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ORIGINAL ARTICLE

Sowing enriched pastures for extensive livestock enhances the abundance of birds and arthropods in Mediterranean grasslands

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Abstract
A great number of farmland wildlife species has shown a sharp population decline in European countries, mainly caused by changes in agricultural practices leading to habitat alterations. Within this scenario, the identification of agricultural practices providing economic benefits to farmers and, at the same time, favoring higher biodiversity levels is a key challenge. This is especially interesting in Mediterranean livestock farming environments where bird numbers decrease due to intensification. Aiming at assessing the benefit to biological diversity of certain types of management practices in grasslands, we experimentally planted enriched pastures. Through a monitoring program of the bird and arthropod communities performed in Extremadura (W Spain) during 2 years (2016–2018), we compared relative richness of birds, abundance, and density values of birds and arthropods between treatment (three plots with enriched pastures) and control areas (six plots of natural grasslands). We found that enriched pastures had higher levels of relative abundance and density of wildlife with respect to natural grasslands and provided a greater variability and availability of trophic resources to birds. Habitat use by birds and arthropods not only depended on the type of pastures but also on the season, the study area, the presence of livestock and the vegetation height. Sowing enriched pastures constitutes a proactive measure stimulating biodiversity in Mediterranean extensive livestock farms that is also beneficial at the socioeconomic level. Therefore, co-financing this measure within the framework of subsidies from the Common Agricultural Policy of the European Union, as well as its inclusion in the future operational programs approved by the authorities, are essential.

Keywords Agrosystems · Common agriculture policy · Conservation · Intensive farming · Farmland birds

Introduction

Biodiversity protection entails the need of applying the best techniques of habitat, wildlife, and plant management, within an adaptive framework integrated in the conservation biology discipline (McCarthy and Possingham 2007; Allan and Stankey 2009; Wilmer et al. 2018). In the case of agricultural environments and others assimilated to natural pseudo-steppe lands, the decline in biodiversity indexes during the last 20 years are of great concern in Europe (Inger et al. 2015; Emmerson et al. 2016; Traba and Morales 2019).

A large number of agrosystem-dwelling wildlife species have suffered population declines due to shifts in habitat quality of the landscapes they inhabit. Specifically, changes in human management practices have led to the abandonment of agricultural lands with the subsequent development of forests and shrubby vegetation (Sokos et al. 2013; Zakkak et al. 2015) and, on the other hand, the intensification of agricultural and livestock uses has reduced the availability of feeding, refuge, and breeding areas for wildlife (Benton et al. 2003; Tscharntke et al. 2005; Emmerson et al. 2016). In the case of the European Union, one of the factor triggering changes in agricultural uses comes from the incentives of the Common Agricultural Policy (CAP) with which farming activities and products are subsidized based on regulated principles and priorities (European Parliament and Council of the European Union 2013; Barnes et al. 2016). Although biodiversity

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conservation has been a priority during the most recent cycles of the CAP planning, almost none of the applied indexes and proxies have shown a positive relationship between CAP subsidies and the improvement of the conservation status of species inhabiting these farmlands (Pe'er et al. 2014; Alons 2017; Navarro and López-Bao 2018). Population declines in vertebrates (mainly birds) and invertebrates arise as a result of the mechanization of labors, the earlier harvesting of crops, the generalized use of agrochemicals, or the lack of areas (i.e., copses and fallows) free of agricultural use around crop plots or pastures (Dudley et al. 2017; Palacín and Alonso 2018; Traba and Morales 2019).

Birds and invertebrates are taxa strongly affected by changes in agricultural uses in Europe (Benton et al. 2002; Attwood et al. 2008; Navarro and López-Bao 2018). Certain species are even threatened as is the case of the little bustard *Tetrax tetrax*, the Dupont's lark *Chersophilus duponti*, the lesser kestrel *Falco naumanni*, or the black-bellied sandgrouse *Pterocles orientalis*, so there are specific conservation programs ongoing (Iñigo and Barov 2010a, 2010b; BirdLife International 2015). In the same way, emblematic species such as the great bustard *Otis tarda* are subject to coordinated international initiatives for their protection (Raab et al. 2009). These steppeland birds are highly sensitive selecting specific areas with enough availability of food, refuge, and quietness according to their ecological requirements (Traba et al. 2015; Robleño et al. 2017). Nevertheless, it is important to take into account that nowadays, they depend on the sustainable human activities practiced at farmlands that benefit their ecological requirements.

With the purpose of favoring biodiversity at agricultural environments, it is necessary to apply management measures reconciling the presence of wildlife with socioeconomic uses, in a win-win framework. Farming makes up the livelihoods of many people and must provide sufficient incomes to maintain the socioeconomic structure in rural areas. Therefore, maintaining agricultural and livestock activities should be sustainable over time, including the possibility of subsidizing these actions in compliance with environmentally sustainable criteria (European Parliament and Council of the European Union 2013). In this scenario, it is very useful to know what agricultural practices can provide economic benefits to the farmers and, at the same time, enhance wildlife and plant diversity. This is especially interesting in Mediterranean grazing environments, where the decline of the bird communities has been remarkable due to management intensification (Palacín and Alonso 2018) and where the need for nutrient-rich natural pastures for livestock prevails (Bernués et al. 2011).

We experimentally sow enriched pastures in areas of extensive livestock use in Mediterranean environments of the Iberian Peninsula with the purpose of assessing the differences it could generate on several biodiversity indexes in relation to surrounding natural grasslands. These planted pasturelands met two main expectations: they are beneficial in relation to agronomic interests and there are references in previous studies of positive effects on biodiversity (Potts et al. 2009; Teixeira et al. 2014; Walden and Lindborg 2016; Hernández-Esteban et al. 2019). The objectives were: (1) to know the relative abundance of wildlife species (invertebrates and birds) in pasture plots of different types, comparing natural grasslands with enriched pastures. (2) To determine the spatial and temporal patterns of use by farmland birds, recognizing which groups or species respond more positively to the improved pastures. (3) To assess the type of management—sowing time, intensity and timing of grazing, perimeter protection, mowing, etc.—needed in the enriched pastures for increasing biodiversity. In particular, our hypotheses were the following: (1) planting enriched pastures provides a greater variability and availability of trophic resources, as well as a taller vegetation height (Potts et al. 2009; Walden and Lindborg 2016; Hernández-Esteban et al. 2019). (2) There are higher values of species richness, relative abundance, and density of farmland birds and arthropods in the improved pastures with respect to the surrounding natural pastures which would entail a positive measure to integrate into official programs of environmental subsidies (Navarro and López-Bao 2018). (3) There is variation in the habitat use depending not only on the type of pasture but also on the season, the location, the presence of livestock grazing, and the vegetation height.

