UNIVERSIDAD DE CHILE -FACULTAD DE CIENCIAS -ESCUELA DE PREGRADO

"ABUNDANCE AND MOVEMENT OF CHESTNUT-THROATED HUET-HUET (*PTEROPTOCHOS CASTANEUS*: RHINOCRYPTIDAE) IN CLEARCUTS"

Seminario de Título entregado a la Universidad de Chile en cumplimiento parcial de los requisitos para optar al Título de Bióloga con Mención en Medio Ambiente

Karla Cheryl Ramírez Collio

Director del Seminario de Título:
Dr. Javier A. Simonetti

Co-Director:
Dr. Pablo M. Vergara

Octubre 2016
Santiago - Chile

INFORME DE APROBACIÓN SEMINARIO DE TITULO

Se informa a la Escuela de Pregrado de la Facultad de Ciencias, de la Universidad de Chile que el Seminario de Título, presentado por la Srta. Karla Cheryl Ramírez Collio

"Abundance and movement of Chestnut-throated Huet-huet (*Pteroptochos castaneus*: Rhinocryptidae) in clearcuts"

Ha sido aprobado por la Comisión de Evaluación, en cumplimiento parcial de los requisitos para optar al Título de Bióloga Ambiental.

Director Seminario de Título:
Dr. Javier A. Simonetti

Co-director Seminario de Título:
Dr. Pablo M. Vergara

Comisión Revisora y Evaluadora

Presidente Comisión:
Dr. Rodrigo A. Vásquez

Evaluador:
Dr. Claudio Veloso

Santiago de Chile, Octubre 2016

BIOGRAFÍA

Karla Cheryl Ramírez Collio

Nacida y crecida en Santiago, hija menor del matrimonio entre Erica y Luis, hermana de Andrés y Roberto. Buena hija, estudiante perseverante, amiga fiel y madre abnegada. Desde pequeña muy curiosa y con un profundo interés por dilucidar el porqué de todo. Su admiración por la naturaleza la lleva a estudiar Biología Ambiental en la Universidad de Chile, profesión a través de la cual, aspira aportar un granito de arena para construir una sociedad mucho mejor.

AGRADECIMIENTOS

A mi familia por su paciencia y apoyo incondicional, en especial a mi madre y padre, por contenerme en aquellos momentos más difíciles y animarme a seguir adelante, son mi ejemplo de lucha y tenacidad.

A mi hijo hermoso, quien llego a desbordar mis días de ternura, amor, travesuras y alegrías.......te amo profunda e incondicionalmente.

A mis queridas amigas (os) de pregrado Flavia, Sayaka, Carito-pim, Caro-fer, Luis (nani), Pedro, por su ayuda, cariño y amistad durante todos estos años.

A todos y cada uno/a de mis compañeros del Laboratorio de Conservación Biológica, en especial al grupo "Queules": Sole, Lía y Caracola, por su ayuda en terreno y por los innumerables buenos momentos. También agradezco a Ronny, quien desde el primer día de terreno me acompaño y ayudo generosamente con el trabajo de campo.

A mis profesores tutores, Javier Simonetti y Pablo Vergara, por aceptarme en sus laboratorios y guiarme con mucha paciencia y buen humor.

INDEX OF CONTENTS

Abstract

Sustainable forest management of commercial monoculture plantations involves reducing the impacts on biodiversity. However, sustainability may be difficult to achieve in plantations of Monterrey pine and Eucalyptus because these commercial monocultures are managed under clearcutting, a disruptive practice of harvesting that implies removal and extraction of all standing trees, while understory vegetation is damaged. Until now, environmental factors to mitigate the impact of clearcutting on biodiversity are unknown. However, increasing scientific evidence supports the fact that forestry plantations can support a series of native species, including some endangered, if they maintain a well-development of understory vegetation. I assessed whether understory vegetation in clearcutting enhances the quality of habitat for insectivorous birds especially sensitive to habitat fragmentation, as Chestnut-throated Huet-huet (*Pteroptochos castaneus*). I implemented a Bayesian hierarchical model to: 1) estimate *P. castaneus* abundance in clearcuts, and 2) estimate *P. castaneus* movement from a given habitat to clearcut. The understory vegetation was the main predictor to the abundance in native forest and pine mature plantations but not into clearcut stands. However, understory vegetation improves movement of *P. castaneus* in surrounding matrix which could be favoring biological connectivity between habitats patches.

Key words: Chestnut-throated Huet-huet (*Pterotochos castaneus*), insectivorous birds, abundance, movement, clearcut, understory vegetation, broadcast survey, sustainable forest management.

RESUMEN

El manejo forestal sustentable de plantaciones comerciales de monocultivos implica la reducción de los impactos sobre la biodiversidad. Sin embargo, esta sustentabilidad puede ser difícil de alcanzar en plantaciones de pino Monterrey y eucaliptos pues son cosechados mediante tala rasa, una práctica silvícola perjudicial que implica la remoción y extracción de todos los árboles en pie, mientras que la vegetación acompañante es dañada. Hasta ahora, se desconocen los factores ambientales que mitigarían el impacto de la tala rasa sobre la biodiversidad. Sin embargo, creciente evidencia científica apoya el hecho de que las plantaciones forestales pueden albergar fauna nativa, incluyendo algunas en peligro de extinción, si mantienen un buen desarrollo de la vegetación acompañante. Evaluamos si la vegetación acompañante en rodales de tala rasa mejora su calidad como hábitat de aves insectívoras especialmente sensibles a la fragmentación del hábitat, específicamente del Huet-huet castaño (*Pteroptochos castaneus*). Utilizamos un modelo jerárquico bayesiano para: 1) estimar la abundancia del Huet-Huet castaño en zonas taladas; 2) estimar el movimiento del Huet-huet castaño hacia tala rasa. La vegetación acompañante fue la variable principal para predecir su abundancia en bosques nativos y plantaciones maduras de pino, no así en áreas taladas. Sin embargo, la vegetación acompañante mejora la disposición del Huet-huet castaño a moverse hacia la matriz circundante lo que podría favorecer la conectividad biológica entre hábitats parches.

Palabras clave: Huet-huet castaño (*Pteroptochos castaneus*), aves insectívoras, abundancia, movimiento, sotobosque, experimentos con playback, manejo forestal sustentable, tala rasa.

INDEX OF TABLES

INDEX OF FIGURES

1. Introduction

Forestry plantations represent 7% of the global area covered by forests, ca. 277.9 million ha (Payn et al., 2015). Since 2010, forestry plantations have increased at an average annual rate of 1.2% (i.e., 3.2 million ha per year), while during this same period, native forests has decreased 6.6 million ha per year (FAO, 2015). The growing global demand for forest products, such as pulpwood, timber, firewood, and biomass energy, is the main responsible for the rapid expansion of forestry plantations (WWF, 2015; FAO, 2015).

Forestry practices under a sustainable management have to fulfill the demand for forest products while reducing pressure on biodiversity derived from the replacement of native forest (Paquette and Messier, 2009). Therefore, one of the main challenges for sustainable forest management is the conservation of biodiversity in forestry plantations (Hartley, 2002; Hayes et al., 2005; Lindenmayer and Hobbs, 2004). In fact, as agreed in the Strategic Plan for Biodiversity 2011-2020 of the Convention on Biological Diversity, by 2020: "areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity" (UN 2010).

However, sustainability may be difficult to achieve in the widespread plantations of Monterrey pine (*Pinus radiata*) and Eucalyptus (*Eucalyptus spp*) because these commercial monocultures are managed under a clearcutting system, a disruptive forestry practices involving the simultaneous removal of all standing trees (Pawson et al., 2006; Keenan and Kimmins, 1993). Clearcutting is questioned by its ecological and visual impacts including changes upon vegetation structure and composition, soil proprieties as well as environmental services (Niklitschek et al., 2015). In terms of

3

biodiversity, available scientific evidence of its effects upon biodiversity in commercial plantations is scarce. Hence, the information required to unraveling the effects of clearcut on biodiversity and the potential of clear-felled areas to be re-colonized is insufficient (Simonetti and Estades, 2015). Clearcutting may reduce the richness and abundance of forest-dwelling species at the expense of an increase in open-habitat generalist species (Pawson et al., 2006; Acuña and Estades, 2011), although such an effect is less marked after second year post-logging (Simonetti and Estades, 2015). At the landscape-level, clear-cut stands might act as a barrier for the movement of wildlife, thus reducing their functional connectivity (Popescu and Hunter, 2011; Acuña and Estades, 2011).

