Fallow management for steppe bird conservation: the impact of cultural practices on vegetation structure and food resources

Irene Robleño[a*], Gerard Bota[b], David Giralt[b], Jordi Recasens[a]

[a] Dept. Hortofructicultura, Botànica i Jardineria, Agrotecnio, ETSEA, Universitat de Lleida, Avda. Rovira Roure 191, 25198, Lleida, Catalonia, Spain
[b] Biodiversity and Animal Conservation Lab, Àrea de Biodiversitat, Forest Sciences Center of Catalonia (CTFC), Crta. de Sant Llorenc¸ de Morunys Km 2, E25280 Solsona, Catalonia, Spain

Corresponding author. Tel.: +34 973702911; fax: +34 973238264.

E-mail address: irene.rm@hbj.udl.cat (I. Robleño).

Abstract— *The potential of fallow lands to favor farmland bird conservation is widely recognized . Since fallows provide key resources for birds within the agricultural matrix, such as nesting sites, shelter and forage, complete understanding of the effect of field-management strategies on vegetation structure and food is essential to fulfill bird requirements and improve habitat management. In this study we experimentally compare the most common field practices (ploughing, shredding, herbicide application and cover cropping) on fallow lands by assessing the resources they provide for birds in terms of vegetation structure and food resources (leaf and seed availability), as well as the economic costs of their implementation. Fallow management treatments are ranked for six target species in a lowland area of the north-eastern Iberian Peninsula, according to the available information on their requirements. The different agronomic practices offer various quantities and types of resources, highlighting the importance of fallow management in bird conservation. Shredding and early herbicide application (February) are estimated to be good practices for Little Bustard (Tetrax tetrax) and Calandra Lark (Melanocorypha calandra), providing both favorable habitat and foraging conditions, while being economical. Meanwhile, superficial tillage in spring is found to be optimum for the rest of the species tested, despite being among the poorest food providers. Alternating patches of the best treatments would improve the effectiveness of agri-environmental schemes by maximizing the harboring habitat for the endangered species.*

Keywords— **Non-cropped land; Habitat suitability; Farmland birds conservation; Field practices; Agri-environmental schemes.**

1. Introduction

Thousands of years of agricultural expansion have led to the reliance of wild species on land dedicated to human food production. Thus, their preservation strongly depends on traditional low-intensity practices (Tscharntke et al. 2005). Throughout Europe, the effects of farm management on breeding birds are well documented, and intensified practices as well as the simplification of agricultural landscapes have been identified as the main causes of the decline of farmland bird populations (Benton et al. 2003; Donald et al. 2001). In order to slow and eventually halt this decline, farmland biodiversity has been the focus of important conservation efforts in Europe in recent decades, including various common policy tools and agri-environment schemes (AES) devoting great amounts of funding to the process (Kleijn et al. 2006). Despite these efforts, the negative effects of agricultural intensification on European farmland biodiversity persist (Donald et al. 2006), and it is still unknown how the extensive European agri-environmental budget for conservation on farmland contributes to the policy objectives aimed at stopping biodiversity decline (Guerrero et al. 2014; Kleijn et al. 2011; Vickery et al. 2004) . Kleijn et al. (2006) found that the European schemes had limited usefulness for the conservation of endangered farmland species and, therefore, suggested that the measures currently applied would require elaboration as well as designs more tailored to the needs of these species. Furthermore, appropriate biodiversity conservation targets and measures must also be identified, and modulated according to the landscape characteristics of each region (Concepción et al. 2008; Butler et al. 2009; Cardador et al. 2014).

Cereal pseudo-steppes of the Iberian Peninsula are distinctive agricultural landscapes characterized by open areas with flat or slightly undulated topography, dominated by winter cereal crops and a Mediterranean continental climate (Suárez et al. 1997). These areas also represent a low yield farming system due to climatic and soil limitations, with an average cereal supply of 2500 kg ha^{-1}; compared with the 6000 kg ha^{-1} represented by the European Union (EU) as a whole (Delgado and Moreira 2000; Oñate et al. 2007). Steppe birds that inhabit this landscape are thought to be good indicators of overall farmland diversity due to their narrow niche requirements, strongly linked with these habitats (Butler et al. 2007; Stoate et al. 2001). Their populations have been reduced by almost half since 1970 and are at present the most threatened bird group in Europe; 83% of the species has unfavourable status since it is highly vulnerable to the effects of agricultural change (Benítez-López et al. 2013; Burdfield 2005). In this context, the Iberian Peninsula is home to the most important populations of these endangered species within Europe (Santos and Suárez 2005).

Establishment of temporary habitat patches such as fallow land is one of the most promising approaches to compensate for the loss of semi-natural habitat and mitigate the negative effects of agricultural intensification (Huusela-Veistola et al. 2011). Fallow lands are temporary habitat patches traditionally included into crop rotations as a way to rest the land and get nutrient for the future crop season. In these fields, no crops are sown during one year (sometimes more) and a limited number of agronomic practices are applied (Oñate et al. 2007). Fallow land is an essential substrata during breeding and winter seasons for a variety of steppe land bird species (McMahon et al. 2010; Vickery et al. 2004). Hence, leaving a variable proportion of arable land fallow is one of the most common commitments when creating AES (Oñate et al. 2007). Fallow habitat is extremely variable in terms of structure and composition, thus allowing for the existence of different microhabitats within the same habitat type. Although many of these species can live in similar habitats, differences in microhabitat selection between species or even between different sexes of the same species may explain coexistence in steppe bird communities (Morales et al. 2008; Traba et al. 2015). Therefore, the maintenance and provision of microhabitat structure according to different species' needs should be considered a priority in the management of agricultural environments (Traba et al. 2015).

Agronomic practices applied on fallow land are key factors in understanding that variability, and determining its value for birds since they strongly affect the vegetation development, microhabitat characteristics, and food availability. Management practices act as a filter, changing the composition and structure of plant communities which species select based on certain functional traits (Fried et al. 2012). Grazing was a practice traditionally used in fallow lands, however nowadays shredding –cutting and removal off the biomass-, sowing with a competitive grass –such alfalfa-, ploughing and tillage -of varying depth- or spraying out with herbicide are among the preferred options for farmers, who mainly aim to control weeds and prevent diseases. Regulating the timing and frequency of agricultural labors can also modify the vegetation response. Yet there is a lack of information regarding the most appropriate type of fallow management required to foster a suitable habitat for farmland bird conservation, and particularly in steppe-land bird species (Hyvönen and Huusela-Veistola 2011; Morgado et al. 2010). Previous research emphasizes that the availability of the nesting site, diet, foraging habitat, as well as easy access to food and shelter from predators are the most important resources that explain habitat selection (Cardador et al. 2014; Delgado et al. 2009; Green et al. 2000; Toivonen et al. 2013; Traba et al. 2015). Thus, if habitat associations are largely dictated by the availability of key resources, it is crucial to consider the habitat suitability (both the quantity and quality of the resources provided), rather than the habitat per se (Butler and Norris 2013; Ponce et al. 2014).

While previous studies are mostly based on correlating bird presence with habitat or land-use availability, here we utilized an experimental approach to compare the resources provided for birds among the most common fallow management practices allowed in AES programs. Apart from assessing the vegetation cover and height provided by each fallow treatment, we combined information from multiple functional plant traits and vegetation characteristic to create trophic indexes that seek to inform about leaf and seed availability. Due to the particular case of Iberian pseudo-steppes as a low productivity system, the adoption of the proposed schemes or certain fallow treatments by farmers would be more attractive if they were to combine environmental improvements with cost-minimization. So to address this reality, and since considering the farmer's economy is critical to making progress towards maximizing AES efficiency, the economic cost associated with each treatment or agronomic practice was estimated.