Methods

Studied area and species

We carried out the study in Extremadura (W Spain, Fig. 1) on pseudo-steppe ecosystems dominated by grasslands. The potential vegetation of the study area corresponds to the Luso-extremadurense Mesomediterranean series of holm oak *Quercus rotundifolia* (*Pyrobourgaeanae-querceto rotundifoliae sigmentum*; Rivas-Martínez 1987). According to the Habitats Directive (Annex I; Council of the European Union 1992), the existing plant communities are included as "*Semi-natural dry grasslands and scrubland facies*," the most relevant belonging to 34.5: "*Pseudo-steppe with grasses and annuals (Thero-Brachypodietea)*" which is listed as a priority habitat. The secondary stages of these grasslands consist of Spanish lavenders *Lavandula stoechas* and yellow Mediterranean brooms *Retama sphaerocarpa*.

In study area, the woody vegetation is limited to the surroundings of streams and boundaries between livestock farms, having been generally removed during the nineteenth and twentieth centuries for their conversion into pasturelands (Vicente and Alés 2006). In particular, the area is managed with the purpose of providing food for livestock, traditionally ovine *Ovies aries* but more recently and increasingly bovine *Bos taurus*.

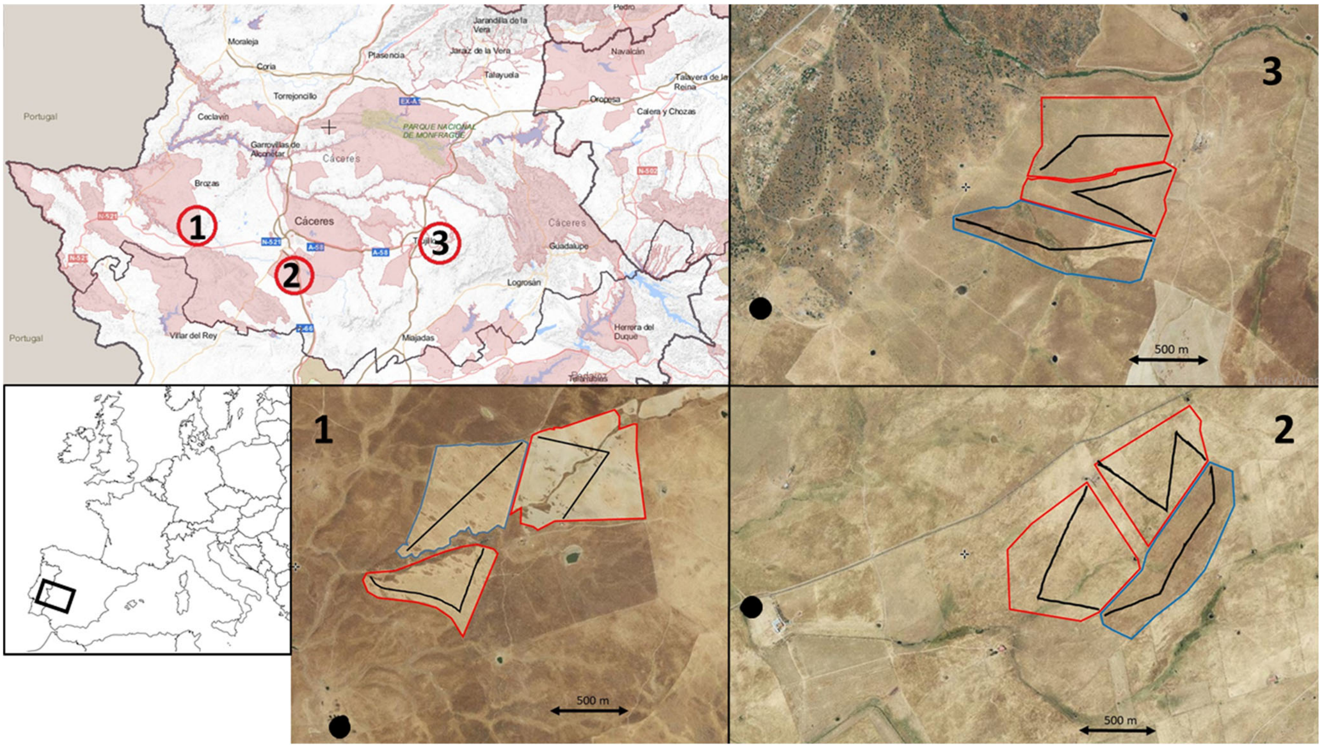

Fig. 1 Study area in western Spain (Extremadura region). The three working zones are marked with red circles and the network of Special Protection Areas for Birds (SPA, Directive 2009/147/CE) is shown as pink shading. Aerial photographs of the treatment plots where enriched pastures were planted (blue contour) and the control plots (red contour) with the performed transect for bird and arthropod monitoring (black lines) in each of the three-labelled working zones are also shown. The black spots indicate the location of the observation points of great bustards *Otis tarda* in each zone

The natural dynamics of the plant communities are dependent on the climate of Mediterranean environments (Allué 1990). Rains usually take place from October to May, being minimal between June and September. The average annual rainfall is 489 mm. The mean monthly temperatures vary between 7.7 °C in January and 26.0 °C in July (data from the National Meteorological Institute. Cáceres Observatory).

Within the aforementioned area, we selected three working zones for assessing the effect of different types of grasslands (treatment and control, see below) on population parameters of birds and arthropods, which met the following requirements. (1) The zones were in Special Protected Areas for Birds (SPA) of the Natura 2000 network characterized by the presence of priority bird species linked to farmlands (MITECO-Junta de Extremadura 2019). (2) The zones belonged to private farms willing to collaborate that accepted the management conditions of our field test—see below—and had a minimum area of 200 ha. (3) There was an extensive or semi-extensive livestock exploitation regime, that is, sheep and/or cows feeding on the grasslands throughout the year—although alternating between different plots of the farm—without developing transhumance (Ruiz and Ruiz 1986) and with food supplementation during the periods of greater shortage of natural pastures.

