

## LOCAL EXTINCTION OF *TROPIDURUS CATALANENSIS* CAUSED BY PLANTATION FORESTRY IN THE PAMPAS OF BRAZIL

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**Abstract.**—We evaluated the impact of a eucalyptus plantation on a population of Western Collared Spiny Lizard (*Tropidurus catalanensis*), a saxicolous lizard of the Pampas biome in Brazil. We monitored the population for 7 y, since before the trees were planted until the trees completely shaded the rocky outcrops occupied by the species. We captured and marked 286 lizards and recaptured 95 individuals throughout the study period. We observed a gradual decrease in the number of monthly captures of adult lizards and a trend of decreasing body mass, body condition, and survival probability. We also found differences on the daily and seasonal activity of *T. catalanensis*. Conversion of native grasslands into tree plantations can result in simplified and homogeneous habitats that exclude most species that depend on native open field environments. These changes affect the fauna, flora, and the physical and ecological processes of a site and our results show that such alterations intensify the threats to *T. catalanensis*.

**Key Words.**—body condition; conservation; ecology; eucalyptus; forestry; saxicolous lizard; shading; survival

### INTRODUCTION

Habitat loss and fragmentation are among the main threats to global biodiversity (Wilson et al. 2016). The conversion of natural landscapes into agricultural fields and tree plantations is one of the main causes of changes in landscape use (Foley et al. 2005). For instance, between 2000 and 2010, there was an increase of five million hectares of cropland annually around the world (Food and Agriculture Organization of the United Nations 2010). In Brazil, up to 2010, eucalyptus (*Eucalyptus* spp.) forests occupied 4,754,334 ha, whereas by 2015, this number had increased to 7,465,000 ha (Instituto Brasileiro de Geografia e Estatística 2015).

The Pampas biome is restricted to the great steppes of southern South America and occupies the southernmost region of Brazil covering 176,000 km<sup>2</sup> in the country (Picolli and Schnadelbach 2007). This biome encompasses great extensions of open formations, where grass species predominate (Overbeck et al. 2007; Suertegaray and Silva 2009). There are also patches of arboreal vegetation such as gallery and hillside forests (Suertegaray and Silva 2009). With the loss of approximately 50% of its natural coverage by 2009 (Instituto Brasileiro do Meio Ambiente 2011), the Pampas is the second most altered Brazilian biome, which makes the expansion of monoculture of woody species even more concerning. Despite this, only

0.36% of the biome is included in the Brazilian National System of Conservation Units (Sistema Nacional de Unidades de Conservação; Schwanz 2010).

Changes in soil quality such as erosion, salinization, and acidification are among the impacts that the monoculture of exotic plant species can cause to the environment (Cannell 1999; Jobbágy and Jackson 2003; Jackson et al. 2005). The interference of water cycles, either by the reduction of water flow into rivers, drying of lentic water bodies, or by other mechanisms (Farley et al. 2005; Jackson et al. 2005) also affects biodiversity. These changes influence the richness, abundance, composition, and structure of the fauna and flora of ecosystems (Silva 2002; Kanowsky et al. 2005; Zahn et al. 2009; Schwanz 2010).

Reptiles are considered a good model for analyzing the effects of environmental perturbations and habitat loss due to their ectothermy and low vagility (Vitt and Caldwell 2014; Saccol et al. 2017). The impact of exotic tree species to reptiles has been studied at a variety of sites (Valentine 2006; Mott et al. 2010; Martin and Murray 2011; Stellatelli et al. 2013; Saccol et al. 2017). Despite the abundant literature concerning the influence of exotic tree monoculture systems on reptile species, most of these studies demonstrate such effects by comparing sites with and without exotic trees, usually evaluating their effect on local communities or assemblages. The saxicolous Western Collared

Spiny Lizard (*Tropidurus catalanensis*) inhabits rocky outcrops in the Pampas and could be impacted by tree monocultures. This lizard is distributed in northwestern Uruguay, northeastern Argentina, southern Paraguay, and southern Brazil (Rodrigues 1987; Kunz and Borges-Martins 2013).

In our study, we monitored a population of *T. catalanensis* that inhabited rocky outcrops since before eucalyptus trees were planted until when they had completely shaded the area. We evaluated the impact of the introduction of a eucalyptus plantation on the body condition and survival of this lizard population. We hypothesized that, with the increase of the shading imposed by the eucalyptus over the outcrops, habitat conditions for the species would be altered. We predicted that the body condition and the survival of these lizards would be significantly worse after trees matured than when the area was treeless.

