	I, F, N <sup>(4)</sup>	M	ELAL
<i>Turdus falcklandii</i> King.	Passeriforms	I, F, G, H <sup>(2)</sup>	R	TUFA
<i>Troglodytes aedon</i> Vieillot	Passeriforms	I, G <sup>(3)</sup>	M	TRAE
<i>Scytalopus magellanicus</i> Gmelin	Passeriforms	I, F, G	R	SCMA
<i>Phrygilus patagonicus</i> Lowe	Passeriforms	G, F, I, H <sup>(1,2)</sup> , N <sup>(6)</sup>	P	PHPA
<i>Tachycineta leucopyga</i> Cabanis	Passeriforms	I	M	TALE
<i>Carduelis barbata</i> Molina	Passeriforms	G, H, I <sup>(1)</sup>	P	CABA
<i>Pygarrhichas albogularis</i> King.	Passeriforms	I	R	PYAL
<i>Cinclodes patagonicus</i> Gmelin	Passeriforms	I, C <sup>(3)</sup>	P, R*	CIPA
<i>Muscisaxicola macloviana</i> Garnot	Passeriforms	I	M	MUMA
<i>Lessonia rufa</i> Gmelin	Passeriforms	I	M	LERU
<i>Anairetes parulus</i> Kittlitz	Passeriforms	I	M	ANPA
<i>Curaeus curaeus</i> Molina	Passeriforms	I, G	P, R*	CUCU
<i>Xolmis pyrope</i> Kittlitz	Passeriforms	I	M	XOPY
<i>Enicognathus ferrugineus</i> Müller	Psittaciforms	H, G, F	R	ENFE
<i>Campophilus magellanicus</i> King.	Piciforms	I	R	CAMA
<i>Theristicus caudatus</i> Boddaert	Ardeiforms	I, C, F <sup>(3)</sup>	M, P*	THCA
<i>Anas flavirostris</i> Vieillot	Anseriforms	H	M	ANFL
<i>Chloephaga poliocephala</i> Sclater PL.	Anseriforms	H, G	M, P*	CHPO
<i>Chloephaga picta</i> Gmelin	Anseriforms	H, G	M, P*	CHPI
<i>Gallinago gallinago</i> L.	Charadriiforms	H, G, I	M	GAGA
<i>Vanellus chilensis</i> Molina	Charadriiforms	I	M	VACH
<i>Milvago chimango</i> Vieillot	Falconiforms	C, Ca, I, F <sup>(3)</sup> , E <sup>(7)</sup>	P, R*	MICH
<i>Polyborus plancus</i> Miller	Falconiforms	Ca, C, F <sup>(3)</sup> , E <sup>(7)</sup>	R, P*	POPL
<i>Falco sparverius</i> L.	Falconiforms	C	M	FASP
<i>Buteo polyosoma</i> Quoy & Gaimard	Falconiforms	C	M	BUPO
<i>Accipiter bicolor</i> Vieillot	Falconiforms	C	M	ACBI
<i>Glaucidium nanum</i> King.	Strigiforms	C, I	R, P(3)	GLNA

Trophic level: (I) – insectivore; (F) – frugivore; (G) – granivore; (H) – herbivore; (N) – nectivore; (C) – carnivore; (Ca) – carrionaire; (E) – egg-nestling. Migration type: (R) – resident; (M) – migratory; (P) – partial migratory. Based on (1) Humphrey et al. (1970); (2) Schlatter (1995); (3) Rozzi et al. (1997); (4) Smith Ramirez and Armesto (1998); (5) Clark (1986); (6) Traveset et al. (1998); (7) Donázar et al. (1996). \*Occasional. When a number follows the classification, the cited authors add another trophic level.

as *Buteo polyosoma* and *Accipiter bicolor*, utilize the edge forest as an observation position (*Falco sparverius*), look for refuge after falling the night (*Theristicus caudatus*), nest in the forest occasionally (*Chloephaga picta*) or use the forest mainly in other seasons (*Curaeus curaeus*). The accustoming and observation periods were adequate, since all species observed during accustoming were also detected during the sampling period. The maximum average observation distance was not greater than 35 m (*Enicognathus ferrugineus*), while another species is not observed beyond 6 m (*Scytalopus magellanicus*) (Figure 3).



Table 3. Number or presence of bird species in timber *Nothofagus pumilio* forests and its unproductive associated environments.