The bird species targeted in our study (see list of species detected in Supplementary Material) are typical of Mediterranean pseudo-steppe environments and are present in the areas where the field work was developed. They show a decreasing population trend in Extremadura and globally in both Spain and the rest of Europe (EEA 2019). The whole bird community was subsequently grouped into various taxonomic and/or behavioral categories as described in Table 1 to inform their particular traits in habitat selection. Special effort was devoted to the great bustard due to its representative and emblematic role in agrosystems and its gregarious behavior (Magaña et al. 2011; Casas et al. 2019), so specific efforts were focused to monitor them with different methodological approaches. In relation to arthropods, we did not propose their study at the specific level, considering only their abundance and relative biomass as a whole. The study began in October 2015 with the preparation and planting of enriched pastures (see below). Subsequently, we performed field sampling during 2 years from March 2016 to February 2018.

Characterization of the study plots: implemented management measure

In each of the three working areas, three 30 ha plots were selected as experimental units (in total nine experimental units

Table 1 Variables considered in the study of the effect of pastures improvement on wildlife, at different levels of study (*field of study*). The variable name, if it was response or explanatory in the statistical analyses (*type*), its consideration as "continuous" or "categorical" depending on the type of measurement applied, the units or categories of each variable, and a description of the aspects evaluated are indicated

Field of study	Variable name	Type	Measurement level	Units/categories	Description
Great bustard	Relative density of great bustard	Response	Continuous	Individuals/ha	Number of individuals observed in each observation session at different type of plots (treatment and control)
Bird community	Relative abundance of steppe-land birds	Response	Continuous	Individuals/km	Number of individuals detected in each monitoring transect
	Relative density of steppe-land birds	Response	Continuous	Individuals/ha	Number of individuals detected in each monitoring transect
	Species richness of steppe-land birds	Response	Continuous	Number of species	Number of species detected in each monitoring transect
	Relative abundance of granivorous passerines	Response	Continuous	Individuals/km	Number of individuals of larks, buntings, and other families of passerines mostly granivorous detected in each monitoring transect
	Relative abundance of sandgrouses	Response	Continuous	Individuals/km	Number of individuals of pin-tailed *Pterocles alchata* and black-bellied sandgrouses *Pterocles orientalis* detected in each monitoring transect
	Relative abundance of bustard species	Response	Continuous	Individuals/km	Number of individuals of little *Tetrax tetrax* and great bustards *Otis tarda* detected in each monitoring transect
Arthropods	Relative abundance of arthropods (butterfly net)	Response	Continuous	Number of individuals	Number of individuals collected in each monitoring transect using a butterfly net
	Biomass of arthropods (butterfly net)	Response	Continuous	Weight (gr)	Weight (wet) of all individuals collected using a butterfly net, with a 0.1 g precision bascule
	Relative abundance of arthropods (open quadrat)	Response & Explanatory	Continuous	Number of individuals	Number of individuals collected in each monitoring transect using an open quadrat
	Biomass of arthropods (open quadrat)	Response	Continuous	Weight (gr)	Weight (wet) of all individuals collected using an open quadrat, with a 0.1 g precision bascule
All	Type of area	Explanatory	Categorical	"Treatment," "Control"	Differentiation between plots with improved pasturelands and other study plots without changes in natural pasturelands
	Zone	Explanatory	Categorical	"1," "2," "3"	Each of the three zones selected in which the three study plots (2 controls and 1 treatment) were designed
	Season	Explanatory	Categorical	"Winter," "Spring," "Summer," "Autumm"	Three-month periods considering "Winter" as December, January, and February, and followed by the subsequent seasons
	Vegetation height	Explanatory	Continuous	centimeters (cm)	Random measurement of the herbaceous plant height in the study plot
	Livestock signs presence	Explanatory	Categorical	"Yes," "No"	Detection of footprints of livestock in the study plot (only for studies on habitat use of the bird community and arthropods)
	Livestock numbers	Explanatory	Continuous	Number of individuals observed	Evaluation of potential disturbances from livestock in study (only for the study of habitat use by great bustard)

monitored). These three plots per area were geographically marked, geo-referenced, and contiguously located (Fig. 1). One of the three plots was randomly selected as treatment (where the enriched pasture was sown with the help of a tractor and the corresponding gears to carry out the work, see below) and the other two acted as control, maintaining their previous vegetation and regular dynamics of livestock use. The shape of each plot was approximately rectangular trying to ease the establishment of sampling transects (see below).

It would have been more appropriate to have an equal and higher number of treatment and control plots for increasing the robustness and representativeness of our results, but it was not possible to expand a greater number of treatment sites due to lack of funding for its implementation. Therefore, we preferred to increase the number of control plots to improve the accuracy of the results in these areas which did not bias the comparison with the treatment areas, but rather implied a better fit of data for the control plots.

The so-called enriched pasture was characterized by dryland herbaceous species adapted to the geological and weather features of the area. The enriched pasture does not depend on additional irrigation to the natural rainfall, has high nutritional and palatable value for livestock, is favored in terms of conservation and regeneration by a sustainable and non-intensive level of grazing, and has an approximate length of about 10 years (Loi et al. 2005; Lüscher et al. 2014). The species composition of these pasturelands was made up of seeds (82 kg/ha planted) of the following groups: four varieties of underground clovers—*Trifolium subterraneum* (12.2%), Persian clover *Trifolium resupinatum* (2.4%), Balansa clover *Trifolium michelianum* (1.2%), lucerne *Medicago sativa* (2.4%)—yellow lupin *Lupinus luteus* (18.3%), common vetch *Vicia sativa* (6.1%), triticale (wheat × rye) *Triticum aestivum* × *Secale cereale* (30.5%), raygrass *Lolium* sp. (8.5%), inoculizers, and seed pelletization (18.3%). Sowing the enriched pasture consisted of a deep labor (25 to 35 cm), turning soil horizons with plows with the objective of eliminating other vegetal remains to reduce competition with the planted vegetation. Then, we made a shallow labor (15 to 20 cm) with a harrow of discs for the preparation of the sowing substrate leaving the ground as smooth and fluffy as possible. It was supplemented with phosphorus (NPK 5-10-10) and carbonates Ca_3 $(PO_4)_2$ fertilization. The sowing was carried out in lines with a front cereal planter, or with a precision planter, and a roller curl to bury the seeds superficially (1–2 cm). The total cost of establishing this enriched pasture, including seeds, fertilizers, and personnel, was 597 €/ha.