#### MATERIALS AND METHODS

**Study site.**—The study site consisted of a 1.9 ha rocky outcrop located at 29°58'42"S, 55°24'59"W (108 m elevation), in the municipality of Alegrete, Rio Grande do Sul State, southern Brazil (Fig. 1). The study area was located in the Pampas biome, and the climate is humid sub temperate with well-defined seasons, with well-distributed rainfall throughout the year. The mean precipitation of the area is 1,574 mm and the mean annual temperature is 18.6° C, varying from a monthly average of 12.7° C in the coldest month (June) to 42.8° C in the hottest (January; Maluf 2000). Originally, the outcrops were surrounded by two main habitats:



FIGURE 1. Location of the study area in the municipality of Alegrete (29°58'42"S and 55°24'59"W), State of Rio Grande do Sul, Brazil.

grassy-woody Steppe (native grasslands) and alluvial Deciduous Seasonal Forest (Boldrini 1997). In August 2008, though, a private company planted eucalyptus seedlings in a linear arrangement around the outcrops about 5 m from its margins.

**Data collection.**—We conducted lizard capture-recapture surveys monthly from May 2008 to December 2011. We did not visit the area in 2012, resuming the monthly fieldwork to verify the presence of lizards from August 2013 to October 2014. In this last period, we also searched for lizards on outcrops nearby the study area, which are inhabited by other populations of the same species, to check for emigration to adjacent areas. To find the lizards, we randomly explored the area by looking at outcrops from above from a distance and then up close, inspected cracks between rocks and loose rocks. We always started searches at 0800 and ended at 1800. In all monthly visits, we standardized the sampling effort (54 person-hours) to avoid bias of different search effort.

When sighted, we captured lizards by hand. We recorded the snout-vent length (SVL) of each lizard with a caliper of 0.02 mm precision, and the body mass (BM) with a 30 or 600 g capacity hand scale with 0.2 and 0.5 g precision, respectively. According to the minimum reproductive size of the species (males: SVL > 81.6 mm, females: SVL > 74.8 mm; Arruda 2009), we classified them as juveniles or adults, and we determined the sex of adult individuals. According to Pinto et al. (2005), males have wider heads and thinner bodies than females of the same size and have colored ventral scales (yellow and black), while females have uniform colored ventral scales.

We marked and identified all lizards by assigning a number to each toe and amputating the last phalanx in a unique combination for each individual (Verrastro 1991). To avoid unnecessary disturbance, we noted naturally occurring markings to identify individuals when possible, such as blotches, colored scales, and scars. After capturing and marking, we released lizards in the same locations of capture.

**Data analysis.**—Data were both normally distributed ( $P = 0.402$ ) and homoscedastic ( $P = 0.105$ ). We used Analysis of Variance (Zar 1999) to compare the capture ratio of adults across different years, using the Holm-Sidak method for comparisons between years. We used Linear Regression to evaluate sexual dimorphism by comparing the SVL (mm) and the BM (g) of female and male adults, as well as the variation of body condition (quotient between BM and SVL) for each sex in relation to the years. We tested if the body condition varied through the years, between sexes, and the interaction between year and sex. Data met parametric assumptions

for Linear Regression (following Zuur et al. 2009). We applied Tukey's Contrast Tests for pairwise comparison of body condition between years. We used Likelihood Ratio Tests to test the significance of the variables in the linear models, starting with the general model (with interaction term) and dropping variables sequentially. Linear models and Likelihood Ratio tests were fit on the R platform (R Development Core Team 2019). For all these tests, we considered  $\alpha = 0.05$  for significance.

From the captures of individuals in each visit, we built individual capture histories and applied a Cormack-Jolly-Seber (CJS) mark-recapture model for open populations (Cormack 1964; Jolly 1965; Seber 1965), following the procedures of Lebreton et al (1992). This model estimates the apparent survival probability ( $\Phi$ , probability of an individual surviving and staying in the study area) between sampling occasions, and the capture probability ( $p$ ) on the sampling occasions. We included the effect of the sampling year (correspondent to the growing stage of the trees) or/and the age class of the individual (i.e., juvenile or adult) on the apparent survival probability, and the effect of the age class of the individual and/or air temperature (linear and quadratic effects) on the capture probability.

