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Grassland vegetation height affects bird responses to forest edges in Mediterranean open farmland

João Faria ^{a,b,c,*}, Luís Reino ^{b,c,d}, Pedro Beja ^{b,c,d,e}, David Gonçalves ^{a,b,c},
 Juan S. Sánchez-Oliver ^{b,c,d,f}, Francisco Moreira ^{b,c,d,g}, Inês Catry ^{b,c,d},
 John T. Rotenberry ^h, Rui Morgado ^{b,c,d}, Lluís Brotons ^{i,j,k}, Stefan Dullinger ^l,
 Stefan Schindler ^{m,n}, Joana Santana ^{b,c}

^a Departamento de Biologia, Faculdade de Ciências, Universidade do Porto, 4169-007 Porto, Portugal

^b CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Campus de Vairão, Universidade do Porto, 4485-661 Vairão, Portugal

^c BIOPOLIS Program in Genomics, Biodiversity and Land Planning, CIBIO, Campus de Vairão, 4485-661 Vairão, Portugal

^d CIBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Instituto Superior de Agronomia, Universidade de Lisboa, 1349-017 Lisboa, Portugal

^e Cátedra EDP Biodiversidade, CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal

^f ECB Ecology, Conservation, Biodiversity S. Coop, Alicante, Spain

^g REN Biodiversity Chair, CIBIO/InBIO, Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Campus Agrário de Vairão, Rua Padre Armando Quintas, 4485-601 Vairão, Portugal

^h Department of Ecology, Evolution, and Behavior, University of Minnesota, Saint Paul, MN, USA

ⁱ InForest Joint Research Unit, (CTFC-CREAF), 25280 Solsona, Spain

^j CSIC, 08193 Cerdanyola del Vallès, Spain

^k CREAF, 08193 Cerdanyola del Vallès, Spain

^l Department of Botany and Biodiversity Research, University of Vienna, Rennweg 14, Vienna 1030, Austria

^m Division of Conservation Biology, Vegetation and Landscape Ecology, University of Vienna, Vienna, Austria

ⁿ Faculty of Environmental Sciences, Community Ecology and Conservation Research Group, Czech University of Life Sciences Prague, Prague 6, Czech Republic

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ABSTRACT

Afforestation affects Mediterranean farmland biodiversity due to loss and fragmentation of grassland habitats. While the influence of landscape context and plantation edges on farmland bird responses to afforestation is well-documented, less is known about the influence of grassland vegetation height and how it interacts with afforestation to influence bird communities. Here, we examined how changes in grassland vegetation height affect bird responses to afforestation in a farmland region in southern Portugal, and how these are affected by plantation type and edge. This region has experienced afforestation with eucalyptus, pine and oak stands, agricultural intensification, and frequent dry periods. To capture local and landscape-level changes, we collected data in two periods (2005 and 2014–15). Grassland vegetation height varied between sampling periods, emerging as a key factor affecting changes observed. Ground-nesting and cereal-associated species increased in abundance with taller vegetation in 2014–15, while in 2005, with drier weather and shorter vegetation, the species associated with ploughed fields were

* Correspondence to: Centro de Investigação em Biodiversidade e Recursos Genéticos, Universidade do Porto, Campus Agrário de Vairão, 4485-661 Vairão, Portugal.

E-mail address: joao.faria@cibio.up.pt (J. Faria).

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more abundant. Vegetation height effects on bird assemblages depended on plantation type and distance to plantation edges. Farmland bird abundance, including ground-nesting and cereal crops-associated species, increased with taller vegetation, particularly near oak and pine plantations. Conversely, species associated with ploughed fields declined with taller vegetation, especially near eucalyptus plantations. Results highlight complex interactions between vegetation height, plantation type, and edge proximity shaping avian assemblages. This study supports the importance of field and landscape-level management with special focus on grassland vegetation height and landscape heterogeneity for preserving open-farmland birds in fast-changing Mediterranean farmland landscapes.

1. Introduction

Afforestation, prominently discussed for its potential in carbon reduction and sequestration (Potter et al., 2007; Lin et al., 2013), poses conservation concerns due to its transformation of natural and semi-natural ecosystems into smaller fragmented habitats (Liu et al., 2019). This is particularly concerning when open habitats of conservation significance are replaced (Reino et al., 2009; Bond et al., 2019; Jacoboski et al., 2019; Faria et al., 2022), as newly formed plantation edges reinforce fragmentation effects, potentially reducing the quality of the remaining open-habitat fragments (Ries et al., 2004; Ewers and Didham, 2007). Open farmland bird species are particularly affected by this (Brotons et al., 2005; Reino et al., 2009; Morgado et al., 2010; Pretelli et al., 2018; Jacoboski et al., 2019; Jacoboski and Hartz, 2020), experiencing increased nest predation in grasslands adjacent to these plantations (Santos et al., 2006; Sánchez-Oliver et al., 2014a; Faria et al., 2022). Afforestation effects on farmland biodiversity are influenced by various factors. Different plantations provide varying understorey vegetation and tree species composition, which influences avian community composition adjacent to open habitats, including potential predators and competitors (Reino et al., 2010a; Calviño-Cancela et al., 2012; Faria et al., 2022). Additionally, taller tree growth and higher density may amplify edge effects, modifying suitability for certain species and increasing predation pressure in the adjacent grasslands (Santos et al., 2006; Reino et al., 2010a; Faria et al., 2022).