The control plots were natural grasslands, with typical species of the habitat type "*Pseudo-steppe with grasses and annuals (Thero-Brachypodietea)*": *Agrostis castellana*, *Brachypodium distachyon*, *Festuca elegans*, *Poa bulbosa*, and *Rumex bucephalophorus Trifolium subterraneum* (Ríos and Salvador 2009). The dynamics of these pastures depends on the rainfall as well as on the livestock numbers, so that the vegetative period generally occurs during winter and spring. Each of these plots also accounted for 30 ha approximately.

Cattle and sheep were the only livestock present in the study areas (cattle in two of the three sampling areas and sheep only in the area called Mingalozana). They grazed the monitored plots throughout the year in an extensive way (without solid food supplementation except in summer) and with densities per unit area between 0.2 and 0.5 UGM/ha. UGM—*bigger livestock unit*—is equivalent to an animal with energy needs of 3000 forage units. A cow of about 550 kg corresponds to one UGM and an adult sheep to 0.15 UGJM approximately (MARM 2010). In the case of enriched pastures, with the purpose of their proper implantation, their consumption by livestock was avoided until the first natural seed production in order to ensure its natural reseeding. Therefore, these plots of pastures lacked grazing for at least 9 months after their sowing.

Fieldwork

After the selection of the experimental units (plots) and sowing of the enriched pasture, we started a monitoring program especially focused on birds and invertebrates, consisting of three sampling methods.

First, with the purpose of assessing the habitat use by the great bustard, we selected one elevated observation point in each of the three working zones. These were away from the study plots to avoid disturbances to the great bustards (min. 1 km of distance) and with good visibility of the entire zone. From these points, on a weekly basis, we visually counted the individuals present distinguishing between those within the treatment plot and in the rest of the observable territory that performed as control plots. The census lasted for 1 h during the maximum foraging activity period, avoiding the central hours. We recorded in each count: time, maximum simultaneous number of great bustards in each plot, maximum total number of different individuals observed in each plot, activity carried out (feeding, resting, courtship), and number of livestock heads present in each plot.

Second, within the three plots—one treatment and two controls—of each of the three working zones, linear census transects of 1 km length were established. Two field technicians previously standardized for the identification of targeted wildlife and in the methods to collect data were the only that sampled the transects on foot with the purpose of recording all birds detected (heard or observed) in two lateral bands: up to 50 m and more than 50 m from the observer up to the boundaries of the study plot. The birds were assigned to their species and to their presence within or outside these lateral bands aiming at subsequently calculate relative abundances (number of birds observed in the plot divided by the length in km of the transect) and relative densities (number of birds observed in the plot within the area in ha delimited by the two 50 m lateral bands on each side of the observer for the entire length of the transect). Census was performed once a month, during the maximum activity time of the birds (from sunrise to 3 h later).

Thirdly, during the return along transects described above, arthropods were sampled to check if a greater abundance would be related to the grassland type (enriched pastures or natural grasslands). For this, we carried out standardized captures through two methods: the first one with butterfly net (Joern 2005; Pocco et al. 2010) so that every 200 m of advance, we stopped and collected during 30 s the arthropods perched on the vegetation around that point. Thus, in each itinerary, there were five different collection events of arthropods with butterfly net. After each collection event, the net was covered to avoid captured arthropods from escaping so individuals were finally counted and weighed. The second method consisted of collecting the arthropods located on the ground and vegetation included within a 40 × 40 cm open quadrat (Gardiner and Hill 2006) that was randomly thrown every 200 m of transect. We put the collected arthropods in a pot for later counting and weighing without drying them. Both methods alternated sequentially every 100 m along the 1000 m transect. The targeted arthropods were > 1 mm in length according to the mesh size of the butterfly net used and the visual capability for its collection through the open quadrat.

Coinciding with arthropod sampling, we measured the height of the vegetation with the help of a 50 cm long ruler at a minimum of four points randomly distributed along the transect, subsequently recording the resulting average in centimeters.

Variables considered and statistics

Following the fieldwork, we considered different response and explanatory variables which were subsequently subject of statistical analyses. In total, we assessed eight response and six explanatory variables (Table 1).

For studying the habitat use by the great bustard, the number of observed individuals was assigned to treatment plot (30 ha) or, on the contrary, to the rest of observable area from the observation point. This latter varied according to the working zone ("1" = 930 ha; "2" = 685 ha; "3" = 738 ha; Fig. 1) and acted as control plots. In relation to the bird community (see Supplementary Material), the analysis of the *relative abundance* (birds/km) and *relative density* (birds/ha) showed a high correlation between each other (Spearman $r = 0.85$), so we chose the variable *relative density* in the subsequent analyses for simplification. For arthropods, the correlation values between the proposed response variables (*biomass* and *relative abundance* in the two sampling methods) were always less than 0.62, so both were included in further analyses.

The response variables (Table 1) were analyzed with respect to all explanatory variables, except in the case of the *great bustard relative density* that did not include the presence/absence of livestock signs in their analyses. Owing to the observations of this species were made at > 1 km, it was not possible to detect the presence of tracks in the studied plots, so the number of livestock heads (sheep and cattle) observed in each plot was used as alternative index. The relative abundance of arthropods was also considered explanatory only analyzing the bird abundance and richness patterns. For studies of the bird and arthropod communities, we neither included the *number of livestock heads* in the plots as explanatory variable because this was only proposed for the distant observations of great bustards (Table 1). We nested the explanatory variables *zone* and *season* in the variable *type of area* to know their influence in relation to the type of pasture management. On the other hand, since there was a high number of null observations during the sampling of great bustards, the variable *great bustard relative density* was log10-transformed to include it in the multivariate analyses.