We fitted the mark-recapture models under a maximum likelihood approach using MARK (Cooch and White 2016). We corrected irregular time intervals between occasions to obtain the apparent survival probability by month. We tested the model adjustment (goodness of fit) by calculating the median c-hat for the most parameterized model. Then, we incorporated the c-hat value to correct the estimates and to compute the Quasi-Likelihood Information Criteria of second order (QAICc), which was used to rank the models (i.e., the best ranked model is the one with the lowest QAICc value). We tested the effects of age and year in apparent survival contrasting different model hypotheses using AIC criteria. Similarly, we tested the effects of age and temperature (including a quadratic effect, i.e., inverted U shape relationship).

## RESULTS

We captured and marked 286 lizards (55 males, 69 females, 162 juveniles) and recaptured 95 individuals (39 males, 27 females, 29 juveniles). Of these 286 individuals, 49 were captured in 2008 (34 adults), 84 in 2009 (32 adults), 78 in 2010 (38 adults) and 75 in 2011 (20 adults). The mean SVL of 93 males was  $108.89 \pm 11.71$  (standard deviation) mm (range, 85.86–130.5 mm) and BM was  $55.47 \pm 18.02$  g (range, 18.50–90.00 g). For 96 females, mean SVL was  $88.05 \pm 7.17$  mm (range, 74.90–107.4 mm) and BM was  $25.98 \pm 8.55$  g (range, 13.75–50.00 g). The SVL and BM of males were significantly greater than those of females (SVL:

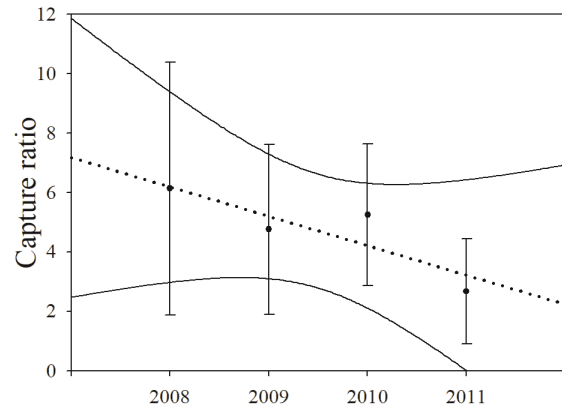


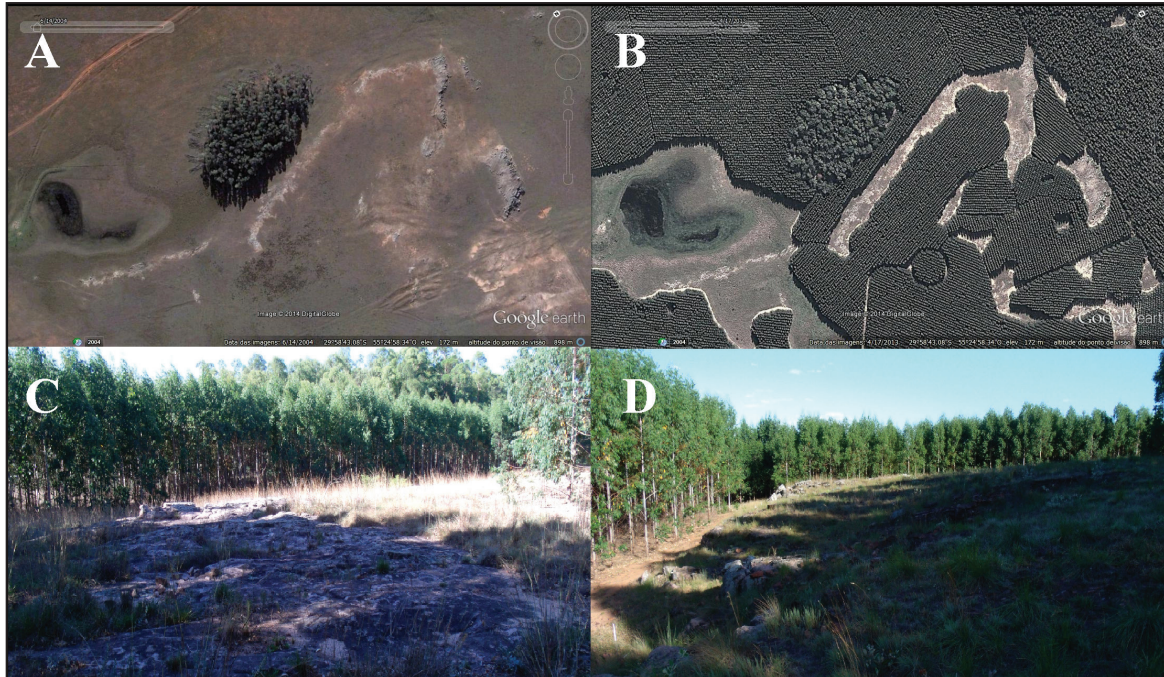
FIGURE 2. Monthly capture ratio of adult individuals of the Western Collared Spiny Lizard (*Tropidurus catalanensis*) from 2008 to 2011 in the study area in Alegrete, Rio Grande do Sul, Brazil. Dotted line indicates the linear tendency through the years.

