Riparian galleries can act as refuge for birds in Eucalyptus plantations hit by wildfires

As galerias ripícolas podem atuar como refúgio para aves em eucaliptais atingidos por incêndios florestais

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ABSTRACT

Eucalyptus monocultures are known to hold reduced terrestrial biodiversity. We aimed to measure the effect of native riparian galleries embedded in plantations of the non-native *Eucalyptus globulus* in Portugal on bird richness and abundance. Between 2017 and 2019, we surveyed the breeding bird communities in native forests and two types of eucalyptus plantations: those bordering and those without native riparian galleries. The incidental occurrence of huge wildfires after the first year, allowed measuring the effects of native riparian galleries on the bird communities colonizing both types of plantations before and after the wildfires. Before the wildfires, bird communities in plantations with galleries were similar to those from native forests, presenting higher richness and abundance than those in plantations without galleries. After the wildfires, bird communities were similar in burnt and non-burnt plantations with galleries, which tended to have higher richness and abundance than both burnt and non-burnt plantations without galleries. Therefore, the presence of a riparian gallery was a better predictor than the fire occurrence to explain richness and abundance of bird communities in eucalyptus plantations. These striking results can be related to the relatively high availability of resources for birds in riparian galleries. We showed that native riparian galleries in eucalyptus plantations can act as a refuge for biodiversity, suggesting that they can contribute to maintain ecosystem functioning in landscapes threatened by wildfires.

Keywords: Exotic species, habitat changes, Mediterranean region, monoculture, native vegetation

RESUMO

É do conhecimento geral que as monoculturas de eucalipto possuem reduzida biodiversidade terrestre. O nosso objetivo foi medir o efeito da manutenção de galerias ripícolas nativas de Portugal em plantações de *Eucalyptus globulus* na riqueza e abundância de aves. Entre 2017 e 2019, amostrámos as comunidades de aves nidificantes em florestas nativas e em dois tipos de plantações de eucalipto: com e sem galerias ripícolas nativas. A ocorrência acidental de grandes incêndios florestais após o primeiro ano de amostragem, permitiu medir os efeitos das galerias ribeirinhas nativas nas comunidades de aves que colonizam ambos os tipos de plantações antes e depois dos incêndios. Antes dos incêndios, as comunidades de aves em plantações com galerias eram semelhantes às de florestas nativas, apresentando maior riqueza e abundância do que aquelas em plantações sem galerias. Após os incêndios florestais, as comunidades de aves foram semelhantes em plantações ardidas e não ardidas com galerias, que tenderam a ter maior riqueza e abundância do que plantações ardidas e não ardidas sem galerias. A presença de uma galeria ripícola revelou ser um preditor melhor do que a ocorrência de incêndios para explicar a riqueza e abundância de comunidades de aves em plantações de eucalipto. Esses resultados podem estar relacionados com a disponibilidade relativamente alta de recursos para as aves nas galerias ripícolas. Mostrámos que as galerias ripícolas nativas em plantações de eucalipto podem funcionar como um refúgio para a biodiversidade, sugerindo que podem contribuir para manter o funcionamento do ecossistema em paisagens ameaçadas por incêndios florestais.

Palavras-chave: Espécies exóticas, mudanças de habitat, região Mediterrânea, monocultura, vegetação nativa

Introduction

Monocultures tend to hold less biodiversity than natural habitats as result of their artificial homogeneity (e.g., limited availability of micro-habitats; Jacktel et al. 2017, Bohada-Murillo et al. 2020, Wang et al. 2022). Eucalyptus have been planted at large scale, often in monocultures, for timber, paper and oil production, in Brazil, China, India, South Africa, and some European countries, especially over the last five decades (Turnbull 1999; Bayle 2019). Currently, *Eucalyptus globulus* is the second most abundant non-native tree in Europe, where it covers 1.46 million ha, mainly concentrated in Portugal and Spain (Brus et al. 2019).

Eucalyptus plantations are known to hold lower biodiversity than native woodlands (Calviño-Cancela 2013; Fork et al. 2015; Goded et al. 2019; Hanane et al. 2019; Silva et al. 2019). Overall, the exotic status and chemical characteristics of eucalyptus plants strongly constrain the number of potential interacting species, which would require a long time of co-evolution to increase (Calviño-Cancela 2013; Ferreira et al. 2015). Abundance and species richness of native plant species are also negatively affected by the establishment of eucalyptus plantations (Proença et al. 2010; Goded et al. 2019; Silva et al. 2019). Changes in soil composition and reduction of water availability in eucalyptus plantations have been highlighted for possibly affecting native vegetation (Tererai et al. 2013; Yang et al. 2017). Nevertheless, a significant seedbank of native species can be found in areas of resprouting eucalyptus after a soil disturbance such as tree logging or fire occurrence (Maia et al. 2014; Moreira et al. 2013).