Species	Environment													
	LF		MHLF		BLR		ÑF		W		S		Others	
	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su	Sp	Su
MICH	2(0)	P(P)	5(1)	–	2(1)	P(P)	2(P)	P(P)	2(1)	–	–	–	P	P
POPL	–	P(P)	–	–	–	P(P)	P(P)	P(P)	0(2)	4(0)	–	–	P	P
FASP	–	–	–	–	–	P(P)	–	P(P)	–	–	–	–	P	P
ACBI	–	P(P)	–	–	–	–	–	–	–	–	–	–	–	–
BUPO	–	P(P)	–	P(P)	–	–	–	–	–	–	–	–	–	–
GLNA	–	–	–	–	1(0)	–	–	–	–	–	–	–	–	–
CABA	33(1)	1(0)	21(9)	13(0)	74(5)	134(0)	28(2)	–	34(6)	70(14)	7(7)	13(0)	–	–
ZOCA	9(5)	–	16(2)	–	18(2)	–	19(7)	P(P)	51(4)	P(P)	23(5)	–	–	–
APSP	23(7)	77(21)	7(4)	71(15)	8(12)	86(44)	23(3)	44(24)	18(4)	41(28)	24(6)	75(9)	–	–
TRAE	28(2)	–	12(4)	0(2)	2(0)	–	12(2)	–	28(1)	2(0)	24(7)	–	–	–
ELAL	30(9)	–	8(7)	P(P)	16(1)	–	23(3)	–	15(0)	–	21(1)	–	–	–
TUFA	3(2)	9(0)	10(2)	2(0)	16(0)	3(2)	6(5)	0(3)	1(0)	–	3(2)	2(0)	–	–
TALE	2(0)	–	1(0)	–	4(0)	–	1(0)	P(P)	3(2)	–	1(5)	–	P	–
PHPA	0(1)	–	3(0)	–	2(0)	8(0)	0(1)	2(3)	9(1)	–	2(1)	–	P	–
PYAL	4(0)	4(3)	0(2)	8(0)	4(0)	9(4)	0(3)	–	1(0)	P(P)	–	5(0)	–	–
CIPA	–	–	–	–	–	–	–	–	5(2)	0(1)	P(P)	P(P)	P	P
SCMA	–	–	–	–	–	–	–	–	3(0)	4(0)	–	1(0)	–	–
MUMA	–	–	–	–	–	–	–	–	–	–	–	–	–	P
LERU	–	–	–	–	–	–	–	–	–	–	–	–	–	P
ANPA	–	–	–	–	–	2(0)	P(P)	2(9)	–	5(0)	–	1(0)	–	–
CUCU	–	–	–	–	–	–	P(P)	P(P)	–	–	–	–	–	–
XOPY	–	–	–	–	–	–	–	–	–	–	–	–	–	P
GAGA	–	–	–	–	–	–	–	–	–	–	–	–	–	P
VACH	–	–	–	–	–	–	–	–	–	–	–	–	–	P
CAMA	–	4(1)	–	–	–	–	1(0)	P(P)	–	–	–	–	–	–
ENFE	2(0)	P(P)	5(0)	P(P)	2(2)	8(0)	0(3)	P(P)	3(0)	4(0)	3(0)	6(0)	–	P
ANFL	–	–	–	–	–	–	–	–	0(2)	3(0)	3(2)	2(0)	P	P
CHPO	–	–	–	–	–	–	–	–	0(1)	–	1(0)	–	P	–
CHPI	–	–	–	–	–	–	–	–	P(P)	–	–	–	P	–
THCA	–	–	–	–	–	–	P(P)	–	–	–	–	–	P	P

Sp – spring 1999, Su – summer 2000. P – species presence detection. LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio* – *N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests, Others – rangelands and peatlands. Within each column, morning determination is to the left while afternoon counting is in parentheses to the right.

Changes in bird activity were detected on an hourly base when a homogeneity test was done. To do this, sampling frequencies of morning and afternoon were compared for all species along seasons and forest environments. Bird activity significantly ( $p < 0.001$ ) differed between morning and afternoon hours, except for summer frequencies in S treatment ( $p < 0.04$ ). Bird observation was different along seasons and studied environments, since frequencies

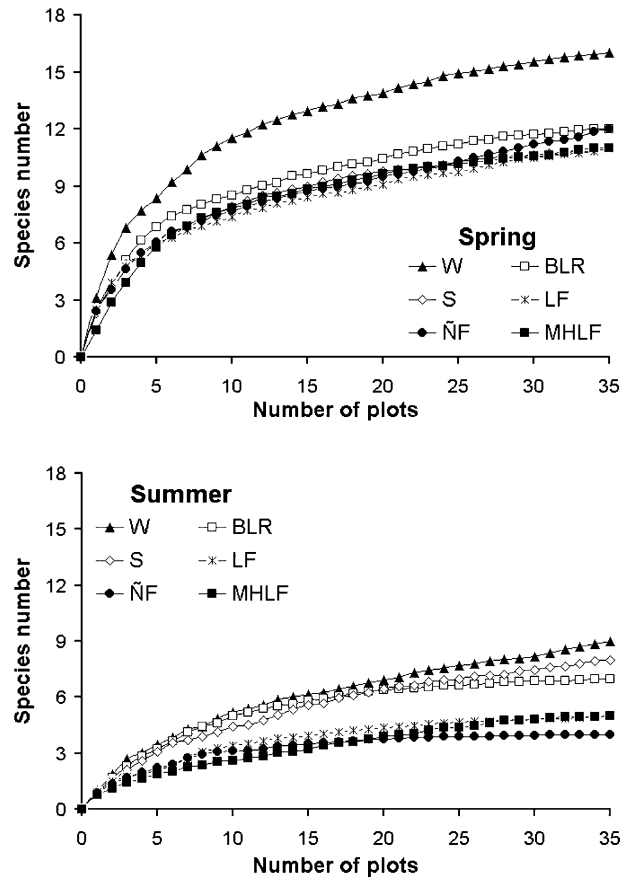


Figure 2. Species number as a function of sampling effort in timber and unproductive associated stands between seasons. LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio*–*N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests. Each curve is an average of 50 times random of the morning and afternoon samplings of each treatment and season.

differed significantly ( $p < 0.0001$ ) between seasons and treatments. The homogeneity for the abundance between different times during the day was not analyzed, because data were obtained with an unequal number of plots.

#### Bird richness

Passeriforms is the most important bird group of these forests (Table 2 and 3), being the 96% of the sightings. The other orders contribute with an important richness to the forest system, but with a few individuals (4% of the observed

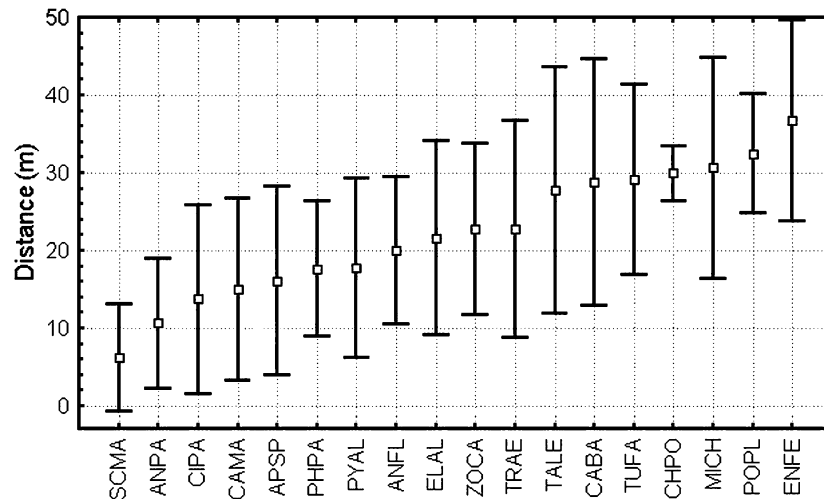


Figure 3. Mean observation distances and standard deviation of bird species for all sampled individuals. Species codes appear in Table 2.

