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Conifer-plantation thinning restores reptile biodiversity in Mediterranean landscapes

Jairo S. Azor [a], Xavier Santos [b,*], Juan M. Pleguezuelos [a]

[a] *Dep. Zoología, Fac. Ciencias, Univ. Granada, E-18071 Granada, Spain*
[b] *CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos da Universidade do Porto, R. Padre Armando Quintas, 4485-661 Vairão, Portugal*

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ABSTRACT

Habitat loss and transformation are the greatest threats to biodiversity. In the Mediterranean Basin, planting pines has been a widespread practice that has transformed and degraded natural habitats. Understanding the response of living organisms to these anthropogenic disturbances and their management is essential for the conservation of biodiversity. Reforestation in Spain until the end of the 20th century was conducted primarily with *Pinus* species at unnaturally high densities. We have analyzed the response of a reptile community to thinning management in pine plantations within the Sierra Nevada National Park (SE Spain). Surveyed plots covered a gradient of tree densities (according treatments) from unlogged plots, 50% logged trees, 66% logged trees, and surrounding areas of open landscape with sparse trees. Four replicates (plots) were considered per treatment, with 4 visits per plot. In each plot, we measured three reptile community metrics, species richness, abundance, and Pielou's evenness. We hypothesize that reptile metrics will increase with the reduction of pine density and canopy, and an increase of solar radiation. Our results showed a negligible response after a 50% thinning, but a significant response of the reptile community after a 66% reduction. This study demonstrates that intense logging in pine plantations restores reptile diversity in the Mediterranean Basin. This is intended to serve as a model for forest management to restore biodiversity in this region.

1. Introduction

Global biodiversity is declining worldwide (Pimm et al., 2014) and the main cause of this trend is habitat loss and transformation (Todd and Andrews, 2008). Habitat transformation disrupts ecosystems, communities or populations, and changes resource availability (White and Pickett, 1985). Throughout the twentieth century, conifer planting represented a generalized practice to provide a timber source in the European Mediterranean Region (Fabbio et al., 2003). The total area covered by these plantations has increased dramatically in recent decades, now representing about 140 million hectares (FAO, 2006). In Spain, until 1986, ca. 3.7 million ha have been restored mainly with *Pinus* species (Madrigal, 1998), this representing 7.3% of the country's surface area. At some sites, these plantations addressed more than merely economic interests, also serving recreational purposes and providing ways of protecting nature and mitigating soil erosion (Erwin, 2000; Spiecker, 2003). Forests are generally species-rich ecosystems, harboring a wide range of biological diversity (Lindenmayer, 1999). However, conifer plantations are usually monospecific, have high non-natural pine densities, and several studies have reported that these plantations harbor poor plant and animal communities (Vance et al., 2007; Gómez-Aparicio et al., 2009; Bremer and Farley, 2010; Mateos et al., 2011; Torre et al., 2014). Moreover, these plantations have high pest incidence (Hódar et al., 2012), poor soil characteristics (Kainulainen and Holopainen, 2002), and a greater frequency and intensity of wildfires (Maestre et al., 2004; Bremer and Farley, 2010)

Many of the negative effects of plantations are the result of the dominance of a single habitat structure. This transformation is a key trend in explaining the composition, richness, and relative abundance of species in many communities of organisms, particularly reptiles (Pianka, 1966; Enge and Marion, 1986). In Mediterranean environments, preferred habitats of many reptiles include low vegetation cover and strong radiation (review in Salvador, 2014). Continuous tree canopies, such as those artificially provided by most coniferous plantations, block solar radiation for reptiles, implying less favorable habitat compared to sites with more variable or open canopies (Todd and Andrews, 2008). Forest restoration in the form of logging (Harrod et al., 2009) can, to some extent, offset the problems arising from reforestation (Russell et al., 2004; Verschuyl et al., 2011). The reduction of tree density leads to the development of understory vegetation due to

* Corresponding author.
E-mail address: xsantossantiro@gmail.com (X. Santos).

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increased light availability under the canopy (Homyack et al., 2005), which increases plant diversity (Gómez-Aparicio et al., 2009; Franklin and Johnson, 2014), and encourages colonization of many animal species (Carey, 2003; Verschuyl et al., 2011).

Logging of conifer plantations favors birds (Hunter, 2001; Kalies et al., 2010), small mammals (Zwolak, 2009), arthropods (Yi, 2007), snails (Torre et al., 2014), and other invertebrates (see a review in Verschuyl et al., 2011). Unfortunately, information on how reptiles respond to forest management is scarce and limited to the USA (Gibbons, 1988; Russell et al., 2004; Gardner et al., 2007; Todd and Andrews, 2008; Sutton et al., 2013). Based on the scarce data to date, there is some disagreement related to the effects of logging on reptile species (see a review in Russell et al., 2004, and Verschuyl et al., 2011). For example, in Florida and Alabama pine woodlands many reptiles responded favorably to logging (Campbell and Christman, 1982; Greenberg et al., 1994; Sutton et al., 2013) but the response is unclear after a low intensity fuel reduction is applied (Greenberg and Waldrop, 2008). In general, reptiles showed contrasting responses to forest thinning depending on the species, the habitat structure, the spatial scale at which organisms selected their habitats, and biotic and abiotic interactions developed by the focal species (Adams et al., 1996; Renken et al., 2004; Russell et al., 2004; Greenberg and Waldrop, 2008).

