Abundancia y movimiento de roedores en un paisaje forestal sometido a tala rasa

Tesis

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TESIS DE MAGÍSTER

Se informa a la Escuela de Postgrado de la Facultad de Ciencias que la Tesis de Magíster presentada por el candidato.

Matías Barceló Carvajal

Ha sido aprobada por la comisión de Evaluación de la tesis como requisito para optar al grado de Magíster en Ciencias Biológicas en el examen de Defensa Privada de Tesis rendido el día 11 de Diciembre de 2017.

Director de Tesis:

Dr. Javier A. Simonetti ....

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Dr. Rodrigo Vásquez ....

Dr. Claudio Veloso ....

Now it feels like I don't have to worry at all. It's finally forever.

Chris Cornell

RESUMEN BIOGRÁFICO

Matías nació en Santiago de Chile. De joven no fue naturalista, de hecho, ingresó a la carrera de Biología en la Universidad Católica por sus intereses en la biología celular. Este interés por la biología celular desapareció a los primeros años de carrera cuando comenzó a salir a cerros y conectarse con la naturaleza. Esto despertó su interés en la ecología, camino que finalmente tomó en su pregrado.

Naturalista tardío, amante de lo vivo, pajarólogo de corazón, aficionado por la fotografía, buscando "el momento decisivo", tal como Cartier-Bresson.

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RESUMEN GÉNERAL

La sustitución de bosque nativo por plantaciones forestales constituye el principal agente de cambio en la zona centro de Chile. Además disminuye la abundancia y riqueza de los pequeños mamíferos. Las plantaciones forestales son cosechadas mediante un sistema de tala rasa, que cambia la estructura del hábitat, reduciendo la abundancia de roedores de bosque. Dada la asociación de estos pequeños mamíferos con variables estructurales, mi hipótesis de trabajo indica que la presencia de vegetación arbustiva en plantaciones de pinos jóvenes después de operaciones de tala de árboles podría aumentar la abundancia de pequeños mamíferos de bosque y así, facilitar el movimiento del ratón de pelo largo (*Abrothrix longipilis*) desde bosques nativos o plantaciones de pinos a plantaciones de pinos jóvenes. La abundancia de roedores fue mayor en las plantaciones de pinos jóvenes con vegetación arbustiva desarrollada en relación cuando esta no estaba desarrollada. El ratón pelo largo está dispuesto a usar plantaciones de pinos jóvenes cuando se desarrolla la vegetación arbustiva. El manejo de las plantaciones de pinos jóvenes, a través del desarrollo de la vegetación, es necesario para mantener la diversidad de especies a lo largo de este paisaje forestal heterogéneo y para facilitar la recolonización de especies de roedores de bosque.

GENERAL ABSTRACT

Replacement of native forests by monoculture plantations of exotic species constitute the principal driver of land change in central Chile and decrease abundance

and richness of small mammals. In addition plantations are managed under a clearcutting system, which further change the habitat structure, reducing abundance of forest rodent species. Given the association of forest rodent species with structural variables, I hypothesized that presence of shrub vegetation at young pine plantations after clearcutting operations might increase the abundance of small mammal species and facilitate the movement of the forest rodent species, Long-haired field mouse (*Abrothrix longipilis*) from native forest or mature pine plantations to young pine plantations. Abundance of small mammals species were higher in young pine plantations with shrub vegetation developed than in it absence. The Long-haired field mouse are willing to use young pine plantations when shrub vegetation is developed. Management of young pine plantations, through developed of vegetation, would be necessary to maintain species diversity along this heterogeneous landscape and to facilitate rewilding of forest rodent species.

GENERAL INTRODUCTION

The replacement of native forest by exotic monoculture plantations is a widespread tendency worldwide (FAO 2010). Forestry plantations cover about 7% of global forest mass (FAO 2010) and pine plantations represents at least 20% of forestry plantations worldwide (Carle et al. 2002). A decrease in abundance and richness of mammals is observed due to replacement of native habitat by pine plantations (Ramirez and Simonetti 2011, Simonetti et al. 2013). Also, forestry activities are managed under a clearcutting system, which generate immediate changes in habitat attributes (Roberts & Zhu 2002, Niklitschek 2015). Hence, clearcutting further decreases the abundance of forest small mammals (Zwolak 2009; Bogdziewicz & Zwolak 2014). Despite information about the role of shrub vegetation on monoculture plantations enhancing habitat quality for mammals (Ramírez & Simonetti 2011), knowledge about rewilding harvested sites after clearcutting is scarce (Simonetti & Estades 2015). The aim of this work is (1) to assess abundance and richness of small mammals and his relation with microhabitat variables in a landscape dominated by monoculture of pine plantations, and (2) to assess movement of a forest rodent species at edges of contrasting habitats to test if vegetation facilitate the rewilding of forest rodent species to post harvested sites. In this sense, we hypothesized that shrub vegetation cover on post-harvested sites (i.e. young pine plantations) increases abundance of forest rodent species facilitating the movement from adjacent habitats.

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CHAPTER I

ENHANCING HABITAT QUALITY FOR SMALL MAMMALS AT YOUNG PINE PLANTATIONS AFTER CLEARCUTTING

ABSTRACT

Pine plantations represents at least 20% of plantations worldwide. Replacement of native habitat by monoculture pine plantations decrease abundance and richness of mammals. In addition plantations are managed under a clearcutting system, which further change the habitat structure, reducing abundance of forest rodent species. Given the association of forest rodent species with structural variables, I analyzed this relation. I hypothesized that presence of shrub vegetation at young pine plantations after clearcutting operations might increase the abundance of forest rodent species. Forest rodent species inhabiting native forest as well as mature pine plantations are related with structural complexity variables (e.g. shrub cover). Abundance of forest rodent species were higher in young pine plantations with shrub vegetation developed than in it absence. Knowing associations between species and microhabitat allows management practices at young pine plantations to facilitate an earlier rewilding. Management of young pine plantations, through developed of vegetation, would be necessary to maintain species diversity along this heterogeneous landscape.