birds). *Aphrastura spinicauda*, *Carduelis barbata*, *Zonotrichia capensis*, *Troglodytes aedon* and *Elaenia albiceps* concentrated 84% of the observations in all the environments. Most of the bird species were insectivores, but also utilized other food resources (Table 2). The majority of the birds species are migratory (toward warmer zones in the continent) or partial migratory (toward more benign zones within Tierra del Fuego) (Table 2).

Very few species were detected as resident during the winter season. In sunny days, mixed flocks of *Aphrastura spinicauda* and *Pygarrhichas albobularis* searching for larvae or insects inside the bark of trees were observed. Groups of *Turdus falcklandii* were also observed, mainly in stands with poor site quality and large quantity of branches. Large flocks of *Enicognathus ferrugineus* were observed in timber lenga forests. Within the carnivorous birds, it was possible to observe isolated individuals of *Milvago chimango* and *Polyborus plancus*.

Variations in species number between spring and summer samplings (Table 3) highlight the short breeding period. In example, 161 individuals of *Zonotrichia capensis*, 134 of *Elaenia albiceps* and 19 of *Tachycineta leucopyga* were observed during spring, while no individuals of these species were detected during the summer samplings. Similarly, 140 individuals of *Troglodytes aedon* were observed in the spring and only 4 towards the end of summer.

All study environments showed low bird species richness between 12 and 18 bird species, with no differences among them. A large number of the observed species was detected in all the environments (Table 3 and Figure 4), but many of them were only observed in the non-timber environments. A higher number of exclusive bird species than timber stands (LF and MHLF) was found in high water availability environments (W and S) (6 exclusive species each) and those

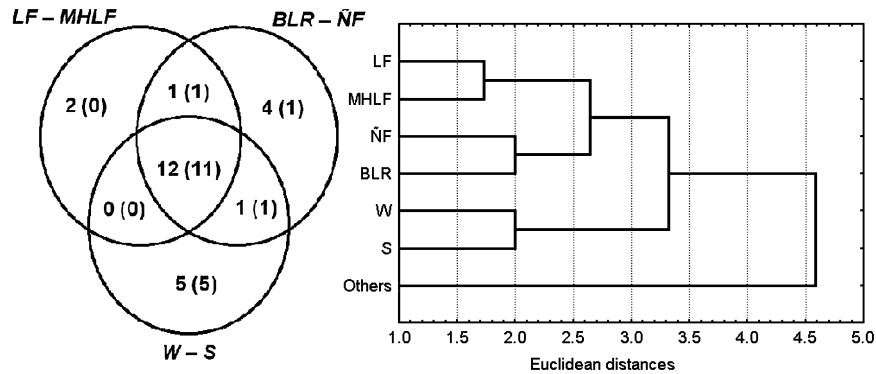


Figure 4. Species number overlapping among the sampled stands presented as: detected species (sampled species), and cluster analysis (data of species *presence* or *absence*) with a complete linkage amalgamation rule and euclidean distance measure. LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio*–*N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests.

at the forest edges (BLR and ÑF) (3 and 4, respectively). However, open areas (rangelands and peat lands) showed the most important difference in exclusive species (11 species) in comparison with the timber forest environments. The bird richness of the studied forest environments are very similar among them (Figure 4), with 12 species shared in timber stands, edge environments, and stands with high water availability. By the way, only two species were observed exclusively in the timber lenga forest (*Accipiter bicolor* and *Buteo polyosoma*).

A cluster analysis allowed to determine the following linkage: (a) a first group conformed by the timber forests (LF and MHLF) (1.7 of euclidean distance); (b) a second group of edge forest environments (2.0 of euclidean distance) was the most closely related to the first group (2.6 of euclidean distance); (c) S and W conformed the third group (2.0 of euclidean distance), which were secondarily related to the previous groups at an euclidean distance of 3.3; and (d) other environments (rangelands and peat lands) were far joined to the forest groups at an euclidean distance of 4.6 (Figure 4). DCA allowed assembling the sampled bird species according to the environment classifications obtained through cluster analysis (Figure 5). Axis one (eigenvalue of 0.072) and two (eigenvalue of 0.030) were utilized in the analysis. Axis one are related to the water availability in the forest, while axis two indicates canopy closure as well as the closeness or presence of open areas. Some species located in the middle of the graph, where the axes crossed, had a wide spectrum of environment utilization and was observed in all treatments. On the other hand, there were smaller species groups which showed preference or association to determined environments. Finally, six species were only associated to one given environment, mainly in W and S.