Our study represents a new contribution from an untested region of the world, the Mediterranean Region. We sampled reptiles in Sierra Nevada National Park (SE Spain), where approximately 80% of woodlands (30,000 ha) are pine plantations (Bonet et al., 2009). In 2010, the Regional Administration logged conifer plantations to different degrees. The objective of this study was to examine the response of reptiles (i.e. species richness, abundance and diversity) to this management along a thinning gradient. This study seeks to provide the first guidelines in Europe and the Mediterranean Basin for the management of coniferous plantations with the goal of restoring reptile biodiversity.

2. Material and methods

2.1. Study area and forest management

The study was performed on the western edge of the Sierra Nevada National Park (Ermita Vieja, Dílar municipality, province of Granada, SE Spain; coordinates 3° 34′W, 37° 2′N; Supplementary Material Fig. S1). The area has limestone lithology, 600 mm of annual rainfall on average, and altitudinal range of 940–1420 masl. The landscape is dominated by dense pine plantations established 60 years ago with maritime pine *Pinus pinaster* and Aleppo pine *Pinus halepensis*. Currently pines have a height of 7–10 m and the tree density of about 600 trees/ha.

In 2010, the Regional Administration started a thinning program with two treatment intensities, 50% and 66% of pine reduction in plots of 20–37 ha. In spring 2014 we started a reptile survey on plots with no thinning, with 50% thinning, and with 66% thinning. Prior to the reforestation, the landscape in the study area was dominated by open areas with isolated Holm oak *Quercus rotundifolia* stands. To study the impact of pine reforestation and subsequent thinning management on the reptile community, 4 replicates (hereafter plots) were chosen for each of the three treatments (no thinning, 50% thinning, and 66% thinning). On the surrounding open landscape, we also choose 4 plots of similar size to the plots in thinned areas. Plots were arranged in a mosaic to avoid spatial autocorrelation (Camarero and Rozas, 2006), distant from ecotones (e.g. roads, firewalls), and north facing, with a slope less than 20% to minimize effects other than pine density (Supplementary Material Fig. S1).

Each plot was designed as a 100 × 35 m rectangle. The four corners of rectangles were georeferenced and coordinates transferred to a recent Google Earth imagery. We then estimated tree density in each stand following Olivares (2008) which is effective for monitoring and tree counting for agricultural purposes.

2.2. Reptile sampling

We conducted field sampling during May and June 2014. Reptiles were surveyed using line transects at the 16 study plots, as this is a widely followed method for measuring the population structure of terrestrial reptiles (Nomani et al., 2008; Foster, 2012). Within each plot, the transect had a "U" shape, with both sides of the path separated from each other at least 25 m, thus minimizing the possibility of data pseudoreplication (double counting of the same individual) according to the vagility of Iberian reptiles (review in Salvador, 2014). Surveys were time constrained (20 min) to standardize sampling effort, and performed at a constant speed. Active animals were recorded by visual encounters; complementarily, rocks and logs were turned on to find individuals since some of the reptiles in the study area can take shelter under them. Reptiles were identified at species level without catching and marking them. Surveys were conducted on sunny days, at temperatures between 13–26 °C, between 10:00–19:00, when reptile activity is maximum in the study area (Caro et al., 2010). Each plot was surveyed four times due to the low detectability of some reptile species (Fitzgerald, 2012). As we did not individually mark reptiles, we did not discard that some reptiles could be re-observed in consecutive visits. To diminish data pseudo-replication, visits were done at least five days apart one of the other, thus increasing the possibility of reptiles to move and relocate freely in their habitats.

2.3. Statistical analyses

Two reptile-community metrics were calculated for each plot and transect: species richness and total abundance of reptiles seen. We examined differences in these metrics by General Linear Mixed Models (GLMM) with treatment as a fixed effect and visit as a random effect. To meet the assumption for ANOVA, residuals of the dependent variable on the grouping factor (i.e. treatment) were examined. When differences among treatments were significant, we conducted post hoc Sheffé tests between pairs of treatments.

An ordination analysis was conducted from the matrix of relative abundance of species in the plots (summing records of the four visits to each plot to account for a maximum number of species seen) with the goal of associating reptile species and forest management treatments. First, we ran a Detrended Correspondence Analysis (DCA) and quantified the length of the major gradient as 1.742. According to ter Braak and Šmilauer (2002) and Lepš and Šmilauer (2003), for scores of less than 4 in the DCA it was assumed that the relationship between the relative reptile abundance in the plots was linear and not unimodal; therefore, the association between species abundance and treatment was examined by a redundancy analysis (RDA) instead a Canonical Correspondence Analysis. For the RDA, the relationship between the axes and variables were statistically checked using 1000 Monte Carlo permutations with the software CANOCO for Windows (version 4.55; ter Braak and Šmilauer, 2002). The ordination analysis was made including all species, although we assume that small counts of some species preclude a strong statistical value.

3. Result

Tree density significantly differed among treatments (K–W test, $H_{3,16} = 14.12$, $P = 0.003$), with a gradient from no thinning to open-landscape plots (Fig. 1a). In total, 101 individuals from seven