INTRODUCTION

The replacement of native forest by exotic monoculture plantations is a widespread tendency worldwide (FAO 2010). In South America and Asian regions, replacement has reached over 50% during the last 20 years (Kröger 2012). Pine plantations represents at least 20% of forestry plantations worldwide (Carle et al. 2002). Replacement of native habitat by forestry plantations often decrease abundance and richness of mammals (Ramirez and Simonetti 2011), which in turn, alters the strength of interaction and ecological process (Fahrig 2003; Simonetti et al. 2006). In addition to the effect of habitat replacement, forestry plantations are managed under a clearcutting system, which is the most used technique for harvesting. Clearcutting generate effects by itself, increasing mortality of small mammal species and immediate changes in habitat attributes, such as structural, compositional and microclimate changes (Chen et al. 1995, Roberts & Zhu 2002, Niklitschek 2015). Clearcutting can also decrease the abundance of amphibians and forest birds (Williams et al. 2001, Knapp et al. 2003), decrease richness and change species composition of insects and small mammals (Niemela et al. 1993, Hansson 1994) because species respond differentially to abrupt changes to structural modifications in clearcuts (Pawson et al. 2006, Simonetti & Estades 2015). Despite several studies of clearcutting, only a 3% of studies report the effects of clearcutting on biodiversity and fewer studies are based on exotic monoculture plantations and small mammals. Besides, information about re-wilding harvested sites after clearcutting is scarce (Simonetti & Estades 2015). Hence, information to understand how to rewild areas after clearcutting to maintain diversity of species present before harvest are necessary.

Despite changes produced by the replacement of native habitat by pine plantations, mature pine plantations can harbor some native small mammal species if understory vegetation in mature pine plantations is well developed (Simonetti 2006, Ramirez and Simonetti 2011 Simonetti et al. 2013). However, the importance of this structural complexity given by vegetation at young pine plantations after clearcutting remains unknown.

Abundance and richness of forest small mammal species on harvested sites is low (Zwolak 2009; Bogdziewicz & Zwolak 2014). Therefore, assessing habitat selection allows us to understand distribution and abundance of species (Hodara & Busch 2010) at disturbed sites like young pine plantations. Beyond the composition of vegetation, habitat structure is relevant for the occurrence of species, such as small mammals (Garden et al. 2007). Hence, the information about this relationship and the importance of variables related with structural complexity will allow to manage the sites after clearcutting to ensure the presence of forest small mammal species.

In Chile, *Pinus radiata* and *Eucalyptus sp.* dominate the landscape of central Chile with 2.4 million of ha covered (Echeverría et al. 2006; INFOR 2016). Clearcutting of pine plantations generate at least a 40% of mortality of forest rodent species in central Chile

(Escobar et al. 2015) and information about re-wilding at disturbed sites after clearcutting is necessary to achieve a sustainable forestry at early stage.

In this context, I explored the composition and structure of small mammal assemblages within of a heterogeneous landscape dominated by Monterrey pine plantations of different ages in central Chile. The aim of this study was (1) evaluate the association of forest small mammals and micro habitat variables related with structural complexity and (2) evaluate the importance of shrub cover on abundance and richness of small mammals at young pine plantations. I hypothesized that richness and abundance of forest small mammals will be higher at young pine plantations with more shrub cover, due to microhabitat characteristics that they confers (i.e. structural complexity), than young pine plantations with low development of shrub. If abundance of forest small mammal species are related with shrub cover on young pine plantations, this results will inform ways to achieve a sustainable management of young pine plantations after clearcutting to rewilding with forest species.

MATERIALS AND METHODS

I conducted my study at Tregualemu, coastal range of Maule region, central Chile. The study area comprises remnants of native forest, which is surrounded by exotic Monterrey pine plantations (*Pinus radiata*) of different ages (from young pine plantations to mature plantations). Native forest is represented by *Nothofagus glauca, N. oblicua, Cryptocarya alba, Peumus boldus* and *Gomortega keule*, a threatened species. The understory of native forest is dominated by native species like *Aristotelia chilensis, Chusquea cumingii* and *Greigia sphacelata.* Mature plantations (> 15 year) are monocultures of *Pinus radiata*, while understory includes few species like *Aristotelia chilensis, Rubus ulmifolius, Teline monspessulana* and *P. boldus.* Within young pine plantations habitats (< 3 year) I find young pine plantation with shrub vegetation like *Aristotelia chilensis, Rubus ulmifolius* and young pine plantation without vegetation.

During 2016 I seasonally lived trapped small mammals in 4 sampling periods. Three sampling plots were placed in each of the 4 habitat types sampled: (1) continuous native forest (NF), (2) mature pine plantations (MP), (3) young pine plantations with shrub vegetation (YPV) and (4) young pine plantation without vegetation (YP). Each plot was a 7x10 grid consisting of 70 Sherman traps set at 10m intervals. Traps were baited with oat meal and vanilla scent, and were active during 4 consecutive nights. Once captured, animals were identified, ear-tagged for recognition in future recaptures. After handling, animals were released at the site of capture. I used the minimum number of individuals known to be alive (MNKA) as an index of population abundance (Lancia et al. 1994).

To describe microhabitat variables, I measured variables that are selected by small mammals present in study area (Saavedra & Simonetti 2005). Also, I incorporated other variables that could be important in order to describe young pine plantations habitat. Four transects were performed at each trap, 2 meters long each. I measured 14 variables of cover percentage at different levels: ground (0-50 cm), shrub (50 cm to 3 m) and tree (more than 3 m). Measures were made following Glanz (1970) and Saavedra & Simonetti (2005). At ground level, I measured litter cover (G-Litter), branch cover (G-Branch), stem cover (G-Stem), herb cover (G-Herb). At shrub level, juvenile native trees cover (S-Njuvenile), juvenile pine trees cover (S-Pjuvenile), branch cover (S-Branch) and shrub cover (S-Shrub). At tree level, I measured native tree cover (T-Native) and pine tree cover (T-Pine). Density of vegetation was measured placing vertically a 2 m pole, estimating the percentage cover observed from vegetation. The pole was place 1 m away from the trap station. Density of vegetation was measured at 0-10 cm (DEN010) of ground, 11-15 cm (DEN1115) and 1-2 m (DEN12). I also determined the maximum height of herb (Max-Herb), ground branches (Max-Branch) shrub (Max-Shrub), as well as, the depth of soil (Soil).

To evaluate the relation of small mammals with microhabitat variables, I performed a canonical correspondence analysis (CCA). CCA was performed only with significant microhabitat variables (Adonis test). I performed Monte Carlo permutation to test if variation on the principal axis is explained by model. Since abundance at level species present excess of zeros and overdispersion in count data, I used Zero-inflated negative binomial models (ZINB) (Zuur et al. 2009). I utilized habitat, season and the interaction between this factors to predict the abundance of small mammals. Effect of habitat and season on total abundance was performed using ANOVA. To assess the level of similarity between habitats, I calculated Jaccard index, defined by J = c / a + b – c), where (a) is the number of species in habitat (a), (b) is the number of species in habitat (b) and (c) is the number of species shared between both habitats. All analysis and test were performed with R Studio.