Grassland vegetation height is thus of particular importance in the resulting grassland fragments (Moreira, 1999), as in addition to protection from nest predation (Faria et al., 2022), taller vegetation can provide adequate cover, food and nesting resources to numerous open farmland species (Batáry et al., 2007; Erdős et al., 2009). Vegetation height may be directly affected by changes to farming systems, e.g., in the context of agricultural policy reforms, such as the Common Agricultural Policy (CAP) introduced by the EU in 2003 (Ribeiro et al., 2014). The Mediterranean farmlands of southern Portugal are part of the cereal-steppes of the Iberian Peninsula, representing a High Nature Value Farmland (HNVF) system critical for the conservation of a range of open farmland birds (Suárez et al., 1997; Bota et al., 2005; Reino et al., 2009). It was mostly composed of extensively farmed traditionally mixed-rotational systems of dry cereal, fodder crops and fallow land and pastures grazed by sheep (Ribeiro et al., 2014). However, this is currently changing with the increased cultivation of intensive woody crops and the establishment of specialised livestock systems, associated with an increased cover by permanent pastures (Ribeiro et al., 2014; Ren et al., 2018; Morgado et al., 2020).

Concerns regarding the impact of extreme climatic conditions (i.e., droughts and heat waves) on grasslands have also been raised (Conrey et al., 2016; Zuckerberg et al., 2018). These result in less biomass production and changes to soil properties (Wu et al., 2022) decreasing vegetation cover (Conrey et al., 2016), and shifting grazing patterns (Li et al., 2018). Lower vegetation height, driven by droughts (Conrey et al., 2016), intensive grazing (Reino et al., 2010b; Ribeiro et al., 2014), or a combination of both, likely raises nest-detectability (Bellamy et al., 2018) and vulnerability to predators near plantation edges (Beja et al., 2014; Faria et al., 2022). Thus, farmland birds inhabiting these habitats are expected to be particularly susceptible to changes in grassland vegetation height. However, while both the effects of afforestation and (to a lesser extent) vegetation heights on bird communities have been studied, little is known about the interaction of these two factors, i.e., how variations in vegetation height may affect farmland bird responses to afforestation differentially depending on plantation type.

In this study we aimed to analyse afforestation's impact on Mediterranean open farmland bird communities in two periods (2005, 2014–15) with contrasting vegetation heights in grasslands adjacent to different plantation types. We focused on a representative area of Iberian cereal steppes that has experienced recent afforestation (Reino et al., 2010a) and has been facing increasing drought severity (García-Ruiz et al., 2011; FFMS, 2022). This area is also among the European farmland landscapes with the highest conservation relevance to farmland birds (Bota et al., 2005; EEA, 2006). Specifically, we examined: 1) variations in bird composition and local and landscape characteristics, and 2) the influence of those characteristics that changed significantly between periods on avian assemblages' responses to plantation edges and types. We hypothesise that (i) grassland vegetation is shorter in the drier period (Conrey et al., 2016); (ii) ground-nesting species, especially those associated with cereal fields, increase in abundance with taller vegetation due to the role played by vegetation cover in nest survival (Delgado and Moreira, 2000), while those specifically associated with ploughed fields decrease; and (iii) steppe birds benefit from increased vegetation height in grasslands adjacent to the softer edges of oak plantations and higher distances to the plantation edge (Reino et al., 2009; Sliwinski and Koper, 2012; Besnard et al., 2016).

2. Methods

2.1. Study area

The study was conducted in southern Portugal, mostly within the Special Protection Area (SPA) of Castro Verde. Since 1995, this