In summary, we aim to contribute to progress in improving AES effectiveness and farmland bird conservation goals by 1) predict habitat suitability from these practices for different steppe bird species during the breeding period through a structural and functional approach; 2) experimentally compare the effects of the most common agronomic practices on bird resources such as availability of food and shelter habitat provided by fallows; 3) identify fallow management treatments that better optimize bird benefits, taking the economic cost of implementation.

2. Material and methods

2.1 Study area and species

Our study area is located in the NE Iberian Peninsula, in a flat area of the Ebro basin with a Mediterranean continental climate and only 300–400 mm of annual rainfall. A total of four separate fallow lands sites were selected as study areas: Montcortés (41°42'35.22"N; 1°13'52.33"E), Ballobar (41°32'55.37"N; 0°5'59.06"E), Balaguer (41°44'38.92"N; 0°45'21.63"E) and Mas de Melons (Castelldans) (41°30'14.26"N; 0°42'40.18"E) owing to the homogeneous nature of the landscape.

All are included in Special Protection Areas (SPA), which are sites established under the 2009/147/EC Birds Directive and included in the Natura 2000 network (i.e., the European network of natural protected areas). These sites are classified as such due to the coexistence of many steppe bird species of conservation concern in the region (Brotons et al. 2004; Estrada et al. 2004), and so they benefit from an AES focused on steppe land bird conservation. According to regional AES, a fallow scheme forces an interruption of cereal production for ≥1 years (the agreement can be renewed annually) with no agricultural activities allowed during the breeding period which is from the 15th of April to the 1st of September. The potential beneficiary species include Black-bellied sandgrouse (*Pterocles orientalis*) and Little Bustard (*Tetrax tetrax*), species classified as endangered and vulnerable respectively at a European level (BirdLife International 2015), and other species of conservation concern or protected species at the European, national or regional level: Stone-curlew (*Burhinus oedicnemus*), Short-toed lark (*Calandrella brachydactyla*), Calandra Lark (*Melanocorypha calandra*) and Pin-tailed sandgrouse (*Pterocles alchata*). All are ground-nesting species with specialized habitat requirements but depend on fallow to a greater or a lesser extent during breeding period. Previous studies have described the vegetation structure (cover and height range values) and the main food requirements preferred by our targets and other ecologically similar bird species (e.g. Cardador et al. 2014; Martin et al. 2010; McMahon et al. 2010; Sanza et al. 2012; Suarez et al. 1997; Traba et al. 2013). From this information, a range of habitat suitability for the selected species has been defined in terms of vegetation cover and height, and food resources (Table 1).

2.2 Experimental design

We conducted a 3-year field experiment (from the 2012 to the 2014 agronomic season, from October to June-July) to examine the development of vegetation communities on fallow lands under different cultural practices. In each of the four study sites, one fallow field (ranging from 5.18 to 14.54 ha) was divided into 21 plots of 200 m^2. A scheme of the experimental design is given in the Supplementary Online Material (Online Resource 1). With the aim to reproduce some of the most common cultural practices, the following treatments were applied in each experimental plot: chisel plow, set to a minimum tillage of 10 cm; shredding; a glyphosate herbicide spray at a 1.5 l ha^{-1} dosage; alfalfa sowing, with *Aragon* seed variety at 30 kg ha^{-1} dose. Treatments were applied each year and administered at different times according to common practices: “early dates” (February) for chisel and herbicide, and “late dates” (April) for chisel, herbicide and shredding. Alfalfa was sown once in October of the first season. Furthermore, some plots were untreated (control), giving a total of seven treatments repeated three times in each study area: early-chisel (EChi), late-chisel (LChi), early-herbicide (EHer), late-herbicide (LHer), late-shredding (Shre), early-alfalfa (Alf) and untreated/control (Cnt). Pictures of the different management practices are given in the Supplementary Online Material (Online Resource 2). Traditionally, fallow lands are treated two times per agronomic season. In order to reflect a real situation, the vegetation of all experimental plots was mowed at the end of each agronomic season (October) to remove an excess of organic matter accumulated after spring and summer seasons. By mowing, we allow the maintenance of the soil seed bank and so, the preservation of the history effect of the previous treatments.

2.3 Vegetation sampling

Vegetation data were collected each year from five fixed quadrates of 0.25 m^2 located on each experimental plot in May, coinciding with the breeding period of the target bird species. Vegetation structure (cover and height) was measured per each 0.25 m^2 quadrate. All species presents in each quadrat were identified wherever possible (a total of 118 plant species). Coverage of each species was visually estimated as a percentage of the area of the entire quadrate. Maximum height vegetation was measured in each quadrat. Mean vegetation cover and height per plot was obtained by averaging the five quadrat height and cover measures independently of the species identity.

2.4 Trophic indexes

By using functional traits information obtained from different data bases along with field data, seed and leaf availability indexes were calculated to estimate the foraging value of each management type. Due to the high mobility of arthropods and the size and proximity of the experimental plots, no arthropods availability data was estimated as the results obtained could not be attributed directly to a specific treatment. Despite this food component is relevant for chick survival or as an important part of the adults' diet during the breeding period (Delgado et al. 2009; Holland et al. 2006; Jiguet 2002), arthropod availability could be positively correlated with the leaf availability index across management treatments given that most invertebrates and particularly the most abundant ones (usually phytophagous species) are highly dependent on primary production (Di Giulio et al. 2001; Hoste-Danyłow et al. 2010).

2.4.1 Leaf availability index

To define leaf availability index, each plant species was given a value according to the data (coverage x height x Specific Leaf Area (SLA, $mm^2\ mg^{-1}$). The index of each plot was the result of summing each species´ index value. As a vegetation volume approach, cover and height data were taken into account. Coverage data was obtained for each species by field sampling. However, height data was taken in the field as a unique value independently of species identity, and for this reason, we obtained species-specific height values from literature (de Bolòs et al. 1993). To avoid overestimation of height, field data was utilized if the literature measure was higher than the average plot height, and vice versa when literature data was smaller than the average height of the plot. SLA is a plant leaf trait obtained from literature (Kattge et al. 2011), which is directly related to palatability, or the degree of toughness (low SLA) or softness (high SLA) of leaves´ tissues. This measurement ultimately determines the leaves' value to be assimilated by herbivories (Storkey et al. 2013; Weiher et al. 1999).

2.4.2 Seed availability index

In a similar way, seed availability was quantified for each species as the product of its coverage x height x seed mass (average of 1000 seed weight, g) and weighted by flowering period (months). The seed availability index was finally obtained by the summation of each species´ index, which had been previously calculated. Cover information was taken per species and seed mass data obtained from databases (Klotz et al. 2002; Royal Botanic Gardens Kew 2014). According to regional AES requirements, no agricultural practices is allowed from the $15^{th}$of April to the 1^{st} of September. Per this rule, we weighted the index highlighting the species in flower during this period (de Bolòs et al. 1993), giving 0 to species with no flower during the AES restriction period and values 1, 2, 3 or 4, depending on the months in bloom. Considering the coverage and months of blossom (most were between two and four months) during birds´ breeding period gives an idea of the plants' fecundity and available resources. This assumption is based on studies in the region which confirm that both invertebrates (mainly harvester ants) and vertebrates remove seeds available on the soil surface during this period, causing a strong weed suppressive effect (Baraibar et al. 2009). This makes it necessary to consider the species in bloom in order to estimate the actual seed availability of the system at a specific time. High seed availability index values are not linked with an increase in seed mass. Due to the lack of information on the number of seeds produced by a plant and following the ecological rule directly relating the trade-off between seed size and number of seeds produced (Leishman 2001), we assume that species with similar seed mass will produce a comparable number of seeds. Averaging the seed weight of the most common plant species present in the study (Figure 3) reveals that all of them have a comparable seed weight (1.2 ± 0.20 mg) and thus similar seed production assumed.