Mature pine plantations in central Chile often support a dense understory vegetation whose diversity and structural complexity improve habitat quality for forest dwellers (Vergara and Simonetti, 2003; Estades and Escobar, 2005). In fact, there is increasing scientific evidence for enhancement of the habitat quality for native wildlife in forestry plantations supporting a well-developed and structurally complex understory (Lindenmayer and Hobbs, 2004; Simonetti et al., 2013). Several animal species native of central Chile forests use pine plantations depending on the presence of dense understory vegetation. Currently, abundance of endangered mammals, like the kodkod (*Leopardus guigna*), and ground-dwelling insects, such as *Ceroglossus chilensis* (Coleoptera; Carabidae) is positively associated with the percentage of understory cover present in mature and juvenile pine stands (Simonetti, 2006; Simonetti et al., 2012; Saavedra and Simonetti, 2005; Acosta-Jamett and Simonetti, 2004; Cerda et al., 2015; Grez et al., 2003). Similarly, the abundance and movement of Tapaculos (Rhinocryptidae) is positively related with understory cover in pine plantations (Estades

4

and Temple, 1999; Estades and Escobar, 2005; Vergara and Simonetti, 2006; Castellon and Sieving, 2006; Tomasevic and Estades, 2008). Tapaculos are territorial and particularly sensitive to habitat fragmentation because they have poor dispersal capability due to their terrestrial habits and lower flight capacity (Willson et al., 1994; Sieving et al., 1996; Vergara and Simonetti, 2006). Among Tapaculos, the Chestnut-throated Huet-huet (*Pteroptochos castaneus*), endemic to the deciduous forest of Central Chile is the most sensitive species to the absence of understory cover (Vergara and Simoneti 2003; 2004; 2006). In fact, in experiments with broadcasting songs, *P. castaneus* has been willing to move to pine plantation if pine stand supports a well-developed understory (Vergara and Simonetti, 2006; Tomasevic and Estades, 2008). Although understory vegetation can improve habitat conditions for Tapaculos in pine plantations, its role as a key factor enhancing habitat quality and recovery of biodiversity after clearcutting has not been well established yet. In fact, the lack of knowledge about how understory vegetation facilitates the re-establishment of biodiversity contrasts with the progress in silvicultural practices that ensure the re-establishment of next forestry generation (Kogan et al., 2002).

Within this framework, I tested two hypotheses. 1) The abundance of *P. castaneus* increases with increasing coverage of the understory vegetation, but the effect of understory is less pronounced in clearcut stands compared with native forest and mature pine plantations (that have not recently harvested with clearcutting) because habitat suitability improves as the canopy closes. 2) Both, the willingness of *P. castaneus* to move into clearcut stands and the distance they enter into clear-felled areas will increase with increasing coverage of understory vegetation.

2. Materials and Methods

2.1. Study area

This study was conducted in central Chile (72° 40'W, 35° 60'S), in a geographical area which comprises Los Queules National Reserve (35°59' S, 72°41' W) and nearby small (<100 ha) fragments of temperate deciduous forest, surrounded by plantations of pine Monterrey harvested by clearcutting with rotations of 15 – 20 yr (Vergara and Simonetti, 2004). Temperate deciduous forest includes *Nothofagus glauca* and *N. obliqua* as dominant species, and the evergreen *Cryptocarya alba* and *Peumus boldus* (Bustamante et al. 2005). Understory vegetation is composed by native shrubs, such as *Chusquea cumingii* and *Aristotelia chilensis*.

I selected mature pine plantations of 15 years or more, whose height is equal or higher than 8-10 meters (Tomasevic and Estades, 2008). Understory vegetation in mature pine plantation is a combination of *A. chilensis*, *P. boldus* with exotic species, such as *Teline monspessulana* and *Rubus ulmifolius* (Poch and Simonetti, 2013).

I selected clearcutting stands consisting of a 5-10 ha that were harvested in the year before the survey (i.e., year 2013). Ground vegetation (henceforth "understory" in clearcut) that will give origin to the understory is composed mainly by shrubs (e.g. *Aristotelia chilensis, Teline monspessulana, Rubus ulmifolius*), woody and herbaceous species (e.g. *Silybum marianum, Hypochaeris sp*) including small trees of pine.

6

2.2. Bird abundance

Abundance of *P. castaneus* was recorded from a total of 30 sample points using 50 m fixed radius point counts (see Vergara and Simonetti, 2006). All individuals of P. castaneus seen or heard by point-count (n/point) were registered. Point count surveys involve a combination of two different survey methodologies: passive survey (see Appendix) and broadcast survey. We applied a repeated measures design to simultaneously model occupancy and detection probabilities resulting from both survey methodologies. At each visit to point-count, we employed a methodology involving an 8-min broadcast survey (Saracco et al., 2010). Broadcast surveys consisted of playing *P. castaneus* vocalizations and territorial songs using a portable speaker during two 1-min periods, each one separated by 3 min to detect birds (1+3+1+3= 8 min; Table 1). I set 18, 6 and 6 points in clearcutting, mature pine and native forest fragments, respectively (Table 1). Points were located at the center of forest stands, i.e., >100 m from the nearest edge and > 200 m from the other sampled stands. The understory cover was measured in each habitat using 50 m line-intercept transects. Understory coverage differed between habitats (ANOVA; F-value=35,95; n=30; p-value=$2,45 \times 10^{-8}$). Clearcut stands (14.1 ± 1.4%) exhibit less understory cover than the native forest fragments (30.2 ± 1.6%) (Tukey test; p-value=$1,6 \times 10^{-6}$) and mature pine plantations (31.1 ± 1.1% (Tukey test; p-value=$6,3 \times 10^{-7}$) (Fig. 1).
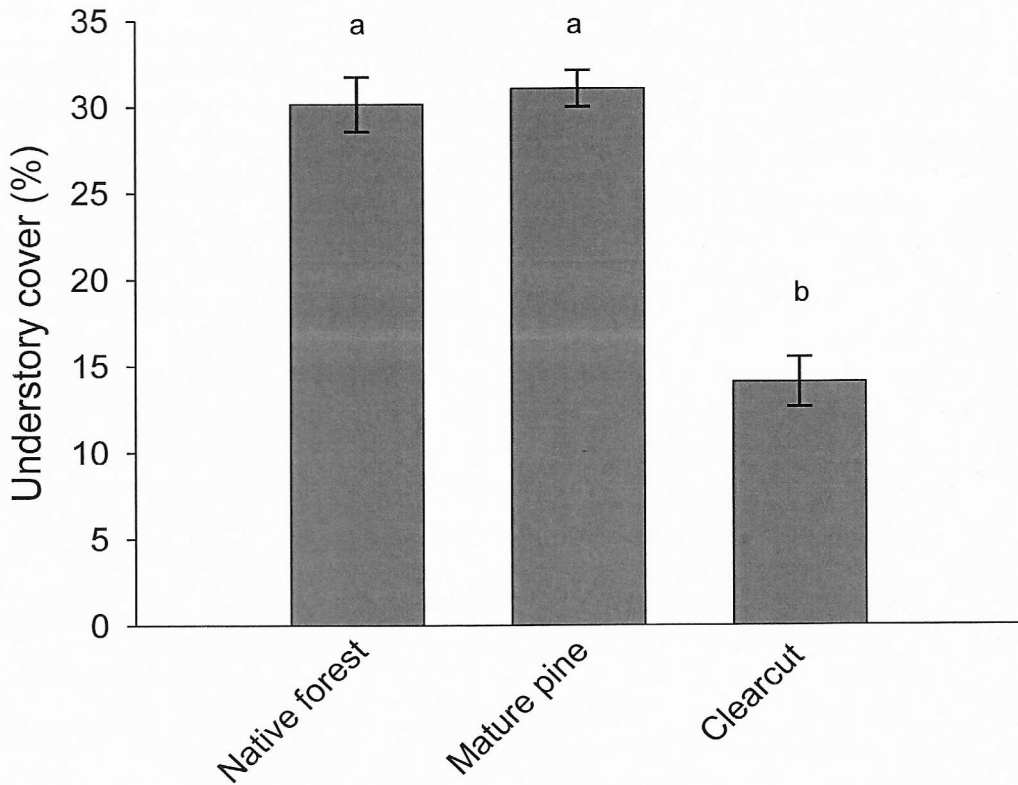
Fig. 1: Understory cover (%) in native forest, mature pine and clearcut. Different letters indicate significant differences.