First, aiming at determining a greater predictive power of the different potential subsets of explanatory variables in the results, we calculated the most parsimonious model using the Akaike's information criteria (AIC, Burnham and Anderson 2002). We subsequently selected those combinations with the lowest AIC value and evaluated the estimates (β ± SD) for each level of the variables to know their relationship (+/−) with the response variable, as well as the Type 1 LR test (χ^2) to know the significance value (p) of the covariates jointly included in the most parsimonious model.

Next, we performed GLMM for each of the response variables which showed a Poisson distribution and a log-function, in order to know what explanatory variables, as well as their interactions, influenced the results. The results (statistics, degrees of freedom, and value of statistical significance) of the analyses resulting in a confidence level greater than 95% ($p < 0.05$) are shown. All analyses were conducted with the Statistica 7.0 software (StatSoft, Tulsa, USA).

Results

We performed 300 different observation days of great bustards in the three working areas, with 27 different individuals counted in the treatment plots and 356 in the control areas. Regarding the counts of the bird community, in the 207 transects, we obtained a relative density of 5.83 birds/ha ± 8.41, for a total of 29,248 individuals corresponding to 43 different species. The mean species richness was 7.08 species/transect ± 2.19. The most abundant species registered were de calandra lark Melanocorypha calandra, the corn bunting Emberiza calandra, the Eurasian skylark Alauda arvensis, and the meadow pipit *Anthus pratensis* (Table 2). In the 207 samplings of arthropods with the butterfly net, we captured 2933 different individuals with a total body mass of 148.7 g, while with the open quadrat methodology, we counted 3881 specimens with a total body mass of 148.1 g.

Great bustard

The relative density of the great bustard varied according to environmental characteristics, being the *type of area* the variable with a greater explanatory power (Table 3). In the treatment plots, great bustards were observed more abundantly (mean 0.0059 birds/ha ± 0.0205) than in the control plots (mean 0.0030 birds/ha ± 0.0204). Additionally to the *type of area* ($F_{1,56} = 75.08$; $p < 0.0001$), the GLMM analyses showed

Table 2 General results on the total number of individuals observed (*n*), the mean number of birds counted per transect, the relative abundance (as the number of birds observed/km of transect) and the relative density (as number of birds observed/ha) in the total of transects sampled—Total—in treatment plots with implanted enriched pastures—T—and in control plots without enriched pastures—C. The data are provided for the total number of registered birds ("all steppe-land birds"), for certain avian groups ("granivorous passerines": passerine species mainly feeding on plant seeds and sprouts; "sandgrouses": jointly pin-tailed *Pterocles alchata* and black-bellied *Pterocles orientalis* sandgrouses; "bustard species": jointly great *Otis tarda* and little bustards *Tetrax tetrax*), and for 12 agrosystem-dwelling bird species

Group/species	Individuals observed (*n*)	Mean (birds/transect)		Relative abundance (birds/km) ± SD			Relative density (birds/ha) ± SD		
	Total	T	C	Total	T	C	Total	T	C
All steppe-land birds	29.248	156.83	133.53	129.9 ± 138.2	138.9 ± 148.5	118.3 ± 122.0	5.83 ± 8.41	7.24 ± 9.66	5.12 ± 6.95
Granivorous passerines	23.608	128.39	106.88	112.2 ± 132.7	125.6 ± 133.0	105.5 ± 92.8	5.70 ± 8.40	7.03 ± 10.2	5.02 ± 7.22
Sandgrouses	189	1.72	0.51	0.85 ± 4.54	1.63 ± 3.52	0.47 ± 6.8	0.03 ± 0.28	0.06 ± 0.33	0.02 ± 0.18
Bustards	106	0.38	0.58	0.49 ± 2.04	0.36 ± 3.01	0.56 ± 1.55	0.01 ± 0.10	0.02 ± 0.19	0.01 ± 0.09
Great bustard	53	0.17	0.30	0.12 ± 0.95	0.08 ± 1.15	0.14 ± 0.77	0.009 ± 0.07	0.013 ± 0.09	0.006 ± 0.06
Little bustard	53	0.20	0.28	0.13 ± 1.09	0.10 ± 1.44	0.14 ± 1.20	0.009 ± 0.07	0.010 ± 0.07	0.007 ± 0.05
Pin-tailed sandgrouse	51	0.48	0.13	0.12 ± 1.44	0.23 ± 1.80	0.06 ± 1.68	0.015 ± 0.21	0.040 ± 0.28	0.002 ± 0.09
Black-bellied sandgrouse	138	1.25	0.38	0.33 ± 2.20	0.63 ± 2.72	0.18 ± 1.71	0.022 ± 0.12	0.026 ± 0.18	0.020 ± 0.10
Montagu's harrier	8	0.09	0.01	0.02 ± 0.15	0.04 ± 0.18	0.007 ± 0.19	0.001 ± 0.03	0.002 ± 0.08	0
Calandra lark	7.971	36.88	39.32	19.3 ± 54.2	18.4 ± 30.2	19.3 ± 59.7	2.55 ± 7.41	2.69 ± 9.09	2.49 ± 7.30
Eurasian skylark	1.946	11.68	8.28	4.70 ± 18.4	5.82 ± 23.3	4.13 ± 11.1	0.52 ± 1.93	0.62 ± 3.45	0.47 ± 2.23
Crested lark	460	0.77	2.95	1.11 ± 2.02	0.48 ± 2.16	1.47 ± 3.63	0.15 ± 0.25	0.04 ± 0.19	0.21 ± 0.09
Greater short-toed lark	274	0.62	1.67	0.66 ± 2.60	0.31 ± 3.88	0.83 ± 4.51	0.01 ± 0.10	0.02 ± 0.16	0.01 ± 0.06
Meadow pipit	1.885	11.10	8.11	4.55 ± 13.5	5.50 ± 10.3	4.05 ± 15.8	0.66 ± 1.92	0.78 ± 1.72	0.61 ± 1.95
Zetting cisticole	250	2.46	0.58	0.62 ± 1.33	1.28 ± 3.45	0.28 ± 1.05	0.07 ± 0.21	0.16 ± 0.26	0.02 ± 0.08
Corn bunting	4.914	40.17	15.56	11.8 ± 27.3	20.1 ± 33.4	7.7 ± 27.1	1.57 ± 3.54	2.76 ± 4.89	0.97 ± 3.80

a significant influence of the *vegetation height* ($F_1 = 4.11$; $p = 0.047$) so that bustards were more frequent in areas with higher vegetation (Fig. 2).