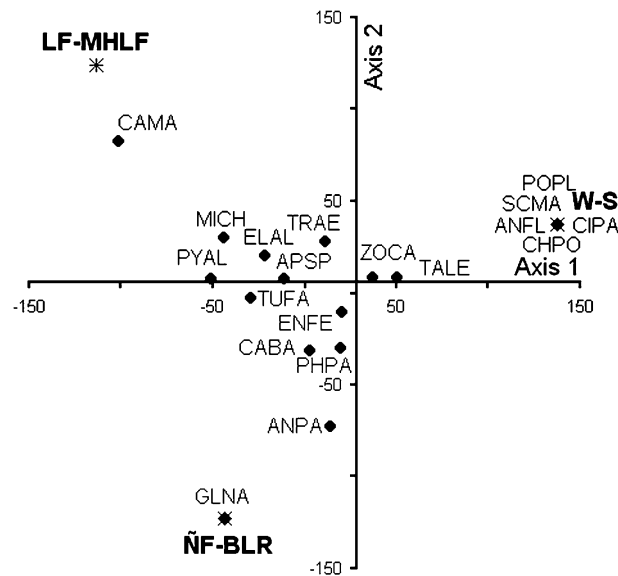


Figure 5. Ordination analysis by DCA without rare species ponderation of main environments and abundance of species. LF – *N. pumilio* stand in the plain ground, MHLF – *N. pumilio* stand in a hillside, BLR – edge between *N. pumilio* forest and rangeland, ÑF – *N. antarctica* stand, W – *N. pumilio*–*N. antarctica* forest wetland, S – riparian environment in *N. pumilio* forests. Species codes appear in Table 2.

#### Bird density

The number of observed birds varied according to the treatments. Of the total number of censuses, 27% corresponded to timber forests (15% for LF and 12% for MHLF), 38% to edge forest (26% for BLR and 12% for ÑF) and 35% to W (21%) and S (14%). These differences are due to the forest structure of each treatment (Table 1). The maximum observation distance significantly influence over the sampling, and are also important when trying to make bird density comparisons between forest types. Maximum observation distances were 65 m for W, 55 m for LF and S, 45 m for MHLF and BLR, and 35 m for ÑF. In the proposed density method estimation, the half of the maximum observation distance was used as the radius of a plot, which varied according to the study environment.

Edge environments had high bird densities, but they varied according to the sampling season (Table 3). During spring, a high bird density was observed in the *N. antarctica* forest (ÑF) (34 birds/ha), diminished towards the end of summer (17 birds/ha). This was due to changes in *Carduelis barbata* populations, modifying their habits in the use of this environment between spring and summer. This species utilized ÑF during the nesting period, and thereafter left this environment to make big flocks in open forests at the end of the summer. Other species that utilized this environment during the spring and then

migrated during the summer were *Elaenia albiceps* and *Troglodytes aedon*. In BLR stands, a high bird density was observed in the summer (30 birds/ha). This was due to the presence of large flocks of *Carduelis barbata* (30–50 individuals) and numerous juvenile and mature individuals of *Aphrastura spinicauda* which foraged in the canopy, stems and forest floor. However, during spring season, a low density was observed (18 birds/ha), partly because of low frequency of this two bird species compared to that in summer.

The remaining environments did not differ in bird densities (12–17 birds/ha); also there were no differences between sampling seasons. Although the total bird density did not vary, the population composition of each stand has changed between seasons. In timber lenga forests (LF and MHLF), a decrease in *Carduelis barbata*, *Zonotrichia capensis*, *Troglodytes aedon* and *Elaenia albiceps* was observed between spring and summer, due to migration of these species. An increase in *Aphrastura spinicauda* populations raised summer bird densities to spring values. Environments with high water availability (W and S) present similar trends, with decreasing migrant bird populations, and increases in *Aphrastura spinicauda* and *Carduelis barbata* densities. This later species increased their presence during the summer, as well as in BLR and ÑF, seeking for forest environments with an open canopy in order to form big flocks.

## Discussion

### *Ecological characterization of the stands*

Forest environment diversity generates many ecological conditions (Figure 1), which cover all the requirements of the bird species of these forests. Dominant forest species influence mainly in the quantity of light could reaches to the forest floor. Timber stands had a large and closed canopy, which generates a sparse understory (Martínez Pastur et al. 2002b), making this environment less adequate for herbivorous birds (i.e. *Zonotrichia capensis*). However, these closed canopy stands offer a great quantity and richness of insects (Spagarino et al. 2001), which cover many of food requirements for the small bird species (i.e. *Troglodytes aedon* and *Pygarrhichas albogularis*).

Soils originated in *Nothofagus pumilio* and *N. antarctica* forests differ substantially in their fertility and depth (Frederiksen 1988; Godagnone and Irisarri 1990). These generate different amounts of understory covers and biomass (San Martín et al. 1987; Collantes et al. 1989; Martínez Pastur et al. 2002b), which formed closed communities with a high availability of seeds for bird foraging. This occurs mainly during the filling and maturation of the grains, being widely utilized by many Passeriform bird species.

The edge environments possess the condition necessities to attracting determinate bird species (i.e. *Theristicus caudatus* and *Falco sparverius*), which lives in open places during the day and look for refuge during the night; or those hunting birds that utilize edge trees for the observation of their preys

(Báldi 1996; Báldi and Kisbenedek 1999). By the way, the remainder environments (S and W) offered excellent ecological conditions to birds which search for the proximity of water ponds, with large food availability and the forest protection (i.e. *Anas flavirostris* and *Chloephaga* spp.).

#### *Analysis of the sampling method*

The most common techniques in bird sampling are: (1) transects and (2) point counts (Blondel et al. 1981; Jiménez 2000). This last method provides several advantages and was chosen for this study because it is the most efficient for sampling birds in structurally complex habitats such as forests (Reynolds et al. 1980; Drapeau et al. 1999), and was successfully implemented previously in Tierra del Fuego (Schlatter 1995; Deferrari et al. 2001). However, several authors continue recommending the use of transects in forest sampling (Wilson et al. 2000).

Jiménez (2000) proposed no more than a 6 min observation period in point counts, and Deferrari et al. (2001) used an 8 min observation period, in agreement with reports by Rozzi et al. (1997) and Schlatter (1995). In this period, the majority of the individuals were observed begin some birds to appear twice while it moves from one tree to another. For this reason, this observation time is considered adequate. However, longer sampling periods (20–25 min) have been proposed for other forest types (Drapeau et al. 1999).