RESULTS

A total of 881 individuals of 8 species were captured: Long-haired field mouse (*Abrothrix longipilis*), Olivaceous field mouse (*Abrothrix olivaceus*), Chilean arboreal-rat (*Irenomys tarsalis*), Bridges's degu (*Octodon bridgesi*), Long-tailed rice mice (*Oligoryzomys longicaudatus*), Darwin's leaf-eared mouse (*Phyllotis darwini*), Llaca mouse-opossum (*Thylamys elegans*), and the introduced Black rat (*Rattus rattus*). Chilean arboreal-rat was excluded from further abundance analysis because the trapping method used here underestimate its presence and abundance (Kelt 1993). In fact, I only was able to capture one individual with this methodology.

Habitat similarity between young pine plantations with vegetation and habitat control (native forest and mature pine plantation) were 71.4% and 66.7% respectively. Otherwise, similarity between young pine plantations without vegetation was 42.9% with native forest and 60% with mature pine plantations (Table 1).

Table 1. Compositional similarity (%) between different habitats. NF: Native forest; MPP: Mature pine plantation; YPV: Young pine plantation with vegetation; YP: Young pine plantation without vegetation.

	NF	MPP	YPV	YP
NF	-	66.6	71.4	42.8
MPP	-	-	66.6	60
YPV	-	-	-	66.6
YP	-	-	-	-

Regarding species and microhabitat relation, the relationship between species abundance and environmental variables was significant and positive (CCA, F = 5.88; P = 0.001). From all the variables measured, the following variables were statistically significant and associated with small mammals: (i) ground level: herb, branch, stem and litter cover; (ii) shrub level: shrub, native juvenile tree, pine juvenile tree and branch cover; and (iii) tree level: native tree and pine tree cover. The first two axes of canonical correspondence analysis (CCA) explained 83.9% of total variance in species composition among microhabitat variables (Table 2).

Table 2. Summary of canonical correspondence analysis (CCA).

	Axis 1	Axis 2	Axis 3	Axis 4	Axis 5	Axis 6
Eigenvalue	0.398	0.250	0.095	0.021	0.007	0.002
Proportion Explained	0.515	0.324	0.123	0.027	0.009	0.002
Cumulative Proportion	0.515	0.839	0.962	0.989	0.998	1.0
Species-environment Correlations	0.746	0.621	0.411	0.201	0.116	0.055

The Long-haired field mouse, as well as the Black rat, were correlated with shrub cover, branch cover at shrub level and pine tree cover. The Long-tailed rice mice, the Bridges's degu and the Llaca mouse-opossum were correlated with native tree cover, native juvenile tree cover, stem cover and litter cover. Otherwise, the Olivaceous field mouse and the Darwin's leaf-eared mouse were correlated with juvenile pine tree cover and herb cover (Figure 1).

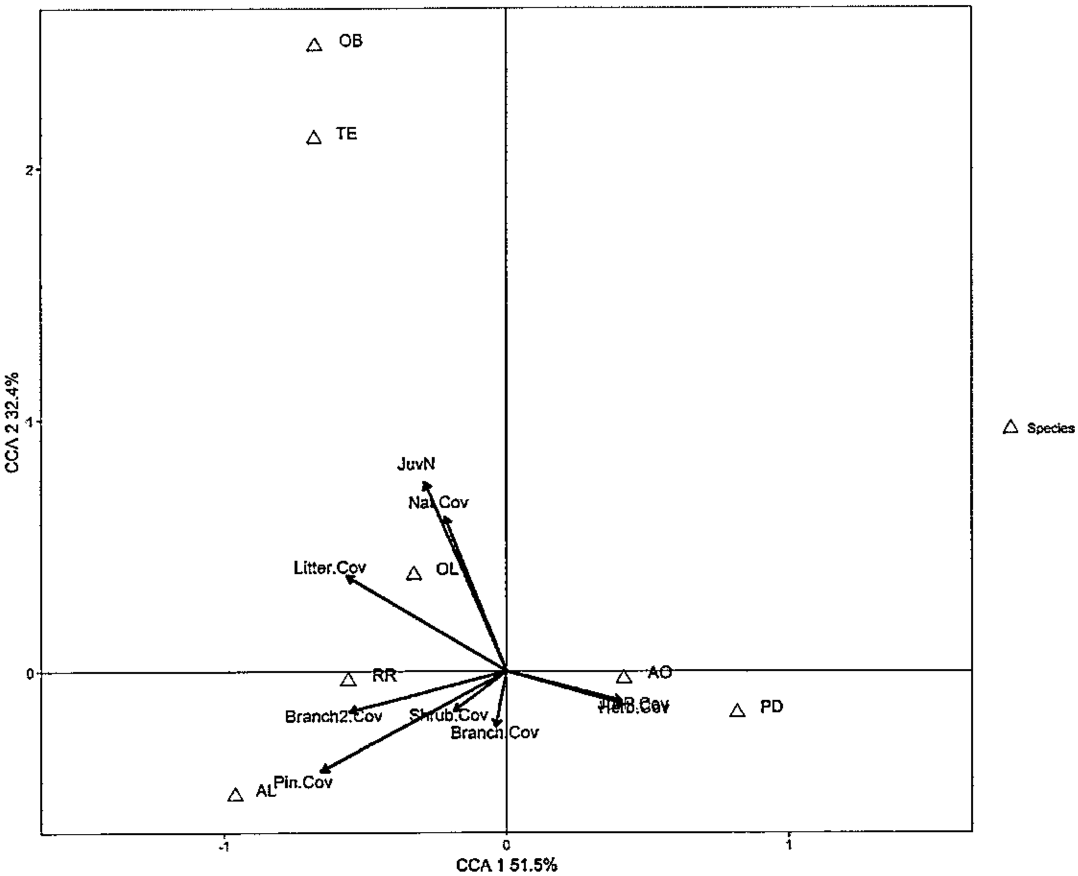

Figure 1. Canonical correspondence analysis (CCA) showing relationship between microhabitat variables and small mammal occurrence. Axis 1 explain 51.5% of variation, while Axis 2 explain 32.4% of variation.