Both trophic indexes were standardized, resulting in typed variables with zero mean and a standard deviation of one.

2.5 Economical evaluation

Economic cost data of the implemented managements was provided by the agricultural services company CUPASA. All the data was taken according to the average price of the season 2013-2014. With these values, we calculated the estimated annual cost of each treatment per hectare. Also, it is important to take into account that management practices could possibly favor the preponderance of high competitive plant species that could affect negatively the yield of the future crop and so, cause an economical damage.

2.6 Statistical analysis

In a first step, we analyzed the differences in vegetation structure, coverage (in %) and height (in cm), between field managements. A linear mixed model (LMM) and a post-hoc Tukey´s pairwise comparison was utilized to determine differences among treatments, including locality and plot as random factors.

The same analysis was done to estimate differences among treatments on dietary availability. Both trophic indexes values were square-root transformed.

Information provided from previous studies was used to build habitat suitability range models for the selected birds in terms of vegetation structure and food availability (Table 1). The degree of overlap between the mean values (±CI) of each variable per field treatment and the bird species requirements was quantified. To analyse flora community patterns in more detail, rank-abundance curves were constructed for each of the seven field treatments at species level.

Statistical analyses were performed using R (R Development Core Team, 2011) with VEGAN (Oksanen et al. 2011), lme4 (Bates et al. 2008) and BiodiversityR (Kindt & Coe 2005) packages.

3. Results

Vegetation cover shows a significantly positive correlation to height ($R=0.465$; $p<0.001$) and management practices display different habitats regarding vegetation structure (Figure 1). Late chisel differs significantly from the other treatments, leading to less vegetation coverage and height (a mean of 35% and 28 cm, respectively) (Table 2). Early chisel application shows higher cover and height values (up to 50% and 55 cm, respectively) compared to late chisel management, while we found similar structural values between early and late herbicide applications (65-61% coverage and 41-43 cm height). We observe similar height values between late chisel and late herbicide treatments, whilst not in coverage. Shredding management is not significantly different from alfalfa sowing, late herbicide, early chisel and herbicide treatments. Alfalfa and unmanaged plots (control) are significantly different in both structural variables under late chisel management and they provide the highest values of cover and height (80-79% and 52-61 cm).

The observed differences in vegetation structure greatly determine the fallow suitability for the different target species. Control plots and alfalfa sowed fields do not fit into the vegetation structure requirement of any of the target species, while the early chisel treatment does it partially, because of a tall and/or dense resulting vegetation (Figure 1; Table 2). Moreover, the late chisel treatment provided fallows with a vegetation structure adequate for all species, except for Calandra Lark. Furthermore, four species (Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse) would only find an optimal habitat under this treatment. Finally, shredding and chemical treatments resulted in vegetation structure that fit the main requirements for two species: Little bustard and Calandra lark. Food availability indexes were positively correlated ($R=0.653$; $p<0.001$), indicating that the birds were finding more palatable leaves when there were more seeds available in the system (Figure 2). Given that vegetation structure of alfalfa and control plots was not suitable for birds, trophic indexes were not calculated for these treatments since, yet providing food resources, they are not accessible for species Both trophic index values were determined by management timing. Early treatments (February) led to significantly higher foraging values than treatments applied in April (around 2.5 ± 0.5 and 1.5 ± 0.4, respectively) (Table 3). However, shredding (only applied on April) supplied significantly comparable seed resources when compared with early herbicide. Early chisel is the treatment which offers the greatest amount of food resources (2.7±0.7 and 2.5 ± 0.7 seed and leaf availability index values, respectively). Despite being the only valuable treatment in terms of vegetation structure for Stone curlew, Short-toed lark and both sandgrouse species, late chisel management is among the poorest regarding food resources (1.4 ± 0.3 and 1.3 ± 0.3 seed and leaf availability index values, respectively).

Among the patterns of rank-abundance, there was pronounced dominance of *Anacyclus clavatus* (Figure 3) in all seven treatments. . However, its dominance is less noticeable in early treatments (herbicide and chisel), comprising only around 30% of the total abundance, while it later increases by around 60% (70% in control plots). The presence of *Salsola kali* as the second abundant species in early treatments shows that the intervention time is a key factor for the germination of this late-spring species. Furthermore, late management led to the appearance of *Malva sylvestris* as a common species. Soil remotion seemed to promote graminoid species, such as *Lolium rigidum* that is always present as an important species in this type of management including alfalfa (after *Medicago sativa*). An increase in hemicryptophyte forms was observed in shredding treatment (*Seseli tortuosum* and *Crepis sp.*) since they have a greater likelihood of surviving due to the possession of perennial buds at ground level**.**

The economic cost of the agricultural work carried out reveals that shredding and herbicide application are the cheapest treatments (26€/ha and 26.7 €/ha, respectively), while alfalfa sowing is the most expensive one (295 €/ha). Alfalfa is, however, a perennial forage crop that is normally sown every two-four years (Table 4). Based on previous analysis, we constructed a ranking to 1) consider both the most suitable treatments for the target species selected, based on the vegetation structure and trophic resources, and 2) weigh the economic side (Table 5). Taking vegetation structure and food resources into account, the optimal treatments for the target species appear to be early herbicide application, shredding and chisel (early or late). If we consider both suitability for birds and the economic cost of each treatment, the shredding and herbicide treatments seem to be the best options. However, in the case of Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse, only late chisel treatment is suitable to their optimal habitat range.

4. Discussion

Our results reveal that field management and timing can play a key role in the aptitude of fallows for steppe birds during the breeding season. Through an experimental approach, we show how different fallow agronomic practices and timings determine the vegetation structure, as well as the amount and type of food resources; two key factors behind bird habitat selection.

Among analysed managements, alfalfa sowing and untreated plots presented the greatest coverage and vegetation height. At the other end of the spectrum, we find the late chisel plots with twice lower values for the same variables. Early chisel, shredding and both herbicide treatments presented intermediate values. Application time appears to be an important factor in determining trophic availability, while early management provided more seed and leaves resources than late practices. This difference is reflected by the breaking of *Anacyclus clavatus´* prominence, allowing for the recovery of that species, and leading us to believe that early management promoted diversity enhancement.

Plant succession dynamics after different disturbance practices are the key to explaining the contrasting result between two treatments made at the same time. It is known that life forms are relevant to discriminate weeds according to physical or chemical disturbances (Gaba et al. 2013). Ploughing allows for equal weed expansion dominated by pioneer annual plants with fast life cycles (Sojneková and Chytrý 2015). Meanwhile, herbicides favour the establishment of perennial species as well as ones with a short interval between recruitment and anthesis (Gaba et al. 2013; Gulden et al. 2010). Glyphosate is a non-selective contact herbicide that can affect a wide range of weeds. However, phanerophytes, chamaephytes and most of the hemicryptophytes are less harmed, resulting in a rather heterogeneous habitat. The role of these biological forms against annuals allows for a sparse and patchy habitat with lower density vegetation. This diverse structure is also promoted by the layer of dead organic matter that remains on the soil surface after the herbicide treatment.

As it has been previously mentioned, the identity of the plant species favoured by determined management practices could affect the yield of the crop that follow fallow period. As an example, *Lolium rigidum* and *Papver rhoeas* are two high competitive weeds considered as harmful in cereal crops of Mediterranean regions (Izquierdo et al. 2003; Torra and Recasens 2008).