Eucalyptus plantations tend to hold simpler versions of the regional bird community with an overrepresentation of habitat-generalist species, which are mainly associated with shrubs at young stands and canopies at older ones (Proença et al. 2010; Calviño-Cancela 2013; Goded et al. 2019; Jacoboski and Hartz 2020). Often, exotic monocultures have short rotation times and are not connected with native forest remnants, resulting in reduced availability of nesting and food resources for birds (Castaño-Villa et al. 2019). Moreover, monocultures tend to be established in large patches reducing the connectivity between native vegetation remnants (Giubbina et al. 2018; Iezzi et al. 2018). Biodiversity hotspots, like the Mediterranean basin, are particularly vulnerable to the replacement of native forests by exotic monocultures due to the singularity of their communities (de la Hera et al. 2013; Bohada-Murillo et al. 2020). The negative effect of plantations on bird diversity is not consistent across large geographical areas as it depends clearly on the surrounding landscape (Pereira et al. 2014; Pedley et al. 2019; Lourenço et al. 2021). However, there is little knowledge about the potential positive impacts of riverine ecosystems (e.g., riparian galleries) on the biodiversity of eucalyptus plantations (Santos et al. 2018). In central Portugal, *Eucalyptus globulus* is planted in small non-managed properties that have great capacity for natural establishment from seed (Catry et al. 2015). Currently, the region holds the main plantations in the country, and an average 10-year productivity of about 10 Mg / ha / year, which is only slightly above the national average (Alves et al. 2007). Eucalyptus plantations correspond to 16% of the land uses in central Portugal, while native forest corresponds to 6% (Uva 2019).

Eucalyptus plantations often burn (Meneses et al. 2018), and even though the impact of these fires vary, they are an important threat to terrestrial and aquatic ecosystems that are particularly relevant in the Mediterranean basin (Moreira et al. 2011; Botequim et al. 2013; Pastro et al. 2014). In recent decades, there has been a tendency for increased frequency of wildfires due to the combination of factors, such as land abandonment and climate change (Gonçalves and Sousa 2017; Fernandes et al. 2019). Central Portugal has been described as the most vulnerable region to wildfires in the country, considering its vegetation cover, altimetric slope, and historical record of wildfires (Parente and Pereira 2016). In 2017, Europe suffered a particularly strong heatwave, with central Portugal suffering the most devastating wildfires of the continent: 993,557 ha burnt in the European Union, of which 540,630 ha were in Portugal, where at least 114 people died (San-Miguel-Ayanz et al. 2018; Fernandes et al. 2019; Molina-Terrén et al. 2019; Turco et al. 2019).

In Europe, most studies analysing the effects of wildfire on woodland bird communities were developed in pinewood plantations (Moreira et al. 2001; Herrando and Brotons 2002; Battisti et al. 2008; Poirazidis et al. 2017). However, during the last decades, eucalyptus plantations have increased greatly in southern Europe replacing some areas historically covered by pinewoods (Goded et al. 2019; Fernandes et al. 2019). Considering this context, we aimed to assess (1) the effect of native riparian galleries embedded in plantations of the non-native *Eucalyptus globulus* in Portugal on bird richness and abundance, and (2) the role of native riparian galleries in reducing the impact of wildfires in the same bird parameters.

Methods

Study area

Field work was conducted in a region of central Portugal (Coimbra and Leiria districts) with high density of *Eucalyptus globulus* plantations (Figure 1). Native oak-pine forests are composed by *Pinus pinaster* and at least one native oak species (*Quercus suber, Q. faginea* or *Q. robur*). Native riparian galleries are dominated by *Quercus robur, Castanea sativa, Salix* spp. and *Rubus* spp.. The terrain is hilly, ranging from 50 to 700 m a.s.l., and climate is Mediterranean with Atlantic influence.

Data collection

The breeding bird community was surveyed by recording all birds detected, either visually or aurally within 300 m long, 50 m wide (with 25m to each side of the transect line, totalizing 3 ha) transects that were walked at a continuous slow pace. The transects were conducted in May 2017 (i.e., before the wildfires) as well as in May 2018 and 2019 (Figure 1) in three land use types: (1) eucalyptus stands bordering native riparian galleries (hereafter plantations with galleries: n = 20 sites; mean patch size and standard error: 11.1 ± 2.5 km^2); (2) eucalyptus stands without native riparian vegetation (hereafter plantations without galleries: n = 18 sites; mean patch size and standard error: 8.3 ± 1.9 km^2); and (3) oak- pine forests bordering riparian galleries (hereafter native forest: n = 20 sites; mean patch size and standard error: 6.3 ± 1.4 km^2). Both eucalyptus plantation types (1 and 2) were about 10/12-year-old, had densities of around 1,400 trees/ha, and were not logged or managed for shrub clearing during the study period. All transects were performed at least 50 m away from the edge of the patch. In plantations with riparian galleries and native forests, the 3 ha were surveyed by transects were performed along rural tracks with riparian galleries at one side and non-riparian vegetation at the other side. The minimum distance between adjacent transects was 700 m. All bird species around or above the size of a thrush (*Turdus* spp.), and aerial planktivores (swallows and swifts) were excluded, to avoid double counting in adjacent transects due to their large home ranges (Peach et al. 2004; Ringhofer and Hasegawa 2014).