Overall, abundance was higher at young pine plantations with shrub vegetation (YPV), followed by mature plantations (MP), native forest (NF) and young pine plantations without shrub vegetation ($F = 10.8$, $P = 0.003$). At species level, abundance did not follow the pattern described above (Figure 2). Abundance of the Long-haired field mouse was 0.5 times higher in mature pine plantations than native forest and at least 1.5 times higher than young pine plantations. Abundance of the Olivaceous field mouse was at least 1.5 times higher at young pine plantations with shrub cover than other habits. Long-tailed rice mice showed higher abundance in native forest, being a 0.6 times higher than other habitats. Abundance of the Darwin's leaf-eared mouse was 1.3 times higher at young pine vegetation without vegetation than young pine plantations with shrub cover. Also, the Darwin's leaf-eared mouse was no present at native forest and mature pine plantations. The black rat was 0.3 and 0.2 times more abundant in young pine plantations with shrub cover than mature pine plantations and native forest, respectively. Abundance of the Llaca mouse-opossum was 0.7 times higher in native forest than mature pine plantations and young pine plantations with vegetation cover. The Bridges's degu was only present at native forest and young pine plantations with shrub cover, where his abundance was 0.8 times higher in young pine plantations with shrub cover.

Comparing abundance at young pine plantations, I found that

at least, abundance were 0.5 times higher in young pine plantations with developed shrub vegetation than young pine plantations without shrub cover for forest species like the Long-haired field mouse, the Long-tailed rice mice, the Bridges's degu, the Llaca mouse-opossum and the Black rat (Figure 2).

The type of habitat, be it native forest, mature or young pine plantations was the best explanatory variable to describe abundance of the Darwin's leaf-eared mouse and the Black rat. Season was the main explanatory variable to describe abundance of the Long-tailed rice mice, the Bridges's degu and the Llaca mouse-opossum, being autumn the season with higher abundance for these species (Figure 2, Table 3). The interaction between habitat and season was an explanatory variable to describe the abundance of the Olivaceous field mouse and the Long-haired field mouse (Table 3).

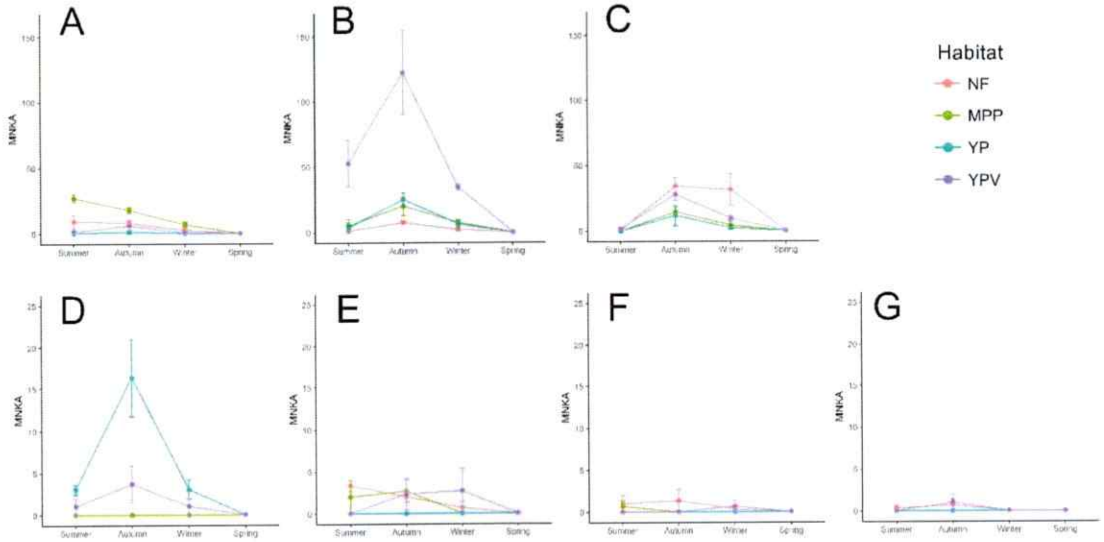

Figure 2. Abundance (means ± standard error) of each small mammal along a year, from summer to spring, in all habitats. a) Long-haired field mouse, b) Olivaceous field mouse, c) Long-tailed rice mice, d) Darwin's leaf-eared mouse, e) Black rat, f) Llaca mouse-opossum and g) Bridges's degu. Note different y-scales between a-c and d-g. NF: Native forest; MPP: Mature pine plantation; YPV: Young pine plantation with vegetation; YP: Young pine plantation without vegetation.

Table 3. Model selection results for abundance of species in the study area. Models for species are ranked in ascending order based on AIC_C values. Models also include number of parameters (*K*), log-likelihood values (logLik), AIC_c differences (Δ_i) and Akaike weights (wi). Models with AICC differences ≥2 are not shown.

Species	Model	*K*	logLik	AIC_C	Δ_i	w_i
Long-haired field mouse	Habitat x Season	18	-67.32	194.23	0	0.99
Olivaceous field mouse	Habitat x Season	18	-113.49	286.56	0	0.98
Bridges's degu	Season	6	-11.79	37.64	0	0.67
Bridges's degu	Habitat	6	-12.51	39.08	1.4	0.33
Long-tailed rice mice	Season	6	-102.59	219.23	0	0.99
Darwin's leaf-eared mouse	Habitat	6	-52	118.06	0	0.99
Llaca mouse-opossum	Season	6	-20.88	55.8	0	0.62
Llaca mouse-opossum	Habitat	6	-21.35	56.75	0.9	0.38
Black rat	Habitat	6	-44.68	103.41	0	0.59
Black rat	Season	6	-45.04	104.13	0.7	0.41

DISCUSSION

Presence of shrub cover at young pine plantations could improve habitat quality, increasing the similarity between native forests or mature pine plantations and young pine plantations. Although dispersing individuals are willing to rewild plantations after clearing (Friend 1979), rewilding capacity will depend on structural complexity of harvested area.

Results on the relationship between occurrence of species and microhabitat variables agree with habitat preferences of Chilean small mammals in other areas (Murua & González 1982, Glanz 1984, Muñoz-Pedreros et al. 1990, Patterson et al. 1990), showing the importance of shrub vegetation in small mammal abundance (Glanz & Meserve 1982). Specific vegetation assemblages can allow species survival providing food or shelter against predators (Simonetti 1989). This relationship with shrub cover suggest that shrub vegetation on young pine plantations may facilitate presence of forest species like Long-haired field mouse.

