Eur J Wildl Res (2016) 62:663–671
DOI 10.1007/s10344-016-1039-4

ORIGINAL ARTICLE

Exploring nest destruction and bird mortality in mown Mediterranean dry grasslands: an increasing threat to grassland bird conservation

Nuno Faria[1] · Manuel B. Morales[1] · João E. Rabaça[2,3]

Received: 4 February 2016 / Revised: 23 May 2016 / Accepted: 27 July 2016 / Published online: 5 August 2016

Abstract In recent years, haying has extended to Iberian Mediterranean dry grasslands potentially impacting on grassland bird ecology. We evaluated the impact of haying on a grassland bird community of South Portugal. Our main goals were: (1) to investigate the exposure of different species to haying, (2) to investigate potential removal of nests and dead birds from hayed fields by haying machinery using the ratio (REC) between the expected number of records and the number of records collected and (3) to link clutch destruction and bird mortality with haying management practices. Hayed fields were surveyed for signs of breeding and birds censused prior to mowing. Linear models were computed, linking the REC with haying machinery and sward properties. GLMs and model averaging were used to obtain models linking clutch destruction, bird mortality and haying management variables. Only 4 % of records evidenced successful nesting attempts ($N = 177$). REC evaluation suggested high nest or dead bird removal by the machinery, particularly in fields with lower vegetation biomass prior to cutting. Sickle bar mowers and one-rotor rotary rakes returned higher REC but lower probability of found nests removed from the original nesting sites comparatively to discs mowers and wheel rakes. Higher probabilities of mortality events were found in fields mown earlier (but not in all years). On the other hand, lower mortality was found in fields raked with two-rotor rotary rakes. Delayed haying, silage production in temporary crops and the use haying machinery enabling simultaneously mowing and gathering hay in lines are discussed as management alternatives.

Keywords Clutch destruction · Hay · Haying machinery · Semi-natural grasslands · Mowing · Haying

Introduction

The use of grasslands for hay production is a common and ancient agricultural practice in Europe. In recent years, haying has extended to Iberian Mediterranean dry grasslands. The abandonment of mixed cropping systems of cereal grain and sheep raising for beef–cattle production and the intensification of beef farms is associated in South Portugal (and other parts of south-western Iberia), with an increase in mown area in order to ensure the demands of plant biomass for cattle. There are no official statistics available on the area mown yearly, but in south Portugal (Alentejo and Algarve regions) between 1989 and 2013, bovine numbers experienced a 107 % increase (INE 2014). Also, the area of the main crops used for haying (forage oats, grass-legume crops or pure legume crops) increased 34 % between 1989 and 2009.

Iberian Mediterranean environments provide, under adequate soil and hydrological conditions, moderate to high primary production for hay or silage (Carpintero et al. 1991; Hernández et al. 1994; Rodríguez et al. 2006; San Miguel 2009). Here, mowing for hay occurs on average 1 month earlier than the harvesting of cereal crops for grain, which

Electronic supplementary material The online version of this article (doi:10.1007/s10344-016-1039-4) contains supplementary material, which is available to authorized users.

✉ Nuno Faria
farnuno@gmail.com

[1] Grupo de Ecología Terrestre (TEG), Departamento de Ecología, Universidad Autónoma de Madrid, 28049 Madrid, Spain

[2] LabOr – Laboratório de Ornitologia, ICAAM-Instituto de Ciências Agrárias e Ambientais Mediterrânicas, Universidade de Évora, 7002-554 Évora, Portugal

[3] Departamento de Biologia, Universidade de Évora, 7002-554 Évora, Portugal

implies an additional machinery pass through fields (raking) and often produces shorter stubbles than harvesting for grain. Also, mowing is not confined to cereal and legume forage crops or wet meadows, but it also frequently occurs on pastures or fallow land, which hold important populations of threatened or near-threatened birds at European or global level, such as the great bustard (*Otis tarda*), the little bustard (*Tetrax tetrax*) or the Montagu´s harrier (*Circus pygargus*).