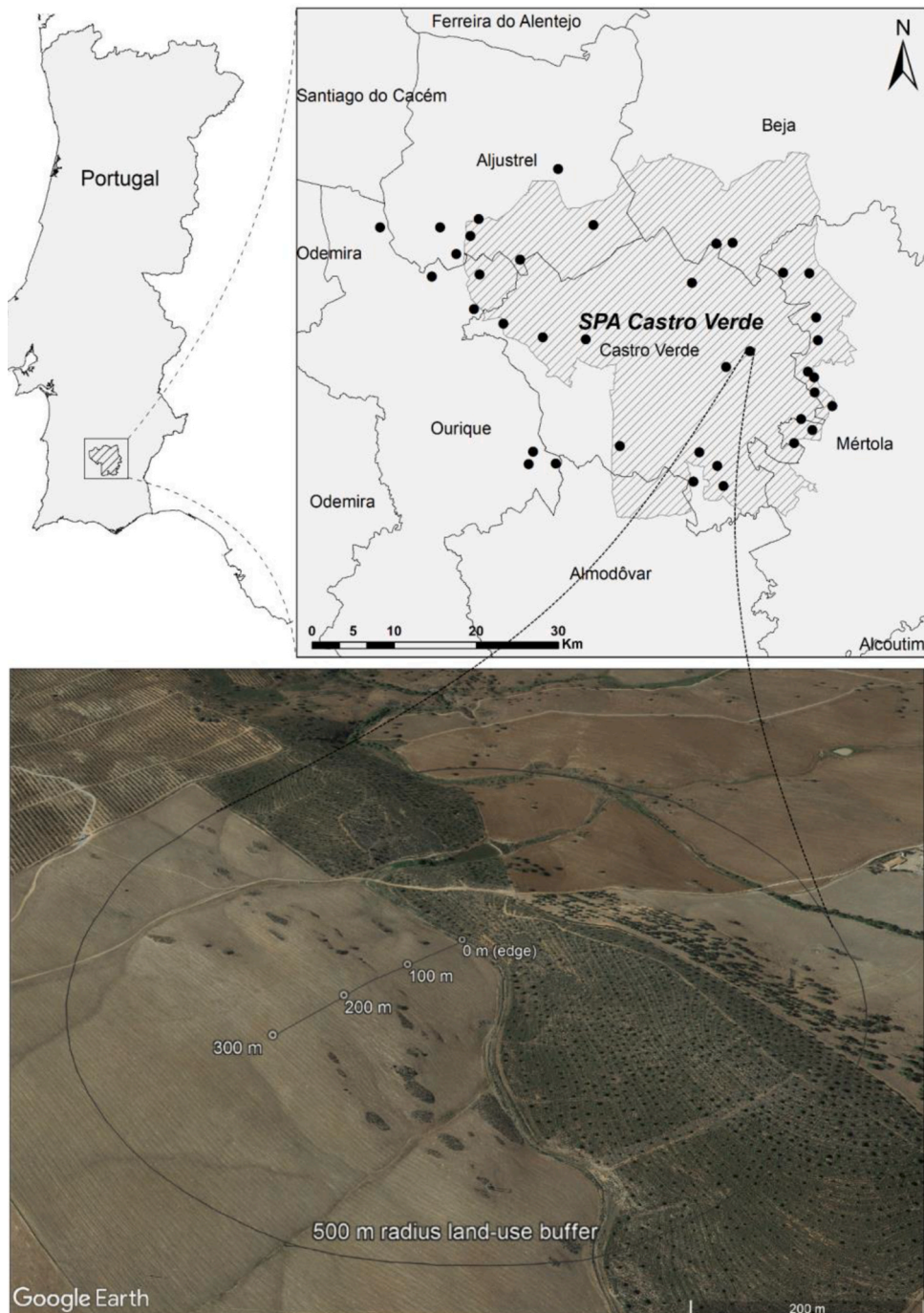


Fig. 1. Study area located in Southern Portugal, showing the Special Protection Area (SPA) of Castro Verde (Alentejo region), and the distribution of the 38 sampled sites. Below is highlighted an example of the spatial distribution of the survey points used in the grasslands (fallow or pastureland) adjacent to each forest plantations (oak, pine or eucalyptus; oak plantation in the photo). See methods section for further details. Image source Google Earth Pro (ver. 7.3.4.857).

area has benefitted from an agri-environment scheme targeting the conservation of steppe birds under the European Union Birds Directive 2009/147/EC, through the maintenance of traditional farming systems (Ribeiro et al., 2014) (Fig. 1). The region has a Mediterranean climate, characterised by mild winters (averaging 9 °C [5–14 °C] in January) and hot summers (24 °C [16–32 °C] in July), with > 75% of annual rainfall (500–600 mm) concentrated between October and March (Moreira et al., 2005; Morgado et al., 2020). Over the past 30 years, there has been a decrease in annual rainfall (from 584 to 547 mm) and an increased number of days without rain (from 150 to 155) (FFMS, 2022).

The landscape is predominantly flat or gently undulating (100–300 m a.s.l.) (Moreira et al., 2005) and consists mostly of open farmland, traditionally composed of old fallow fields (lasting up to 10 years) or agricultural fields cultivated with dry cereal crops in rotations with fallows (2 to 5 years). Historically, these farmlands were grazed by sheep at low densities (Delgado and Moreira, 2000; Santana et al., 2017). Following the implementation of the European Economic Community regulation 2080/92 in the mid to late 1990 s (Institute for Forestry Development, 2001), there was an increase in afforestation with umbrella pines (*Pinus pinea*) and holm and cork oaks (*Quercus rotundifolia* and *Q. suber*, respectively) in the periphery of the SPA (Reino et al., 2010). Until then, tree cover largely consisted of eucalyptus plantations (*Eucalyptus* sp.) and a few open-oak woodlands, grazed by livestock (Delgado and Moreira, 2000; Moreira et al., 2005; Reino et al., 2009). More recently, the traditional mixed system has shifted towards specialised production of cattle or sheep (Ribeiro et al., 2016), with declines in cereal and fallow land, and increases in forage crops and permanent pastures (Ribeiro et al., 2014, 2016; Santana et al., 2017).

2.2. Sampling design

We sampled 38 grassland parcels twice in each sampling period (2005, 2014–15), each time along 300-m transects perpendicular to the edge of one of three types of forest plantations commonly found in the region, including younger pine, and oak stands (mean age = 15.4 ± 4.9 years and 12.9 ± 5.9 years, respectively) and older eucalyptus stands (mean age = 41.8 ± 18.1 years). Grassland parcels consisted of fallow fields and pastures (i.e. rainfed cereal fields were excluded) to reduce variation unrelated to the variables tested, and due to their particular importance for steppe bird species (Delgado and Moreira, 2000; Reino et al., 2009).

Site selection was carried out prior to the 2005 sampling period, based on 1:25,000 land cover maps from 1990, updated through systematic field checking of new forest stands planted up to early 2005 (Reino et al., 2009). Each site included a grassland parcel plus an adjacent plantation, selected only if the grassland parcel was at least 600 m long and wide, to allow sampling up to 300 m from the nearest plantation edge. Additionally, only one grassland parcel per plantation was considered to avoid pseudo-replication and spatial autocorrelation (Fortin and Dale, 2009; Vasconcelos et al., 2019). For the 2014–15 sampling period, we were able to resample several of the original sites, retaining 38 sites that did not undergo major land-use changes, such as ploughing or cereal cultivation in the grassland parcel, and tree harvest or thinning in the adjacent plantations (Vasconcelos et al., 2019; Faria et al., 2022). These included grassland parcels adjacent to 8 eucalyptus, 13 pine and 17 oak plantation stands.