Abundance of forest species at young pine plantation with shrub cover support this idea, being individual abundance of forest species 0.5 times higher than young pine plantations without shrub vegetation (Figure 2). Furthermore, the presence of shrub vegetation on young pine plantations confers a higher similarity with native forest or mature pine plantations than young pine plantations without shrub vegetation, sustaining the idea that structural complexity given by vegetation, enhances the richness of small mammal species on young pine plantations (Table 1).

The absence of shrub vegetation in young pine plantations can act as a barrier to dispersal of forest small mammals. An early management in young pine plantations might facilitate forest rodent's movement across the landscape and thus population connectivity (see Chapter 2).

Even if the abundance of species like the Long-haired field mouse, the Olivaceous field mouse and the Long-tailed mice showed the same pattern in mature pine plantations as well as in native forest, other species showed lower abundance (Saavedra

& Simonetti 2005). For example, abundance of Bridges's degu was low, especially on mature pine plantation, where none individual were captured, showing the decline of this species in about 15 years from Saavedra & Simonetti (2005). This particular decline of population is due to the use of chemicals on barks of young pines to control this species in forestry plantations, because pines is a component in the diet of this species since the establishment of pine plantations (Muñoz-Pedreros et al. 1990; Muñoz & Murúa 1990). Hence, management practices are necessary to maintain population persistence of small mammals to avoid decrease in abundance of native small mammal species (Lindenmayer et al. 1999, Lindenmayer & Hobbs 2004).

Knowledge of associations between species and microhabitat allows a correct management practices at young pine plantations to facilitate an earlier rewilding of forest small mammal species. Here, I showed the importance of microhabitat variables like shrub cover in young pine plantations to maintain and enhance the richness and abundance of forest small mammal species in a landscape dominated by Monterrey pine plantations. Management of young pine plantations, through developed of vegetation are necessary to maintain species diversity along this heterogeneous habitat since young pine plantations with shrub vegetation enhance habitat quality for forest small mammal species.

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CHAPTER II

MOVEMENT BEHAVIOR ON HABITAT EDGE OF A FOREST RODENT TO REWILD CLEARCUTS: A STEP TO SUSTAINABLE FORESTRY

ABSTRACT

Land use change is a threat to biological diversity. Replacement of native forests by monoculture plantations of exotic species constitute the principal driver of land change in central Chile. Richness and abundance of native species decrease in relation to native forest. Presence of shrub vegetation enhances habitat quality for small mammals in mature pine plantation. Plantations are managed under clearcutting system, ignoring the conditions that facilitate rewilding of forest small mammal species. Disturbed habitats as young pine plantations after clearcutting can act as a barrier to movement of forest small mammal species. I analyzed if shrub vegetation on young pine plantations facilitate the movement of a forest rodent species from native forest or mature pine plantations. I assess habitat use as well as movement trajectories like indicators of habitat quality at edge of contrasting habitats as young pine plantations and native forest or mature pine plantations. To test my hypothesis, I selected the Long-haired field mouse (*Abrothrix longipilis*), a forest species inhabiting native forests as well as mature pine plantations. I found that Long-haired field mouse are willing to use young pine plantations when shrub vegetation is developed. Also, turning angles are more tortuous, indicating a good

habitat quality. Management of monoculture plantations should facilitate the early presence of shrub vegetation after clearcut operations to increase permeability and facilitate rewilding of forest species.

INTRODUCTION

Land use change is a threat to biological diversity (Sala et al. 2000). The replacement of native forests by monoculture plantations of exotic species is increasing. Forestry plantations represents about 7% of global forest mass and with continuous raising (FAO 2010). Monoculture plantations are managed under clearcutting operations, which is the main method of harvesting in forestry plantations (Niklitschek 2015). Clearcutting implies a sudden perturbation of structural properties of harvested areas, creating abrupt edges between harvested areas and adjacent habitats (Roberts & Zhu 2002). As a result, a change of rodents composition is observed, where generalist and open habitat species are favored while forest species experience negative ecological impacts (Zwolak 2009; Bogdziewicz & Zwolak 2014). Monoculture plantations can harbor native small mammal species if structural complexity of understory vegetation is allowed to be developed (Ramírez & Simonetti 2011). Abundance of native species is higher when monocultures have understory vegetation in relation with plantations in absence of understory vegetation (Nájera & Simonetti 2010; Estades et al. 2012; Simonetti et al. 2013). However, the role of structural complexity at young pine plantations, remains unknown. Hence, knowing the role of shrub vegetation as factor determining rewilding of forest species is a key management action in young pine plantations.

Monoculture plantations constitutes a landscape with a variety of edges with different permeability degrees (Schultz & Crone 2001), where animal movement depends on structural attributes of habitats. Movement strategy itself plays a central role determining, for instance, habitat navigation, dispersal and foraging across these patchy landscapes (Schtickzelle et al. 2007; Wells et al. 2008). The way in that animals move allow them to explore, search for food and shelter and reproduce, being movement a limiting factor (Prevedello & Vieira 2010). At the individual level, species may respond differently in heterogeneous landscapes adjusting movement strategies towards an efficient search pattern (e.g., changing step length and turning angles, Bender & Fahrig 2005). This capacity of adjustment may allow to certain extent that animals persist in spatio-temporal dynamic habitats, even such those represented by young pine plantations. Presence of young pine plantations in a landscape dominated by monoculture plantations of exotic species may be hostile for forest species movement. However, some forest species do move towards young pine plantations when shrub vegetation is present (Cline & Hunter 2014; Ramirez-Collio et al 2017).

In central Chile, Monterrey pine (*Pinus radiata*) plantations cover around 1.5 million of ha (Echeverría et al. 2006; INFOR 2016). This area constitutes a heterogeneous landscapes with presence of young pine plantations. Considering that through the study of animal movement we could improve the management of monoculture plantations after clearcutting, I assessed movement strategies performed by forest rodent species. The aim of this study is to test movement into young plantations, measured as (1) edge-crossing between contrasting source habitats as native forest or mature pine plantations and young pine plantations and (2) habitat use in edge of contrasting habitats. Also, to assess habitat quality, I assessed (3) step length, (4) turning angles and (5) changes in individual variation of step length in both habitats, as a shorter step length and more tortuous movements are indicative of better quality habitats. In this sense, I hypothesize that the presence of shrub vegetation at young pine plantations (after clearcutting) will promote the use of young pine plantations of rodents by increasing edge permeability between contrasting habitat types (i.e. native forest or pine plantation to young pine plantation areas). Besides, I expect that step length will be shorter and turning angles more tortoise when shrub vegetation is present in young pine plantations.

