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The role of fire history, land-use, and vegetation structure on the response of Mediterranean lizards to fire

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ABSTRACT

Fire is a critical component of terrestrial ecosystems and essential to understand the composition and diversity of communities in fire-prone regions. Nevertheless, fire does not act alone, and other factors such as land-use type and vegetation structure can also operate at different scales, prompting the response to fire of ectotherm communities such as reptiles. We have evaluated the influence of environmental factors on the abundance, diversity, and richness of reptile communities in Serra da Estrela Natural Park (northern Portugal), at both the landscape and micro-habitat scales. In spring 2014 and 2015, 20 transects were surveyed eight times, the vegetation structure and composition were measured, and the extent of land-use types around each transect calculated in this Mediterranean community. At the landscape scale, reptile abundance was higher in natural woodlands and more complex habitats (higher vegetation heterogeneity and plant richness), and reptile evenness was affected by vegetation heterogeneity and time since fire. By contrast, species richness was not related to any environmental factor measured in this study. Only two lizard species were common in the park, *Psammodromus algirus* and *Podarcis guadarramae*. Their relative abundances increased with contrasting habitat variables as the former is a ground-dwelling lizard specialist that prefers heterogeneous (unburnt) habitats and the second is a rock lizard that selects open (burnt) stands. At the micro-habitat scale, the probability of reptile presence, reptile abundance, and reptile richness increased with plant richness and decreased with tree cover. This study highlights the importance of several environmental factors, that operate from micro-habitat to landscape scales to understand the response of reptiles to fire.

1. Introduction

Fire is a fundamental driver of many terrestrial biomes, including Mediterranean type ecosystems (Bond et al., 2005; Bowman et al., 2009, Pausas and Keeley, 2009), and many species have adaptive traits that enable them to persist in these fire-prone habitats (Keeley et al., 2012, Santos and Cheylan, 2013). In the Mediterranean basin, vegetation structure (e.g. heterogeneity, plant diversity, vegetation cover), land-use and fire history (e.g. fire recurrence and time since fire), synergistically interact and shape species habitats (Blondel et al., 2010), with important consequences for the diversity and abundance of different animal species (Moreira and Russo, 2007), but particularly for taxa with low-dispersal ability such as reptiles (Santos et al., 2014; Badiane et al., 2017). Reptiles are sensitive to alterations in habitat attributes such as vegetation structure (e.g. heterogeneity and cover of the different vegetation strata) because they are ectotherms, narrow-ranging species, and characterized by low vagility and dispersal rates (Huey, 1982; Valentine and Schwarzkopf, 2008; Azor et al., 2015).

There is evidence that fire history characteristics (e.g. fire recurrence and time since fire) are not the only drivers affecting reptile communities in fire-prone ecosystems, and other processes, like habitat structure, biogeographic affinity, and food availability, operating at different spatial scales, might be equally important (Driscoll and Henderson, 2008; Pastro et al., 2013; Ferreira et al., 2016b). Besides the direct impact of fire on animals (i. e. mortality; Smith et al., 2001; Couturier et al., 2011), shifts in vegetation along postfire successional stages are important in order to characterize reptile communities in fire-prone ecosystems (Driscoll et al., 2012; Santos and Cheylan, 2013; Smith et al., 2013; Santos et al., 2016). The complex relationship between fire and vegetation structure (Nimmo et al., 2014) makes it

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advisable to incorporate vegetation factors into fire-history models to better understand the response of reptiles to fire (Santos et al., 2016).

At the landscape scale, vegetation heterogeneity (Nimmo et al., 2012) and land-use type can be key factors explaining total abundance and species richness in reptile communities (Ribeiro et al., 2009; Azor et al., 2015; Santos et al., 2016). At the micro-habitat scale, characteristics such as vegetation cover or plant richness can be important because they influence the habitat by affecting the availability of shelters, food, or sun exposure (Webb and Shine, 1998; Kim and Holt, 2012; Elzer et al., 2013). These factors can operate in concert with fire history to shape reptile communities in fire-prone ecosystems according to the specific life-history traits of each reptile species (Ferreira et al., 2016b; Santos et al., 2016). For this reason, landscape- and micro-habitat-scale factors have to be integrated to attain a comprehensive view of the composition of reptile communities in fire-prone ecosystems.

This study was conducted in the Serra da Estrela Natural Park (northern Portugal), and performed at two different scales: at the landscape scale, we analyzed the effect of fire history (fire recurrence and time since fire), vegetation heterogeneity, and land-use (main land-use type and land-use diversity) on the reptile abundance, richness and evenness. At the micro-habitat scale, we analyzed the role of plant richness and vegetation cover (tree, shrub, and herbaceous cover) on the probability of reptile presence, reptile abundance and evenness.

We hypothesize that species richness, reptile abundance and evenness are higher in natural areas (woodlands and scrublands) and in areas with higher land-use diversity (landscape scale) as well as in locations with higher plant diversity and lower tree cover (micro-habitat scale). Furthermore, we also expect that fire history (number of fires and time since fire) will affect the reptile community by altering the habitat structure (Ferreira et al., 2016b; Santos et al., 2016).