In each sampling point, we conducted four bird surveys during the breeding season of *P. castaneus* (Sep-Dec 2014, the austral spring) and 4 bird surveys during their post-breeding season (Jan-March 2015, the austral summer), resulting in a total of 240 visits to sampling points (i.e., 3,2 hr; Table 1). Surveys were started at dawn (05:30 a.m.) and continued until 12:00 p.m.

Table1. Sampling effort allocated to broadcast surveys per type of habitat (native forest, mature pine and clearcut) and season (breeding vs. post-breeding season). For each treatment the number of visits, number of points-counts, duration of each survey (min) and total duration of sampling (h) are included.

Habitat	Broadcast survey							
	Breeding season				Post-breeding season			
	Visits/point	Points	min	Total (h)	Visits/point	Points	min	Total (h)
Native forest	4	6	8	3.2	4	6	8	3.2
Mature pine	4	6	8	3.2	4	6	8	3.2
Clearcut	4	18	8	9.6	4	18	8	9.6

2.3. Bird movement

We used playback experiments to assess the willingness of *P. castaneus* to move from native forest and mature pine stands into adjacent clearcut stands. We selected 20 clearcut stands adjacent to a native forest fragment and 20 clearcut stands adjacent to a mature pine plantation stand. Trials were repeated 2 or 3 times (Table 2). Playback trials involve of playing *P. castaneus* vocalizations and territorial songs using a portable speaker. We followed the protocol described by Tomasevic and Estades (2008), which consists in playing vocalizations and territorial songs during three 1-min periods separated by 3 min (1+3+1+3+1+3= 12 min). First, the bird was attracted to the edge between the clearcutting and either, a native forest or a mature pine stand. Then, the playback experiment started only if the attracted bird approached to less than 2 m from the edge. Failed attempts for attracting birds to the edge were discarded for posterior analysis (Table 2). Second, one successful trial involved that the observer moving 25 m into the clearcut stand, perpendicularly to the edge. Third, if the bird was observed crossing to the clearcut stand, then the observer moved an additional 25 m into the stand, with a new playback session being carried out at 50 from the edge. We recorded two edge crossing responses, firstly, the binary response of *P. castaneus* to move, or

not to move, into de clearcut stand, and secondly, the distance traveled by the bird, measured with 1 m resolution (i.e., 0-1, 1-2, 2-3,.., 49-50 m). We selected 20 native forest-clearcut edges and 20 mature pine-clearcut edges that were visited during the breeding (Oct 2014-Dec 2014) and post-breeding seasons (Jan 2015-March 2015; Table 2). Experimental playback trials started at dawn (05:30 a.m.) and continued until 12:00 p.m.

Table 2. Summary of playback experiments designed to evaluate the movement of *P. castaneus*, including the number of experimental locations, number of attempts for attracting birds to edges, number of trials and success rate for each edge type (native forest or mature pine) and season (breeding or post-breeding season).

Edge type	Stand (n)	Season	Attempts (n)	Trials (n)	Success (%)
Mature pine	20	Breeding	42	33	78.6
Mature pine		Post-breeding	39	25	64.1
Native forest	20	Breeding	41	33	80.5
Native forest		Post-breeding	47	34	72.3
Total	40		169	125	73.9

In order to assess the effect of understory development upon the movement of *P. castaneus*, we measured the understory cover in each edge type (native forest-clearcut and mature pine-clearcut) along a 102 m linear transect, perpendicularly to the forest edge. The understory cover within the native forest and mature pine stands was 4.4 and 3.2 times higher than the understory cover at the adjacent clearcut stand respectively (t-test; n=40; p-value=$5,84 \times 10^{-12}$; Fig. 2).

-15	-10	-5	0	5	10	
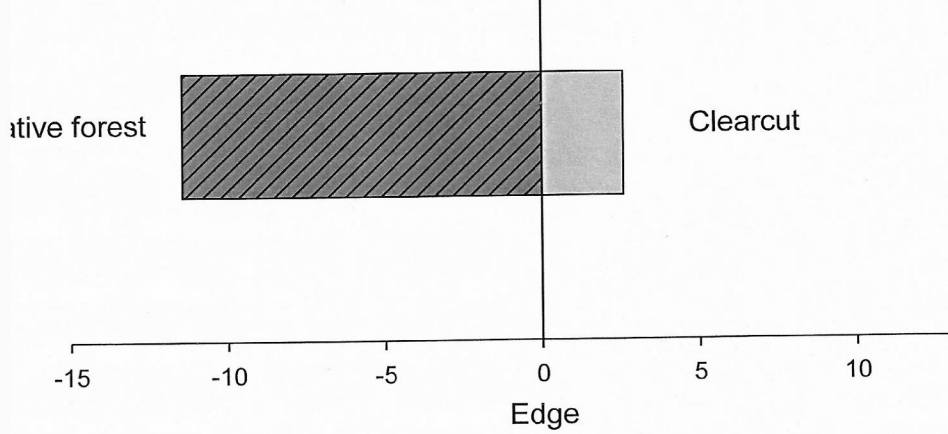
Edge

Understory cover (intersections/circular plot)

…rstory cover (intersections/circular plot) of each edge type: native forest-mature pine-clearcut.

alysis

Poisson-binomial mixture Bayesian model, as proposed by Royle (2004a, b)

…ry et al. 2005), to assess the abundance of *P. castaneus* from samples of

…int counts ($j=1, 2,....k$; with k being the number of survey visits at the point i)

…nting for imperfect detections of bird individuals resulting from sampling

…ors. This modelling approach assumes that *P. castaneus* observed on

…ounts at the same point (C_{ij}) are k independent realizations of a Binomial

…iable, $C_{ij} \sim$ Binomial (N_i, p_{ij}). Parameter N_i is an unknown latent Poisson

11

distributed variable, $N_i \sim Poisson (z_i \lambda_i)$, such that λ_i is the mean abundance in the point i and z_i a coefficient (ranging between 0 and 1) accounting for overdispersion resulting from zero inflation (Kéry and Schaub, 2012). The detection probability, p_{ij}, varies over repeated counts and depends on temporal covariates (see as follows below). The function establishing the relationship between the local mean abundance (λ) and habitat covariates is:

$$log(\lambda_i) = \beta_0 + \beta_1 \, UC_i + \beta_2 H_i + \beta_3 (UC_i \times H_i) \qquad [1]$$

Where β_l (l=0, 1,..4) are the fixed-effect model coefficients (including an intercept), UC_i is the understory (%) covering the point i, H_i is a factor giving the habitat type in the point i (i.e., clearcut, native forest or mature pine). $UC_i \times H_i$ is an interaction term between the latter two covariates accounting for an understory cover effect depending on the type overstory habitat. Detection probability, p_{ij}, at site i during the time period j was estimated with the following logit function:

$$logit(p_{ij}) = \alpha_0 + \alpha_1 \, SM_{ij} + \alpha_2 S_j \qquad [2]$$

Where SM_{ij} is the survey method (passive or broadcast survey) used during the survey repetition j at the point i whereas S_j is the season (breeding or post-breeding) during which the point was surveyed.