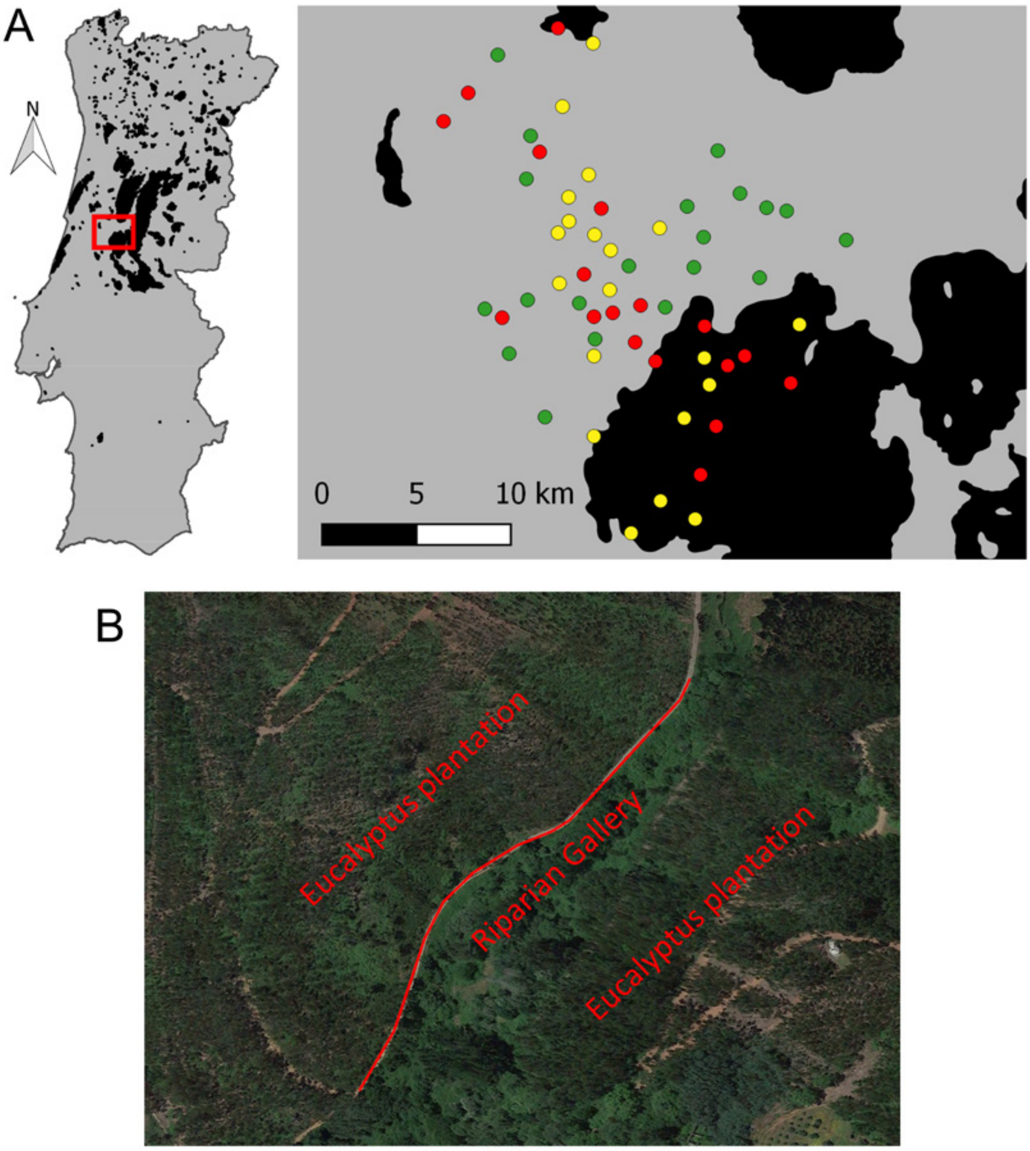
Between June and August 2017, huge wildfires burned a significant part of the study area (Figure 1; Fernandes et al. 2019; Turco et al. 2019). Native forest patches visited in this study were not affected by the fire.

Data analyses

We analysed the effect of land use type and occurrence of fire on the richness and abundance of bird communities. We used the density of all surveyed bird species within the 3 ha of the transect as a proxy of abundance (hereafter total abundance). We used a generalized linear model with Poisson distribution to analyse the effect of land use type in a situation before the wildfires (2017) considering a categorical explanatory variable with the three types of studied land uses: native forests with riparian galleries, eucalyptus plantations with riparian galleries, and eucalyptus plantations without riparian galleries. Regarding the data collected in eucalyptus stands during the three years of the study, we analysed the effect of plantation type and occurrence of fire using generalized linear mixed models with Poisson distribution. To analyse the effect of fire we used a BACI (before-after-control-impact) approach, with inclusion of two categorical explanatory variables: one indicating if the sampling was before or after wildfires, and other indicating if the sampling site was impacted or not by wildfires.

Figure 1- (A) Study area showing the burnt area by wildfires in Portugal in 2017 (black patches) after the first bird survey in three types of land uses: eucalyptus stands bordering native riparian galleries (plantations with galleries; yellow dots); eucalyptus stands without native riparian vegetation (plantations without galleries; red dots); and native mixed oak – pine forests bordering riparian galleries (green dots). Dots represent the location of transects for bird sampling. Sampling sites were affected by wildfires on 17 June 2017 (southeast patches) and 12 August 2017 (north patches). Burnt area data source: Copernicus Emergency Management Service (n.d.). (B) Example of a 300 m-length transect located in a eucalyptus plantation with a riparian gallery.

Figura 1 - (A) Área de estudo mostrando a área ardida pelos incêndios florestais em Portugal em 2017 (manchas a negro) após a primeira amostragem de aves em três tipos de usos do solo: eucaliptais adjacentes a galerias ripícolas nativas (plantações com galerias; pontos amarelos); eucaliptais sem galerias ripícolas nativas (plantações sem galerias; pontos vermelhos); e florestas mistas nativas de carvalhos e pinheiros adjacentes a galerias ripícolas (pontos verdes). Os pontos representam a localização dos transetos utilizados para a amostragem de aves. Os locais de amostragem foram afetados por incêndios florestais em 17 de junho de 2017 (manchas sudeste) e 12 de agosto de 2017 (manchas norte). Fonte de dados da área ardida: Copernicus Emergency Management Service (s.d.). (B) Exemplo de um transeto de 300 m localizado numa plantação de eucaliptos com galeria ripícola.