No treated fallows (control plots) and alfalfa-sowed ones offered vegetation cover and height values above the habitat selection ranges of the objective species. The over fertilization with pig slurry detected in many areas of the Ebro Valley (Berenguer et al. 2008) may explain the lack of fitness, characteristic to the non-managed fallows, while the high nutrient load may be responsible for the overdevelopment of the vegetation. Areas that are encroached on by dense vegetation result in the loss of farming habitat and cause weed problems in future crop seasons, so it is usually a non-preferred scenario for farmers. This implies that in other circumstances (considering different climate or soil fertilization), the results could be lower than the ones obtained in our region. Even if our experimental approach is conditioned by the soil fertilization levels of the study area, all treatments should be affected in the same way by those soil conditions, allowing us to assume that the differences in vegetation structure we found between treatments would remain constant, or at least very similar, in other areas where steppe and birds reside.

Previous studies described the importance of legume fields as a good habitat for steppe birds and particularly for Little Bustard (Bretagnolle et al. 2011; Ponce et al. 2014). Here, alfalfa was not as successful as expected, probably due to dry weather conditions after sowing. This undermined the competitive capacity of alfalfa against other weeds that, along with the absence of any other treatment after the sowing date, led to an evolution similar to that of the control plot vegetation. Maybe an annual reseeding in these dryland areas could enhance alfalfa growth. Early chisel has the highest trophic index values, but it is above the optimal range of all the bird species in terms of vegetation height, suggesting that the latter would restrict the access to those food resources.

We predict that the early and late herbicide application together with shredding would offer the best conditions for Little Bustard and Calandra Lark, as these treatments match their optimal habitat range for both cover and height, according to bibliography. Nevertheless, if we also consider food resources, only early herbicide application and shredding remain the best treatments for Little Bustard, while Calandra Lark prefers the former. It seems paradoxical to suggest an herbicide treatment as one of the best ways to achieve the optimal conditions on fallows for Little Bustard, considering that its diet is based on green leaf resources (Jiguet 2002), so shredding seems to be a more conservative option than any chemical treatment. Also, and based on the provided information, shredding and herbicide are among the less expensive farmland practices. The controversial role of herbicide in conservation is mainly because of its negative influence on floristic diversity and the invertebrate community (Boatman et al. 2004; Wilson et al. 1999), as some insect groups are important food sources for chicks. Pollination decline is a well-documented consequence of agricultural pesticide application, especially in places where spraying time coincides with flowering time (Nicholls and Altieri 2012). Nevertheless, previous studies have found that reduced herbicide inputs allow for the maintenance of a diverse invertebrate community (Vickery et al. 2002). In summary, we do not know the extent to which the benefits of early chemical application for some of the target species exceed the potential damage that application could cause to the insects or wildlife in general, which is why more specific studies are needed to explore the short and long-term effects of chemical treatments in fallows. Furthermore, it would be necessary to assess the invertebrate availability under different agronomic practices in future studies because breeding success for some bird species may be dependent on this kind of food supply (Holland et al. 2006; Holland et al. 2014; Jiguet 2002).

According to our results, the other four bird species (Stone-curlew, Short-toed lark, Pin-tailed sandgrouse and Black-bellied sandgrouse) would only find suitable vegetation structure conditions in late chisel treated fallows. Thus, even if this treatment does not offer the highest food resources that early treatments appear to provide, the microhabitat requirements of those species strongly limit the choices to manage fallows for them. Short vegetation height and low cover is reported by other studies as the optimal habitat for sandgrouse species (Martín et al. 2014), probably to better detect predators and reduce predation risk (Butler and Gillings 2004). The Short-toed lark also shows a positive response to bare ground, selecting low shrub cover, more herbaceous plants and low vegetation height (Moreira 1999; Suárez et al. 2002). It mainly feeds on seeds found on the ground, so this type of open microhabitat following mechanical treatment favors food accessibility and visibility (Llusia and Oñate 2005; Moreira 1999). Both processes (anti-predator behaviour and foraging strategy) would be favoured by late chisel treatments on fallows.

4.1 Conservation implications

Temporary non-crop habitat establishment specifically designed with biodiversity goals in mind are reported by several studies to offer suitable habitats for species of conservation concern (Cardador et al. 2014; Gillings et al. 2010; Huusela-Veistola et al. 2011; McMahon et al. 2010). To improve the effectiveness of management actions, conservation guidelines for steppe birds should consider microhabitat preferences giving importance not only to the amount of habitat provided but also to vegetation structure and food availability. Moreover, it is also necessary for managers and farmers to know how to achieve the desired microhabitats if biodiversity goals exist. This study contributes to better understanding of how to attain the most suitable vegetation structure and food availability in fallows designed for steppe bird conservation, whilst providing economic assessment of each agronomic practice, essential to maintaining an environmentally-concerned farming culture with conservative aims. Although it may be possible to find other ways to manage fallows, such as grazing (Kruess and Tscharntke 2002; Hoste-Danyłow et al. 2010), in our experiment we reproduce the most common agricultural practices so these results can be useful for other regions and farmland landscapes. Our study shows that early management applications (February) play a relevant role in fostering habitats with more food resources for birds than applications made in early spring. These effects are also results of the mowing treatment applied in early autumn to homogenize and control the vegetation biomass in all the plots. A good example of effectiveness maximization would be the shredding and early-herbicide application treatment for Little bustard and Calandra lark, respectively, offering greater food resources and optimal habitat parameters at a minimum cost. In contrast, managing fallows for the other four target species (Short-toed lark, Stone-curlew, Pin-tailed sandgrouse and Black-bellied sandgrouse) is more constrained by the sparse vegetation requirement of those species, only achieved through ploughing in early spring. It is clear from our results that for suiting the needs of different target species in the geographical same area, it is necessary to combine different types of management techniques and avoid the over implementation of a particular treatment at landscape scale. Instead, alternating patches with management that promote suitable habitat for foraging, such as early chisel, with others that offer good shelter and breeding conditions, such as herbicide applications, shredding and late chisel, could lead to the ideal heterogeneous mosaic needed to sustain a high diversity of bird species.

The main contribution of this study has been to experimentally assess how different microhabitats can be achieved through fallow management and to make predictions on how the resulting vegetation structures and food availability matches the main requirements of steppe land birds, one of the more threatened groups of farmland birds. Now, as a next step, a validation of the study results will be required to confirm the relationships between fallow management and our predictions on habitat suitability. Our study focuses on the breeding period, which is a crucial step in the life cycle of any species or population, but in future studies it would be desirable to explore the effects of fallow management on habitat suitability during the whole year, given that species' habitat requirements may be season dependent (Marfil-Daza et al. 2013).

Acknowledgements

The present work has been financed by the Spanish National Program (proyect: AGL2010-22084-C02-01). We gratefully acknowledge the field assistance of B. Baraibar, JA. Conesa, N. Moix , J Rey, A. Royo, X. Solé-Senan and J. Torra. Thank are also due to J. Caus, P. Forns, J. Messegue and JM Montull for allowing us to use their fields and for their patience and hospitality. Field work permits were issued by the ‘Departament de Medi Ambient de la Generalitat de Catalunya’. We appreciate the comments of J. Traba to improve the final draft and S. Lade for the English correction. A pre-doctoral FPI scholarship was provided by the Spanish Ministry of Science and Education for I. Robleño.

References

Baraibar B, Westerman PR, Carrión E, Recasens J (2009) Effects of tillage and irrigation in cereal fields on weed seed removal by seed predators. J Appl Ecol 46:380–387. doi: 10.1111/j.1365-2664.2009.01614.x

Benítez-López A, Viñuela J, Hervás I, et al (2013) Modelling sandgrouse (Pterocles spp.) distributions and large-scale habitat requirements in Spain: implications for conservation. Environ Conserv 41:132–143. doi: 10.1017/S0376892913000192

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol Evol 18:182–188. doi: 10.1016/S0169-5347(03)00011-9

Berenguer P, Santiveri F, Boixadera J, Lloveras J (2008) Fertilisation of irrigated maize with pig slurry combined with mineral nitrogen. Eur J Agron 28:635–645. doi: 10.1016/j.eja.2008.01.010

BirdLife International (2015) European Red List of Birds. Luxembourg: Office for Official Publications of the European Communities.