2.3. Bird data

Bird surveys were conducted during the breeding season in 2005 (from April 1st to May 31st), and again in either 2014 or 2015 (from April 1st to June 5th, 2014, and April 11th to June 5th, 2015). Surveys were conducted twice per sampling period. They consisted of four sequential point-counts performed at 0, 100, 200, and 300 m perpendicularly from the plantation edge, where for 10 min, each bird seen or heard within 50 m from the observer was recorded. Sampling was conducted preferably at dawn, or at either dawn or dusk in the two sampling occasions for each period, as Mediterranean farmland birds have similar peaks of activity during these periods (Caro et al., 2015). To help reduce detectability problems, surveys were only conducted on nearly windless and rainless days on mostly flat grassland parcels (Bibby et al., 2000; Reino et al., 2009) by two experienced observers (LR and RM). At each point, individual birds and flocks were identified and mapped (Fig. 1). To minimise double counting of individuals, birds in flight were not recorded, except in the case of song flights (e.g., calandra lark). Additionally, extra care was taken to not count any birds flushed between counts that landed at a subsequent survey point, which was always within sight (Reino et al., 2009). To address identification challenges in the field, crested and Thekla larks (*Galerida cristata* and *G. theklae*, respectively) and common and Spanish sparrows (*Passer domesticus* and *P. hispaniolensis*, respectively) were categorised at the genus level.

For each sampling period, we estimated bird abundance (i.e., the highest number of birds counted between the two surveys per distance point per site) for the overall assemblage and at a species level. To evaluate differences in responses in the bird community according to their habitat affinities, we categorised species into guilds: woodland; farmland; ground-nesting; open-farmland (steppe) specialists (Reino et al., 2009); cereal, fallow or ploughed fields (Delgado and Moreira, 2000; Santana et al., 2014); and threatened species, including near threatened, vulnerable or endangered on the IUCN European red list of birds (BirdLife International, 2022; Table A1). Species-specific analyses were carried out for the 13 most widespread bird species in either period (higher than 25% occurrence, Table A2): tawny pipit (*Anthus campestris*), red-legged partridge (*Alectoris rufa*), greater short-toed lark (*Calandrella brachydactyla*), European goldfinch (*Carduelis carduelis*), zitting cisticola (*Cisticola juncidis*), carrion crow (*Corvus corone*), corn bunting (*Emberiza calandra*), Galerida larks (*Galerida* spp.), common linnet (*Linaria cannabina*), calandra lark (*Melanocorypha calandra*), European stonechat (*Saxicola rubicola*), little bustard (*Tetrax tetrax*) and Eurasian hoopoe (*Upupa epops*).

2.4. Variable selection

Plantation structure was characterised by tree height and edge density, estimated using ground-level photographs taken at

70–100 m perpendicular to the plantation edge. A field scale was employed at the edge to determine pixel size, which was then used to calculate average tree height. Tree density was derived from the total number of trees per metre of edge captured in the photographs. Additionally, plantation type was included to account for other potential effects of different plantation characteristics, such as plantation age, vegetation structure and composition, and avian predator abundance.

For vegetation height, grassland vegetation height was estimated from the average of four measurements evenly spaced in a ca. 50-cm radius centred at each sampling point, using a 50-cm ruler. This process was repeated in both periods (Table A3). The potential influence of livestock grazing on vegetation height was also considered by recording the occurrence (presence/absence) of livestock (sheep and cattle) at each grassland parcel during counts.

Furthermore, we also considered weather conditions in the study area for both periods. Data from the nearest weather station (Beja weather station) (<https://www.pordata.pt>; FFMS, 2022), was used to extract three precipitation indicators: annual precipitation (annual rainfall), maximum monthly precipitation (max. precipitation) and total number rainless days. To accommodate the potential influence of the preceding year’s precipitation on grassland conditions (Zuckerberg et al., 2018), annual data from 2004 and 2005 were used for the first sampling period (2005), and data from 2013 to 2015 were used for the second (2014–2015).

For landscape context, land cover maps for both periods were created within 500-m radius buffers centred on the plantation-grassland edge (Fig. 1). Images from Google Earth Pro (ver. 7.3.4.857) from 2005–2007 and 2015–2016 were used. Land-use categories were obtained from a governmental database (DGT, 2007, 2015), and included agricultural area; eucalyptus, pine, and oak plantations; shrubland; wood-pastures; water bodies; urban areas; and olive groves. These were selected to broadly reflect all land-use types within the area, with greater detail provided for plantation cover (Table A3). Landscape heterogeneity metrics (Elkie et al., 1999), including area-weighted mean shape index (AWMSI), mean patch size (MPS), and edge density (ED) were computed using the Patch Analyst plugin in ArcGIS (ver. 10.2.2; ESRI Inc, 2014).

2.5. Statistical analysis

Variation in the abundance of avian assemblages at each site (i.e., relative abundance per site, including all distance points) and local and landscape variables between periods was evaluated through individual paired t-tests or Wilcoxon rank-sum test with continuity correction, preceded by Shapiro-Wilk tests for sample normality (Hollander et al., 2013).