For each successful experiment trial i carried out in the experimental clearcut stand j the distance moved by $P.\ castaneus$ into the stand was evaluated using a zero-inflated Poisson (ZIP) model. ZIP models were appropriate for analyzing our movement data because they included excess zeros that resulted from birds deciding not to enter into the clearcut. The discrete response variable (the distance interval; see above) is

modeled with a likelihood function that combines the Bernoulli-distributed binary response of *P. castaenus* to move into thee clearcut stand (with probability *P*) and the distance (m) traveled by the *P. castaneus* into the clearcut stand, which is drawn from a Poisson distribution, with parameter Λ being the mean distance moved. Λ was modeled as a function of habitat covariates:

$$log(\Lambda_{ji}) = \beta_0 + \beta_1 \, UC_j + \beta_2 \, UF_j + \beta_3\left(UC_j \times ET_j\right) + \beta_4\left(UF_i \times ET_j\right) \quad [3]$$

where UC_j is the understory cover (%) in the clearcut stand *j*, UF_j is the understory cover (%) in either, the native forest or pine plantation, adjacent to the experimental clearcut stand *j*, ET_j is the habitat or "edge" type adjacent to the clearcut stand (i.e., native forest or mature pine). The interaction terms $UC_j \times ET_j$ and $UF_j \times ET_j$ assess if the effect of understory cover changes with the edge type. The probability a *P. castaneus* enters into the clearcut (*P*) was modeled as:

$$logit(P_{ij}) = \alpha_0 + \gamma_j \quad [4]$$

This is basically a function of a random effect coefficient (*γj*) for the experimental stand j representing the effect of individuals responding differently to vocalizations and territorial songs in each spatial location.

We developed models containing all possible combinations of covariates, including Poisson-binomial mixture models for bird abundance (Eq.[1] and Eq.[2]) and ZIP models for movement distance (Eq.[3] and Eq.[4]). The Deviance Information Criteria (DIC) and differences in DIC (ΔDIC) were used to interpret the strength of evidence for each competing model (Spiegelhalter et al., 2003). Models with ΔDIC<2 were considered to be supported by the data. The importance of each fixed effect coefficient

was evaluated by examining their Bayesian Credible Intervals (BIC) estimated from posterior distribution of parameters. The 95% BCIs that did not overlap zero were considered as being significant. We used vague non-informative prior distributions for all model parameters. Parameters γ_r were assumed to be Gaussian distributed associated to each experimental stand. Parameter distributions were based on three Markov Chain Monte Carlo (MCMC) samples, each with 20,000 iterations, discarding the first 10,000 iterations and thinning by 3. MCMC Convergence was visually examined and by using the Potential Scale Reduction factor. Models were run using OpenBUGS via the R2 OpenBUGS package of R.

3. Results

3.1. Bird abundance

The observed abundance of *P. castaneus* varied between habitats and seasons (Fig. 3). *P. castaneus* does not dwell clearcut stands. Even more, in 144 visits to the clearcuts stands only one individual (0,69%) was observed in post-breeding season by broadcast survey (Fig. 3). Nevertheless, the observed abundance of *P. castaneus* in both breeding and post-breeding season, in native forest was higher than in mature pine.
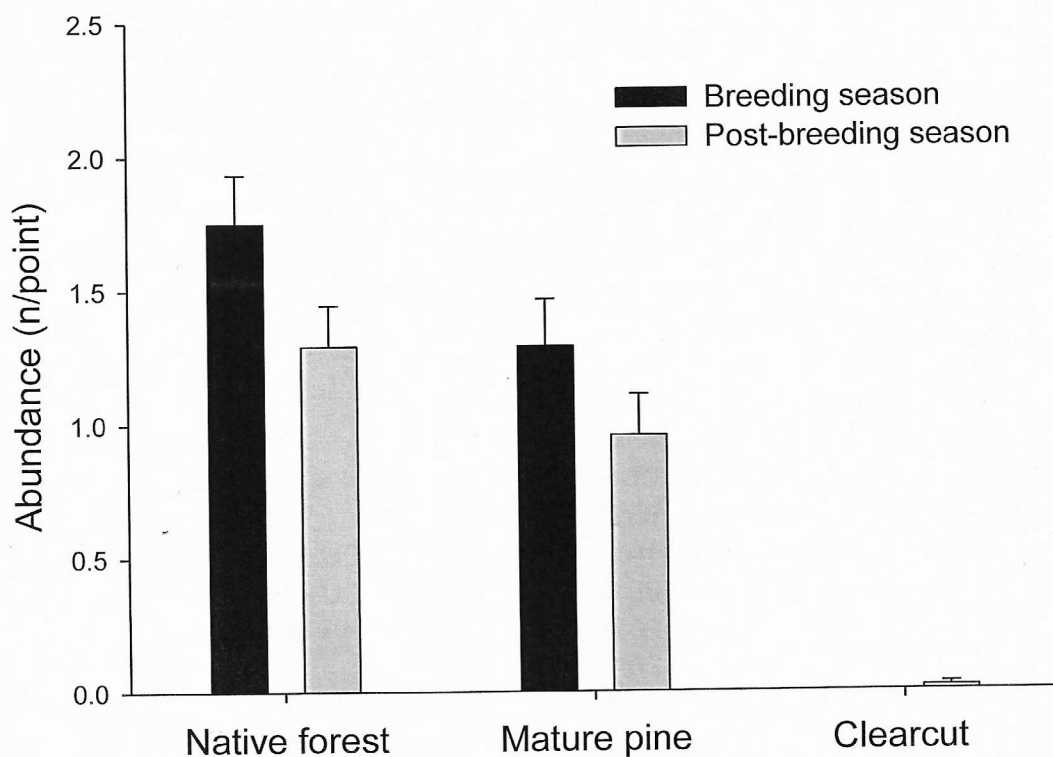
Fig 3: Observed abundance (n/point) of *P. castaneus* in native forest, mature pine and clearcut in breeding season (black bars) and post-breeding season (grey bars).

The two models with better fit to the data (Table 3) included as covariates understory cover (UC) and its interaction with habitat type (UC x H). Abundance of *P. castaneus* is positively associated whit the understory cover in both native forest and mature pine plantations (understory cover vegetation was approximately 30%) but not in clearcut stands (Table 4). The significant interaction between understory cover and habitat type (UC x H; Table 4) indicates that *P. castaneus* responds to the understory cover only in those habitats that provide them with a canopy developed such as pine plantations and native forest.

Table 3. Poisson-binomial mixture Bayesian models to predict the abundance of *P. castaneus*. Covariates of abundance and detectability models are shown separately. The mean, standard deviations (SD), 95% lower and upper Bayesian credible intervals, Deviance's Information Criterion (DIC) and difference DIC with the lowest model (ΔDIC) are shown. Codes of covariates of the detectability model are: SM=survey method and S=season. Codes for covariates of the abundance model are: UC=understory cover and H=habitat

Detectability model	Abundance model	Deviance Mean	SD	2.50%	97.50%	DIC	ΔDIC
SM + S	UC	434.83	5.36	427.1	447.6	449.17	0.00
SM + S	UC × H	435.42	5.59	420.6	450.2	450.22	1.05
SM	UC	438.56	5.14	431.3	450.9	451.76	2.59
SM + S	H	434.69	6.42	425.4	450.1	455.21	6.04
SM + S	UC + H	437.09	6.06	428.0	451.3	455.29	6.11
SM	UC × H	440.58	5.54	432.3	453.6	455.90	6.73
SM + S	UC + UC × H	437.58	6.19	428.3	452.0	456.71	7.54
SM	UC + H	441.41	5.85	432.4	454.6	458.53	9.36
SM + S	UC + H + UC × H	438.81	6.91	428.8	455.7	462.27	13.10
SM	UC + H + UC × H	442.45	6.38	432.9	457.3	462.70	13.52
SM	UC + UC × H	442.11	6.69	432.4	458.6	464.42	15.25
SM	H	439.92	7.32	429.5	457.2	466.13	16.96
SM + S	H + UC × H	438.69	11.05	425.9	468.3	497.23	48.05
SM	H + UC × H	454.05	16.22	430.9	479.3	524.17	75.00

Table 4. Coefficients values of the best-supported zero-inflated Poisson (ZIP) model of Table 3. The means, standard deviations (SD) and 95% lower and upper Bayesian credible intervals are shown. Codes of covariates for the abundance model are: UC=understory cover and H=habitat. Codes of covariates of the detectability model are: SM=survey method and S=season

Effect	Mean	SD	2.50%	97.50%
Abundance model				
UC	0.13	0.03	0.08	0.18
UC × H (native forest)	0.34	0.12	0.15	0.65
UC × H (mature pine)	0.33	0.12	0.14	0.64
Detectability model				
SM	0.86	0.19	0.49	1.25
S	-0.35	0.18	-0.71	-0.01

3.2. Bird movement

Movements of *P. castaneus* to clearcutting stand were scarce. From a total of 125 trials, only 18 times (14.4%) birds crossed to clearcutting (Table 5). The proportion of *P. castaneus* that moved from native forest to clearcut stand was not different from the proportion that moved from mature pine to clearcut stand (Table 6).