Boatman ND, Brickle NW, Hart JD, et al (2004) Evidence for the indirect effects of pesticides on farmland birds. Ibis (Lond 1859) 146:131–143.

Bretagnolle V, Villers A, Denonfoux L, et al (2011) Rapid recovery of a depleted population of Little Bustards Tetrax tetrax following provision of alfalfa through an agri-environment scheme. Ibis (Lond 1859) 153:4–13. doi: 10.1111/j.1474-919X.2010.01092.x

Brotons L, Mañosa S, Estrada J (2004) Modelling the effects of irrigation schemes on the distribution of steppe birds in Mediterranean farmland. Biodivers Conserv 13:1039–1058.

Burfield I (2005) The conservation status of steppic birds in Europe. In: Ecology and Conservation of Steppe-land Birds, ed. G.Bota,M.B. Morales, S. Mañosa & J. Camprodon, pp. 119–139. Barcelona, Spain: Lynx Edicions & CentreTecnològic Forestal de Catalunya.

Butler SJ, Brooks D, Feber RE, et al (2009) A cross-taxonomic index for quantifying the health of farmland biodiversity. J Appl Ecol 46:1154–1162. doi: 10.1111/j.1365-2664.2009.01709.x

Butler SJ, Gillings S (2004) Quantifying the effects of habitat structure on prey. Ibis (Lond 1859) 146:123–130.

Butler SJ, Norris K (2013) Functional space and the population dynamics of birds in agro-ecosystems. Agric Ecosyst Environ 164:200–208. doi: 10.1016/j.agee.2012.11.001

Butler SJ, Vickery JA, Norris K (2007) Farmland biodiversity and the footprint of agriculture. Science 315:381–384. doi: 10.1126/science.1136607

Cardador L, De Cáceres M, Bota G, et al (2014) A resource-based modelling framework to assess habitat suitability for steppe birds in semiarid mediterranean agricultural systems. PLoS One 9:1–14. doi: 10.1371/journal.pone.0092790

Concepción ED, Díaz M, Baquero RA (2008) Effects of landscape complexity on the ecological effectiveness of agri-environment schemes. Landsc Ecol 23:135–148. doi: 10.1007/s10980-007-9150-2

de Bolòs O, Vigo J, Masalles RM, Ninot JM (1993) Flora Manual Dels Paisos Catalans, Barcelona, Spain: Pòrtic 2nd Edicions

Delgado A, Moreira F (2000) Bird assemblages of an Iberian cereal steppe. Agric Ecosyst Environ 78:65–76. doi: 10.1016/S0167-8809(99)00114-0

Delgado MP, Morales MB, Traba J, Garcia De La Morena EL (2009) Determining the effects of habitat management and climate on the population trends of a declining steppe bird. Ibis (Lond 1859) 151:440–451. doi: 10.1111/j.1474-919X.2009.00927.x

Di Giulio M, Edwards PJ, Meister E (2001) Enhancing insect diversity in agricultural grasslands: the roles of management and landscape structure. J Appl Ecol 38:310–319.

Donald PF, Green RE, Heath MF (2001) Agricultural intensification and the collapse of Europe's farmland bird populations. Proc Biol Sci 268:25–9. doi: 10.1098/rspb.2000.1325

Donald PF, Sanderson FJ, Burfield IJ, van Bommel FPJ (2006) Further evidence of continent-wide impacts of agricultural intensification on European farmland birds, 1990–2000. Agric Ecosyst Environ 116:189–196. doi: 10.1016/j.agee.2006.02.007

Estrada J, Pedrocchi V, Brotons L, Herrando S (2004) The Catalan Breeding Bird Atlas 1999-2002. Barcelona, Catalonia, Spain

Fried G, Kazakou E, Gaba S (2012) Trajectories of weed communities explained by traits associated with species' response to management practices. Agric Ecosyst Environ 158:147–155. doi: 10.1016/j.agee.2012.06.005

Gaba S, Fried G, Kazakou E, et al (2013) Agroecological weed control using a functional approach: a review of cropping systems diversity. Agron Sustain Dev 34:103–119. doi: 10.1007/s13593-013-0166-5

Giannangeli L, Sanctis ADE, Manginelli R, Medina FM (2004) Seasonal variation of the diet of the Stone Curlew Burhinus Oedicnemus Distinctus at the island of La Palma, Canary Islands. Ardea 92:175–184.

Gillings S, Henderson IG, Morris AJ, Vickery JA (2010) Assessing the implications of the loss of set-aside for farmland birds. Ibis (Lond 1859) 152:713–723.

Green RE, Tyler GA, Bowden CGR (2000) Habitat selection, ranging behaviour and diet of the stone curlew (Burhinus oedicnemus) in southern England. J Zool 250:161–183. doi: 10.1017/S0952836900002028

Guerrero I, Carmona CP, Morales MB, et al (2014) Non-linear responses of functional diversity and redundancy to agricultural intensification at the field scale in Mediterranean arable plant communities. Agric Ecosyst Environ 195:36–43. doi: 10.1016/j.agee.2014.05.021

Gulden RH, Sikkema PH, Hamill AS, et al (2010) Glyphosate-resistant cropping systems in Ontario: multivariate and nominal trait-based weed community structure. Weed Sci 58:278–288. doi: 10.1614/WS-D-09-00089.1

Holland JM, Hutchison MAS, Smith B, Aebischer NJ (2006) A review of invertebrates and seed-bearing plants as food for farmland birds in Europe. Ann Appl Biol 148:49–71. doi: 10.1111/j.1744-7348.2006.00039.x

Holland JM, Storkey J, Lutman PJW, et al (2014) Utilisation of agri-environment scheme habitats to enhance invertebrate ecosystem service providers. Agric Ecosyst Environ 183:103–109. doi: 10.1016/j.agee.2013.10.025

Homem de Brito P (1996) Nest site selection by the stone curlew (Burhinus oedicnemus) in southern Portugal. In: Fernández J, Sanz-Zuasti J (Eds) Conservation of steppe birds and their habitats. pp. 231-238. Junta de Castilla y León.

Hoste-Danyłow A, Romanowski J, Żmihorski M (2010) Effects of management on invertebrates and birds in extensively used grassland of Poland. Agric Ecosyst Environ 139:129–133. doi: 10.1016/j.agee.2010.07.009

Huusela-Veistola E, Alanen EL, Hyvönen T, Kuussaari M (2011) Ecosystem service provision by establishing temporal habitats in agricultural environments. Biodivers Agric 7:24–26.

Hyvönen T, Huusela-Veistola E (2011) Impact of seed mixture and mowing on food abundance for farmland birds in set-asides. Agric Ecosyst Environ 143:20–27. doi: 10.1016/j.agee.2011.04.008

Izquierdo J, Recasens J, Fernández-Quintanilla C, Gill G (2003) Effects of crop and weed densities on the interactions between barley and Lolium rigidum in several Mediterranean locations. Agron Sustain Dev 25:529–536. doi: 10.1051/agro

Jiguet F, Jaulin S, Arroyo B (2002) Resource defence on exploded leks: do male little bustards, T. tetrax, control resources for females? Anim Behav 63:899–905. doi: 10.1006/anbe.2001.1970

Kattge J, Díaz S, Lavorel S, et al (2011) TRY - a global database of plant traits. Glob Chang Biol 17:2905–2935. doi: 10.1111/j.1365-2486.2011.02451.x

Kleijn D, Baquero RA, Clough Y, et al (2006) Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol Lett 9:243–254. doi: 10.1111/j.1461-0248.2005.00869.x

Kleijn D, Rundlöf M, Scheper J, et al (2011) Does conservation on farmland contribute to halting the biodiversity decline? Trends Ecol Evol 26:474–81. doi: 10.1016/j.tree.2011.05.009

Klotz S, Kühn I, Durka W (2002) BIOLFLOR-Eine Datenbank zu biologisch-ökologischen Merkmalen der Gefäßpflanzen in Deutschland. Schriftenreihe für Vegetationskunde, 38. Bundesamt für Naturschutz, Bonn.