Following a multi-model inference approach, for each community metric, we built seven alternative models: three models included only one of the explanatory variables (plantation type, before/after wildfires, impacted/not impacted by wildfires); three models included the different combinations of two explanatory variables in interaction; and finally, we also include the null model (without variables) as a measure of the explanatory power of the models. We did not built models with three variables (and their interactions), due to limitations in the representativeness and sample size in the different combinations of the categorical variables. We used altogether the two years after the wildfire, i.e., 2018 and 2019, because we found no differences in richness or abundance between them (GLM Poisson: richness: estimate = 0.0638; SE = 0.069; z = 0.928; p = 0.35; abundance: estimate = -0.0012; SE = 0.049; z = -0.025; p = 0.98). We used the criteria ΔAICc <2 to identify the best models (Liddle et al. 2009). Models were validated by checking the plots of residuals. In addition, we computed pairwise comparisons between land use types using Tukey post hoc tests (significance was set at $p < 0.05$). All analyses were computed in R 3.6.1 (R Core Team 2020) using the packages lme4 (Bates 2010), emmeans (Length et al. 2018) and ggplot2 (Wickham et al. 2016).

Results

We detected 31 bird species during this study (Table 1). The most abundant species in all land use types were the Blackcap (*Sylvia atricapilla*) and the Robin (*Erithacus rubecula*). Wren (*Troglodytes troglodytes*) was the species more frequently recorded in the third position of the ranking of species abundance. Other species that reached high positions in the ranking were the Chaffinch (*Fringilla coelebs*) and the Coal Tit (*Periparus ater*) in burnt plantations without galleries, respectively in the second and third position; and the invasive Red-billed Leiothrix (*Leiothrix lutea*) in the second position in non-burnt plantations with galleries.

Before the occurrence of wildfires in central Portugal, in spring 2017, plantations of eucalyptus with riparian galleries showed a similar species richness and total abundance of birds to native forests and higher values than in plantations without galleries for both parameters (Figure 2.i, ii; Supporting information, Tables S1; S2). We obtained two best models (with ΔAICc <2) to explain bird richness in plantations of eucalyptus: one model that included only the plantation type (weight = 0.52) and another model including the interaction between the variables plantation type and before/after the fire (weight = 0.41; Supporting information, Table S3; S4). Species richness was higher in eucalyptus plantations with riparian galleries than in plantations without riparian galleries (z = 5.330, $p < 0.001$; Figure 3i). Species richness was negatively affected by the variable before/ after the fire (z = -2.217, p = 0.0266; Figure 3iii). The interaction between these variables showed that species richness was higher plantations with galleries before the fire than in plantations without galleries (in both situations; Figure 3vii). Illustrating this is the fact that after wildfires, species richness was higher in plantations with galleries than in plantations without galleries (z = 4.098, $p < 0.001$).

There were two best model to explain bird abundances in central Portugal, one which included the interaction between the plantation type and before/after the fire (weight = 0.68) and another which included only the variable plantation type (weight = 0.26; Supporting information, Table S5; S6). The pattern of interacting factors was similar to those described for the richness (Figure 3vii, viii).

Table 1 - Mean abundance and standard deviation for each bird species per land use type: plantations of eucalyptus with galleries before the wildfires (G), plantations of eucalyptus without galleries before the wildfires (nG), native forests (N), burnt plantations with galleries (BG), burnt plantations without galleries (BnG), non-burnt plantations with galleries (nBG), non-burnt plantations without galleries (nBnG). Numbers in parentheses indicate the hierarchical position of each species within the respective land use treatment considering its abundance. Identical abundances (considering one decimal place) were classified as belonging to the same position in the ranking.

Tabela 1 - Abundância média e desvio padrão para cada espécie de ave por tipo de uso do solo: plantações de eucalipto com galerias ripícolas antes dos incêndios (G), plantações de eucalipto sem galerias antes dos incêndios (nG), florestas nativas (N), plantações queimadas com galerias (BG), plantações queimadas sem galerias (BnG), plantações não queimadas com galerias (nBG), plantações não queimadas sem galerias (nBnG). Os números entre parênteses indicam a posição hierárquica de cada espécie dentro do respectivo tratamento de uso do solo considerando a sua abundância. Abundâncias idênticas (considerando uma casa decimal) foram classificadas como pertencentes à mesma posição no ranking.