According to the stand conditions, from 6 to 10 point counts are recommended per treatment in order to capture a representative bird richness sample (Morrison et al. 1981; Willson et al. 1994; Rozzi et al. 1997). In this study, the number of counts needed for a correct sampling of the stands, varied with forest structure and seasons, being necessary more than 20 counts (Figure 2). When a sampling with fewer numbers of counts was conducted in timber forests (Venegas 2000) an underestimation of the richness could be obtained. Reynolds et al. (1980) and Jimenez (2000) highlighted the sensitivity of the sampling for detecting rare species, which needs large number of point counts. In the studied forests, six bird species were not observed during the sampling, and could only be detected outside the observation periods. Two of them could be considered as rare species of high conservational importance (Humphrey et al. 1970): *Buteo polyosoma* and *Accipiter bicolor*. These falconiforms live mainly in high site quality *Nothofagus* forests, as the timber stands described in this work. The study of these species needs a more complex sampling, because the point count sampling seems to be inappropriate (Bibby et al. 1993). The sighting of these species is casual, because they live in extremely low densities in the forests, and are migratory or partially migratory. Widén (1997) cites foraging home ranges from 2000 to 6000 ha of boreal forest areas for *Accipiter gentilis* L. and densities no greater than 3 ind/100 km<sup>2</sup>.

*Nothofagus* forests showed a simple forest structure without presence of a closed shrubbery understory, which facilitates bird observation. For these

reasons, during the sampling was only counted the sight birds, since the majority of them are easy to be located through their songs and trills in the forest floor or in the canopy. In similar forest types to those described in this work, Jiménez (2000) found that bird diversity did not change significantly beyond a radius of 50 m in the sampling plots. Deferrari et al. (2001) reached similar results, and both are in agreement with Rozzi et al. (1997) and Schlatter (1995). In our study, the average observation distance for all bird species did not overcome 37 m (Figure 3), but distances significantly varied according to the sampled environment.

Through the proposed density estimation method, bird densities varied from 12 to 34 individuals per hectare. Jiménez (2000) found 36 individuals per hectare at Chiloé Island (Chile), and Ralph (1985) found 19 individuals per hectare at Bariloche (Argentina). These densities can be related to the number of observations carried out during the sampling and the observation distances, which adapted to the different forest structures of the studied timber stands and their associated environments. In this study the sampling effort was equivalent (same number of counts but with different proportional size of plots) for each sampled forest environment, arriving to a different amount of individuals observed in each treatment (from 230 to 490 birds). In our case, the edge between the *N. pumilio* forest and the rangeland (BLR) accumulated 26% of the total observations, mainly due to the presence of flocks of *Carduelis barbata* towards the end of the summer. Finally, sampling at different times during the day and season was necessary to capture variations in diversity of the studied environments. Similar results were reported by Drapeau et al. (1999), found significant differences when samplings were taken at different times during the day and season in several forest types (*Betula populifolia* Marsch., *Ulmus americana* L., *Acer saccharum* Marsch., *Tsuga canadensis* (L.) Carricre., *Pinus strobus* L. and an open-field stands).

#### *Diversity and density of birds in timber forest and its associated environments*

Specific richness observed in the *Nothofagus* forests of Tierra del Fuego shows the scarce bird diversity of them. The majority of the species identified in this study utilizes several environments to live. Fifteen bird species were observed in timber forests, and 25 in the remaining studied environments. This richness is comparable to other studies. Schlatter (1995) identified 25 species, Venegas (2000) 10 species and Deferrari et al. (2001) 12 species in *Nothofagus pumilio* primary forests. On the other hand, Jiménez (2000) cited 24 species in closed *Nothofagus* evergreen forests in Chile. None of the species detected in our study are endemic of Tierra del Fuego, but many of them are endemic for Patagonia (i.e. *Aphrastura 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 (Humphrey et al. 1970; Clark 1986; Schlatter 1995; Deferrari et al. 2001).

The insectivorous species, mainly of Passeriform order, were the most important groups in all the studied stands, which are in agree with reports of Schlatter (1995) and Deferrari et al. (2001). However, a great percentage of the bird species may utilize several food resources according to their availability (Humphrey et al. 1970; Clark 1986; Schlatter 1995; Donázar et al. 1996; Rozzi et al. 1997; Smith Ramírez and Armesto 1998; Traveset et al. 1998; Deferrari et al. 2001). Raptor richness is scarce in these forests, which density is low when it is compare to the high availability of captures (McNutt 1981). Small owls (*Glaucidium nanum*) were observed hunting and eating small birds during this study. However, it is highlighted the non-recorded of big owls, like *Bubo virginianus* Gmelin, *Strix rufipes* King., *Tyto alba* Scopoli and *Asio flammeus* Pontoppidan, which diet included mainly small rodents of *Akodon* Meyen, *Euneomys* Couest and *Olygorizomys* Bangs genera (Humphrey et al. 1970; Jaksic et al. 1978; López and Domínguez 2002). *Chloephaga poliocephala* was only sampled in wet environments (W and S) and detected in open areas, being consistent as the requirements described by Schlatter et al. (2002). *Accipiter bicolor* and *Buteo polyosoma* are very scarce and few individuals were reported along Tierra del Fuego (Humphrey et al. 1970; Schlatter 1995; Navas and Manghi 1991). These Falconiforms have special conservation interest, because they have only been observed in timber, deep forest environments, with a high canopy density and good site quality.

The studied environments could be grouped into three types according to their richness. These possessed a high percentage of shared diversity, but there are species specific to the associated environments. This gives to unproductive environments special conservation characteristics since: (a) they could receive birds that were displaced from stands under forest management, (b) they could act as reserves of bird diversity to reestablish the managed stand, once forest structure has recovered some of their original characteristics (Deferrari et al. 2001), and (c) they are environments where specific species develop which are not frequent in the timber forests. These environments are not proportionally distributed across the landscape (Figure 1), but some of them can have a high bird density. These densities varied with seasons, which permits to the species utilize better the food offer along the year in all the environments. Differences in bird diversity in these forests are partly due to special nesting requirements, as for *Campephilus magellanicus* or *Glaucidium nanum* (Willson et al. 1994; López and Domínguez 2002), food specialization and need of an open canopy for hunting (Rozzi et al. 1997).