Table 1

Average number of birds detected per site per period (site abund 05, site abund 15) and respective differences in relative bird abundance (guilds and species) (Δ abund) between periods (2005 and 2014–15) and *p*-value of the t-test; **bold** signs denote $P < 0.05$. For each guild and species, we provide model averaging (GLMM) coefficient estimates (β) for effects of vegetation height (veg. height), distance, plantation type (young oak; young pine; old eucalyptus - default level) and two-level interactions.

	site abund 05	site abund 15	Δ abund	<i>P</i> -value	veg. height	distance	young oak	young pine	distance: veg. height	oak:veg. height	pine:veg. height
Bird guilds											
All species	15.92	20.34	4.42	< 0.001		1.48	2.17	2.29			
Woodland	6.03	5.58	-0.45	0.017	0.55	1.98	2.16	2.36			
Farmland	9.84	14.76	4.92	< 0.001	-0.55		0.58	0.53		0.45	0.11
Ground-nesting	8.34	12.13	3.79	< 0.001	-0.11		0.55	0.18			
Steppe	4.63	4.45	-0.18	0.301	0.15	0.24	0.16	0.08	-0.43		
Cereal related	1.82	5.45	3.63	< 0.001	0.35	0.06			0.17		
Fallow related	2.63	2.95	0.32	0.859	-0.04	0.25	0.20	-0.06	-0.29		
Ploughed related	1.68	0.82	-0.87	0.002	-0.10	-0.13	0.04	0.10	-0.08		
Threatened species	1.13	1.74	0.61	0.114		-0.13	-0.03	0.12			
Species											
Calandra lark	2.16	2.29	0.13	0.874	-0.09	0.20	0.15	-0.07	-0.23		
Carrion crow	0.21	0.53	0.32	0.433			-0.11	-0.11			
Common linnet	0.37	0.37	0	1		0.06					
Corn bunting	1.53	3.68	2.16	< 0.001	0.02	-0.07			0.19		
Eurasian hoopoe	0.08	0.29	0.21	0.050	-0.07	-0.05			0.06		
European goldfinch	0.53	0.53	0	0.899	0.05						
European stonechat	0.47	0.50	0.03	0.828	-0.07	-0.06			0.07		
Galerida larks (spp.)	1.32	1.95	0.63	0.039	-0.16		0.11	0.04			
Little bustard	0.47	0.66	0.18	0.660	0.03						
Red-legged partridge	0.37	0.05	-0.32	0.012	-0.02	0.01					
Short-toed lark	1.11	0.63	-0.47	0.053	-0.09	-0.16	0.07	0.10	-0.04		
Tawny pipit	0.42	0.11	-0.32	0.005	-0.04	-0.01	0.05	0.06	-0.04	-0.02	0.01
Zitting cisticola	0.05	1.45	1.39	< 0.001	0.23	-0.02			-0.06		

Then, we modelled how changes in guilds and species abundance between 2005 and 2014–2015 were associated with variables that differed significantly between these periods (i.e., vegetation height; see [Table A3](#)), across distances from different plantation edge types. Bird abundance differences were measured by subtracting bird counts at each distance in 2005 from those in 2014–2015 (i.e., dif. abundance = bird abund [2014,2015] – bird abund [2005]). Changes in vegetation height were estimated likewise, after being standardised (dif. height = veg height [2014,2015] – veg height [2005]). Generalised Linear Mixed Models (GLMMs) were used with a Gaussian distribution and identity link function ([Bolker, 2015](#)). To address the lack of independence among samples, transect (representing the site) was used as a random factor ([Zuur et al., 2009](#); [Santana et al., 2014](#)).

Model selection was performed using a Multi-model Inference approach ([Burnham & Anderson, 2002](#)), generating a table of subset model combinations using standardised coefficients and ranking them based on weights derived from Akaike Information Criteria corrected for small samples (AICc). Model averaging was then conducted for models with $\Delta AICc < 2$, using partial standardized regression coefficients to estimate the relative importance of each coefficient on the final models ([Cade, 2015](#)).

All analyses were performed using R (ver. 4.2.0; [R Core Team, 2022](#)). GLMM models were developed using “glmer” function, from the lme4 package ([Bates et al., 2015](#)), and model selection and averaging were performed using “dredge” and “model.avg” functions from MuMIn package ([Bartoń, 2023](#)).

3. Results

3.1. Overall patterns

Overall bird abundance was significantly higher in the second period (Δ abund, [Table 1](#)), primarily driven by an increase in farmland birds. Contrastingly, woodland birds decreased during this time ([Table 1](#)). Among farmland species, there were significant increases in ground-nesting birds (Δ abund = 3.79, $p < 0.001$) and those associated with cereal fields (3.63; $p < 0.001$), while species

