

Lizard assemblages in a fragmented landscape of central Chile

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Abstract We studied lizard assemblages assessing abundance, richness, and nestedness in a fragmented landscape of central Chile including native temperate forest, forest fragments, and commercial pine plantations. Fragmentation and plantations increase the availability of edge habitats triggering both the support of additional lizard species, absent at the continuous forest, and the nestedness of lizard assemblages, where interior habitats of forest and plantations are nested subsets of habitat edges. A vulnerable lizard (*Liolaemus tenuis*) thrives at fragments in abundance similar to the continuous forest. Therefore, remnants ought to be considered in the conservation of lizard assemblages.

Keywords Chile · Fragmentation · *Liolaemus* lizards · Maulino temperate forest

Introduction

Habitat fragmentation can modify biodiversity composition and structure of species assemblages (Fahrig 2003). The remaining biota in forest fragments and that inhabiting the matrix surrounding them could be a nested subset of the biota of the original continuous habitat if species are

lost in a deterministic order. Similarly, the biota of the continuous habitat may be nested in the biota of forest fragments and the surrounding matrix if more species inhabit these habitats due to differential invasions (Lomolino 1996). Among other taxa, the distribution, abundance, and richness of reptiles are indeed affected by habitat fragmentation (e.g., Díaz et al. 2000; MacNally and Brown 2001; Hokit and Branch 2003).

The Coastal Maulino Forest is an endemic temperate forest of central Chile. This forest has been deforested and fragmented due to agriculture and forest plantations. Between 1975 and 2000, the annual forest loss rate reached 4.5% per year, reducing its area by 67% (Echeverría et al. 2006). Currently, the landscape is a mosaic of Maulino forest fragments immersed in large extensions of commercial pine (*Pinus radiata*) plantations (Grez et al. 1997). In this landscape, species richness of different taxa including birds and insects (coleopterans and dipterans) is higher in forest fragments and pine plantations than in the continuous forest. Other taxa, such as rodents and carnivores, show a reduction of their richness in plantations and forest remnants compared to the continuous forest (see Bustamante et al. 2006 for a review). The response of herpetofauna to forest fragmentation though is yet to be assessed, particularly considering that the coastal Maulino forest might be the northern fringe of several lizard and frog species as well as harbors new herpetofauna taxa (Rubio et al. 2004; Veloso et al. 2005; Donoso et al. 2010). Within this context, we analyze richness, abundance, and nestedness of lizard assemblages in a landscape mosaic characterized by a continuous tract of Maulino forest, forest fragments, standing Monterrey pine plantations and recently clear-cut pine plantations, which are surrounding the native vegetation.

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Materials and methods

Study area

We studied a 16-km² area in the Cordillera de la Costa of central Chile (Fig. 1). This area comprises Los Queules National Reserve, a forest tract of 145 ha connected to 600 ha of native forest of Coastal Maulino Forest (35°59' S, 72°41' W), acting as the continuous forest. The study area also includes Monterey pine (*P. radiata*) plantations, including recently clear-cuts, and fragments of native forest. Pine plantations cover c. 865 ha, surrounding the native forest remnants. Most plantations grow on former agricultural fields, being at least 20–40 years old. Consequently, most forest fragments are probably older than 40 years.

Lizard assemblages were assessed in nine different habitats: (1) interior of the continuous forest, (2) edge of the continuous forest, (3) interior of forest fragments, (4) edge of forest fragments with contrasting matrix (e.g., roads, clear-cut pine plantations), (5) edge of forest fragments with adult pine plantation as matrix, (6) pine plantation interiors and (7) edges of pine plantations, (8) clear-cut plantations, and (9) clear-cut plantations with growing (height±80 cm) *Aristotelia chilensis* (an evergreen native tree species). Forest fragments ranged from 1.5 to 20 ha in size. The distance of these fragments to the

continuous forest ranged from 730 to 2,440 m. We considered as edge a 20-m-wide strip from the border toward the interior of all habitats, after other studies in the area (Donoso et al. 2003) and similar distances used to assess potential edge effects upon herpetofauna (e.g., Schlaepfer and Gavin 2001). Interior habitats were considered either the geometric center (in forest fragments) or sites located at least 50 m from the edge.

Field work and analysis

During January–February 2006 and 2007 (Austral summer), we randomly located 30 10×10-m plots at each habitat by simple random sampling (Newton 2007), totaling 270 plots. Within each plot, lizards were sampled using visual encounter surveys, walking and moving litter and debris through the plot during 10 min on sunny days only. Each plot was visited once. In 2006, we sampled 20 plots in each habitat. Another ten different plots were sampled during 2007. No differences between these years were found, and data from both years were pooled. Sampling at clear-cuts was performed in 2007, as plantation was partially harvested in 2006.