#### *Forest management implications and mitigation alternatives*

The silvicultural management proposed for *Nothofagus pumilio* in Tierra del Fuego (Schmidt and Urzúa 1982; Martínez Pastur et al. 2000) significantly

affects horizontal and vertical structure, as well as major food offer for birds (Deferrari et al. 2001). This management aims to create a regular stand and to maintain a productive system in early growth stage. Second growth forests generates adverse conditions for the maintenance of several bird species, especially those that need space to fly, hunt or hollow trees for nest (Deferrari et al. 2001; López and Domínguez 2002). However, most of these sensible species live in the unproductive associated environments, which acquire an enormous importance for bird species conservation.

Tierra del Fuego (Argentina) forests cover an area of 712,000 ha. Between them, 317,000 ha corresponding to *Nothofagus pumilio* forests, 181,000 ha *N. antarctica* forests, 192,000 ha to mixed forests (*N. pumilio* and *N. betuloides* (Mirb.) Oersted) and 21,000 ha to degraded forests. Only 214,000 ha are considered as timber forests (30%), and only 20% of them were partially harvested in the past (Collado 2001). Forest management planning must be carried out before logging of the forests, but usually is centered in the timber stands, leaving off the unproductive associated environments. However, to define a better forest management with conservation strategies, it would be necessary: (1) to include major studies about the forest type, area and conservation status of the associated environment to the timber stands under management; (2) to determine the balance between the areas that will get into a silvicultural management and the associated environments which will not be intervened; (3) to determine the auto ecology of the forest birds species, especially those most affected to silvicultural practices; (4) to determine the relationship of such species with the timber and unproductive environments along the seasons; (5) to avoid the installation of forest worker camps, piling zones and road construction in the associated environments (especially in edge stands), as well as avoiding the drainage of forest wetlands and peat-lands; and (6) to incorporate forest management within a forestry ordination planning, avoiding the concentration of activities in any one sector of the ranch for a long time.

Forest management should be modified and adapted according to requirements of species potentially sensitive to forest harvesting. A new silviculture method started to be applied in 2001 in Tierra del Fuego, which proposes dispersed or aggregated retention areas (Franklin et al. 1997). These silvicultural practices could better maintain bird diversity in these forests, and should be accompanied with a preservation of specific hollow-bearing trees in the managed areas (Gibbons and Lindenmayer 1996; Pattanavibool and Edge 1996; Rozzi et al. 1997), and studies about habitat fragmentation (Cornelius et al. 2000).

Arroyo et al. (1996) cited six species of *Nothofagus pumilio* forests in Tierra del Fuego (Chile) as sensitive to harvesting: (1) two of them were not found in our study (*Strix rufipes* and *Colorhamphus parvirostris* Darwin); (2) it is possible that the third species (*Buteo ventralis* Gould) not live in Tierra del Fuego (Navas and Manghi 1991) and could be easily confused with *Buteo polyosoma*; (3) other two species (*Campephilus magellanicus* and *Scytalopus magellanicus*) have a wide dispersion in timber secondary forests (Deferrari et al. 2001) and

unproductive associated environments ( $\tilde{NF}$ ,  $W$  and  $S$ ); and (4) one last species could have only been seen in timber forests (*Accipiter bicolor*). This raptor could be the most appropriate key bird species for the evaluation of the conservation status in forest under management.

### Conclusions

Timber productive stands of *Nothofagus pumilio* in Tierra del Fuego support a relatively low number of bird species. Most of them are opportunistic, but few species prefer these woods over other forested or afforested areas. This low bird density and richness characterizes these austral forests, and share the diversity with a high variety of ecosystems along Patagonia. It is possible that conservation of bird species gives a marginal value to timber *N. pumilio* forest, especially when taking into account that this forest are only a small percentage of the total landscape in Tierra del Fuego, where timber and unproductive forests are mixed.

Several works analyze the forest management impact over bird diversity and has centered their sampling just only on timber stands. These works promote the creation of reserves for timber environment preservation (Fridman 2000). However, timber forests are mixed with unproductive environments. Because of this, incorporation of studies on unproductive environments is critical to analyze and rank the real importance of forest management impact on loss of bird species and density in timber forests. It is necessary to make studies at a landscape level and arrange them into models for analyzing forest dynamics and bird responses to disturbances if the integrity of bird communities must be preserved (Drapeau et al. 2000).

### Acknowledgements

Thanks to Sigfrido Wolfsteller of *Ushuaia* ranch, Ricardo Vukasovic of *Servicios Forestales* Consultancy, *Centro Austral de Investigaciones Científicas* and *Universidad Nacional del Sur* for their invaluable help and support during the realization of this work. Helpful comments on the manuscript were provided by Adrián Schiavini. To Guillermo Fassi of Lenga Patagonia S.A. for permits to access to their climate databases. To Paola Rivero, Florencia Rojas Molina and Rosana Sottini for their assistance during field work.

### References

- Arroyo M.T.K., Donoso C., Murúa R.E., Pisano E.E., Schlatter R.P. and Serey I.A. 1996. Toward an ecologically sustainable forestry project: concepts, analysis and recommendations. Departamento de Investigación y Desarrollo, Universidad de Chile, p. 253.