In temperate areas of central Europe and North America, several authors suggested a link between important declines in grassland bird populations and changes in timing and frequency of hay mowing (Green et al. 1997; Herkert 1997; Grüebler et al. 2008). Haying machinery and mowing timings are likely to put grassland bird population at risk by causing reproductive failure through loss of nests and eggs, chick mortality or adult mortality (Vickery et al. 2001; Grüebler et al. 2008). Most of the studies on this subject focused on bird abundance before, during and after haying under different scenarios of haying, aiming to propose haying practices to suit grassland bird requirements. Nocera et al. (2005) and Perkins et al. (2013), for instance, highlighted the importance of applying agreements with individual farmers to adapt their haying timings to the birds' breeding cycles. Broyer (2003) focused on the importance of alternative haying practices such as inside-out meadow mowing and the creation of uncut strips in meadows. Others simply tested scaring devices to frighten families of black-tailed godwits *Limosa limosa* and keep them off a field shortly before mowing (Kruk et al. 1997). However, very few studies have aimed at quantifying net losses of nests or chick and adult mortality (see, for instance, Perlut et al. 2006; Grüebler et al. 2008) and particularly at evaluating how different machinery, notably mower and rake configurations, influence these parameters (see, Humbert et al. 2009). Moreover, the succession of events during haying works that ends up in a potential nest loss or mortality event is largely unknown, which could hamper the design of adequate management measures.

In southwest Iberia, haying occurs shortly before vegetation dries, typically during May, a month where most birds are incubating or have unfledged chicks. Therefore, after a clutch/brood loss due to haying works, both the renesting opportunity and the productivity of renesters are expected to be low. As far as we know, this is the first study focusing on the evaluation of direct impacts of haying practices in a Mediterranean dry grassland context (Alentejo region, Portugal). Our aims were: (1) to investigate the exposure of different grassland bird species to haying practices, (2) to investigate the removal of nests and dead birds from hayed fields by the machinery using the ratio between the expected number of records and the number of records actually collected (REC) and assessing the roles of type of machinery and sward properties as well the potential biases on the detectability of records and (3) to analyze the influence of haying machinery types and the timing of haying on clutch destruction and bird mortality.

Material and methods

Study area

The study area is located in Évora region, Alentejo province, south Portugal (centre of the study area at 38° 32′ N, 7° 53′ W, see Supplementary Fig. 1), in the Mesomediterranean biogeographic region (Rivas-Martínez et al. 2004). Average temperatures vary from 9.6 °C in winter to 24.1 °C in summer and the annual rainfall rounds 586 mm (1981–2010 period; IPMA 2014). Most important land use types consist of extensive livestock grazing (mostly cattle) and cereal, leguminous or mixed crops for hay production. Cereal crops for grain are nowadays less common due to recent conversion of farms for beef–cattle production. Haying is usually accomplished in four stages: (1) mowing to cut the vegetation, (2) raking to gather the vegetation in lines, (3) baling to compact the vegetation into bales and (4) bale collection by a stacker and truck. In wet springs and in early mown fields, it may be necessary to let the vegetation dry for a few days after mowing and before raking. As mentioned above, there are no official haying statistics for the region of Évora, and therefore, the only data available refer to the fields monitored by our team from 2012 to 2015 in a larger study (Table 1).

Sample fields were distributed in 9 farms, all larger than 500 ha and selected for this study based on the pasture/crop ratio, aiming to collect comprehensive information along a gradient in crop/pasture ratio (farms with low crop/pasture ratio are the commonest in the study area). Within these farms, we sampled most of the hayed fields, giving preference to the fields that were previously randomly selected for bird census (see 'Field methodology' section). Mean field size in the study area is around 62 ha.

The study area is partly included in the Special Protection Area for birds of Évora. It holds important populations of protected grassland birds species such as the little and great bustards, Montagu's harrier, black-bellied sandgrouse (*Pterocles orientalis*) and the calandra lark (*Melanocorypha calandra*). No special regulation on haying is applied inside the Special Protection Area.

Field methodology

Mown fields for hay were surveyed during the months of May and June using 4 × 4 vehicle transects (the distance between transect lines was 10 m; fields mown for silage production were scarce and therefore were not included here). Vehicle transects were chosen instead of foot transects because the

Table 1 Haying statistics in the study area for the 2012–2015 period

Statistics	2012	2013	2014	2015
Haying				
Number of sampling fields	45	45	47	39
Fields with tall/dense vegetation with potential for haying[a]	10	17	23	16
Fields partly or fully hayed	3	12	15	11
Haying start date	16 May	06 May	06 May	05 May

[a] The adequacy of vegetation for haying was based on the vegetation structure measured in the last fortnights of April and May

speed of progression in the former is overall higher and the number of working hours per day can double, allowing to cover a larger area and a larger number of fields, despite the fact that, presumably, detectability of records from foot transects should be higher.