2. Materials and methods

2.1. Fire regime in Portugal and in the study area

Portugal has the highest fire incidence in Europe (Nunes et al., 2005; Catry et al., 2006; Oliveira et al., 2012), and fire is considered one of the most important agents of landscape change (Silva et al., 2011). Fire frequency and intensity have increased remarkably since the 1960s due to a combination of socioeconomic and environmental conditions such as rural abandonment, and conversion of marginally productive agriculture to eucalypt and pine plantations (Moreira et al., 2001, 2011; Fernandes et al., 2013). The climate is warm temperate characterized by hot, dry summers and cool, wet winters; likewise, natural vegetation is typically evergreen, resistant to drought, and pyrophytic (Nunes et al., 2005). Thus, both socioeconomic and environmental conditions lead to a high accumulation of fuel leading to a high risk of fire (Moreira et al., 2001, 2009). Catry et al. (2009) concluded that human activities were the primary cause of wildfires since about 60% of ignitions have occurred in areas of high population density and close to roads.

Serra da Estrela is a mountainous area located in the east-central region of Portugal (Supplementary materials Fig. S1), characterized by a high elevational gradient (250–1993 m). The mean annual rainfall ranges from 1000 mm in the lowest elevations to approximately 2500 mm at highest elevations (SNIRH, 2015), and the mean annual temperature ranges from 22 °C to 4 °C at the lowest and highest elevations, respectively. The Serra da Estrela Natural Park (hereafter SENP) is the largest protected area in Portugal (1.0106 km^2) and encloses most of this mountain area. The park is a landscape mosaic shaped by a long fire history (Connor et al., 2012) and multiple land uses (including woodlands, scrublands, coniferous plantations, and agriculture areas) arranged across an elevational gradient.

The reptile community at the SENP is composed of 20 species, i.e. 12 lizards and 8 snakes (Lesparre and Crespo, 2008; Supplementary materials Table S2), from both Mediterranean and Atlantic origins (following Sillero et al., 2009).

2.2. Site selection and environmental characterization

Twenty sites were selected across a fire-history gradient (Supplementary materials Fig. S1). The fire history was provided by the Instituto da Conservação da Natureza e Florestas (ICNF). Each site was characterized according to two fire-history variables, time since last fire (ranging from 0 to > 40 years) and fire recurrence (number of fires, ranging from 0 to 6 fires over a period of 40 years; Supplementary materials Table S3). Sites were a minimum of 600 m apart (mean distance and standard deviation between pairs: 17 ± 10 km) and sites with a similar fire history were placed as far as possible from each other to avoid spatial autocorrelation.

Land-use was examined in 200-m buffers around each transect. Raw data were obtained from the Portuguese land-cover map (IGP, 2008) and reclassified to five land-use types: monocultures (pine or eucalyptus plantations), agriculture fields, natural woodlands, scrublands, and urban areas (Supplementary materials Fig. S1). Our interest was in the effects of these major land-use types on the abundance and diversity of Mediterranean reptiles (Ribeiro et al., 2009; Azor et al., 2015). We calculated the land-use diversity as the Simpson diversity index of all land uses within the 200-m buffer, and according to the commonest land-use types (i.e. monoculture, scrubland and natural woodland; Supplementary materials Fig. S4). The spatial distribution of the transects by land-use classification was clustered, with the majority of monocultures located on the western part and scrubland areas on the eastern part of the study area.

Elevation was considered during site selection due to its influence on reptile presence and distribution (McCain, 2010; Kutt et al., 2011). Transects were selected within the elevational range of 250–1250 m, to avoid sampling on mountaintops that are characterized by the presence of alpine reptile species (i.e. *Iberolacerta monticola* and *Coronella austriaca*) and the absence of fires.

To characterize vegetation structure and heterogeneity, each transect was divided into 20-m sections. In each section, the vegetation within 2 m on either side of the transect ("left" and "right") was identified to the species level (only for perennial species, because their constancy over the sampling period of the study). For each transect, the vegetation heterogeneity was accessed through a similarity index (Baselga et al., 2007) ranging between 0 and 1, with values approaching 1 indicating greater dissimilarity (higher vegetation heterogeneity). This index provided an estimate of overall compositional heterogeneity among sections, regardless of differences in species richness. For this, we divided the total number of plant species in each 20 m section by the sum of the minimum values of species not shared between each pair (left and right) of sections. For each transect and at each 20-m section, we described the vegetation structure according to the extent of tree, shrub, and herbaceous layers, ranging each layer from 0% to 100% cover.

2.3. Reptile sampling

Transects were placed on trails to facilitate reptile detectability (see a similar procedure in Santos and Cheylan, 2013), with an average length of 1 km (SD: 159 m; range 770–1250 m) and were as linear as possible to avoid recording the same individuals along the transect. Between May and September of 2014, and May and June of 2015, each transect was visited eight times (four visits in spring 2014, 1 visit in autumn 2014, and 3 visits in spring 2015) for 45 min each, walking slowly at a constant speed. During each visit, all transects were surveyed within 4–5 days, and visits were at least a week and a half apart. The surveys were made on sunny days and during the hours of reptile activity (from 09h00 to 18h00). Searches included open sites and we also turned rocks and other refuges to maximize observations (Santos and Cheylan, 2013; Santos et al., 2016). All the reptiles recorded were