- Báldi A. 1996. Edge effects in tropical versus temperate forest bird communities: three alternative hypotheses for the explanation of differences. *Acta Zool. Acad. Sci. Hung.* 42(3): 163–172.
- Báldi A. and Kisbendek T. 1999. Species-specific distribution of reed-nesting passerine birds across reed-bed edges: effects of spatial scale and edge type. *Acta Zool. Acad. Sci. Hung.* 45(2): 97–114.
- Bibby C.J., Burgess N.D. and Hill D.A. 1993. *Bird Census Techniques*. Academic Press, London, p. 257.
- Bitterlich W. 1984. The relascope idea. *Relative Measurements in Forestry*. Commonwealth Agricultural Bureaux, London, p. 242.
- Blondel J., Ferry C. and Frochot B. 1981. Point counts with unlimited distance. *Stud. Avian Biol.* 6: 414–420.
- Burgos J. 1985. El clima del extremo sur de Sudamérica. In: Boelcke O., Moore D. and Roig F. (eds), *Transecta Botánica de la Patagonia Austral CONICET (Argentina)*. Instituto de la Patagonia Austral (Chile) and Royal Society (Great Britain), Buenos Aires, Argentina, p. 733.
- Clark R. 1986. *Aves de Tierra del Fuego y Cabo de Hornos*. Guía de campo. LOLA ed, p. 294.
- Collado L. 2001. Los bosques de Tierra del Fuego: Análisis de su estratificación mediante imágenes satelitales para el inventario forestal de la provincia. *Multequina* 10: 1–15.
- Collantes M., Ontivero J. and Bianciotto O. 1989. Análisis de las comunidades de *Nothofagus* de Tierra del Fuego. *Parodiana* 6(1): 185–195.
- Cornelius C., Cofré H. and Marquet P.A. 2000. Effects of habitat fragmentation on bird species in a relict temperate forest in semiarid Chile. *Conserv. Biol.* 14(2): 534–543.
- Deferrari G., Camilión C., Martínez Pastur G. and Peri P. 2001. Changes in *Nothofagus pumilio* forest biodiversity during the forest management cycle: birds. *Biodiv. Conserv.* 10: 2093–2108.
- Donázar J.A., Travaini A., Rodríguez A., Ceballos O. and Hiraldo F. 1996. Nesting association of raptors and buff-necked ibis in the Argentinian Patagonia. *Colon. Waterbirds* 19(1): 111–115.
- Douglas Robinson W., Brawn J. and Robinson S. 2000. Forest bird community structure in central Panamá: influence of spatial scale and biogeography. *Ecol. Monogr.* 70(2): 209–235.
- Drapeau P., Leduc A. and McNeil R. 1999. Refining the use of point counts at the scale of individual points in studies of bird–habitat relationships. *J. Avian Biol.* 30: 367–382.
- Drapeau P., Leduc A., Giroux J.F., Savard J.P., Bergeron Y. and Vickery W. 2000. Landscape-scale disturbances and changes in bird communities of boreal mixed-wood forests. *Ecol. Monogr.* 70(3): 423–444.
- Franklin J., Berg D., Thornburgh D. and Tappeiner J. 1997. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. In: Kohm K. and Franklin J. (eds), *Creating a Forestry for the 21st Century: The Science of Ecosystem Management*. Island Press, Washington, DC, pp. 111–140.
- Frederiksen P. 1988. Soils of Tierra del Fuego: a satellite-based land survey approach. *Folia Geographica Danica*. Tomo XVIII, p. 159.
- Fridman J. 2000. Conservation of forest in Sweden: a strategic analysis. *Biol. Conserv.* 96: 95–103.
- Fuller R. and Langslow D. 1984. Estimating number of bird by point counts: How long should counts last? *Bird Study* 31: 195–202.
- Gibbons P. and Lindenmayer D. 1996. Issues associated with the retention of hollow-bearing trees within eucalypt forests managed for wood production. *J. Forest Ecol. Manage.* 83: 245–279.
- Godagnone R. and Irisarri J. 1990. Mapa de suelos del Territorio Nacional de Tierra del Fuego. In: Moscatelli G. (ed), *Atlas de suelos de la República Argentina*. SAGyP-INTA-Proyecto PNUD. Vol. II, pp. 615–641.
- Hagar J., McComb W. and Emmingham W. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. *Wildlife Soc. B.* 24(2): 353–366.
- Humphrey P., Bridge D., Reynolds P. and Peterson R. 1970. *Birds of Isla Grande (Tierra del Fuego)*. Ed Smithsonian Institution, Washington, DC, p. 411.
- Jaksic F., Rau J. and Yáñez J. 1978. Oferta de presas y predación por *Bubo virginianus* (Strigidae) en el Parque Nacional ‘Torres del Paine’. *Anales del Instituto de la Patagonia* 9: 199–202.
- Jiménez J.E. 2000. Effect of sample size, plot size, and counting time on estimates of avian diversity and abundance in a Chilean rainforest. *J. Field Ornithol.* 71(1): 66–87.