Bird community

The sampling of farmland birds showed that *species richness* followed a model in which the *season* was the more parsimonious variable (Table 3), resulting in higher values during spring and summer. GLMM analyses supported this pattern and only offered significant results for the interaction between *type of area**season* ($F_{6,191} = 2.08$; $p = 0.050$) and *livestock signs presence* ($F_{1,191} = 4.32$; $p = 0.038$).

Meanwhile, numbers of counted birds depended on the environmental traits. The model with a greater explanatory power (Table 3) ratified how the areas with enriched pastures and higher vegetation height hosted higher relative densities of birds, which also increased during the autumn (the *type of area**season* interaction offered significant values in the multivariate analyses: $F_{6,191} = 3.03$; $p = 0.007$; Fig. 3). In addition, a greater number of *livestock signs* was negatively related to the *relative density* of birds ($F_{1,191} = 4.39$; $p = 0.037$).

By groups of species as described in Table 1, the granivorous passerines also responded positively to a combined effect of the treatment plots and a higher vegetation height, the season being also significant with greater abundances during autumn (*type of area**season* $F_{6,191} = 2.29$; $p = 0.036$; Table 3). Regarding the two bustard species jointly, none variable significantly determined a greater or lesser relative abundance. However, the model that best explained the relative abundance included the *vegetation height* and the *type of area*, as well as the respective interactions between these two variables and the *season* (Table 3). Finally, the higher abundances of sandgrouses better adjusted to the model composed of the greater *arthropod abundance*, the *type of area*, with increased numbers in areas with enriched pastures ($F_{1,191} = 4.80$; $p = 0.029$), a greater *vegetation height* ($F_{1,191} = 5.58$; $p = 0.019$),

Table 3 Models assessing the effect of the explanatory environmental variables (see Table 1) on different response variables studied to assess the effect of pastures improvement on wildlife. The explanatory variables part of the most parsimonious model including those cross-interactions between them through an asterisk (*) are shown, indicating the AIC values—Akaike's information criterion—and other resulting statistics (L-ratio χ^2, degrees of freedom, level of significance) as well as the estimates of each level or categories of the explanatory variables (β ± SD)

Response variable	Most parsimonious model	AIC	L-ratio χ^2	*df*	*p*	Level of the explanatory variable	β ± SD
Log_{10} relative density of great bustard	Type of area	21.45	0.164	1	0.702	Type of area: treatment	0.34 ± 0.95
Species richness of steppe-land birds	Season	766.70	4.69	2	0.095	Season: spring	0.06 ± 0.05
						Season: summer	0.006 ± 0.05
						Season: autumm	− 0.10 ± 0.05
Relative density of steppe-land birds	Type of area + season + vegetation height*season + type of area*season + arthropods (quadrat)	1413.87	405.09	16	< 0.001	Type of area: treatment	0.14 ± 0.03
						Season: spring	− 0.36 ± 0.07
						Season: summer	− 0.31 ± 0.06
						Season: autumm	0.63 ± 0.05
						Vegetation height	0.004 ± 0.001
						Arthropods (quadrat)	0.002 ± 0.000
Relative abundance of granivorous birds	Type of area + season + vegetation height + area + area*season + type of area*season + type of area *area + type of area*season*area	17,131.12	5513.35	25	< 0.001	Type of area: treatment	0.03 ± 0.00
						Season: spring	− 0.48 ± 0.01
						Season: summer	− 0.13 ± 0.01
						Season: autumm	0.52 ± 0.01
						Vegetation height	0.05 ± 0.00
						Area: Martinagomez	0.18 ± 0.01
						Area: Mingalozana	− 0.08 ± 0.01
Relative abundance of bustards	Type of area + vegetation height + type of area*area + type of area*season + area*season*type of area	401.65	227.89	13	< 0.001	Type of area: treatment	1.41 ± 343.7
						Season: spring	3.49 ± 114.5
						Season: summer	0.12 ± 114.5
						Season: autumm	− 2.67 ± 343.7
						Vegetation height	− 0.04 ± 0.01
						Area: Martinagomez	− 1.25 ± 687.4
						Area: Mingalozana	− 7.69 ± 916.6
Relative abundance of sandgrouses	Type of area + vegetation height + arthropods (butterfly net) + area + type of area*area + type of area*season + area*season*type of area	515.60	598.64	9	< 0.001	Type of area: treatment	2.66 ± 0.18
						Season: spring	3.07 ± 398.3
						Season: summer	0.95 ± 421.0
						Season: autumm	0.22 ± 421.0
						Vegetation height	− 0.02 ± 0.00
						Area: Martinagomez	− 4.59 ± 785.8
						Area: Mingalozana	− 3.19 ± 405.0
						Arthropods (butterfly)	0.02 ± 0.00
Relative abundance of arthropods (butterfly net)	Zone + season + zone*season + season*type of area + zone*season*type of area	2386.49	1232.01	20	< 0.001	Type of area: treatment	0.04 ± 0.02
						Season: spring	0.95 ± 0.03
						Season: summer	0.22 ± 0.04
						Season: autumm	− 0.95 ± 0.06
Biomass of arthropods (butterfly net)	Season + season*type of area + season*type of area*season	424.90	127.58	12	< 0.001	Type of area: treatment	0.78 ± 0.26
						Season: spring	4.22 ± 263.2
						Season: summer	4.33 ± 263.2
						Season: autumm	− 1.91 ± 263.2
Relative abundance of arthropods (open quadrat)	Season + season*type of area	8962.81	3794.03	6	< 0.001	Type of area: treatment	0.66 ± 0.04
						Season: spring	0.44 ± 0.06
						Season: summer	0.13 ± 0.07
						Season: autumm	− 2.55 ± 0.13
Biomass of arthropods (open quadrat)	Season + season*type of area	535.87	128.26	6	< 0.001	Type of area: treatment	0.75 ± 1.09
						Season: spring	2.84 ± 211.1
						Season: summer	1.94 ± 211.1
						Season: autumm	− 4.90 ± 0.85

and the interactions among *type of area*, *area*, and *season* (Table 3).