Plots were ≥40 m apart and each plot was considered a replicate. First, *Liolaemus* lizards exhibit home ranges ranging from 22 to 140 m² (Frutos et al. 2007), suggesting that distance between plots was large enough to render

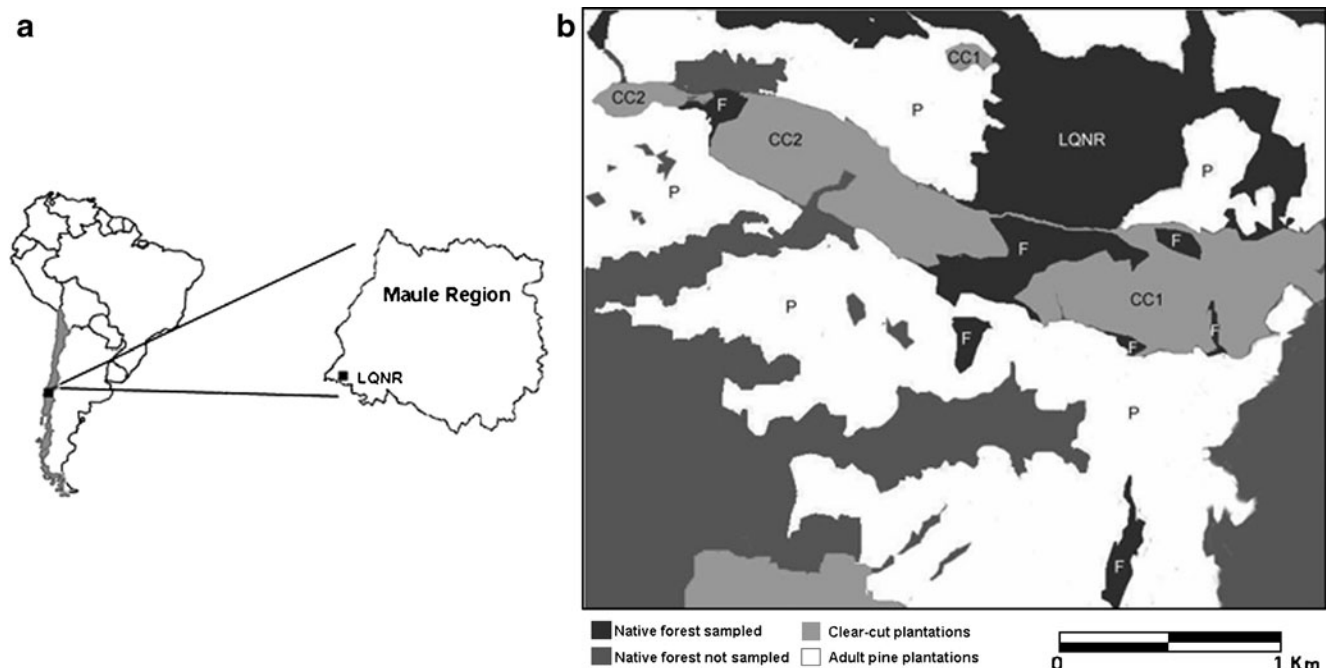


Fig. 1 **a** Political map of the study region. *Black square* is the location of Los Queules National Reserve (LQNR). **b** Study area showing sampling locations: the continuous forest, including the National

Reserve (LQNR), forest fragments (F), adult pine plantations (P), and clear-cut plantations (CC1 and CC2). Roads are not shown

them independent samples. Secondly, species similarity between plots was unrelated to distance between them (Mantel test, 10,000 iterations, $r_p < 0.4$, $P > 0.3$; Zar 1999).

Species richness and abundance were estimated as the cumulative number of taxa and number of individuals recorded, respectively. Based on the species accumulation curves, according to the linear dependence model (Soberón and Llorente 1993), we assume sampling effort was adequate because all habitats had an acceptable level of estimated completeness (average completeness of all nine habitats=96%; see Fig. 2). Richness and abundance at different habitats were compared using one-way ANOVA and Tukey honestly significant difference (HSD) test. For the nestedness analysis, we constructed presence–absence matrices (PAM) with species as rows and habitat type as columns. PAM elements are either ones or zeroes, denoting presences and absences of species in habitat type, respectively. For each PAM, we first measured their degree of nestedness through the “modified temperature index” (MT; Ulrich and Gotelli 2007). This index is a modification of the “matrix temperature index” (Atmar and Patterson 1993) which measures “the biogeographic heat” of the PAM using the distribution of unexpected species’ presences and absences within the matrix. Significance of nestedness was determined comparing the observed MT value with that of 200 random matrices obtained by the null model RANDOM1 (R1; Patterson and Atmar 1986). We used the software Nestedness to carry out this analysis (Ulrich and Gotelli 2007).