The area covered by transects was 158 ha in 2012 (7 fields), 148 ha in 2013 (15 fields) and 199 ha in 2014 (19 fields; see Supplementary Fig. 1). The mean area covered by field was 12.30 ± 8.55 ha. These 41 fields were mostly large fields (only three fields were less than 20 ha) and were located within a polygon of ca. 23,000 ha dominated by grasslands and cereal fields (ca. 70 % of land use). The surveyed area in each field was dependent on field size and on the area mown in each field, ranging from 5 to 100 % of fieldsize (41 % of fields were only partly mown at the end of the hay season). Transects were carried out at low speed (ca. 5 km/h) after fields had been raked, using two observers searching in both sides and front of the vehicle for nests, eggs, feathers, dead birds, fledging/walking juveniles or adult birds carrying food or suspect of breeding. Following the detection of one of these signs of breeding, we stopped the vehicle and intensively searched the grass on foot within a 10-m radius from the point of detection, aiming to identify the status of the record: destroyed/active clutch, dead/living juveniles, dead adults or unknown. Feathers, eggs and for some species nests were used to identify the grassland species involved. Adult mortality was confirmed if body parts of individuals or cut flight feathers were found (see supplementary Fig. 2). Records with evidences of predation such as nests with eggs partly consumed or partly consumed birds, and nests evidencing abandonment prior to mowing (i.e. constructed with old materials, easily shattered) were not considered (these were about 5 % of all observations). Failed nests found were classified in removed or not removed (those found upside down, tilted to the side or partly cut) from the original nesting sites.

Also, we conducted grassland bird censuses through point counts prior to mowing in order to assess potential removal of nests and dead birds from fields by haying machinery (i.e. eventual nests not found due to their inclusion in hay lines and bales). Census results were used to calculate the expected number of records (RE) in the surveyed area of each mown field, defined as the number of territories per hectare multiplied by the number of hectares surveyed at each mown field. A radius of 250 m around the point count station and a count period of 15 min were assumed, recording the location and number of individuals of each species displaying clear territorial or nesting behaviour and adjusting if necessary the geographical location of territories (this procedure is particularly important in high density areas were birds spend most of their time chasing each other). The counting buffer was mostly coincident with the surveyed area of mown fields, so we assumed that bird territory densities found at point counts reflect the expected number of records at the surveyed mown fields. Bird counts were made in the first three and a half hours after sunrise or in the last two and a half hours before sunset, in the last fortnight of April and repeated in the last fortnight of May. However, since some fields were already mown before May counts, we only considered April data for the analyses. In order to obtain homogenous sampling areas, counts were only made in fields with enough size to fit the whole buffer. Due to this limitation, combined with some shifts in the fields that were actually mown some days later, bird territory estimates (and thus the RE) were available only for 29 of the 41 surveyed fields over the 3 years of sampling. The vegetation structure was measured after bird counts, in the same day or at most 2 days later. Biomass samples were collected in May, in two random replicates, separated by 200 and within a square of 50 × 50 cm, using a portable cutter. In the same day, samples were transported and dried in laboratory, and later weighted using a precision balance. All independent variables are presented in detail in Table 2.

Data analyses

Data analyses were accomplished in four steps. First, we calculated for the 3 years of study cumulative descriptive statistics on the exposure of different grassland bird species to haying in terms of number of records per species and status of the record: clutch destroyed/active, dead/living juveniles, dead adults or unknown.

Second, using the ratio between the expected number of records (RE) and the number of records actually collected (RC), we assessed the removal of nests and dead birds from hayed fields by haying machinery and potential biases on

Table 2 Variables used to describe haying management influence on ground nesting grassland birds

Variable	Description
Year	Factor variable indicating the type year where field works took place
VCover	Percent of cover prior to mowing. Estimated visually at field within a 50 × 50 cm square, using 18 sampling replicates disposed around each point count station
Vbiomass	Biomass in grams of dry vegetation in a square of 50 × 50 cm (prior to mowing). Calculated from 2 biomass replicates 100 m distant from point count stations
DMow	Date of mowing
Mower	Factor variable indicating the type of mower: SB - Sickle bar; RD – Rotary discs; M – Multiple types
Rake	Factor variable indicating the type of rake: W - Wheel rake; R1 – Rotary rake with one rotor; R2 – Rotary rake with two rotors

detectability of records. To avoid numerical problems in the fields where no records were found, this ratio (hereafter REC) was used in the form: "REC = (RE + 1)/(RC + 1)". The differences in the mean number of records expected *vs*. collected for each species and bird groups were tested using Student's *t* tests. Then, using pooled data for all species, linear models were computed to test for relationships between the REC and the type of mower and rake used for haying. A similar approach was followed for sward cover and sward biomass prior to mowing (biomass estimates were log-transformed to normalize data and minimize the influence of extreme values). Model ranking was performed by calculating Akaike's Information Criterion corrected for small sample size (AICc).

Third, using generalized linear models (GLM, McCullagh and Nelder 1989), we investigate for the nests found, the relationship between the removal of nests from ground and haying machinery, but here given the binary nature of this variable (nest removed or not), a binomial error and a logit link-function were assumed.