Although *P. castaneus* individuals were reluctant to enter into clearcutting at high frequencies (distance intrusion = 0) in both breeding and post-breeding season, some birds did do so. Distance of intrusion traveled by a *P. castaneus* to clearcutting is greater if coming from native forest (Figs. 4 and 5).

Table 5. Results playback experiments to assess movement *P. castaneus.*

Edge type/Season	To clearcut stand	
	Crossing	Not cross
Native forest/breeding season	6 (18,2%)	27 (81,8%)
Native forest/post-breeding season	4 (11,8%)	30 (88,2%)
Mature pine/breeding season	3 (9,1%)	30 (90,9%)
Mature pine/post-breeding season	5 (20%)	20 (80%)
Total	18 (14,4%)	107 (85,6%)

Table 6. Total number of *P. castaneus* that crossed from native forest or mature pine plantation to clearcut (n), mean distance of intrusion and total numbers of playback experiments (trials) are shown. Differences in proportions between individuals moving from a given habitat to clearcut stand are tested by Fisher exact test (one-tailed).

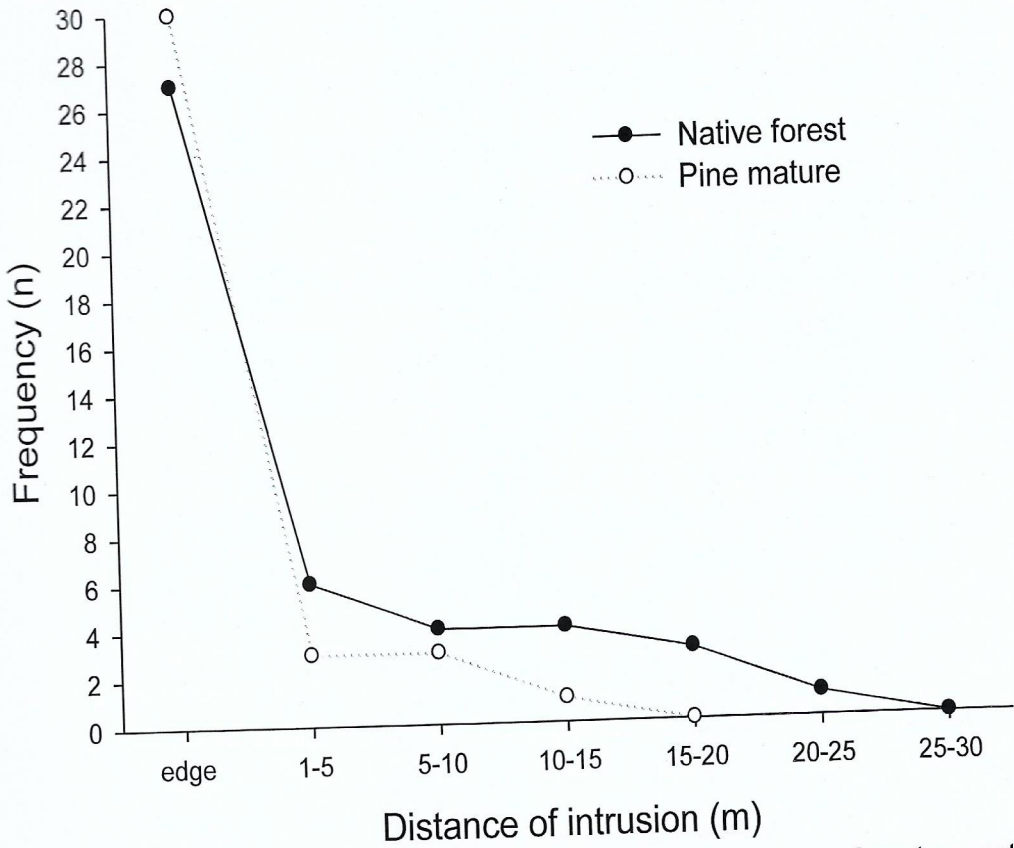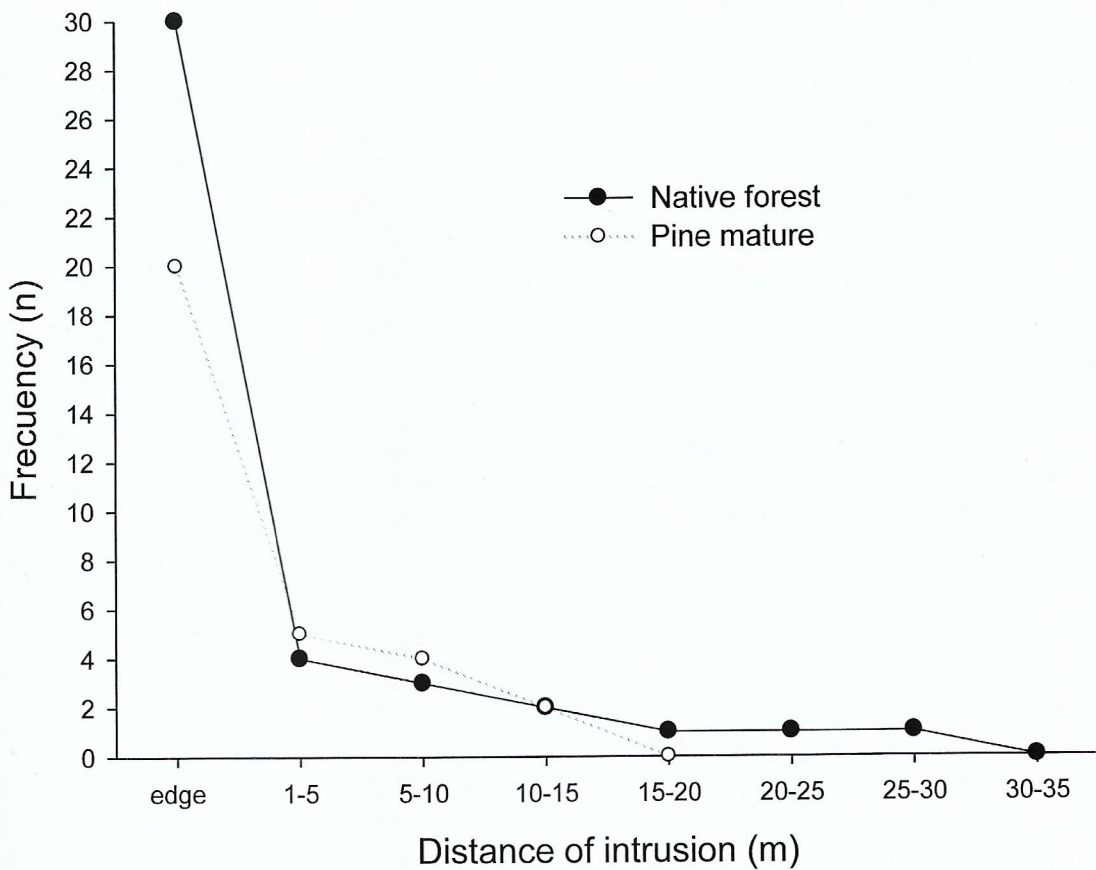| Edge type	Crossing (n)	Mean distance of intrusion (m)	SE	Trials (#)	Fisher (p)
Native forest	10	11,3	±2,4	67	0,66
Mature pine	8	8,4	±1,3	58	

Fig. 4: Frequency of *P. castaneus* that crossing edge from native forest or mature pine plantation, entering to clearcut stand in breeding season.