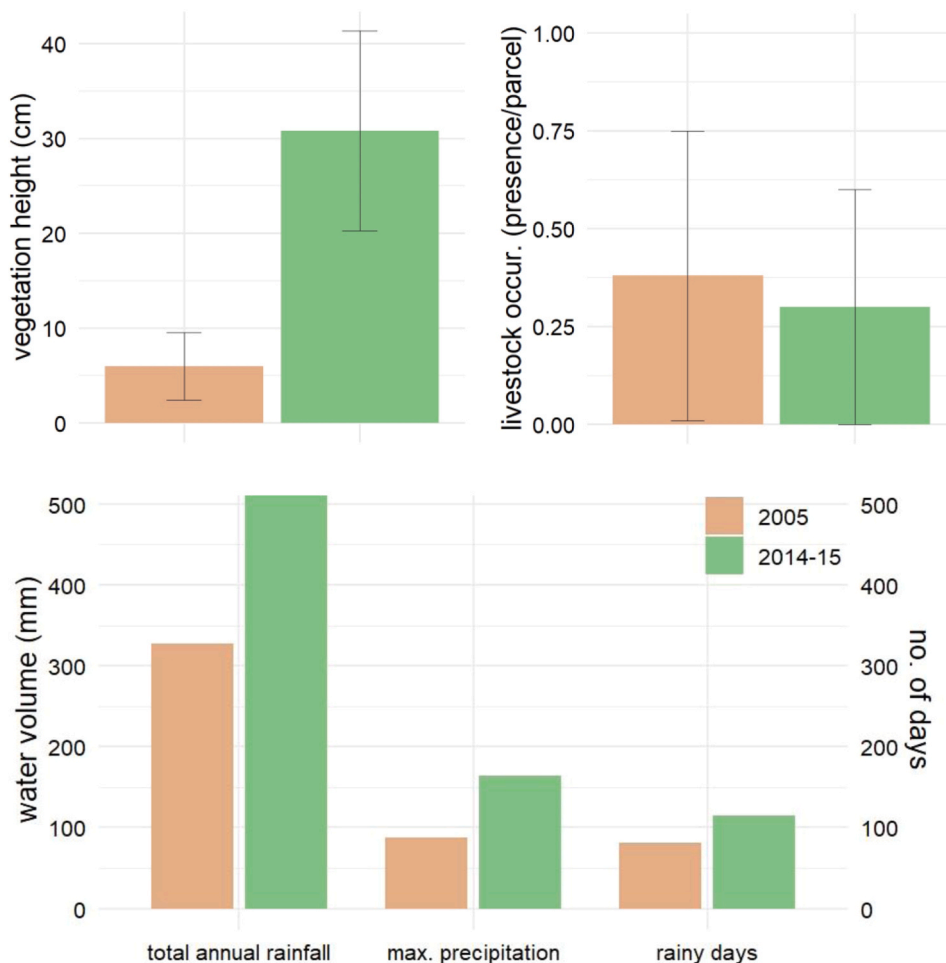


Fig. 2. Temporal changes in vegetation height, livestock occurrence and precipitation variables between periods. Full details and tests on landscape context and plantation attribute variables provided in [Table A3](#).

associated with ploughed fields decreased. Abundance of steppe specialists, birds associated with fallow fields and threatened species remained relatively stable (Table 1).

The corn bunting, Eurasian hoopoe, *Galerida* larks and zitting cisticola were significantly more abundant in 2014–15, while the red-legged partridge and the tawny pipit were more abundant in 2005. Short-toed lark abundance decreased slightly, whereas other species remained relatively constant (Table 1).

Vegetation height was significantly higher in the second period (Fig. 2). This period (2014–15) was characterised by heightened annual rainfall, maximum precipitation, and number of rainy days. Livestock occurrence and all other variables regarding plantation attributes and landscape context remained stable between periods and were thus not included in further analyses (Fig. 2; Table A3).

3.2. Effects of vegetation height and distance from different plantation edges

As initially expected, vegetation height significantly influenced various guilds and species abundance (Table 1; Table A4). Increased vegetation height was positively related to woodland birds' abundance regardless of plantation type ($\beta_{\text{heig}} = 0.55$). However, the impact of grassland vegetation height on farmland bird abundance varied based on adjacent plantation types. Vegetation height negatively influenced farmland bird abundance near eucalyptus plantations but was associated with their abundance near oak and pine plantations ($\beta_{\text{oak:heig}} = 0.45$; $\beta_{\text{pine:heig}} = 0.11$). Ground-nesting birds slightly decreased with increasing vegetation height ($\beta_{\text{heig}} = -0.11$). Steppe birds' abundance showed a positive association with higher vegetation height near plantation edges, with this effect diminishing at greater distances ($\beta_{\text{D:heig}} = -0.43$).

Distance to the plantation edge played an important role in the overall assemblage's abundance, as well as that of woodland birds, depending on the adjacent plantation type (i.e., increased distances only had a positive effect in eucalyptus plantations) (Table 1; Table A4). It also interacted with vegetation height in several cases. For instance, species linked to fallow and ploughed fields not only decreased slightly with taller vegetation, but also exhibited a more pronounced decrease as distance to the plantation edge increased (respectively, $\beta_{\text{D:heig}} = -0.29$; $\beta_{\text{D:heig}} = -0.08$). Contrastingly, cereal crops-associated species marginally increased in abundance with greater distance to the plantation edge ($\beta_{\text{D}} = 0.06$), with larger increases where vegetation was significantly taller ($\beta_{\text{D:heig}} = 0.17$).

The abundance of farmland, ground-nesting and fallow-related species increased in certain plantation types regardless of distance, generally favouring oak plantations (respectively, $\beta_{\text{oak}} = 0.58$; $\beta_{\text{oak}} = 0.55$; and $\beta_{\text{oak}} = 0.20$). Indeed, farmland bird abundance increased with taller vegetation, primarily in grasslands adjacent to oak plantations ($\beta_{\text{oak:heig}} = 0.45$).