I tested the hypothesis with Long-haired field mouse (*Abrothrix longipilis*), a forest species, associated to habitats with high shrub cover and closed canopy. The Long-haired field mouse are present in native forest, as well as in mature pine plantations (Saavedra & Simonetti 2005). Mortality is at least 40% only due to crushing by machinery of clearcutting operations being a sensitive species to clearcutting (Escobar et al. 2015). Hence, enhancing habitat quality of young pine plantations is necessary to rewild at early stage with forest rodent species.

MATERIALS AND METHODS

This study was conducted in Trehualemu, coastal range of Maule region, central Chile. The area comprises remnants of native forest, immersed in a matrix of monocultures plantations of Monterrey Pine. I selected habitat as mature pine plantation (< 15 year), native forest and young pine plantation (> 3 year). At young pine plantations, also I identified the presence of shrub vegetation (e.g. *Aristotelia chilensis, Genista monspessulana, Rubus ulmifolius*) characterizing it according to shrub vegetation cover: young pine plantations with vegetation and young pine plantations without vegetation.

To assess edge-crossing behaviour of the Long-haired field mouse, I measured the number of times that the same individual was captured on both habitat type. To do so, I conducted a bimonthly live trapping from March 2016 to January 2017, setting a grid consisting of 4 transects of 10 living traps each, baited with oat at each study site. Each study site consisted of two habitat types, specifically: (1) native forest with habitat adjacent to a young pine plantation with vegetation cover (NFYPV); (2) native forest with habitat adjacent to young pine plantation without vegetation cover (NFYP); (3) mature pine plantation with habitat adjacent to young pine plantation with vegetation cover (PYPV); (4) mature pine plantation with habitat adjacent to young pine plantation without vegetation cover (PYP). Within each grid, two transects were set in native forest or pine plantation while the remaining two transects were set inside young pine plantations. Transects were set at 5m and 15m parallel to the edge of a habitat type. Individual traps were separated by 10m from each other. Traps were activated during 4 nights and were inspected every morning. Individuals were weighted and ear-tagged.

To assess habitat use of the Long-haired field mouse, I radio-tracked Long-haired field mouse from September 2016 to March 2017. I recorded age class and weight. Only adults (>40 g) were selected to the study. Five individuals at each study site were ear-tagged and equipped with a 2.0 g radio-collar (Model BD-2C Holohil Systems Ltd., Carp, Ontario, Canada). We tracked animal movement using a portable receiver (R-1000, Communication Specialists, Inc., California, USA) equipped with a handheld 3-element Yagi antennas (RA-150, Communication Specialists, Inc., California, USA). Individuals were tracked during 4 to 5 consecutive nights, starting radio-telemetry 24h after individuals were equipped with a radio-collar to avoid bias associated with manipulation. At the end of the radio-telemetry study, individuals were recaptured and radio-collars were removed. Locations of individuals were obtained by triangulation using two bearings taken simultaneously by two independent observers at fixed-location stations, with 15-min intervals to assess short-term movement. Individuals were captured using the same grids described above at each study site (i.e. NFYPV, NFYP, PYPV, PYP). I defined fixed stations (with GPS error <3 m) where always one station was located in the edge of habitats. All data were collected after sunset. Locations were estimated using LOAS 4.0 software (Ecological Software Solutions, Switzerland). With locations coordinates, I estimated home range of individuals at 50% and 95% isopleths using Minimum Convex

Polygon algorithm (MCP). Based on home range information, using a GIS layer, I estimated the ratio of home range occupying young pine plantations. MCP was chosen over other home range estimators (e.g. fixed kernel, adaptive kernel) because MCP is more accurate for small samples and the data interpretation at abrupt habitat edge (Boyle et al. 2009). Further, I calculated descriptors of animal trajectories, step length and turning angles, which indicates habitat quality perceived by rodents. Movements were analyzed assuming that individuals moved in straight line between two consecutives locations.

To compare ratio of home range on young pine plantations sites general linear models with binomial distribution were carried out. To compare differences in step length between study sites I used ANOVA. Since turning angles are circular data, Watson-Williams test were performed. Correlations data were evaluated using Spearman correlation. Data transformations log (x+1) for step length were necessary to satisfy the assumptions of variance analysis when necessary. All statistical test and data analyses were performed in R. Animal trajectories were analyzed using *adehabitat* package (Calenge 2006).

RESULTS

Regarding edge-crossing, I captured a total of 52 individuals in 960 night-traps (5.4% trapping success). Only one individual crossed from native forest to young plantation out of 34 recaptures (Table 1).

Table 1. Minimum number of individuals known to be alive (MNKA), trapping success (TS) and number of edge-crossing at each study site of *A. longipilis*.

	Study Site				Total
	NFYPV	NFYP	PYPV	PYP	
MNKA	9	18	17	8	52
TS	0.94	1.88	1.77	0.83	5.42
Recaptures	2	11	15	6	34
Edge-crossings	0	1	0	0	1

Regarding habitat use, I obtained a total of 813 fixes (in average 38.8 ± 2.06 SE fixes per individual). The average 95% home range were 0.43 ± 0.14 ha and 0.22 ± 0.09 ha at native forests bordering young pine plantations with and without vegetation (NFYPV and NFYP), respectively. In mature pine plantations habitats bordering young pine plantations with and without vegetation (PYPV and PYP), average 95% home ranges were 1.01 ± 0.29 ha and 0.21 ± 0.04 ha, respectively. Core home ranges (50% isopleth) were 0.09 ± 0.04 ha and 0.05 ± 0.03 ha for NFYPV and NFYP, respectively, while core home range for PYPV were 0.25 ± 0.07 ha and 0.07 ± 0.02 ha for PYP. Ratio of home range on young pine plantation were 0.81 on NFYPV and 0.44 on NFYP (P = 0.13; Figure 1a), while 0.12 were on PYPV and 0 on PYP (P = 0.99; Figure 1b). Ratio of core home ranges on young pine plantation were 0.94, 0.47, 0.11 and 0, respectively (native forest: P = 0.10, Figure 1a; mature pine plantation: P = 0.99, Figure 1b).