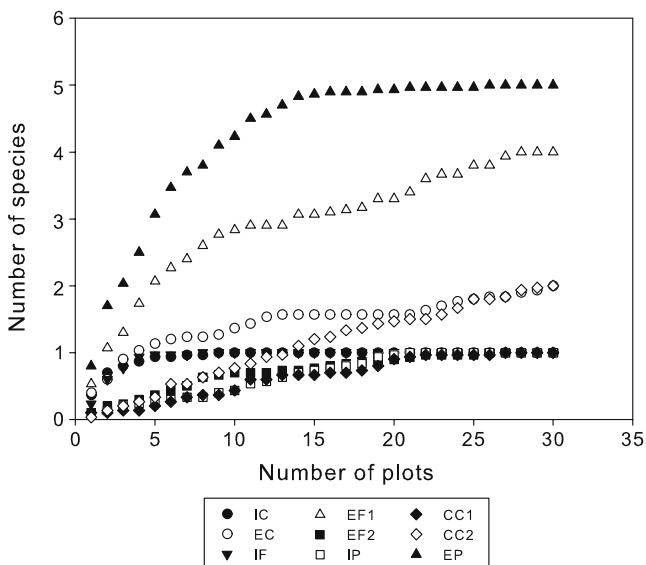


Fig. 2 Randomized species accumulation curves for lizards observed along plots at nine different habitat types. Values calculated from 30 repetitions at each habitat type using Species Diversity and Richness 4.1.2 computer package. Letters indicate habitat types (see Table 1 for details of the abbreviations)

Results and discussion

A total of 140 lizards from five species of *Liolaemus* (Iguanidae) were recorded: *Liolaemus chiliensis* (2.9% of the lizards sampled), *Liolaemus cyanogaster* (2.9%), *Liolaemus lemniscatus* (19.3%), *Liolaemus schroederi* (11.4%), and *Liolaemus tenuis* (63.6%). All species are native and the last two are endemic to Chile. The highest species richness occurs at the edges of pine plantation followed by edges of those forest fragment edges surrounded by clear-cuts and roads (Table 1). The lowest species richness was recorded at the interior of the continuous forest, forest fragments, pine plantations, and forest fragments edges neighboring a pine plantation (Table 1). Abundance also differed among habitats, being higher at edges of plantations and forest fragments ($F_{8, 261}=8.6$, $p < 0.001$; Table 1). *L. tenuis*, the most widely distributed lizard (present in eight out of nine habitats sampled), is significantly more abundant in the continuous forest, forest fragments, and adult pine plantation edges (Table 1). Neither fragment size (FS) nor distance to continuous forest (D) influenced richness and pooled abundance of lizard assemblages (FS richness: $r^2=0.03$, $p=0.11$; abundance $r^2=0.005$, $p=0.5$, D richness: $r^2=0.02$, $p=0.16$; abundance: $r^2=0.02$, $p=0.2$, respectively).

Species composition exhibited significant nestedness (Table 2). Species at the interior habitats (native forest and adult pine plantations) and clear-cut plantations are a nested subset of the fauna occurring at the edges of pine plantations and forest fragment edges ($MT=4.15$, $Z=-2.31$, $p < 0.05$). Edges are not only richer in species but also holds all species occurring at other habitats, rendering the lizard assemblage of the continuous forest a subset of the fauna inhabitant of the edges (Table 2).

The fragmentation of the Maulino forest significantly alters biodiversity modifying species composition, population abundance, and the strength of ecological interactions and processes (Bustamante et al. 2006; Simonetti et al. 2006). Lizard assemblages at the Maulino forest respond to habitat fragmentation similar to birds, bees, coleopterans, and dipterans, with high species richness and abundance in forest fragments and several species thriving in plantations (Jaña-Prado and Grez 2004; Vergara and Simonetti 2004; Valdovinos et al. 2009). The interior habitats of both the continuous forest and pine plantations support just one species, the arboreal *L. tenuis*. Fragmentation of the Maulino forest and the incorporation of commercial pine plantations are increasing the amount of edges, supporting additional lizard species absent at the continuous forest. This fact could be accounted for by differences in thermal preferences. Lizards thriving on edges (*L. cyanogaster* and *L. lemniscatus*) use substrate temperatures (soil/ground) 1.6°C to 4.1°C higher than *L. tenuis* (Labra et al. 2008), which might explain their presence in sunnier and hotter

Table 1 Mean abundance of lizards (individual per 100 m²±SE) and species richness (total number of species, denoted by *S*) in nine different habitats (30 plots per habitat)