Fig. 5: Frequency of *P. castaneus* that crossing edge from native forest or mature pine plantation, entering to clearcut stand in post-breeding season.

The covariates of three models with better fit to the data (Table 7) and the values of the coefficients associated with each of these fixed effects (Table 8) indicate that the willingness of *P. castaneus* to move into the clearcutting is positively associated with the understory cover present in clearcut stands as well as the understory cover present in the habitat from where they move to (i.e., native forest or mature pine). The effect of the understory cover, however, was significantly larger when individuals entered from mature pine plantations than when doing from native forest (Table 8).

Table 7. Poisson-binomial mixture Bayesian models explaining the distance moved by *P. castaneus* into clearcut. Codes of covariates are: UF=understory cover in the forest (mature pine or native forest), UC= understory in clearcutting, ET= edge type, S=season.

Model	Deviance				DIC	ΔDIC
	Mean	SD	2.50%	97.50%		
ET×UC + ET×UF + UC + UF	150.3	4.3	143.0	159.9	157.8	0.0
ET×UC + ET×UF + UC + UF + ET	152.5	4.2	145.6	162.0	159.7	1.9
UC+ UF + UC×UF + ET	151.3	4.9	143.0	162.2	159.7	1.9
ET×UC + ET×UF + UC + UC×UF	154.2	3.9	147.7	163.2	160.9	3.1
ET×UC + ET×UF + UC + UF + S	153.9	4.1	147.0	163.1	161.5	3.7
ET×UC + ET×UF + UF + UC + UC×UF	154.6	4.3	147.4	164.2	162.0	4.2
ET×UC + ET×UF + UC	157.1	3.8	150.6	165.5	163.0	5.2
UC+ UF + UC×UF	159.0	5.1	150.2	170.2	165.5	7.8
UC	160.3	4.7	152.1	170.2	166.6	8.8
UC + S	161.5	5.0	152.7	172.3	168.5	10.7
UC + UF	161.6	4.8	153.1	172.0	168.8	11.1
UC + UF +ET	162.0	4.9	153.3	172.6	169.8	12.0
UC+ UF + S	162.7	5.1	154.0	173.5	170.7	12.9
UC + UC×UF +ET	163.6	5.1	154.8	174.4	171.3	13.5
UC + UF + ET + S	162.9	4.9	154.2	173.6	171.4	13.6
ET×UC + ET×UF	168.4	5.0	159.8	179.4	174.6	16.8
UF	177.7	5.1	168.5	188.7	183.4	25.6

Table 8. Coefficients value of the best-supported ZIP models shown in Table 8. The means, standard deviations (SD) and 95% lower and upper Bayesian credible intervals are shown. Codes for independent variables are: UF=understory cover in the forest (mature pine or native forest), UC= understory in the clearcut and ET= edge type.

Effect	mean	SD	2.50(%)	97.50(%)
UC	0.91	0.15	0.58	1.17
UF	0.73	0.39	-0.13	1.43
ET × UC	2.09	0.61	0.95	3.33
ET × UF	1.26	1.22	-1.07	3.77
ET	-1.32	0.84	-3.05	0.18
UF	2.97	0.86	1.19	4.53
UC × UF	-3.12	0.93	-4.79	-1.21

4. Discussion

The presence of a structurally complex and diverse understory vegetation could mitigate the negative effects of clearcutting by improving habitat quality and increasing biological connectivity between remaining habitat patches (Popescu and Hunter, 2011; Acuña, 2010). This positive understory effect could be especially beneficial for understory specialist bird species with a low dispersal capability, such as the Chestnut-throated Huet-huet (*Pteroptochos castaneus*) (Willson et al., 1994). However, my results clearly indicate that understory vegetation at clearcut stands less than 3-4 years old is insufficient to improve the habitat quality for *P. castaneus*. In contrast, understory vegetation present in both native forest and mature pine plantations improves habitat quality for *P. castaneus*. Previous studies support these results, in which the abundance of *P. castaneus* in mature pine stands was directly associated with understory cover (e.g. Vergara and Simonetti, 2006).

The understory vegetation can also promote the movement of animals by improving its willingness to cross open habitats (Sieving et al., 1996; Vergara and Simonetti, 2006; Tomasevic and Estades, 2008). Although our results showed that the *P. castaneus* tends to be reluctant to move to harvested areas, some individuals entered into clearcuttings. These findings are consistent with previous studies of Tapaculos, where both the willingness to enter into mature pine plantations and the distance of intrusion were positively associated with the presence of understory (Vergara and Simonetti, 2006; Tomasevic and Estades, 2008). Clearcut stands are extensive open areas whose sparse understory vegetation does not supply shelter and foraging resources for *P. castaneus*, thus acting as a hostile matrix of high resistance for the movement (e.g. Sieving et al. 1996). The negative effect of clearcutting on forest bird population is

23

consistent with the negative perception of forest birds to open habitats, such as grasslands. In fact, tapaculos inhabiting native forest fragments surrounded by grasslands in agricultural landscapes of southern Chile perceive the open matrix as a barrier, compelling them to move between fragments through riparian corridors (Sieving et al., 1996; 2000).

Several studies in fragmented landscapes support that the structural contrast between vegetation of native forest fragments and the matrix influences the ability of wildlife to cross these boundaries and move to other fragments (Collinge and Palmer, 2002; Kupfer et al., 2006). In our study, we observed that the vegetation contrast across boundaries of mature pine plantation-clearcut stand is less abrupt when compared to the boundary between native forests-clearcut stands. The less structural differences marked between mature pine and clearcutting would explain the stronger understory vegetation effect on individuals moving from pine plantations (see Table 8). Therefore, gradual gradients in the understory vegetation, as observed between pine stands and clearcutting, could lead to boundaries which act as soft barriers (Schieck et al., 1995).

Intensively managed plantations usually have a detrimental effect on the biodiversity (Hayes et al., 2005). Hence, we propose that sustainable forestry management should provide to forest-dwelling birds, understory vegetation through adopting stand- and landscape-level silvicultural practices that promote the retention and growth of understory plants (Willson et al. 2004; Paquette and Messier, 2009; Tomasevic and Estades, 2008; Acuña, 2010; Simonetti et al. 2012; Simonetti and Estades, 2015).For example, through the reducing in the use of herbicides. Understory vegetation in clearcutting is suppressed by up to 80% percent by using herbicides before seeding

and may be repeated one or two seasons after the establishment of the plantation (Kogan et al., 2002). Herbicides are used to ensure the productivity of forest stands through reducing competition for water resources and nutrients between understory plants and planted pine trees (Kogan et al., 2002). Thus, weed control involves a trade-off between the economic gains from forestry and biodiversity conservation. Sustainable forestry practices improving the abundance and movement of Tapaculos may also include the retention of woody debris such as logs, stumps and dead branches on the understory (Vergara and Simonetti 2006, Tomasevic and Estades 2008). At the landscape scale, the negative effect of clearcutting may be reduced though wildlife corridors connecting isolated native forest fragments and/or mature pine plantations (Franklin and Forman, 1987; Popescu and Hunter, 2011; Willson, 2004). In addition, leaving hedges of standing pines after the harvest time could promote the movement of wildlife. These movement corridors should increase the diversity of habitat and ensure the persistence of forest specialist species while maintaining the habitat of early successional species (Constantine et al., 2004). Finally, the conservation of *P. castaneus* in forest plantation landscapes should be carried out through modifying the traditional clearcutting system into sustainable forest practices that ensure habitat suitability and connectivity.