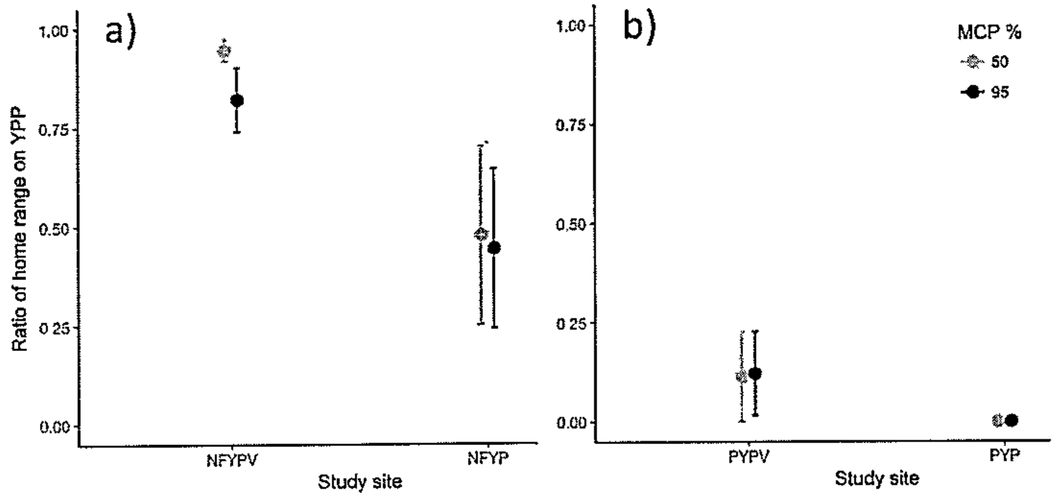

Figure 1. Ratio of home range (50 and 95%) on young pine plantations (YPP) of *A. longipilis* for study sites with (a) native forest and (b) mature pine plantations. Grey dot indicates MCP at 50%; black dot indicates MCP at 95%.

Step length was at least 1.8 times longer when shrub vegetation was developed compared with movements in habitats without such vegetation (native forest sites: $F_{1, 371} = 55.2$, $P < 0.0001$; Figure 2a; mature pine plantations sites: $F_{1, 400} = 39.38$, $P < 0.0001$; Figure 2b). Turning angles were 1 times higher at NFYPV than NFYP ($F_{1, 361} = 7.08$, $P = 0.008$; Figure 3a) but no differences were found between PYPV and PYP $F_{1, 390} = 0.94$, $P = 0.83$; Figure 3b). Individuals showed a positive correlation between step lengths in both habitat types (Rho = 0.93; $P < 0.0001$; Figure 4a), nevertheless, there was no correlation for turning angles between habitats type (Rho = 0.07; $P = 0.83$; Figure 4b).

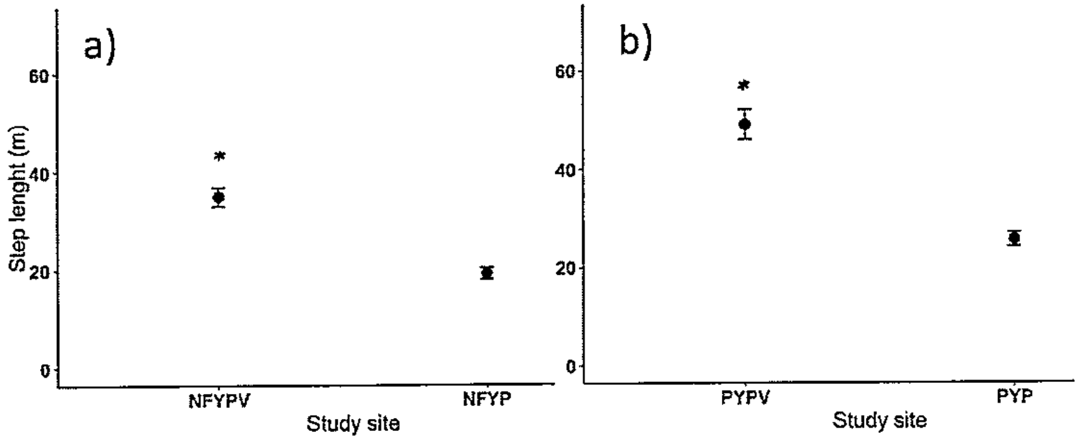

Figure 2. Step length (mean ± SE) of *A. longipilis* at each study site. (a) Native forest study sites and (b) mature pine plantations study sites. * indicates statistical differences (P < 0.001) between study sites, performed with ANOVA.

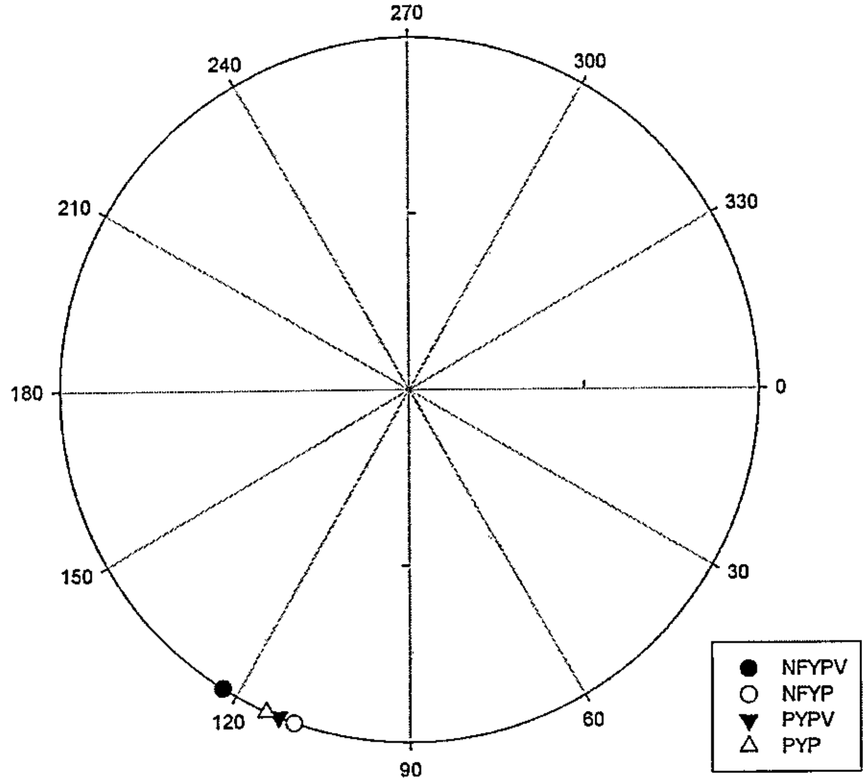

Figure 3. Turning angles (mean, expressed as degrees) of *A. longipilis* at each study site. Dots indicate turning angles in native forest. Triangles indicate turning angles in pine plantations.