$F_{1,185} = 9,753, P < 0.001$ ; BM:  $F_{1,179} = 1,433, P < 0.001$ ).

Throughout the study period, there was a gradual decrease in the number of monthly captures of adults ( $F_{3,40} = 2.92, P = 0.046$ ; Fig. 2), with significant differences between 2008 and 2011 (Holm-Sidak,  $P = 0.010$ ). In 2013 and 2014, we concluded that the population was locally extinct because we conducted six surveys using the same methods as before and we found no individuals. In fact, in 2011 eucalyptus had already grown tall enough to shade a great portion of the study area, and the rocky outcrops received direct sunlight only for about 1 h during the solar zenith (Fig. 3). We did not find any marked lizards in 2013 and 2014 in surrounding rock outcrops.

We found an effect of sex ( $F_{1,202} = 93.08, P < 0.010$ ) and year ( $F_{3,203} = 42.82, P < 0.010$ ) on body condition (Fig. 4), but not a sex-year interaction ( $F_{3,199} = 1.14, P = 0.330$ ). There were no significant differences of body condition between 2008 and 2009 (Tukey HSD;  $P = 0.085$ ), or between 2010 and 2011 (Tukey HSD;  $P = 0.996$ ). Body condition of lizards for all other combinations of years (2008 and 2010, 2008 and 2011, 2009 and 2010, 2009 and 2011) were significantly different (all Tukey HSD;  $P < 0.001$ ). In comparison with individuals captured in 2008, the body condition of males and females was reduced 25.44% and 36.27%, respectively.

According to the top ranked model (Table 1), the average apparent monthly survival probability ( $\Phi$ ) was lower along the sampling years ( $\beta_{2008} = 2.58$ ;  $\beta_{2009} = 1.49 \pm 0.27$ ;  $\beta_{2010} = 1.26 \pm 0.28$ ;  $\beta_{2011} = 0.89 \pm 0.31$ ); while the capture probability ( $p$ ) was affected by the temperature (quadratic effect) and the age class ( $\alpha_{Int} = -4.94 \pm 1.34$ ;  $\alpha_{age} = 0.72 \pm 0.30$ ;  $\alpha_{temp} = 0.38 \pm 0.18$ ;  $\alpha_{temp}^2 = -0.01 \pm 0.01$ ). The monthly survival probability decreased gradually over the four initial years of the



**FIGURE 3.** Satellite images (A in 2004; B in 2013) and photographs (C and D: from 2013) of the rocky outcrops at the study area in Alegrete, Rio Grande do Sul, Brazil. In A and B, the patch of trees in the center were older eucalyptus (*Eucalyptus* sp.), not planted for commercial purposes. In satellite image B and the photographs, outcrops are fully surrounded and shaded by eucalyptus trees. (A and B, Google Earth; C and D photographed by Alexis Grote Kellermann).

study, averaging 93% (95% Confidence Interval [CI] = 67–99%) in 2008 and 71% (95% CI = 57–82%) in 2011 (Fig. 5). The mean recapture probability of adults was higher than younger individuals, and this probability was higher at intermediate temperatures. Recapture probabilities ranged from 4% (95% CI = 1–10%) for juveniles and 8% (95% CI = 3–18%) for adults at a daily mean temperature of 6° C, with a peak of 8% (95% CI = 5–14%) and 16% (95% CI = 10–24%) for juveniles and adults, respectively, at 14° C, to 1% (95% CI = 1–4%) and 3% (95% CI = 1–7%) at 25° C.