Land use type	2017 (before the wildfire)			2018 (1st year after the wildfire)				2019 (2nd year after the wildfire)			
	G	nG	N	BG	BnG	nBG	nBnG	BG	BnG	nBG	nBnG
Species / sampling sites	20	18	20	9	8	11	10	9	8	11	10
Coal Tit *(Periparus ater)*	1.1 ± 0.9 (6)	0.6 ± 0.8 (5)	0.6 ± 1 (11)	0.9 ± 0.8 (6)	0.6 ± 0.7 (3)	0.4 ± 0.7 (8)	0.5 ± 0.7 (5)	0.8 ± 0.7 (6)	0.6 ± 0.7 (3)	0.5 ± 0.5 (7)	0.5 ± 0.7 (6)
Crested Tit *(Lophophanes cristatus)*	0.3 ± 0.5 (13)	0.3 ± 0.5 (9)	0.3 ± 0.6 (13)	0	0.1 ± 0.4 (9)	0.2 ± 0.4 (11)	0.2 ± 0.4 (9)	0.1 ± 0.3 (14)	0	0.1 ± 0.3 (15)	0
Blue Tit *(Cyanistes caeruleus)*	0.8 ± 0.9 (8)	0.4 ± 0.6 (7)	1.1 ± 0.9 (6)	0.8 ± 0.8 (7)	0	0.2 ± 0.4 (11)	0.2 ± 0.4 (9)	0.4 ± 0.5 (9)	0.5 ± 0.8 (4)	0.4 ± 0.5 (9)	0
Great Tit *(Parus major)*	0.5 ± 0.5 (9)	0.3 ± 0.5 (9)	0.7 ± 0.9 (8)	0.4 ± 0.5 (8)	0.1 ± 0.4 (9)	0.2 ± 0.4 (11)	0.1 ± 0.3 (11)	0.2 ± 0.4 (11)	0.5 ± 0.5 (4)	0.5 ± 0.7 (7)	0.2 ± 0.4 (8)
Woodlark *(Lullula arborea)*	0.1 ± 0.4 (18)	0.1 ± 0.2 (13)	0	0.1 ± 0.3 (14)	0.4 ± 0.5 (5)	0	0	0	0	0	0.1 ± 0.3 (10)
Melodious Warbler *(Hippolais polyglotta)*	0	0	0.2 ± 0.5 (14)	0	0	0	0	0	0	0	0
Common Chiffchaff *(Phylloscopus collybita)*	0.1 ± 0.2 (18)	0	0.1 ± 0.2 (19)	0	0	0	0.1 ± 0.3 (11)	0	0	0	0
Iberian Chiffchaff *(Phylloscopus ibericus)*	0	0	0.1 ± 0.3 (19)	0	0	0	0	0	0	0	0
Cetti's Warbler *(Cettia cetti)*	0.1 ± 0.2 (18)	0	0	0	0	0	0	0	0	0	0

Land use type	2017 (before the wildfire)			2018 (1st year after the wildfire)				2019 (2nd year after the wildfire)			
	G	nG	N	BG	BnG	nBG	nBnG	BG	BnG	nBG	nBnG
Species / sampling sites	20	18	20	9	8	11	10	9	8	11	10
Long-tailed Tit *(Aegithalos caudatus)*	0.5 ± 0.8 (9)	0.3 ± 0.5 (9)	0.5 ± 0.6 (12)	0	0	0.3 ± 0.5 (9)	0.1 ± 0.3 (11)	0	0	0.3 ± 0.5 (11)	0
Blackcap *(Sylvia atricapilla)*	4.1 ± 1.7 (1)	1.6 ± 1.4 (2)	3.6 ± 1.6 (2)	3.4 ± 2 (1)	0.5 ± 1.1 (4)	3.3 ± 1.3 (1)	1.3 ± 1.1 (2)	3.2 ± 1.9 (1)	1.3 ± 1.3 (1)	2.7 ± 1.9 (2)	2.1 ± 1.3 (2)
Sardinian Warbler *(Sylvia melanocephala)*	0.5 ± 0.9 (9)	0.3 ± 0.6 (9)	0.2 ± 0.4 (14)	0	0	0.5 ± 0.8 (6)	0.5 ± 0.8 (5)	0.2 ± 0.4 (11)	0	0.6 ± 0.9 (6)	0.6 ± 0.8 (5)
Dartford Warbler *(Sylvia undata)*	0	0	0	0	0	0.1 ± 0.3 (17)	0	0	0	0	0
Red-billed Leiothrix *(Leiothrix lutea)*	1.5 ± 2.3 (4)	0.4 ± 1.1 (7)	1.5 ± 2.4 (5)	0.2 ± 0.7 (11)	0	2.6 ± 2.5 (2)	0.9 ± 1.4 (4)	0.4 ± 1.3 (9)	0.4 ± 1.1 (7)	2.7 ± 1.8 (2)	0.8 ± 1 (4)
Firecrest *(Regulus ignicapilla)*	1.2 ± 1 (5)	0.8 ± 1 (4)	1.6 ± 1 (3)	1.2 ± 0.8 (4)	0.3 ± 0.5 (6)	1.2 ± 0.9 (5)	0.3 ± 0.7 (8)	1.2 ± 0.8 (4)	0.5 ± 0.5 (4)	1.6 ± 1.4 (5)	0.4 ± 0.5 (7)
Nuthatch *(Sitta europaea)*	0	0	0	0	0	0	0	0.1 ± 0.3 (14)	0	0	0
Short-toed Treecreeper *(Certhia brachydactyla)*	0.3 ± 0.6 (13)	0	0.7 ± 0.9 (8)	0.2 ± 0.7 (11)	0	0.2 ± 0.6 (11)	0	0.6 ± 0.7 (7)	0	0.2 ± 0.4 (12)	0
Wren *(Troglodytes troglodytes)*	2.4 ± 1.3 (3)	1.3 ± 1.1 (3)	1.6 ± 1.4 (3)	2.8 ± 2 (2)	0.3 ± 0.5 (6)	2.1 ± 1.5 (4)	1 ± 0.7 (3)	1.3 ± 1.5 (3)	0.4 ± 0.5 (7)	1.9 ± 0.9 (4)	1.4 ± 0.8 (3)
Robin *(Erithacus rubecula)*	2.8 ± 1.1 (2)	1.7 ± 1.4 (1)	4 ± 1.6 (1)	2.8 ± 1.9 (2)	1 ± 0.9 (1)	2.6 ± 1.2 (2)	1.6 ± 1 (1)	3.2 ± 1.3 (1)	0.4 ± 0.5 (7)	2.8 ± 1.1 (1)	2.2 ± 0.9 (1)
Back Redstart *(Phoenicurus ochruros)*	0	0	0.1 ± 0.2 (19)	0	0	0	0	0	0	0	0
Dunnock *(Prunella modularis)*	0.2 ± 0.5 (16)	0	0.1 ± 0.2 (19)	0	0	0	0	0.1 ± 0.3 (14)	0.1 ± 0.4 (13)	0	0
Grey Wagtail *(Motacilla cinerea)*	0	0	0.1 ± 0.3 (19)	0.2 ± 0.4 (11)	0	0	0	0.2 ± 0.4 (11)	0	0	0