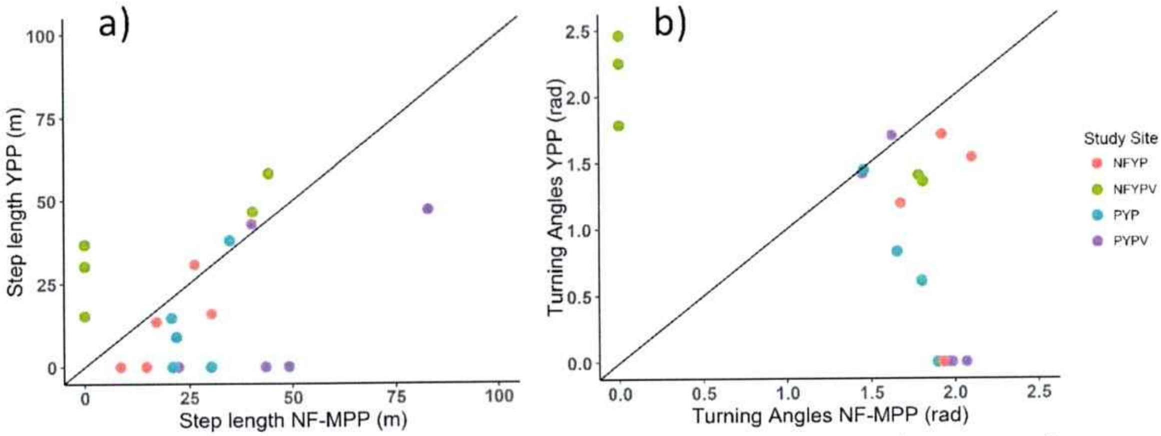

Figure 4. Individual variation of (a) step length (Rho = 0.939; P < 0.0001) and (b) turning angles (Rho = 0.078; P = 0.838) for individuals that use both habitat type at each study site (n = 10). Y-axis represents behaviour at habitat type of young pine plantation and X-axis represents habitat type of native forest or mature pine plantation. Solid line indicates equal values at both habitat types. Individuals at each study sites are represented with red dots (NFYP), green dots (NFYPV), blue dots (PYP) and purple dots (PYPV).

DISCUSSION

Long-haired field mouse might use young pine plantations if shrub vegetation is present. The ability of crossing boundaries will allow population persistence of species, following population dynamic from habitat sources, such as native forest or mature pine plantations, to alternative habitats represented by young pine plantations with presence of vegetation cover. Population persistence over time depends either on individual's movement strategies and landscape structure (Diekötter et al. 2007; Hawkes 2009).

Individuals did not cross edges between habitats types, neither from native forest nor mature pine plantation to young pine plantations. However, some individuals inhabiting mature pine plantations as well as native forest are willing to explore and use young pine plantations habitat when shrub vegetation is present (Figure 1). These findings are consistent with previous information about the importance of vegetation cover in young pine plantations, playing a key role increasing the willingness to explore from a native forest or mature pine plantations for ground dwelling bird and insect (Ramirez-Collio et al. 2017, Russek et al. 2017).

Differences in ratio of utilized area on young pine plantations in native forest and mature pine sites might be due the high presence of coarse woody debris on young pine plantations adjacent to native forests, while in mature pine plantations site, coarse woody debris were extracted. Post-harvested sites with presence of coarse woody debris can harbor forest rodents, working as small habitat patches (Sullivan et al. 2012). Furthermore, coarse woody debris along forest-clear cut edges may mitigate negative effects on rodents' abundance and movement in post-harvested areas (Sullivan & Sullivan 2014). However, after clearcut, coarse woody debris are extracted for energy production, maintaining the negative consequences for species' persistence in a heterogeneous landscape (Hiron et al. 2017).

Regarding individual movement, shorter step length and turning angles between 45° and 135° are characteristics of tortuous movement strategies being associated with good quality habitat (Fahrig 2007). For a ground beetle, *Ceroglossus chilensis*, step length are shorter in mature pine plantation with developed understory than in sites when understory is removed, showing that presence of understory is recognized as good quality habitat (Cerda et al. 2015, Russek et al. 2017). Step length were higher when young pine plantations in study sites have shrub vegetation (Figure 2). However, individuals did not change this movement strategy after crossing the edge (Figure 4a) being consistent with other cases of study, where, step length for other small mammals did not differ between logged and unlogged forest (see Wells et al. 2006), which may suggest that step length is not necessary a good predictor of habitat quality for small mammals, or it is not a very plastic trait for rodents. Turning angles of Long-haired field mouse were tortuous in all habitats, suggesting they use such habitat to some extent. However, at the individual level, when individuals faced young pine plantations without shrub vegetation from mature pine plantations, they changed their turning angles, doing slightly, more straight movements, avoiding young pine plantations without vegetation cover (Figure 4b).

In context of rapid increasing of exotic pine plantations in Chile (Echeverría et al. 2006) and the world (FAO 2010), a management is necessary for post-harvest areas, to enhance habitat quality of young pine plantations to rewild with forest rodent species. Since the shrub cover from the second year of plantation doesn't affect the growth of pines (Kogan et al. 2002; Simonetti et al. unpublished data), I recommend an early management of post-harvested areas adopting practices such as reducing the use of herbicide to allow the growing of shrub vegetation in early stage (Kogan et al. 2002) and the maintenance of woody debris (Nordén et al. 2004). Adopting these recommendations I expect to contribute to the maintenance of local animal populations through the movement of individuals and biodiversity persistence in dynamic landscapes.

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CONCLUSIONS

My results shows the importance of shrub vegetation on young pine plantations for the abundance of native forest rodent species. Enhancing habitat quality of young pine plantations through developing of vegetation cover facilitate the presence of forest species. For instance, some species perceive changes in habitat structure of young pine plantations, making tortuous movement in presence of structural complexity given by vegetation. Hence, forest rodent species begin to use young pine plantations with developed vegetation. Management in monocultures plantation is possible, since development of shrub vegetation does not affect the growth of pine plantations. Hence, management should be carried out changing the clearcutting system into forest practices that ensure connectivity and increasing permeability between habitats.