**TABLE 1.** Cormack-Jolly-Seber model selection results for the apparent survival and detection probability of the Western Colored Spiny Lizard (*Tropidurus catalanensis*) from 2008 to 2011 in Alegrete, Rio Grande do Sul, Brazil. Models were ranked by Quasi-Likelihood Information Criteria of second order (QAICc) adjusted for c-hat (c-hat = 1.24). Acronyms are  $\Delta$ QAICc = difference between the QAICc of the model with the lowest QAICc and the following models, wQAICc = QAICc weights (QAICcw; from 0 to 1), and n Pars = number of parameters of the model. Only the first five models are listed.

Model	QAICc	$\Delta$ QAICc	wQAICc	n Pars
$\Phi(\text{year}) p(\text{age} + \text{temp}^2)$	591.05	0.0	0.355	8
$\Phi(\cdot) p(\text{age} + \text{temp}^2)$	592.98	1.93	0.135	5
$\Phi(\text{year} + \text{age}) p(\text{age} + \text{temp}^2)$	593.04	1.99	0.131	9
$\Phi(\text{year} + \text{age}) p(\text{temp}^2)$	593.68	2.63	0.095	8
$\Phi(\text{age}) p(\text{age} + \text{temp}^2)$	594.01	2.96	0.080	6

## DISCUSSION

We found that after the growth of the eucalyptus plantations in our study area, the population of *T. catalanensis* suffered a decline in numbers, body condition, and survival probability, culminating in the total absence of *T. catalanensis*. To verify a possible migration of the individuals, in the following years we investigated outcrops nearby, where other populations of the species live without the presence of eucalyptus. We did not find any lizards from the study population (i.e., marked specimens), which may indicate that they could not establish themselves in the adjacent outcrops.

Lower capture rates have already been linked to eucalyptus plantations in the Cerrado (tropical savannah) biome of Brazil. The decrease of radiant energy and the habitat homogenization were the main causes of the reduction of the original fauna, presenting substantial loss in species richness, endemism, equitability and captures within the evaluated lizard communities (Gainsbury and Colli 2014). Similarly, smaller abundances of the sand lizard (*Liolaemus wiegmanni* complex) were associated with higher densities of Sydney Golden Wattle (*Acacia longifolia*) in their natural environments, related to a decrease in thermal quality of micro-habitats induced by the shading of the exotic trees (Stellatelli et al. 2013). Although we did not conduct experiments on thermoregulatory quality and efficiency, several studies demonstrated that eucalyptus introduction alters physical

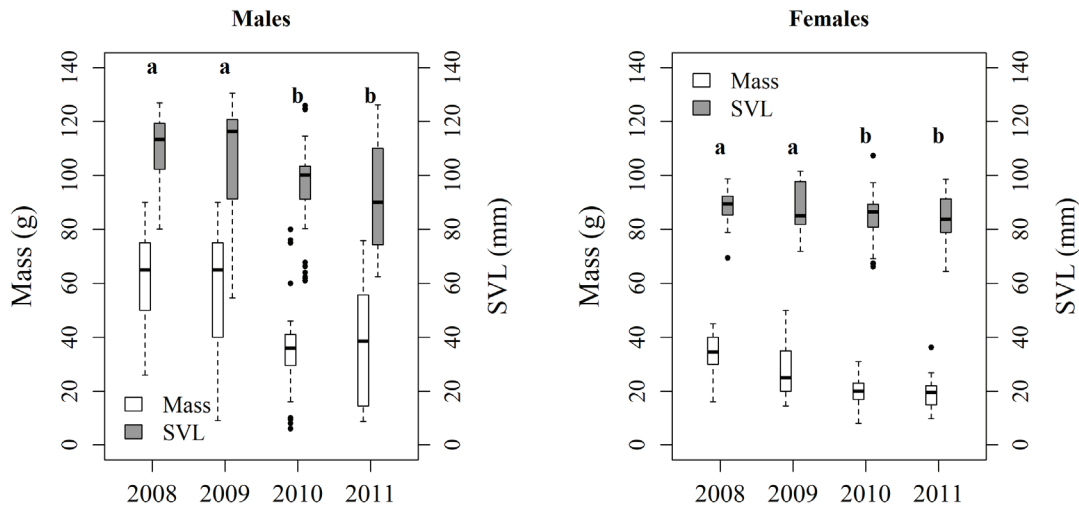


FIGURE 4. Variation in body mass (g) and snout-vent length (SVL; mm) from which the body condition was calculated of males and females of the Western Collared Spiny Lizard (*Tropidurus catalanensis*) from 2008 to 2011 in Alegrete, Rio Grande do Sul, Brazil. Equal letters indicate that there was no significant difference in body condition between those years.