Land use type	2017 (before the wildfire)			2018 (1st year after the wildfire)				2019 (2nd year after the wildfire)			
	G	nG	N	BG	BnG	nBG	nBnG	BG	BnG	nBG	nBnG
Species / sampling sites	20	18	20	9	8	11	10	9	8	11	10
White Wagtail *(Motacilla alba)*	0	0	0	0	0.1 ± 0.4 (9)	0	0	0	0	0	0
Chaffinch *(Fringilla coelebs)*	1 ± 1.1 (7)	0.5 ± 0.7 (6)	1.1 ± 1.3 (6)	1 ± 0.9 (5)	0.8 ± 0.5 (2)	0.5 ± 0.9 (6)	0.4 ± 0.7 (7)	1.2 ± 0.8 (4)	1 ± 0.8 (2)	0.4 ± 0.7 (9)	0
Bullfinch *(Pyrrhula pyrrhula)*	0.2 ± 0.4 (16)	0	0.2 ± 0.4 (14)	0.1 ± 0.3 (14)	0	0.3 ± 0.6 (9)	0	0.1 ± 0.3 (14)	0	0.2 ± 0.4 (12)	0
Greenfinch *(Chloris chloris)*	0.3 ± 0.6 (13)	0.1 ± 0.2 (13)	0.2 ± 0.5 (14)	0.4 ± 0.7 (8)	0.3 ± 0.5 (6)	0.2 ± 0.4 (11)	0.1 ± 0.3 (11)	0	0.3 ± 0.7 (10)	0	0.2 ± 0.4 (8)
Linnet *(Linaria cannabina)*	0.1 ± 0.3 (18)	0.1 ± 0.3 (13)	0	0	0	0	0.1 ± 0.3 (11)	0	0	0	0
Goldfinch *(Carduelis carduelis)*	0	0	0.1 ± 0.3 (19)	0	0	0	0	0	0.1 ± 0.4 (13)	0	0
Serin *(Serinus serinus)*	0.5 ± 0.7 (9)	0.1 ± 0.5 (13)	0.7 ± 1.2 (8)	0.3 ± 0.5 (10)	0.1 ± 0.4 (9)	0.2 ± 0.4 (11)	0.1 ± 0.3 (11)	0.6 ± 0.5 (7)	0.3 ± 0.5 (10)	0.2 ± 0.6 (12)	0
Rock Bunting *(Emberiza cia)*	0	0	0.2 ± 0.4 (14)	0	0	0	0	0	0.3 ± 0.5 (10)	0	0
Cirl Bunting *(Emberiza cirlus)*	0	0	0.1 ± 0.4 (19)	0	0	0	0	0	0.1 ± 0.4 (13)	0	0