Arthropods

The collected arthropods mainly corresponded to insects (Diptera, Orthoptera, Lepidoptera, and Coleoptera) in both the imago and larval stages, as well as arachnids. The differences in arthropod abundance were mostly based on the *season*, the *zone*, and the *type of area* (Table 3). In general, we collected more individuals during spring and summer, and in plots with enriched pastures. These general patterns were observed both for the *relative abundance* and for the total *biomass* of arthropods, through both sampling methods

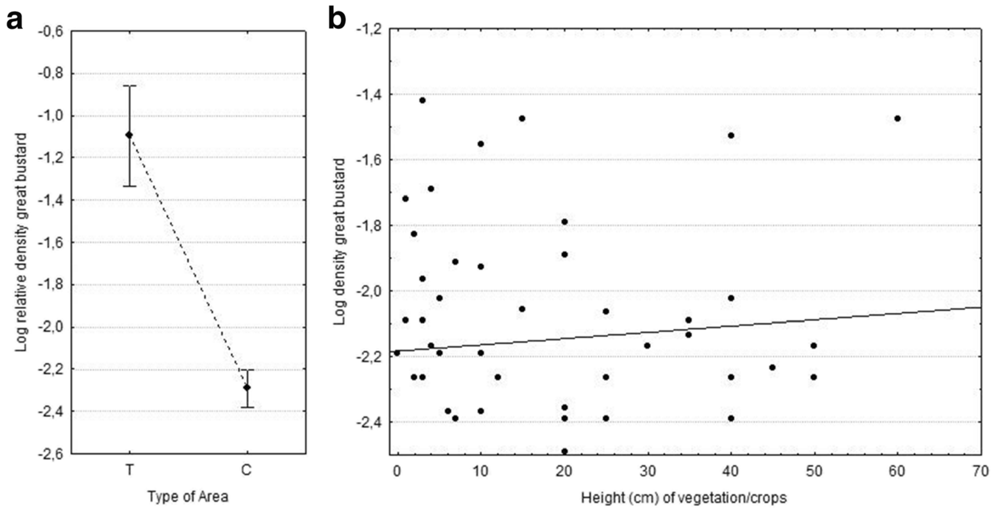

Fig. 2 **a** Mean ± CI (95%) of the *relative density of great bustards Otis tarda* expressed as the number of individuals/ha—log10-transformed—depending on the *type of area* studied (T = treatment, with enriched pastures, and C = control, with natural not improved grasslands). **b** Linear regression (black line) of the relationship between the *relative density of great bustards* expressed as number of individuals/ha—log10-transformed—and the *height of natural vegetation* (grasslands) in centimeters in both T and C zones

(butterfly nets and open quadrats), and were supported by the GLMM (Table 4; Fig. 4).

Discussion

Effects on wildlife

Our results showed a positive effect of enriched pastures on the richness of birds and the relative abundance of birds and arthropods. Although it would have been preferable to expand the number and area of treatment and control sites (90 ha treatment vs. 180 ha control), the sample size under study (a mean of 23 transects per plot with a monthly basis), its geographic distribution among different areas, and the sampling duration (2 consecutive years), our study provides interesting conclusions of a favorable effect of the enriched pastures on the levels of biodiversity proxies considered. Nevertheless, more studies are needed to support these conclusions and to enhance the implications on the management of these pasturelands. In this sense, it would also have been desirable to assess the previous situation in the sampling plots to improve the accuracy of the conclusions with a before-after control-impact approach (BACI, Chevalier et al. 2019). Additionally to enriched pastures, other variables also influenced the bird and arthropod abundances, such as the relative abundance of invertebrate food resources, the variation of conditions at the local scale between the different working zones, the height of the vegetation, and the season, this latter due to the dynamics associated to the different life-cycle periods of the target species (Benton et al. 2003; Ivits et al. 2011).

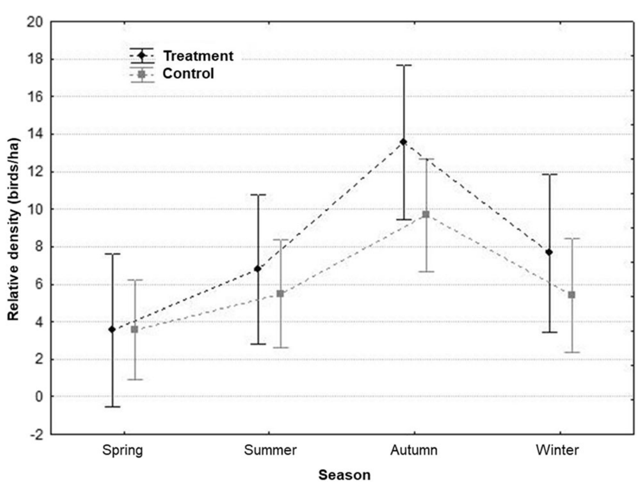

Fig. 3 Mean ± CI (95%) of the *relative density* values of steppe and agrosystem-dwelling birds (number of individuals/ha) observed per sampling transect between treatment areas (with enriched pastures) and control areas (with natural not improved grasslands) between the different seasons of the year

The great bustard exhibited a greater preference for the treatment plots, mainly for feeding purposes, even though the small scale of the sampled areas (30 ha with respect to the rest of the observable territory from the observation points) and considering its large spatial requirements with respect to other steppe-land birds (Alonso et al. 1995; Suárez-Seoane et al. 2002; Concepción and Díaz 2011; Ponjoan et al. 2012). For other bird species, the higher densities recorded in the treatment areas modulated according to the season so the study areas hosted greater bird numbers during the autumn. It is worth noting that several threatened species such as the pin-tailed and black-bellied sandgrouses showed larger concentrations in these improved grasslands, following their habitat selection patterns towards areas of greater abundance of food resources after the breeding season (Martín et al. 2010), including the presence of more arthropods comparatively. The species that most clearly exhibited preference for enriched pastures were those smaller and granivorous. Larks such as the calandra lark, the Eurasian skylark, and the greater short-toed lark Calandrella brachydactyla, as well as the corn bunting, were more abundant in these improved grasslands,