factors such as wind, incidence of solar radiation, and environment temperature (e.g., Yirdaw and Luukkanen 2004; Lemenih et al. 2004; Kanowski et al. 2005; Hejda et al. 2009; Gainsbury and Colli 2014). Also, we observed that the outcrops shifted from a condition of total solar incidence (about 12 h/d, depending on the season) to just one hour on the zenith of the sun. Such reduction may have greatly influenced the gradual decrease in the number of lizards found in each sample because *T. catalanensis* is a heliophilous species highly influenced by environmental variables of open areas (Ribeiro et al. 2007; Vieira 2009).

Lower body condition of lizards has been reported as a consequence of forestation of non-native plants. In another study with the same population of *L. wiegmanni* (mentioned above), Stelletti et al. (2015) observed that lizards in the forested environment were smaller and had a body condition 22% lower than those in natural environments. They attributed this to the reduction in thermoregulatory efficiency, leading to an impairment of cellular functions and/or ability to capture prey. The authors also reported that a 20% reduction in body mass is harmful to animals, given that heavier individuals usually have higher fat reserves or higher energy acquisition rates that increase survival probabilities under poor environmental conditions (Stelletti et al. 2015). In our study, we found that the reduction of body condition of lizards was up to 25.4% (males) and 36.3% (females), indicating that lizards, regardless of size, were thinner in later years. Such reduction may represent an important factor in the 21% decline of the apparent survival probability ( $\Phi$ ) of the population because body condition reflects the previous food intake rate and the size of energy reserves in reptiles (Bonnett and Naulleau 1994;

Forsman and Lindell 1996) and is associated with both direct and indirect costs and benefits that may influence survival (Civantos and Forsman 2000).

Considering this, we conclude that the large-scale silviculture of exotic woody monocultures represents a major threat to the saxicolous reptiles native to open grassland areas, such as the Pampas. Even though the rocky outcrops in our study area remained without planted eucalyptus, the deep shade resulting from the close distance of the trees to the outcrops caused the local extinction of the lizard population. Adequate conservation and management measures of forestry plantations should take into account the distance to rocky

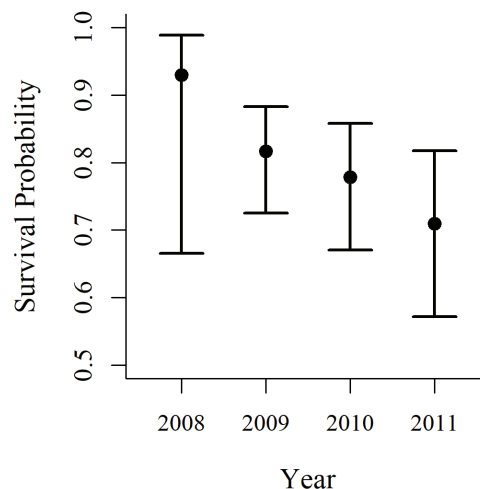


FIGURE 5. Mean survival probability ( $\Phi$ ) of the population of the Western Collared Spiny Lizard (*Tropidurus catalanensis*) studied from 2008 to 2011 in Alegrete, Rio Grande do Sul, Brazil, according to the top ranked model  $\{\Phi(\text{year}) p(\text{age} + \text{temp}^2)\}$ .

outcrops and the connectivity between rocky habitats to guarantee the viability of saxicolous species. Currently, only 50% of original grasslands remains in the Pampas (Cordeiro and Hasenack 2009), mainly due to the conversion into exotic pastures, intensive crops, and forests (Pillar et al. 2009). Despite this, only 453 km<sup>2</sup> (< 0.5%) of the biome is under legal protection (Overbeck et al. 2007).

Finally, degradation and habitat loss are the major extinction threat to animal species (Fontana et al. 2003), and specifically herpetofauna, along with the introduction of exotic species (Gibbons et al. 2000; Rodrigues 2005). Substitution of the natural open landscapes by forests of exotic species dramatically reduces floral diversity and alters irreversibly the fauna composition (Santos 2006). Therefore, to promote sustainable forest production, it is necessary to understand the impact of such activity on biodiversity, and this should be a research priority (Mortelliti et al. 2015) and a requirement for any enterprise that plan large-scale planting of exotic species.

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