Kruess A, Tscharntke T (2002) Contrasting responses of plant and insect diversity to variation in grazing intensity. Biol Conserv 106:293–302.

Leishman MR (2001) Does the seed size / number trade-off model determine plant community structure? An assessment of the model mechanisms and their generality. Oikos 93:294–302.

Llusia D, Oñate JJ (2005) Are the conservation requirements of pseudo-steppe birds adequately convered by Spanish agri-environmental schemes? An ex-ante assessment. Ardeola 52:31–42.

Marfil-Daza C, Pizarro M, Moreno-Rueda G (2013) Do hot spots of breeding birds serve as surrogate hot spots of wintering birds? An example from central Spain. Anim Conserv 16:60–68. doi: 10.1111/j.1469-1795.2012.00569.x

Martín B, Martín CA, Palacín C, et al (2014) Habitat preferences of sympatric sandgrouse during the breeding season in Spain: a multi-scale approach. Eur J Wildl Res 60:625–636. doi: 10.1007/s10344-014-0826-z

Martín CA, Casas F, Mougeot F, et al (2010) Seasonal variations in habitat preferences on Pin-tailed sandgrouse in agrarian pseudo-steppes. Ardeola 57:191–198.

Martínez C (1994) Habitat selection by the little bustard Tetrax tetrax in cultivated areas of Central Spain. Biol Conserv 67:125–128. doi: 10.1016/0006-3207(94)90357-3

McMahon BJ, Giralt D, Raurell M, et al (2010) Identifying set-aside features for bird conservation and management in northeast Iberian pseudo-steppes. Bird Study 57:289–300. doi: 10.1080/00063651003749680

Morales MB, Traba J, Carriles E, et al (2008) Sexual differences in microhabitat selection of breeding little bustards Tetrax tetrax: Ecological segregation based on vegetation structure. Acta Oecologica 34:345–353. doi: 10.1016/j.actao.2008.06.009

Moreira F (1999) Relationships between vegetation structure and breeding bird densities in fallow cereal steppes in Castro Verde, Portugal. Bird Study 46:309–318. doi: 10.1080/00063659909461144

Morgado R, Beja P, Reino L, et al (2010) Calandra lark habitat selection: Strong fragmentation effects in a grassland specialist. Acta Oecologica 36:63–73. doi: 10.1016/j.actao.2009.10.002

Nicholls CI, Altieri MA (2012) Plant biodiversity enhances bees and other insect pollinators in agroecosystems. A review. Agron Sustain Dev 33:257–274. doi: 10.1007/s13593-012-0092-y

Oñate JJ, Atance I, Bardají I, Llusia D (2007) Modelling the effects of alternative CAP policies for the Spanish high-nature value cereal-steppe farming systems. Agric Syst 94:247–260. doi: 10.1016/j.agsy.2006.09.003

Ponce C, Bravo C, Alonso JC (2014) Effects of agri-environmental schemes on farmland birds: do food availability measurements improve patterns obtained from simple habitat models? Ecol Evol 4:2834–2847. doi: 10.1002/ece3.1125

Royal Botanic Gardens Kew (2014) Seed information database (SID). Version 7.1. URL http://data.kew.org/data/sid. Data of the last access: 10 August 2015

Santos T, Suárez F (2005) Biogeography and population trends of Iberian steppe birds. In: Bota G, Morales MB, Mañosa S, Camprodon J. (Eds) Ecology and conservation of steppe-land birds. pp. 69-102. Lynx, Barcelona.

Sanza MA, Traba J, Morales MB, et al (2012) Effects of landscape, conspecifics and heterospecifics on habitat selection by breeding farmland birds: the case of the Calandra Lark (Melanocorypha calandra) and Corn Bunting (Emberiza calandra). J Ornithol 153:525–533. doi: 10.1007/s10336-011-0773-3

Silva JP (2010) Factors affecting the abundance of the little bustard Tetrax tetrax: Implications for conservation. PhD Thesis, University of Lisbon, Lisbon, Portugal.

Silva JP, Estanque B, Moreira F, Palmeirim JM (2013) Population density and use of grasslands by female Little Bustards during lek attendance, nesting and brood-rearing. J Ornithol 155:53–63. doi: 10.1007/s10336-013-0986-8

Sojneková M, Chytrý M (2015) From arable land to species-rich semi-natural grasslands: Succession in abandoned fields in a dry region of central Europe. Ecol Eng 77:373–381. doi: 10.1016/j.ecoleng.2015.01.042

Stoate C, Boatman N, Borralho R, et al (2001) Ecological impacts of arable intensification in Europe. J Environ Manage 63:337–365. doi: 10.1006/jema.2001.0473

Storkey J, Brooks D, Haughton A, et al (2013) Using functional traits to quantify the value of plant communities to invertebrate ecosystem service providers in arable landscapes. J Ecol 101:38–46. doi: 10.1111/1365-2745.12020

Suárez FS, Garza VG, Morales MBM (2002) Habitat use of two sibling species, the Short-toed Calandrella brachydactyla and the Lesser short-toed C. Ruffescens larks, in mainland Spain. Ardeola 49:259–272.

Suárez F, Hervás I, Herranz J (2009) Las alondras de España peninsular. Ministerio de Agricultura, Alimentación y Medio Ambiente. Madrid

Suárez F, Martínez C, Herranz J, Yanes M (1997) Conservation status and farmland requirements on Pin-tailed Sandgrouse Pterocles alchata and Black-bellied Sandgrouse Pterocles orientalis in Spain. Biodivers Conserv 82:73–80. doi: 10.1016/S0006-3207(97)00008-6

Toivonen M, Herzon I, Helenius J (2013) Environmental fallows as a new policy tool to safeguard farmland biodiversity in Finland. Biol Conserv 159:355–366. doi: 10.1016/j.biocon.2012.11.016

Torra J, Recasens J (2008) Demography of Corn Poppy (Papaver rhoeas) in Relation to Emergence Time and Crop Competition. Weed Sci 56:826–833. doi: 10.1614/WS-07-077.1

Traba J, Acebes P, Malo JE, et al (2013) Habitat selection and partitioning of the Black-bellied Sandgrouse (Pterocles orientalis), the Stone Curlew (Burhinus oedicnemus) and the Cream-coloured Courser (Cursorius cursor) in arid areas of North Africa. J Arid Environ 94:10–17. doi: 10.1016/j.jaridenv.2013.02.007

Traba J, Morales MB, Carmona CP, Delgado MP (2015) Resource partitioning and niche segregation in a steppe bird assemblage. Community Ecol 16:178–188. doi: 10.1556/168.2015.16.2.5

Tscharntke T, Klein AM, Kruess A, et al (2005) Landscape perspectives on agricultural intensification and biodiversity - ecosystem service management. Ecol Lett 8:857–874. doi: 10.1111/j.1461-0248.2005.00782.x

Vickery J a, Bradbury RB, Henderson IG, et al (2004) The role of agri-environment schemes and farm management practices in reversing the decline of farmland birds in England. Biol Conserv 119:19–39. doi: 10.1016/j.biocon.2003.06.004

Vickery J, Carter N, Fuller RJ (2002) The potential value of managed cereal field margins as foraging habitats for farmland birds in the UK. Agric Ecosyst Environ 89:41–52. doi: 10.1016/S0167-8809(01)00317-6

Weiher E, van der Werf A, Thompson K, et al (1999) Challenging Theophrastus : A common core list of plant traits for functional ecology. J Veg Sci 10:609–620.