- Lanfranco D. 1977. Entomofauna asociada a los bosques de *Nothofagus pumilio* en la región de Magallanes: I parte: Monte Alto (Río Rubens, Última Esperanza). *Annales del Instituto de la Patagonia* (Punta Arenas – Chile) 8: 319–346.
- Lemmon P. 1957. A new instrument for measuring forest overstory density. *J. Forest.* 55(9): 667–668.
- Lencinas M.V., Martínez Pastur G., Cellini J.M., Vukasovic R., Peri P. and Fernández C. 2002. Incorporación de la altura dominante y la calidad de sitio a ecuaciones estándar de volumen para *Nothofagus antarctica* (Forster f.) Oersted. *Bosque* 23(2): 5–17.
- López B. and Domínguez E. 2002. Presencia de *Strix rufipes* King 1828 (Strigiformes: Strigidae) en el Parque Histórico Rey Don Felipe, Península de Brunswick, Magallanes. *Annales del Instituto de la Patagonia, Serie Ciencias Naturales* 30: 147–150.
- Ludwig J.A. and Reynolds J.F. 1988. *Statistical Ecology: A Primer in Methods and Computing*. John Wiley and Sons Ltd., New York, p. 368.
- 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., Cellini J.M., Peri P., Vukasovic R. and Fernández C. 2000. Timber production of *Nothofagus pumilio* forests by a shelterwood system in Tierra del Fuego (Argentina). *J. Forest Ecol. Manage.* 134(1–3): 153–162.
- Martínez Pastur G., Lencinas M.V., Cellini J.M., Díaz B., Peri P. and Vukasovic R. 2002a. Herramientas disponibles para la construcción de un modelo de producción para la lenga (*Nothofagus pumilio*) bajo manejo en un gradiente de calidad de sitio. *Bosque* 23(2): 69–80.
- Martínez Pastur G., Peri P., Fernández M.C., Staffieri G. and Lencinas M.V. 2002b. Changes in understory species diversity during the *Nothofagus pumilio* forest management cycle. *J. Forest Res.* 7(3): 165–174.
- McNutt J.W. 1981. Selección de presa y comportamiento de caza del halcón peregrino (*Falco peregrinus*) en Magallanes y Tierra del Fuego. *Annales del Instituto de la Patagonia* 12: 221–228.
- Moore D. 1983. *Flora of Tierra del Fuego*. Anthony Nelson – Missouri Botanical Garden, p. 395.
- Morrison M., Mannan R.W. and Dorsey G.L. 1981. Effects of number of circular plots on estimates of avian density and species richness. *Stud. Avian Biol.* 6: 405–408.
- Narosky T. and Yzurieta D. 1987. *Guía para la identificación de aves de Argentina y Uruguay*. Asociación Ornitológica del Plata, Buenos Aires, p. 345.
- Navas J.R. and Manghi M.S. 1991. Notas sobre *Buteo ventralis* y *Buteo albigula* en la Patagonia Argentina (Aves, Accipitridae). *Revista del Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia'* XV(7): 87–94.
- Niemela J. 1990. Habitat distribution of carabid beetles in Tierra del Fuego, South America. *Entomologica Fennica* 29(VI): 3–16.
- Pattanavibool A. and Edge W. 1996. Single-tree selection silviculture affects cavity resources in mixed deciduous forests in Thailand. *J. Wildlife Manage.* 60(1): 67–73.
- Peris S. 1997. Distribution of birds on eastern and western slopes of The Sierra Aconquija in the northwestern Argentine Andes. *Studies in Neotropical Fauna and Environment* 32: 135–141.
- Pulido F., Díaz B. and Martínez Pastur G. 2000. Incidencia del ramoneo del guanaco (*Lama guanicoe*) sobre la regeneración de lenga (*Nothofagus pumilio*) en bosques de Tierra del Fuego, Argentina. *Investigación Agraria: Sistemas y Recursos Forestales* 9(2): 381–394.
- Ralph C.J. 1985. Habitat association patterns of forest and steppe birds of northern Patagonia, Argentina. *Condor* 87: 471–483.
- San Martín J., Troncoso A. and Ramírez C. 1987. Fitosociología de los bosques de *Nothofagus antarctica* (Forst) Oerst en la cordillera costera de Cauquenes (Chile). *Bosque* 7(2): 65–78.
- Reynolds T., Scott J. and Nussbaum R. 1980. A variable circular-plot method for estimating bird densities. *Condor* 82: 309–313.
- Rozzi R., Martínez D., Willson M.F. and Sabag C. 1997. Avifauna of south american temperate forests. In: Armesto J., Villagrán C. and Arroyo M.T.K. (eds), *Ecología de los bosques nativos de Chile*. Chapter 7, Editorial Universitaria. Universidad de Chile, pp. 135–152.

- Schlatter R. 1995. Ornithology. Informe del Subproyecto 94-14. Estudios de línea base: Proyecto Río Condor, p. 51.
- Schlatter R.P., Vergara P. and Briones M. 2002. El canquén (*Chloephaga poliocephala*: Anatidae) en bosques de Tierra del Fuego: distribución y predadores. Anales del Instituto de la Patagonia, Serie Ciencias Naturales 30: 61-66.
- Schmidt H. and Urzúa A. 1982. Transformación y Manejo de los Bosques de lenga en Magallanes. Universidad de Chile, Ciencias Agrícolas no. 11 p. 62.
- Scott J. and Ramsey F. 1981. Length of count period as a possible source of bias in estimating bird densities. Stud. Avian Biol. 6: 409-413.
- Smith Ramírez C. and Armesto J.J. 1998. Nectarivoría y polinización por aves en *Embothrium coccineum* (Proteaceae) en el bosque templado del sur de Chile. Rev. Chil. Hist. Nat. 71(1): 51-63.
- Spagarino C., Martínez Pastur G. and Peri P. 2001. Changes in *Nothofagus pumilio* forest biodiversity during the forest management cycle: insects. Biodiv. Conserv. 10: 2077-2092.
- Traveset A., Willson M.F. and Sabag C. 1998. Effect of nectar-robbing birds on fruit set of *Fuchsia magellanica* in Tierra del Fuego: a disrupted mutualism. Funct. Ecol. 12(3): 459-464.
- Tuhkanen S. 1992. The climate of Tierra del Fuego from a vegetation geographical point of view and its ecoclimatic counterparts elsewhere. Acta Bot. Fennica 145: 1-65.
- Venegas C. 2000. Avifauna de un bosque de lenga (*Nothofagus pumilio*) intervenido y de uno no intervenido en Magallanes continental, Chile. Anales del Instituto de la Patagonia, Serie Ciencias Naturales 28: 101-106.
- Verner J. 1988. Optimizing duration of point counts for monitoring trends in bird populations. US Forest Service Research Note PSW, p. 395.
- Widén P. 1997. How, and why, is the goshawk (*Accipiter gentilis*) affected by modern forest management in Fennoscandia? J. Raptor Res. 31(2): 107-113.
- Willson M.F., De Santo T.L., Sabag C. and Armesto J.J. 1994. Avian communities of fragmented South-temperate rainforest in Chile. Conserv. Biol. 8: 508-520.
- Wilson R., Twedt J. and Elliot B. 2000. Comparison of line transects and point counts for monitoring spring migration in forested wetlands. J. Field Ornithol. 71(2): 345-355.