5. Appendix

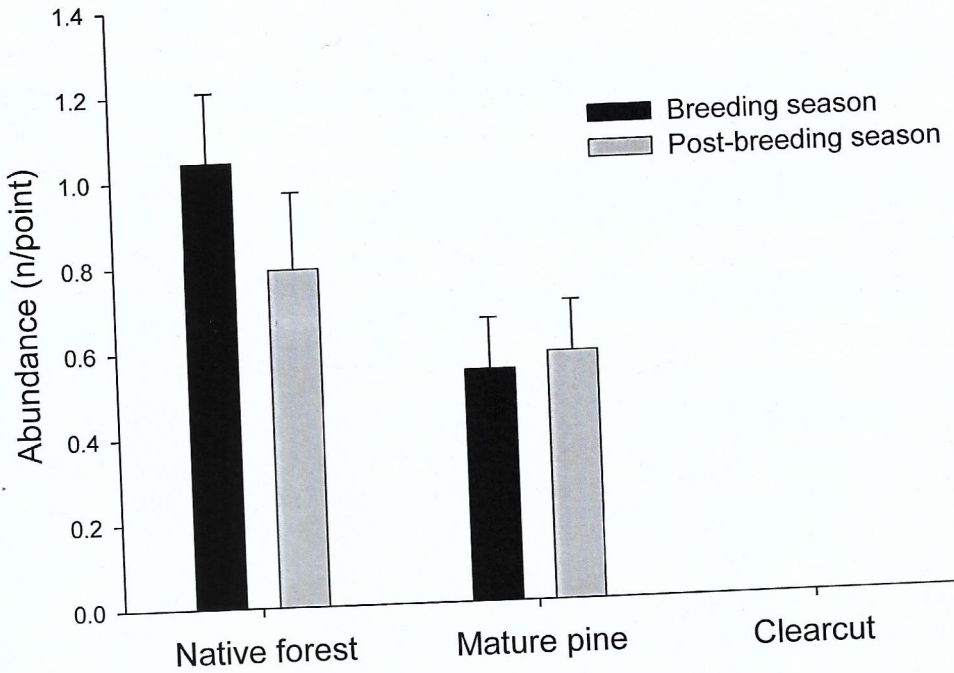A.1. Passive survey: sampling effort, bird abundance and detection probability.

We conducted four passive surveys during the breeding season of *P. castaneus* (Sep-Dec 2014, the austral spring) and 4 passive surveys during post-breeding season (Jan-March 2015, the austral summer), resulting in a total of 240 visits to sampling points (i.e., 3,2 hr; Table A.1). Surveys were started at dawn (05:30 a.m.) and continued until 12:00 p.m.. Using passive survey, abundance of *P. castaneus* varied between season and habitat (Fig. A.1), but the tendency does not differ significantly from that observed by broadcast survey (see above broadcast survey results).

On the other hand, detectability model indicates that detection probability increases using broadcast survey (Table A.2). Broadcast survey improves detectability of territorial *P. castaneus* because once the bird responds to playback through their own singing enables an observer to detect it (Saracco et al. 2011).

Previous studies have shown an increased *P. castaneus* abundance by playback surveys (Vergara and Simonetti, 2006), but these studies have not assessed differences in detection probabilities between passive and broadcast survey, modelled in this study (see above data analysis subsection).

Table A.1. Summary sampling effort by passive survey showing type of habitat (native forest, mature pine and clearcut), season (breeding vs. post-breeding season), number of visits, points-counts, duration of each survey (min) and total duration of sampling (h) are shown.

| Habitat | Passive survey | | | | | | | |
| | Breeding season | | | | Post-breeding season | | | |
	Visits/point	Points	min	Total (h)	Visits/point	Points	min	Total (h)
Native forest	4	6	8	3.2	4	6	8	3.2
Mature pine	4	6	8	3.2	4	6	8	3.2
Clearcut	4	18	8	9.6	4	18	8	9.6

Fig. A.1: Abundance of *P. castaneus* (n/point) in native forest, mature pine and clearcut in breeding season (black bars) and post-breeding season (grey bars).

Table A.2. Detection probability (P) of *P. castaneus* with two methodologies of survey. Table showing results by season, mean, standard deviations (SD) and 95% lower and upper Bayesian credible intervals.

Survey Method / Season	Detection probability (p)			
	mean	SD	2.50%	97.50%
Passive/ reproductive	0.28	0.04	0.20	0.37
Passive/ post-reproductive	0.21	0.04	0.15	0.29
Broadcast / reproductive	0.49	0.06	0.36	0.61
Broadcast / post-reproductive	0.40	0.06	0.29	0.51

6. References

Acosta-Jamett, G., Simonetti, J.A., 2004. Habitat use by Oncifelis guigna and Pseudalopex culpaeus in a fragmented forest landscape in central Chile. Biodivers. Conserv. 13, 1135–1151.

Acuña, M.P., 2010. Simulacion del efecto de diferentes esquemas de cosecha de plantaciones de *Pinus radiata* en la conectividad biológica en Chile Central. Universidad de Chile, Santiago.

Acuña, M.P., Estades, C.F., 2011. Plantation clearcut size and the persistence of early-succesional wildlife populations. Biol. Conserv. 144, 1577–1584.

Bélisle, M., Desrochers, A., 2002. Gap-crossing decisions by forest birds: an empirical basis for parameterizing spatially-explicit, individual-based models. Landsc. Ecol. 17, 219–231.

Burns, C.E., Grear, J.S., 2008. Effects of habitat loss on populations of white-footed mice: testing matrix model predictions with landscape-scale perturbation experiments. Landsc. Ecol. 23, 817–831.

Bustamante, R.O., Simonetti, J.A., Grez, A.A., San Martin, J., 2005. Fragmentación y dinámica de regeneración del bosque maulino: diagnóstico actual y perspectivas futuras, in: Smith-Ramirez, C., Armesto, J.J., Valdovinos, C. (Eds.), Historia, biodiversidad y ecología de los bosques de la Cordillera de la Costa. Editorial Universitaria, Santiago, pp. 555–564.

Castellón, T.D., Sieving, K.E., 2006. An experimental test of matrix permeability and corridor use by an endemic understory bird. Conserv. Biol. 20, 135–145.

Cerda, Y., Grez, A.A., Simonetti, J.A., 2015. The role of the understory on the abundance, movement and survival of *Ceroglossus chilensis* in pine plantations: an experimental test. J. Insect Conserv. 119–127.

Collinge, S.K., Palmer, T.M., 2002. The influences of patch chape and boundary contrast on insect response to fragmentation in California grasslands. Landsc. Ecol. 17, 647–656.

Estades, C.F., Escobar, M.A.H., 2005. Los ecosistemas de las plantaciones de pino de la Cordillera de la Costa, in: Smith-Ramirez, C., Armesto, J.J., Valdovinos, C. (Eds.), Historia, biodiversidad y ecología de los bosques de la Cordillera de la Costa. Editorial Universitaria, Santiago, pp. 600–616.

Estades, C.F., Grez, A.A., Simonetti, J.A., 2012. Biodiversity in Monterrey pine plantations, in: Simonetti, J.A., Grez, A.A., Estades, C.F. (Eds.), Biodiversity Conservation in agroforestry landscapes: challenges and opportunitites. Editorial Universitaria, Santiago, pp. 77–98.

Estades, C.F., Temple, S.A., 1999. Deciduous-forest birds communities in a fragmented landscape dominated by exotic pine plantations. Ecol. Appl. 9, 573–585.

FAO (Food and Agriculture Organization of the United Nations), 2015. Global Forest Resources Assessment.

Franklin, J.F., Forman, R.T.T., 1987. Creating landscape patterns by forest cutting: Ecological consequences and. principles. Landsc. Ecol. 1987.

Garcia, V., Simonetti, J.A., 2014. Procesos limitantes en la regeneracion del sotobosque en las plantaciones de *Pinus radiata* D. Don en Chile Central. Universidad de Chile, Santigo.