Wilson JD, Morris AJ, Arroyo BE, et al (1999) A review of the abundance and diversity of invertebrate and plant foods of granivorous birds in northern Europe in relation to agricultural change. Agric Ecosyst Environ 75:13–30. doi: 10.1016/S0167-8809(99)00064

Table 1 Habitat requirements of the bird species studied

Bird species	Trophic resources	Structure patterns	
	Food	Cover	Height
Little bustard (***Tetrax tetrax***)	Mainly green plants (Jiguet et al. 2002)	25-75% (McMahon et al. 2010; Silva 2010)	Less than 50 cm (Martinez 1994;Morales et al. 2008; Silva 2010; Silva et al. 2013)
Stone-curlew (***Burhinus oedicnemus***)	Plant material, terrestrial invertebrates and occasionally small mammals (Giannangeli et al. 2004; Green et al. 2000 ; Traba et al. 2015)	Not exceed 50% (McMahon et al. 2010; Traba et al. 2013)	Less than 35 cm (Homem do Brito 1996)
Pin-tailed sandgrouse (***Pterocles alchata*)**	Mainly seeds (Suarez et al. 1997; Martin et al. 2010)	Not exceed 50% (Martin et al. 2010)	Less than 30 cm (Martin et al. 2010)
Black-bellied sandgrouse ***(Pterocles orientalis***)	Mainly seeds (Suarez et al. 1997; Martin et al. 2010)	Not exceed 50% (Martin et al. 2010; Traba et al. 2013)	Less than 30 cm (Martin et al. 2010)
Calandra lark (***Melanocorypha calandra***)	Mainly invertebrates and seeds (Sanza et al. 2012)	50-95% (Morgado et al. 2009)	10-45 cm (Cardador et al. 2014; Morgado et al. 2009)
Short-toed lark (***Calandrella brachydactyla***)	Mainly seeds (Suárez et al. 2009)	25-50% (McMahon et al. 2010)	Less than 30 cm (McMahon et al. 2010)

Table 2 Average of cover and height per treatment and post-hoc Tukey test results from linear mixed model between vegetation structures of the management practices

	Average per treatment		**Post-hoc test between field treatments**					
	Coverage (%)	**Height (cm)**	**Control**	**Early-chisel**	**Early-herbicide**	**Late-chisel**	**Late-herbicide**	**Shredding**
Alfalfa	80 (± 7.4)	52 (± 8.5)	C: ns H: ns	C: ** H: ns	C: ns H: ns	C: *** H: *	C: ns H: ns	C: ns H: ns
Control	79 (± 8.8)	61 (±13)		C: * H: ns	C: ns H: ns	C: *** H: ***	C: ns H: ns	C: ns H: *
Early-chisel	50 (±13.8)	55 (±14.6)			C: ns H: ns	C: ns H: *	C: ns H: ns	C: ns H: ns
Early-herbicide	65 (± 7.7)	41 (± 7.4)				C: ** H: ns	C: ns H: ns	C: ns H: ns
Late-chisel	35 (± 8.1)	28 (± 8.8)					C: * H: ns	C: * H: ns
Late-herbicide	61 (± 9.7)	43 (± 6.9)						C: ns H: ns
Shredding	63 (± 21)	38 (±13.3)						

C: coverage, H: height, ns: non-significant result, * = <0.05, ** = <0.01 and *** = <0.001

Table 3 Average of seed and leaf availability indexes per treatment and post-hoc Tukey test results from linear mixed model between trophic indexes of the management practices

	Average per treatment		Post-hoc test between field treatments			
	Seed availability index	**Leaf availability index**	**Early-herbicide**	**Late-chisel**	**Late-herbicide**	**Shredding**
Early-chisel	2.7 (±0.7)	2.5 (±0.7)	S.I.: ns L.I.: ns	S.I.: ** L.I.: *	S.I.: * L.I.: *	S.I.: * L.I.: ns
Early-herbicide	2.5 (±0.6)	2.1 (±0.4)		S.I.: * L.I.: *	S.I.: * L.I.: ns	S.I.: ns L.I.: ns
Late-chisel	1.4 (±0.3)	1.3 (±0.3)			S.I.: ns L.I.: ns	S.I.: ns L.I.: ns
Late-herbicide	1.4 (±0.3)	1.5 (±0.4)				S.I.: ns L.I.: ns
Shredding	1.5 (±0.4)	1.8 (±0.7)				

S.I.: seed availability index, L.I.: leaf availability index, ns: non-significant result, * = <0.05, ** = <0.01 and *** = <0.001

Table 4 Economic cost of the management implemented

Management Type		Dose/ha	€/u	€/ha	Total (€/ha)
Chisel		1	40	40	**40**
Shredding		1	26	26	**26**
Herbicide					**26.7**
	Glyphosate 45%	1.5	7.8	11.7	
	Application	1	15	15	
Alfalfa sowing					**295**
	Subsoiler	1	65	65	
	Seeder (*Precision Planting*)	1	50	50	
	Alfalfa seed (*Aragon*)	30	6	180	

Table 5 Summary of the most effective treatments according to vegetation structure, foraging availability and economic cost for the bird species considered in the study

Bird species	Ranking of the best treatments: Provides good vegetation structure — Treatment name	Coverage suitability	Height suitability	**Provides more food resources***	**Cheapest**	**Final Ranking**
Little bustard	**1.** E. Herbicide L. Chisel L. Herbicide **2.** Shredding **3.** E. Chisel	100% 100% 100% 89% 0%	100% 100% 72% 98% 34%	**1.** E. Chisel E. Herbicide Shredding **2.** L. Herbicide L. Chisel	**1.** Shredding Herbicide **2.** Chisel	**1.** Shredding Early Herbicide **2.** Late Herbicide **3.** Late Chisel **4.** Early Chisel
Calandra lark	**1.** E. Herbicide L. Herbicide **2.** Shredding **3.** E. Chisel	100% 100% 71% 0%	100% 100% 98% 17%	**1.** E. Chisel E. Herbicide **2.** Shredding L. Herbicide	**1.** Shredding Herbicide **2.** Chisel	**1.** Early Herbicide **2.** Shredding Late Herbicide **3.** Early Chisel
Stone-curlew	**1.** L. Chisel	100%	100%	**1.** L. Chisel	**1.** L. Chisel	**1.** L. Chisel
Short-toed lark **Pin-tailed sandgrouse** **Black-bellied sandgrouse**	**1.** L. Chisel	100%	67 %	**1.** L. Chisel	**1.** Chisel	**1.** L. Chisel