Table 4 Results of the multivariate analyses (generalized linear mixed models, GLMM) performed to assess the ratio of the number of arthropods, expressed as the total number of individuals counted (*relative abundance*) and their weight (*biomass*)—following two different sampling protocols, such as butterfly net and the open quadrat—regarding the different explanatory variables studied (see Table 1). Only the variables that offered significant results, which were cross-interactions between two variables, are included in the table. The values of the *F* statistic, the degrees of freedom, and the significance *p* are also shown

Response variable	Explanatory variable	*F*	*df*	*p*
Relative abundance of arthropods (butterfly net)	Type of area*season	9.89	6195	< 0.001
Biomass of arthropods (butterfly net)	Type of area*season	6.68	6195	< 0.001
Relative abundance of arthropods (open quadrat)	Type of area*season	7.40	6195	< 0.001
	Type of area*area	4.04	4195	0.003
Biomass of arthropods (open quadrat)	Type of area*season	3.88	6195	0.001
	Type of area*area	3.82	4195	0.005

particularly during the months of October to December probably due to a greater availability of seeds and vegetable sprouts (Suárez-Seoane et al. 2002; Robleño et al. 2017).

The presence of enriched pastures and the season were the two variables that jointly explained a greater arthropod abundance and biomass. These pastures present a greater diversity of nutritional plants in relation to the surrounding environment due to the implantation of different types of vegetal species with high nutritional properties (especially with more protein content, see "Characterization of the study plots: implemented management measure" section). Spring was the season with a greater abundance, overlapping with the life-cycle phase of invertebrates in which they are more active and detectable (Curry 1993).

Our results are consistent with the previous studies that comparatively assessed the richness of birds, as well as the abundance of birds and arthropods between different types of grasslands, mainly in temperate climates. In general, higher biodiversity values are reached in lands with a greater plant heterogeneity and more resources available (Benton et al. 2003; Attwood et al. 2008; Sokos et al. 2013), which are offered by the planted enriched pastures. Likewise, higher abundances of farmland birds are recorded in areas where herbaceous vegetation shows a higher height and diversity.

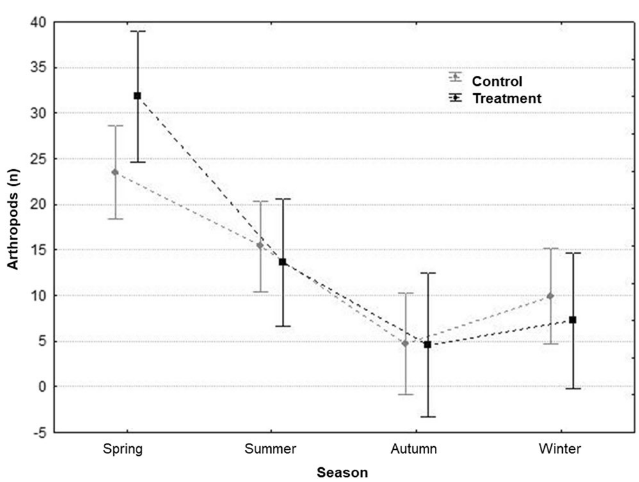

Fig. 4 Mean ± CI (95%) of the *relative abundance* (number of individuals collected per sampling transect) of arthropods between treatment areas (with enriched pastures) and control areas (with natural not improved grasslands) between the different seasons, using the butterfly net collection method

Management of natural and enriched pastures

In relation to the management of the enriched pasture, and following the methodology applied in our study, we recommend the provision of additional resources to the sown plants through inorganic fertilizers during planting. On the other hand, it is necessary to avoid grazing by domestic and wild ungulates on the improved pasture during the first year after its sowing with the help of a perimeter fence. So the growth of the seeds, the proper development of the vegetation, and its subsequent natural seeding, which will provide natural regeneration of these annual herbaceous plants, would be guaranteed.

The geographic expansion of enriched pastures to a greater scale would increase the heterogeneity of landscapes dominated by Mediterranean natural grasslands often overexploited, providing patches of singular within a relatively monotonous environment. It also favors pollinating insects of great importance in promoting the productivity of these habitats (Potts et al. 2009). Anyway, the settlement of improved pasture plots should be posed in a complementary and non-generalized manner so that the natural and priority grassland habitats would not be depleted in their features nor extension, based on the need for their conservation. On the other hand, the difficulty of implanting key elements for landscape diversification on these grazing areas such as field borders, stonewalls, and strips of vegetation without grazing makes this alternative for biodiversity promotion even more important (Fahrig et al. 2011; Šálek et al. 2018).

Future challenges

In the face of the biodiversity crisis of European agrosystems, it is necessary to provide concrete and active measures favoring both the incomes of farmers and the abundance and richness of wild species. The latter, in addition, provide ecosystem services in these environments (Benayas and Bullock 2012; Garfinkel and Johnson 2015) so they must be taken into consideration for their intrinsic value. In this sense, there are plenty efforts made by different institutions encouraging good environmental practices for the management of agricultural lands, enabling their financing through European policies (i.e., Henle et al. 2008). In this sense, the CAP has a key role as an economic engine in rural areas, through the promotion of environmentally sustainable practices. There are not many specific measures in areas devoted to livestock allowing the amelioration of biodiversity levels through actions potentially subsidized by the CAP, by complying eco-conditionality (Pillar 1) or through voluntary measures (Pillar 2), in accordance with the financing lines of the most recently approved programs (Pe'er et al. 2014). For this reason, the implementation of enriched pastures would act as a co-fundable measure within the CAP scope, with the purpose of favoring biodiversity in Mediterranean livestock landscapes. Negotiations on a new operational program should consider this action as a priority either as a precondition for receiving other types of subsidies about productivity or maintenance of herds, or as a voluntary measure aimed at improving the overall quality of the grazed grasslands (Alons 2017; Navarro and López-Bao 2018).

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