Grez, A.A., Moreno, P., Elgueta, M., 2003. Coleópteros (Insecta: Coleoptera) epigeos asociados al bosque maulino y plantaciones de pino aledañas. Rev. Chil. Entomol. 29, 9–18.

Grez, A.A., Zaviezo, T., Tischendorf, L., Fahrig, L., 2004. A transient, possitive effect of habitat fragmentation on insect population densities. Oecologia 141, 444–451.

Hartley, M.J., 2002. Rationale and methods for conserving biodiversity in plantation forests. For. Ecol. Manag. 155, 81–95.

Hayes, J., Schoenholtz, S., Hartley, M., Murphy, G., Powers, R., Berg, D., Radosevich, S., 2005. Environmental consequences of intensively managed forest plantations in the Pacific Northwest. J. For. 103, 83–87.

Jaramillo, Á., 2005. Aves de Chile. Lynx Edicions, Barcelona.

Keenan, R.J., Kimmins, J.P., 1993. The ecological effects of clear-cutting. Environ. Rev. 1, 121–144.

Kéry, M., Royle, A.J., Schmid, H., 2005. Modeling avian abundance from replicated counts using binomial mixture models. Ecol. Appl. 15, 1450–1461.

Kéry, M., Schaub, M., 2012. Estimation of abundance from counts in metapopulation designs using the binomial mixture model, in: Kéry, M., Schaub, M. (Eds.), Bayesian Population Analysis Using WinBUGS. Academic Press, Boston, pp. 383–411.

Kogan, M., Figueroa, R., Gilabert, H., 2002. Weed control intensity effects on young radiata pine growth. Crop Prot. 21, 253–257.

Kupfer, J.A., Malanson, G.P., Franklin, S.B., 2006. Not seeing the ocean for the islands: the mediating influence of matrix-based processes on forest fragmentation effects. Glob. Ecol. Biogeogr. 15, 8–20.

Lindenmayer, D.B., Hobbs, R.J., 2004. Fauna conservation in Australian plantation forests-a review. Biol. Conserv. 119, 151–168.

Lindenmayer, D.B., Wood, J.T., Cunningham, R.B., Crane, M., Macgregor, C., Michael, D., Montage-Drake, R., 2009. Experimental evidence of the effects of a changed matrix on conserving biodiversity within patches of native forest in an industrial plantation landscape. Landsc. Ecol. 24, 1091–1103.

Niklitschek, M.E., 2015. El surgimiento de restricciones al tamaño de la tala rasa, in: Niklitschek, M.E. (Ed.), Tamaño de la tala rasa en plantaciones forestales: efectos y regulación. Editorial Universitaria, Santiago, pp. 17–30.

Paquette, A., Messier, C., 2009. The role of plantations in managing the world´s forests in the Anthropocene. Front. Ecol. Environ. 8, 27–34.

Pawson, S.M., Brockerhoff, E.G., Norton, D.A., Didham, R.K., 2006. Clear-fell harvest impacts on biodiversity: past research and the search for harvest size thresholds. Can. J. For. Res. 36, 1035–1046.

Pawson, S.M., Brockerhoff, E.G., Watt, M.S., Didham, R.K., 2011. Maximising biodiversity in plantation forests: insights from long-term changes in clearfell-sensitive beetles in a Pinus radiata plantation. Biol. Conserv. 144, 2842–2850.

Payn, T., Carnus, J.-M., Freer-Smith, P., Kimberley, M., Kollert, W., Liu, S., Orazio, C., Rodriguez, L., Silva, L.N., Wingfield, M.J., 2015. Changes in planted forests and future global implications. For. Ecol. Manage. 352, 57–67.

Poch, T.J., Simonetti, J.A., 2013. Insectivory in Pinus radiata plantations with different degree of structural complexity. For. Ecol. Manage. 304, 132–136.

Popescu, V.D., Hunter, M.L., 2011. Clear-cutting affects habitat connectivity for a forest amphibian by decreasing permeability to juvenile movements. Ecol. Appl. 21, 1283–1295.

Royle, A.J., 2004a. Generalized estimators of avian abundance from count survey data. Anim. Biodivers. Conserv. 27, 375–386.

Royle, A.J., 2004b. N-mixture models for estimating population size from spatially replicated counts. Biometrics 60, 108–115.

Saavedra, B., Simonetti, J.A., 2005. Micromamíferos en fragmentos de bosque maulino y plantaciones de pino de aledañas, in: Smith-Ramirez, C., Armesto, J.J., Valdovinos, C. (Eds.), Historia, biodiversidad y ecología de los bosques de la Cordillera de la Costa. Editorial Universitaria, Santiago, pp. 532–536.

Saracco, J.F., Siegel, R.B., Wilkerson, R.L., 2011. Occupancy modeling of Black-backed Woodpeckers on burned Sierra Nevada forests. Ecosphere 2, 1–17. doi:10.1890

Schieck, J., Lertzman, K., Nyberg, B., Page, R., 1995. Effects of patch size on birds in Old-Growth Montane Forests. Conserv. Biol. 9, 1072–1084.

Sieving, K.E., Willson, M.F., De Santo, T.L., 2000. Defining corridor functions for endemic birds in fragmented South-temperate Rainforest. Conserv. Biol. 14, 1120–1132.

Sieving, K.E., Willson, M.F., De Santo, T.L., 1996. Habitat barriers to movement of understory birds in fragmented south-temperate rainforest. Auk 113, 944–949.

Simonetti, J.A., 2006. Conservación de la biodiversidad en ambientes fragmentados: el caso del bosque maulino, in: Grez, A.A., Simonetti, J.A., Bustamante, R.O. (Eds.), Biodiversidad en ambientes fragmentados de chile: patrones y procesos a diferentes escalas. Editorial Universitaria, Santiago, pp. 215–231.

Simonetti, J.A., Estades, C.F., 2015. Efectos de la tala rasa sobre la biodiversidad, in: Niklitschek, M.E. (Ed.), Tamaño de la tala rasa en plantaciones forestales: efectos y regulación. Editorial Universitaria, Santiago, Chile, pp. 85–104.

Simonetti, J.A., Grez, A.A., Estades, C.F., 2013. Providing habitat for native mammals through understory enhancement in forestry plantations. Conserv. Biol. 27, 1117–1121.

Simonetti, J.A., Grez, A.A., Estades, C.F., 2012. Biodiversity conservation in agroforestry systems: a pressing and challenging need, in: Simonetti, J.A., Grez, A.A., Estades, C.F. (Eds.), Biodiversity conservation in agroforestry landscapes: challenges and opportunities. Editorial Universitaria, Santiago, pp. 11–13.

Spiegelhalter, D., Thomas, A., Best, N., Lunn, D., 2003. WinBUGS Version 1.4 User manual. Medical Research Council Biostatistics Unit, Cambridge.

Tomasevic, J., Estades, C.F., 2008. Effects of the structure of pine plantations on their "softness" as barriers for ground-dwelling forest birds in south-central Chile. For. Ecol. Manage. 255, 810–816.

UN (UnitedNations), 2010. United Nations Convention on Biological Diversity, Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets. Secretariat of the Convention on Biological Diversity.

Vergara, P.M., Simonetti, J.A., 2003. Forest fragmentation and rhinocryptid nest predation in central Chile. Acta Oecologica 24, 285–288.

Vergara, P.M., Simonetti, J.A., 2004. Avian responses to fragmentation of the Maulino in central Chile. Oryx 38, 383–388.

Vergara, P.M., Simonetti, J.A., 2006. Abundance and movement of understory birds in a Maulino forest fragmented by pine plantations. Biodivers. Conserv. 15, 3937–3947.

Willson, M.F., 2004. Loss of habitat connectivity hinders pair formation and juvenile dispersal of Chucao Tapaculos in Chilean Rainforest. Condor 106, 166–171.

Willson, M.F., De Santo, T.L., Sabag, C., Armesto, J.J., 1994. Avian communities of fragmented South-temperate Rainforest in Chile. Conserv. Biol. 8, 508–520.

WWF (World Wildlife Fund), 2015. Saving Forest at risk, in: Living Forest Report. pp. 1–45.