Species	Continuous forest		Fragments			Plantations				ANOVA	
	IC	EC	IF	EF1	EF2	IP	EP	CC1	CC2	<i>F</i> _{8,261}	<i>P</i>
<i>Liolaemus chiliensis</i>	0	0	0	0	0	0	0.13±0.1	0	0	4.46	<0.001
<i>Liolaemus cyanogaster</i>	0	0	0	0.03±0.03a	0	0	0.1±0.1a	0	0	2.43	0.014
<i>Liolaemus lemniscatus</i>	0	0	0	0.23±0.1b	0	0	0.63±0.2a	0	0.03±0.03b	7.58	<0.001
<i>Liolaemus schroederi</i>	0	0.03±0.03b	0	0.03±0.03b	0	0	0.4±0.1a	0	0.06±0.04b	7.77	<0.001
<i>Liolaemus tenuis</i>	0.7±0.2a	0.6±0.2a,b	0.63±0.2a,c	0.6±0.2a,b	0.1±0.1b,c	0.1±0.1b,c	0.2±0.1a,b	0.03±0.03b	0	5.11	<0.001
Pooled abundance	0.7±0.2b,c	0.63±0.2b,c	0.63±0.2b,c	0.9±0.2a,c	0.1±0.1b,d	0.1±0.1b,d	1.46±0.3a	0.03±0.03b,d	0.1±0.1b,d	8.54	<0.001
<i>S</i>	1b,c	2b,c	1b,c	4a,b	1c	1c	5a	1c	2c	9.56	<0.001

Different lowercase letters indicate significant differences ($P<0.05$, Tukey HSD test) between habitat types

IC interior of continuous forest, EC edge of continuous forest, IF interior of forest fragments, EF1 edge of forest fragments adjacent to roads or clear-cut pine plantations, EF2 edge of forest fragments adjacent to adult pine plantation, IP pine plantation interiors, EP pine plantation edges, CC1 clear-cut plantations, CC2 clear-cut plantations with growing (height±80 cm) *A. chilensis* (an evergreen native tree species)

habitats. In fact, edges have maximum daily air temperatures up to 6°C higher than the interiors, particularly edges at forest fragments (Rubio and Simonetti 2009). Hence, habitat fragmentation would be increasing the amount of suitable thermal environments for *Liolaemus* lizards, as clear-cuts do in Amazonian forests (Vitt et al. 1998). Further, edges might support higher species richness because *L. chiliensis*, *L. lemniscatus*, and *L. schroederi* are ground-dwellers which use open areas or dense herbaceous patches as microhabitat (Jaksic et al. 1980), features provided by the edges of forest fragments and plantations. Edges are supporting lizard species of conservation concern: *L. lemniscatus* (vulnerable), *L. chiliensis*, and *L. schroederi* (inadequately known; Nuñez et al. 1997), which ought to be considered in managerial plans. These lizards are more common at the more open sclerophyllous shrublands (matorral) of central Chile, which is also impacted by high habitat degradation and destruction (Arroyo

et al. 1999). As the Maulino forest has been transformed into more open vegetation, including agriculture and forest plantations, these landscape-level changes might have increased the offer of suitable habitat for these lizards. In the case of *L. tenuis*, its presence at forest fragments at abundances similar to that found in the continuous forest suggests that fragments ought to be considered for the conservation of this threatened lizard, strengthening the claim that despite their small sizes, forest remnants are of high conservation value at the Maulino forest as they support native wildlife such as mammals, insects, birds (Acosta-Jamett and Simonetti 2004; Jaña-Prado and Grez 2004; Vergara and Simonetti 2004; Saavedra and Simonetti 2005), and lizards. Similarly, the scarcity of lizards at the standing pine plantations and clear-cuts reinforces the value of forest remnants for harboring wildlife that otherwise might be lost when pine plantation are harvested.

Table 2 Nestedness analysis for lizard assemblages and packed presence–absence matrix of lizard species at the landscape

	PAM fill	PAM MT	Z-score MT for R1	Packed matrix							Incidence		
				EP	EF1	CC2	EC	EF2	IP	CC1		IF	IC
Nestedness analysis	0.4	4.15	-2.31 ^a										
<i>Liolaemus tenuis</i>				1	1	0	1	1	1	1	1	1	8
<i>Liolaemus shroederi</i>				1	1	1	1	0	0	0	0	0	4
<i>Liolaemus lemniscatus</i>				1	1	1	0	0	0	0	0	0	3
<i>Liolaemus cyanogaster</i>				1	1	0	0	0	0	0	0	0	2
<i>Liolaemus chiliensis</i>				1	0	0	0	0	0	0	0	0	1
Sites richness				5	4	2	2	1	1	1	1	1	

PAM fill indicates the proportion of the matrix filled with species presences, PAM MT is the modified temperature index (Ulrich and Gotelli 2007), and Z-score is the modified temperature of null model RANDOM1 (R1; Patterson and Atmar 1986)

^a Refers to statistically significance value of MT, $P<0.05$

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