At the species level, vegetation height influenced the abundance of all but two (woodland) species (Table 1). Vegetation height was negatively related to red-legged partridge ($\beta_{\text{heig}} = -0.02$) and *Galerida* larks abundances ($\beta_{\text{heig}} = -0.16$), and positively so to goldfinch ($\beta_{\text{heig}} = 0.05$) and little bustard ($\beta_{\text{heig}} = 0.03$). For other species, the vegetation height effect was contingent on the distance to the plantation edge. The positive association of vegetation height with corn bunting abundance ($\beta_{\text{heig}} = 0.02$) increased with distance from the forest edge ($\beta_{\text{D:heig}} = 0.19$), while species like the calandra lark, experienced a negative relationship ($\beta_{\text{heig}} = -0.09$) exacerbated by distance ($\beta_{\text{D:heig}} = -0.23$). Vegetation height had an overall positive relationship with zitting cisticola ($\beta_{\text{heig}} = 0.23$), though that decreased with distance to the plantation edge ($\beta_{\text{D:heig}} = -0.06$). Contrastingly, the abundance of stonechat and hoopoe was negatively associated with increased vegetation height ($\beta_{\text{heig}} = -0.07$ in both cases), especially near wooded edges ($\beta_{\text{D:heig}} = 0.07$; 0.06) (Table 1). Linnet abundance increased solely with distance from the edge ($\beta_{\text{D}} = 0.06$). Regarding plantation type, oak plantations had a positive association with *Galerida*, calandra and short-toed larks, while eucalyptus plantations positively associated with carrion crow ($\beta_{\text{oak}} \& \beta_{\text{pine}} = -0.11$).

4. Discussion

Our results demonstrate that forest edges may impact avian communities differently, depending on locally varying factors such as grassland vegetation height and its interactions with different adjacent plantations and proximity to edge in open-farmland Mediterranean landscapes. Specifically, farmland bird abundance was higher in the wet period (2014–15) and thrived with taller vegetation near oak and pine plantations. Cereal-field associated species benefitted from taller vegetation cover regardless of adjacent plantation type, but preferred greater distances from the forest edge. Conversely, ploughed-field associated species declined, negatively impacted by taller vegetation in 2014–15, particularly close to plantation edges. Thus, results suggest that local field management, such as a more sustainable livestock management, can positively impact open-farmland specialists, such as little bustard and calandra lark, especially during extremely dry years (e.g., 2005). Ultimately, birds' responses to afforestation depend on a complex interplay between the grassland matrix and adjacent plantation edges. Conservation efforts addressing Mediterranean farmland ecosystems should consider these local factors (e.g., vegetation height, grassland heterogeneity) to preserve open-farmland birds under increasingly dry conditions.

4.1. Winners and losers from vegetation height changes

Our findings suggest an association with vegetation height changes and avian assemblage responses near plantations. We observed a significant increase in grassland vegetation height between the two periods, coinciding with a rise in overall farmland bird abundance, particularly ground-nesting and cereal-associated species. Reduced rainfall during the first period (2005) likely affected water availability and, subsequently, the observed vegetation growth (Derner and Schuman, 2007; Cantarel et al., 2013). Livestock (sheep and cattle) occurrence in the parcels remained consistent between sampling periods, though changes to grazing regimes or agricultural practices in some of the grassland parcels could also explain the observed vegetation height differences (Reino et al., 2010b; Beja et al.,

2014; Ren et al., 2018). Our sampling design excluded sites subjected to major changes (corroborated by a lack in changes observed in landscape associated variables) and focused only on grassland parcels composed of fallow and pastures to minimise the influence of factors such as changes to agricultural practices in the grassland (Morgado et al., 2020) on bird responses to afforestation. Increased vegetation height positively affected the difference in abundance of woodland birds and cereal-associated species, regardless of the adjacent plantation. The latter group includes species like the corn bunting, benefiting from taller grassland vegetation, especially farther from the plantation edge. These species typically favour tall and dense vegetation (Moreira, 1999; Delgado and Moreira, 2000) and are often ground-nesting (e.g., the zitting cisticola), benefiting from increased nest-site cover (Batáry et al., 2007; Bellamy et al., 2018) and more readily available resources (Ponce et al., 2018). Contrastingly, we observed a negative relationship of vegetation height to the abundance of species associated with ploughed fields, such as the tawny pipit and short-toed lark, which prefer areas with shorter vegetation (Moreira et al., 2007; Santana et al., 2017). The trend towards less heterogeneity within the agricultural matrix brought by changes implemented after the CAP reform (Ribeiro et al., 2014) may thus lead to negative effects on bird diversity (Reino et al., 2010b; Santana et al., 2017; Lituma et al., 2022) as a mix of plant species and varying vegetation heights support more food sources and nesting sites for bird species than monoculture grasslands (Fisher and Davis, 2010; Jacobs et al., 2012; Hovick et al., 2015).

4.2. Influence of plantation type

Adjacent plantation type influenced the effects of grassland vegetation height on farmland bird abundance. Increased vegetation height had a positive association with farmland birds' abundance near young oak and pine plantations, but a negative one when adjacent to older eucalyptus plantations. Differences in adjacent plantations' characteristics associated with growth and maturity (Reino et al., 2010a, 2010b; Sánchez-Oliver et al., 2014b), and their associated nest-predator community (Beja et al., 2009; Faria et al., 2022), as well as variations in species abundance at the regional level (Reino et al., 2013), could also have affected bird responses to afforestation. For instance, increased avian predator abundance (i.e., carrion crows) near eucalyptus plantations (our data; Faria et al., 2022) may have influenced the observed differences in bird responses compared to younger oak and pine plantations.