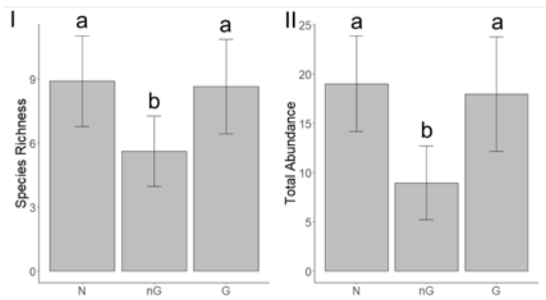
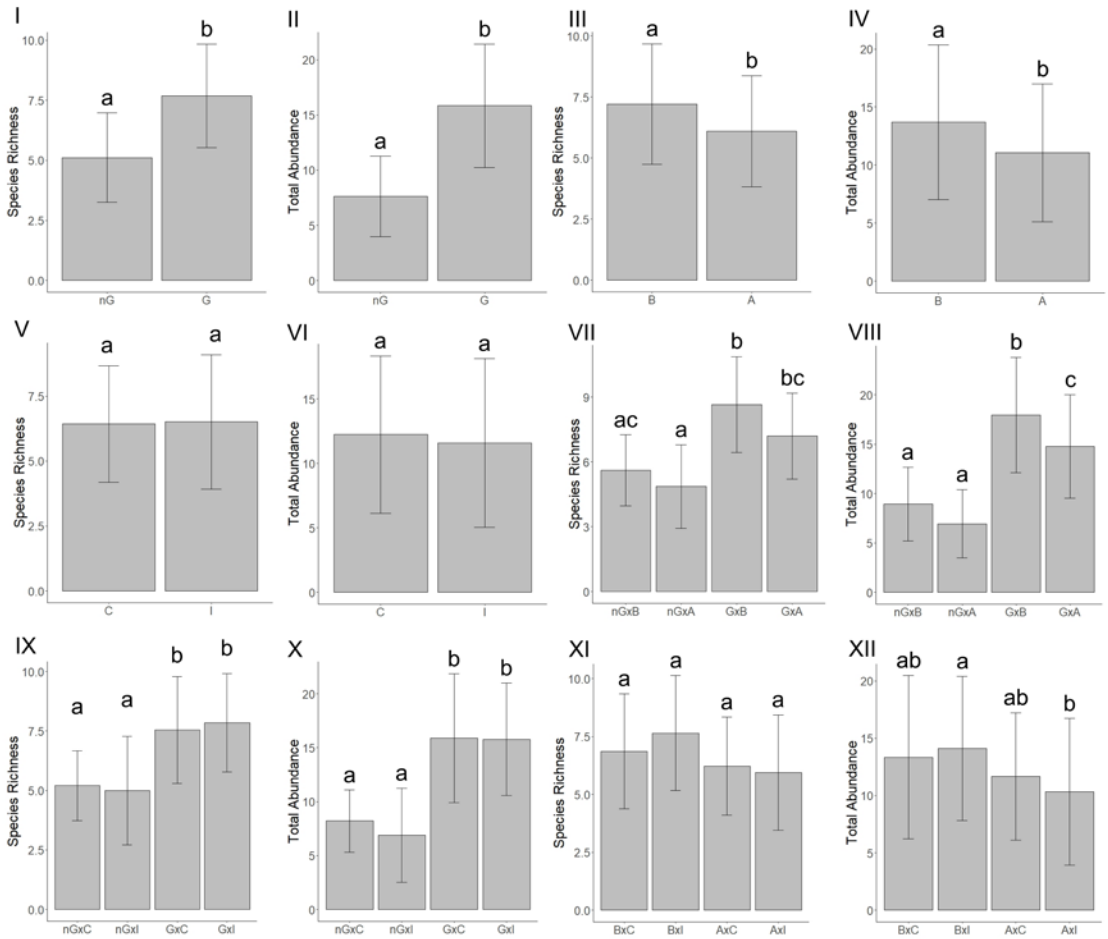


Figure 2 - Mean and standard deviation for bird species richness and total bird abundance according to the land use type: native forests (N), plantations of eucalyptus without riparian galleries (nG), and plantations of eucalyptus with riparian galleries (G). Letters above bars denote significant differences ($p < 0.05$) using post-hoc Tukey tests after generalized linear models.

Figura 2 - Média e desvio padrão da riqueza de espécies de aves e abundância total de acordo o uso do solo: floresta nativa (N), plantações de eucalipto sem galerias ripícolas (nG), e plantações de eucalipto com galerias ripícolas (G). As letras acima das barras denotam as diferenças significativas ($p < 0,05$) usando testes post-hoc de Tukey após modelos lineares generalizados.

Figure 3 - Mean and standard deviation for bird species richness and total bird abundance according to the following environmental variables: plantations of eucalyptus without riparian galleries (nG), plantations of eucalyptus with riparian galleries (G), before wildfires of 2017 (B), after wildfires of 2017 (A), non-burnt sites (C), burnt sites (I), and the interactions between them. Letters above bars denote significant differences ($p < 0.05$) using post-hoc Tukey tests after generalized linear models.

Figura 3 - Média e desvio padrão da riqueza de espécies de aves e abundância total de acordo com as seguintes variáveis ambientais: plantações de eucalipto sem galerias ripícolas (nG), plantações de eucalipto com galerias ripícolas (G), antes dos incêndios florestais de 2017 (B), após os incêndios florestais de 2017 (A), locais não ardidos (C), locais ardidos (I) e as interações entre eles. As letras acima das barras denotam as diferenças significativas ($p < 0,05$) usando testes post-hoc de Tukey após modelos lineares generalizados.



Discussion

Our results shown that eucalyptus plantations conserving native riparian galleries can be important for the community of small breeding birds in central Portugal, as this land use may hold a similar bird richness and abundance to native oak-pine forests. These bird community parameters were clearly lower in pure eucalyptus plantations. Moreover, after the occurrence of a catastrophic change, such as a wildfire, eucalyptus plantations with native galleries kept the relative importance for birds in the region.

Before the wildfires, the bird community in central Portugal showed higher species richness, and total abundance in plantations with galleries than in plantations without galleries. These results agree with other studies in the Iberian Peninsula, which found that the reduced diversity and abundance of arthropods in pure eucalyptus plantations (i.e., without galleries) when compared to oak woodlands contribute to reduce the diversity and abundance of birds (Zahn et al. 2009; Silva et al. 2019). Consequently, bird species occurring on these plantations tend to be generalist species that colonize all woodland uses (Zahn et al. 2009; Silva et al. 2019). Before the wildfires, the most abundant bird species in eucalyptus plantations and native oak-pine forests were widespread and common European woodland species: Blackcap, Robin, and Wren. Many authors found these species not to be very selective concerning the breeding habitat in Europe, which comprises broadleaf, coniferous or mixed forest (Blondel and Farré 1988; Farina 1995; Díaz 2006), including different types of non-native woodland uses (Calviño-Cancela 2013; Kroftová and Reif 2017; Campagnaro et al. 2018). These species may be generalist because they are more dependent on the understorey traits rather than on the arboreal structure of forests, particularly for foraging, nesting, and ensuring protection from predators (Hoelzel 1988; Camprodon and Botons 2006; Santana et al. 2018). The presence of understorey is a common trait to all studied forest land uses, including in pure eucalyptus plantations.