***according to the food preferences per species (i.e. Little bustard mainly herbivorous)

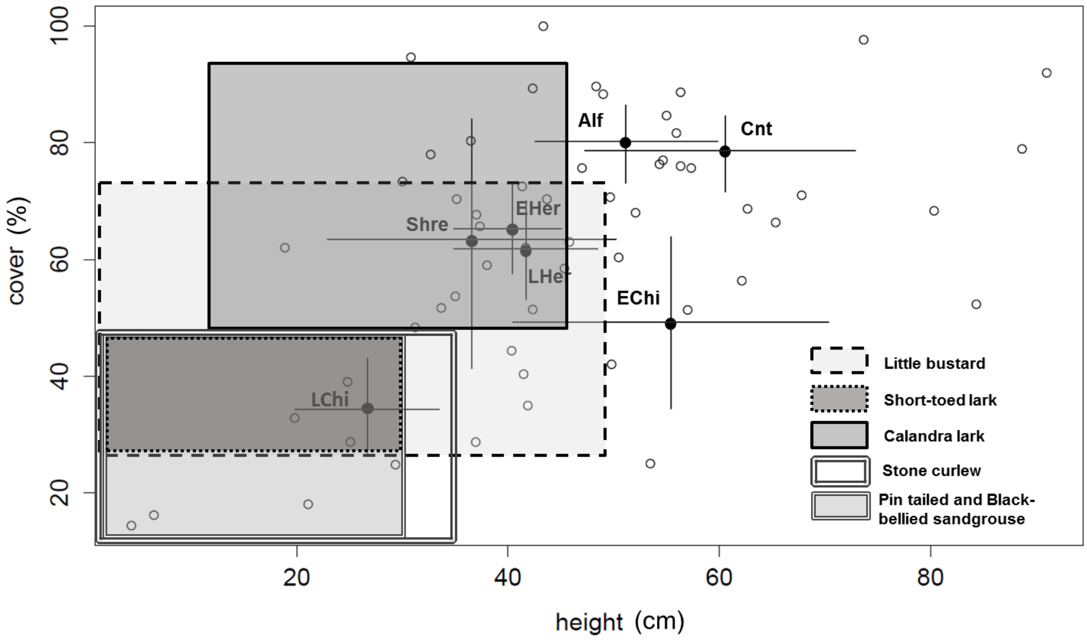

Fig. 1 Average (and the 95% confidence interval) of vegetation coverage and plant height experimentally obtained across several fallow treatments (black dots) and optimal habitat range obtained from bibliography for the selected bird species (overlapping rectangles). Sample sites are marked with white dots

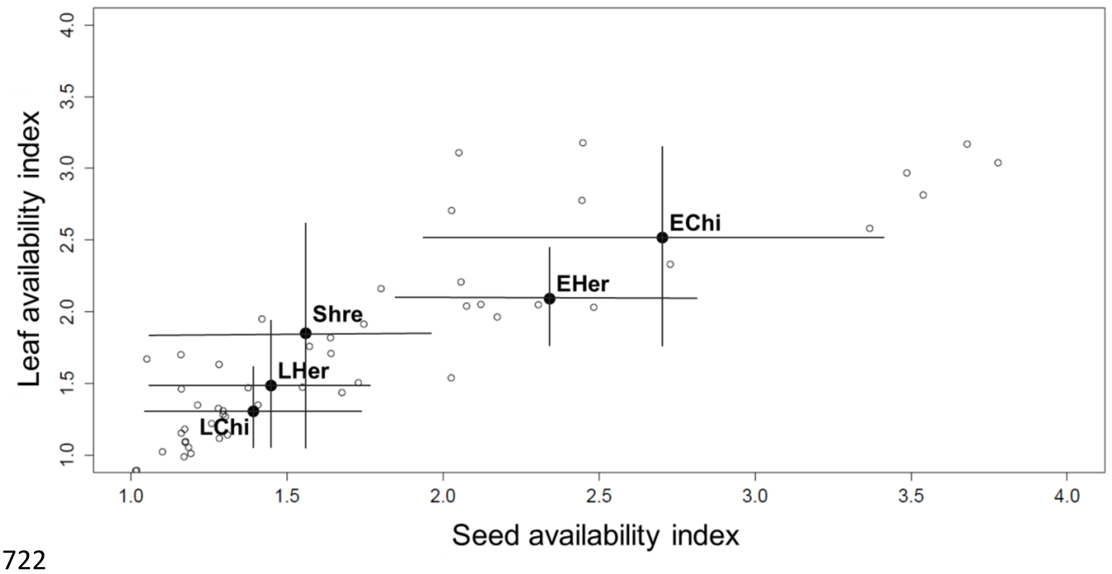

Fig. 2 Black dots indicate the average of leaf and seed availability indexes along field managements (95% confidence limits), white dots indicate surveyed sites

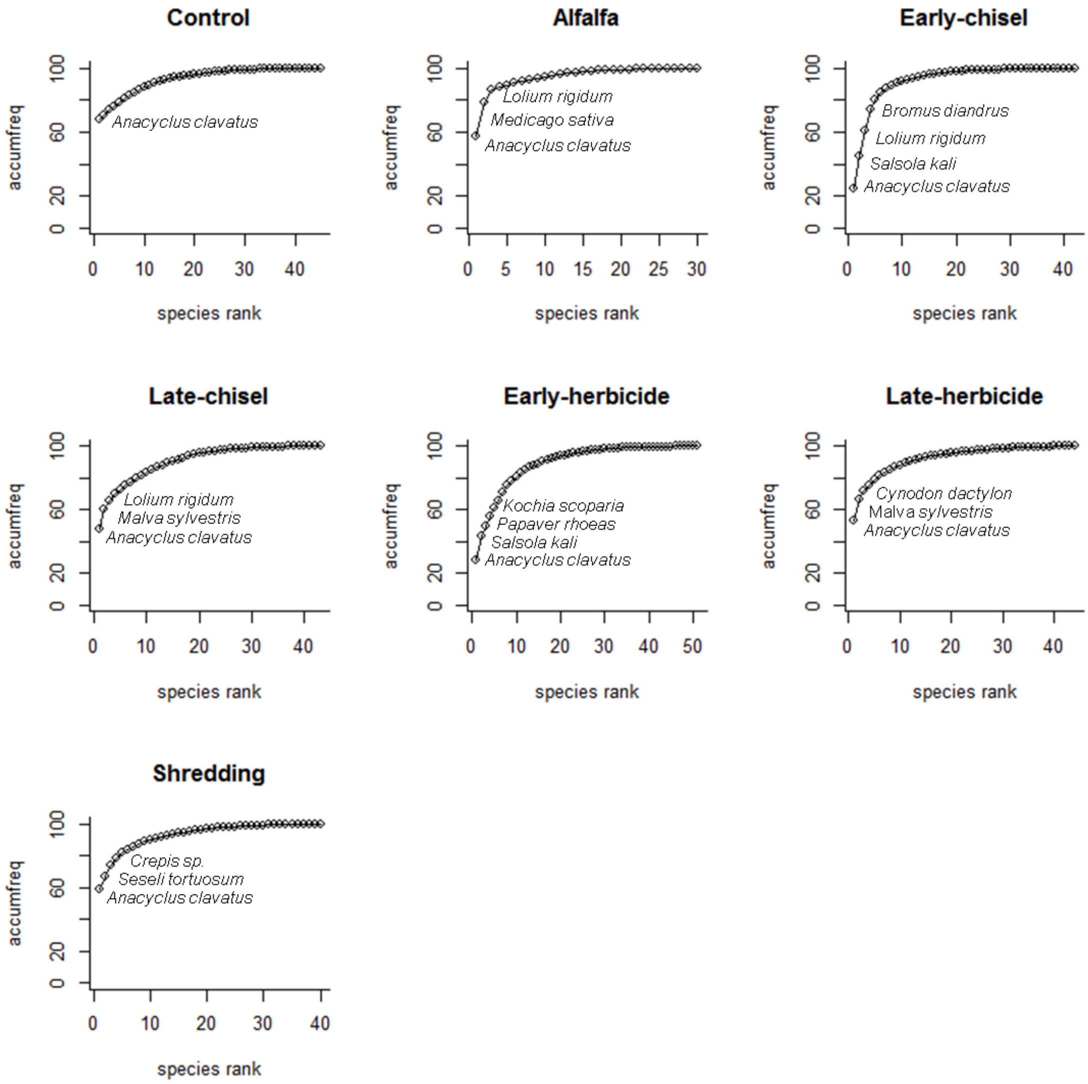

Fig. 3 Rank abundance curves representing the accumulate proportional abundance (as a percentage) of the most common plant species present per management. The X-axis indicates the total number of plant species. Each point in a curve represents a plant species