Species abundance of all species or all ground-nesting birds analysed together had no relationship with vegetation height, likely due to both groups encompassing various species in terms of functional habitat preferences (Delgado and Moreira, 2000; Moreira et al., 2007; Santana et al., 2017). For instance, species like the tawny pipit or short-toed lark, known to breed and occur preferably in ploughed fields (Moreira, 1999; Delgado and Moreira, 2000; Moreira et al., 2007), were negatively affected by increased vegetation height, whereas the zitting cisticola or corn bunting (also ground-nesters), which favour high vegetation cover (Delgado and Moreira, 2000), were positively associated with it. Overall, ground-nesting species abundance was more influenced by the adjacent plantation type, with pine and especially oak plantations being favoured over eucalyptus plantations.

4.3. Influence of distance to plantation edge

Our findings align with previous studies showing mixed edge responses for farmland birds (Reino et al., 2009; Terraube et al., 2016; Phifer et al., 2017). For instance, the tawny pipit and short-toed lark, that typically avoid edges (Sliwinski and Koper, 2012; Besnard et al., 2016), are steppe specialists that favour expansive farmland areas over fragmented landscapes (Morgado et al., 2010; Keyel et al., 2013). Contrastingly, commonly widespread species known to benefit from increased plantation cover, such as the common linnet, (Reino et al., 2009, 2010a), strongly favoured edge proximity. Overall, steppe bird assemblage benefitted from increased vegetation height, though this was much more prevalent near the plantation edge and varied with plantation type. The likely reason is that higher predation rates in proximity to plantation edges (Kaasiku et al., 2022), particularly eucalyptus edges, increase the importance of adequate nest-site cover for nesting success (Hombberger et al., 2017). It could also reflect an upsurge in invertebrate prey near plantation edges (Vasconcelos et al., 2018). Thus, steppe birds primarily benefitted from grasslands adjacent to oak plantations, particularly in areas farther from the plantation edge. Oak plantations are generally less dense with shorter trees, creating softer edges (Reino et al., 2009), which are favoured by edge avoiders (Sliwinski and Koper, 2012; Besnard et al., 2016). Moreover, oak plantations likely have lower predator abundance (Faria et al., 2022), resulting in reduced ground-nesting predation pressure in these grasslands.

Lastly, there were no major changes in the number of threatened birds, which can be attributed to the overall landscape structure stability, including plantation edge density, habitat fragmentation and land-use cover. Both sampling campaigns occurred after the implementation of the CAP reform in 2003, associated with significant land-use changes in this area (Ribeiro et al., 2014). Furthermore, the sampling process deliberately excluded parcels undergoing significant land-use shifts during the latter period. As such, threatened bird abundance was mainly influenced by distance to the plantation edge, and varied significantly between different plantation types. This emphasises the potential impacts of grassland habitats' fragmentation (Reino et al., 2009; Morgado et al., 2010; Pretelli et al., 2018; Jacoboski et al., 2019), especially in relation to forest plantation edges (Sánchez-Oliver et al., 2014a; Faria et al., 2022).

4.4. Conservation implications

Our findings highlight a complex interplay between vegetation height, plantation type and edge avoidance, impacting bird responses to afforestation. This underpins the need for a multifaceted conservation approach to support the diverse avian species inhabiting Mediterranean farmlands under on-going climate and land-use changes. Notably, grassland vegetation height significantly influenced avian assemblage dynamics, affecting various bird guilds and species differently, highlighting the importance of grassland

heterogeneity in preserving diversity and stability in bird communities (Hovick et al., 2015; Traba and Morales, 2019). Grazing regimes, intensity (Batáry et al., 2007; Reino et al., 2010b, Ramos et al., 2021), and annual climatic conditions (Conrey et al., 2016; Zuckerberg et al., 2018) should also be considered by conservation efforts which aim to support a wide range of farmland species, as they directly affect grassland biodiversity and can influence grassland structure. Maintaining a balance in vegetation height diversity can benefit ground-nesting species seeking increased nest-site cover (Erdős et al., 2009), and cereal-associated species that thrive in taller vegetation (Delgado and Moreira, 2000; Batáry et al., 2007), while also preserving open-farmland specialists preferring shorter vegetation (Delgado and Moreira, 2000). Our study also emphasises the importance of the type of forest plantations adjacent to grasslands, with oak and pine plantations having a less detrimental impact on bird abundance and diversity compared to eucalyptus. Prioritising the former is likely to better accommodate open-farmland specialists. Lastly, we emphasise the importance of grassland habitat fragmentation, associated with forest plantation edges, in shaping bird responses. Strategies to reduce predation pressures near edges (Reino et al., 2010a; Faria et al., 2022), preserve large grassland patches (Morgado et al., 2010; Reino et al., 2013) and enhance landscape connectivity (Sánchez et al., 2014a), can help mitigate edge effects. Preserving grassland diversity with varying vegetation heights and minimising the use of new eucalyptus in afforestation are valuable bird conservation measures for Mediterranean farmland landscapes.

CRedit authorship contribution statement

Schindler Stefan: Investigation, Writing – review & editing. **Faria João:** Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. **Santana Joana:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Brotons Luís:** Investigation, Writing – review & editing. **Dullinger Stefan:** Investigation, Writing – review & editing. **Rotenberry John T.:** Investigation, Writing – review & editing. **Morgado Rui:** Investigation, Writing – review & editing. **Moreira Francisco:** Investigation, Writing – review & editing. **Catry Inês:** Investigation, Writing – review & editing. **Gonçalves David:** Supervision, Writing – review & editing. **Sánchez-Oliver Juan:** Investigation, Methodology. **Reino Luís:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. **Beja Pedro:** Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2024.e02818](https://doi.org/10.1016/j.gecco.2024.e02818).

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