The higher diversity and abundance of plants in oak woodlands creates a higher number of available micro-habitats for birds thus contributing to increase their richness and abundance when compared with pure eucalyptus plantations. For instance, allowing the occurrence of trunk hole nesting species, such as the Short-toed Treecreeper (*Certhia brachydactyla*), or farmland species, such as the Serin (*Serinus serinus*; Proença et al. 2010; Calviño-Cancela 2013; Goded et al. 2019; Silva et al. 2019). Natural cavities (i.e., non-originated by man and/or woodpecker activities) are rarer in eucalyptus plantations than in native forests because trees are logged before reaching a maturity that allows to develop natural cavities (de la Hera et al. 2013). Consequently, in our study, the presence of *Quercus* spp. and *Castanea sativa* in plantations with galleries, two tree species that are more prone to creating natural cavities than eucalyptus, may have contributed to promoting trunk hole nesting species when compared to plantations without galleries. Moreover, plantations with galleries also seem to attract riparian specialists (e.g., Long-tailed Tit *Aegithalos caudatus* and Bullfinch *Pyrrhula pyrrhula*), in abundances similar to those recorded in native forests and higher than those observed in plantations without galleries.

When analysing the effect of fire, our results indicated that the presence of a riparian gallery was a better predictor than the of such a catastrophe to explain richness and abundance of bird communities in eucalyptus plantations. When compared to the assemblage of species before the wildfires, higher changes occurred in burnt plantations without galleries as the Chaffinch and the Coal Tit appeared among the most abundant species. Concomitantly, Blackcap and Wren reduced their abundances compared to the situation prior wildfires, probably because the native understorey vegetation was eliminated with the fire. While, the Coal Tit was, for instance, the commonest Paridae species in all types of eucalyptus plantations (burnt or not; with galleries or not), which reveals a higher adaptability, probably due its smaller size allowing it to survive with lesser requirements (e.g., smaller cavities and small food-items) than other species (Van Balen et al. 1982; Atiénzar et al. 2017). Overall, community parameters were higher in burnt plantations with riparian galleries than in plantations without riparian galleries, regardless of the fact these had burn or not. Our results agree with those of Brotons et al. (2005), who analysed the bird community arrangement in burnt mosaic of pine and oak forests with open habitat and found that habitats that are poor in species before the wildfires tend to be also poor after them. The great similarity in bird communities between burnt and non-burnt eucalyptus plantations (regardless of the presence of a riparian gallery) might be related with the great resprouting capacity of eucalyptus, which starts immediately after the wildfires. The resprout of eucalyptus results in a shrubland-like habitat a year after the event (Catry et al. 2013) that can already be used by some bird species. Wildfires affecting species with resprouting capacity lower than that of eucalyptus (e.g., pinewoods) may suffer greater transformations in the bird communities, namely from woodland to open-habitat dominant species (Herrando et al. 2003; Ukmar et al. 2007; Castro et al. 2010; Zozaya et al. 2011; Moreira et al. 2001; Clavero et al. 2011).

It should be noted that our study had a limited sample size, namely in the categories created in 2018 and 2019 that subdivided those that were planned in 2017. This organization resulted from an unpredictable event after the first data collection in 2017, two forest fires. However, these catastrophes resulted in a very unusual natural experiment to occur in areas with previously collected data for which we could not miss the opportunity to collect data in the following two years. Despite the limited sample size, our results show that maintaining riparian galleries with native vegetation inside eucalyptus plantations in central Portugal allows protecting a bird community similar to that of regional native forests, besides favouring recovery after wildfires. Considering the very low proportion of riparian galleries currently found in eucalyptus plantations, we suggest mimicking their effect using stripes of native vegetation (e.g., *Quercus* spp.). Increasing the connectivity of these strips may allow promoting some bird species with very low population densities (Beier and Noss 1998), such as the Common Chiffchaff (*Phylloscopus collybita*) and Dunnock (*Prunella modularis*) that have their distribution limit in our study area. Serving as refuge for birds, native riparian galleries in eucalyptus plantations may also be contributing for ecosystem functioning. Many bird species found in these galleries are insectivorous and thus have the potential to control pests, namely some of those causing the decline of neighbouring oak tree forests (Pereira et al. 2019). Outside the breeding season, the two most abundant species (Blackcap and Robin) are also the two most important seed dispersers in the Mediterranean region (Costa et al. 2018; Sampaio et al. 2021). Connectivity of native vegetation corridors may be ensured by frugivorous birds which developed mutualist relationships with native plants to increase their spread through seed dispersal (Almeida et al. 2021; Pereira et al. 2022). Finally, restoring native riparian galleries in the Mediterranean region is urgent not only to recover ecosystem functions and services, but also to halt the spread of invasive species that may further compromise ecosystems (Deus et al. 2019; Pereira et al. 2017).

Acknowledgements

We are grateful to Ana Diniz Sampaio for fieldwork support.

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