Finally, generalized linear models were computed to obtain explanative models linking the occurrence of (1) clutch destruction (CD), (2) bird mortality (juvenile plus adult mortality, JAM) and (3) records without information of nesting status (RWIS) with haying management variables (see Table 2 for details on the full set of independent variables). We analysed the occurrence of CD, JAM and RWIS using each record as sample unit (presence/absence data). This approach allows avoiding detectability issues due to the removal of nests and dead birds by the machinery or scavengers found at field level (see REC results). A binomial error and a logit link-function were assumed for GLMs. Then, a model averaging procedure was performed following Burnham and Anderson (2002), using in the global model (1) the machinery types (mower and rake) and (2) a fixed interaction between the date of mowing and year. Therefore, we obtained Akaike's information criterion corrected for small sample size (AICc) and Akaike weights. Model averaging was performed using a 95 % confidence set of Akaike weights, thus obtaining the selection probability of each variable. Model performance was evaluated using the area under the curve (AUC) generated by the receiver operating characteristic (ROC; Pearce and Ferrier 2000). AUC values over 0.80 indicate good model performance (Fielding and Bell 1997) and only models over this value were considered.

We previously inspected data for potential confounding relationships between the type of use for hay production (cereal-based crops or pasture) and the management variables considered for each analysis by setting the type of hay as a random factor in a mixed modelling approach. The residuals of global models were tested for spatial autocorrelation through Moran's I statistic (Cliff and Ord 1981). All calculations were performed using R for Windows (version 13.1.1; R Development Core Team 2007) and the packages nlme (Pinheiro et al. 2015), lme4 (Bates et al. 2015), spdep (Bivand et al. 2013) and MuMIn (Bartoń 2015).

Results

Exposure of grassland bird species to haying

Transects in mown fields returned a total of 177 records (RC) of grassland bird nesting attempts. The number of records obtained each year was strongly variable: 12 in 2012 (0.076 RC/ha), 59 in 2013 (0.40 RC/ha) and 106 in 2014 (0.53 RC/ha). Only 4 % of records evidenced successful nesting attempts, 32 % were destroyed clutches, 8 % dead juveniles, 5 % dead adults and 56 % nests with unknown status (Table 3). From this 56 % of nests with unknown status, 27 % were found partially or fully removed from the original nesting sites.

The corn bunting (*Emberiza calandra*) was clearly the species with the largest number of records identified (74.42%) and most of these were destroyed clutches (Fig. 1). Crested/Thekla larks (*Galerida* spp.) represented 8 % of records (14), but contrarily to corn bunting, a larger percent of these records corresponded to dead juveniles (36 %). For 36 % of records (63), it was not possible to identify the

Table 3 Summary results for the records collected by different fates

Records		Total	CD	JAM	RWIS	HNOK
N		177	56	22	99	7
Density (records/ha)	Mean	0.35	0.18	0.04	0.31	0.01
	SD	0.68	0.31	0.08	0.53	0.03
	Max.	3.77	1.37	0.32	2.40	0.13

CD Cclutch destroyed, *JAM* juvenile and adult mortality, *RWIS* records without information of nesting status, *HNOK* hatching successful for nidifugous species or nest active for nidicolous species

passerine species (lark or corn bunting). The species with the highest proportion of nesting success was the common quail (*Coturnix coturnix*), in which four out of seven records refer to hatched eggs, hatchlings or fledglings. The adult mortality found for the little bustard (1 record) and, particularly, for the Montagu's harrier (4 records) is noteworthy since these species are quite rare within the study area.

Nest and dead bird removal: confounding factors and detectability

The inspection of REC values revealed the existence of considerable differences between the number of expected records and the number of records actually collected, in an important number of fields sampled (Fig. 2; for a best evaluation of the magnitude of this effect). Passerines hold in some fields an expected number of records six times or more higher than the records actually collected (bird territory density was not significantly correlated with REC; $r = 0.13$, $p = 0.49$). However, these differences were only significant for the zitting cisticola (*Cisticola juncidis*) and the corn bunting (Fig. 2).

Our models indicate that the REC was higher in fields with lower vegetation biomass prior to mowing (Table 4). Models including the percent of cover prior to mowing or both variables seem to have a poorer performance. REC was also related to the type of haying machinery. The models using mower and rake type as explanatory variables indicate that higher REC values occur in fields where sickle bar mowers and one-rotor rotary rakes were used (Table 5).

GLM analyses on the relationship between the removal of nests from original nesting sites and haying machinery, revealed contrasting results with those of REC analyses, particularly for the type of rake (Table 6). Sickle bar mowers and one-rotor rotary rakes returned lower probabilities of nest removal than discs mowers and wheel rakes. This suggests that the contrasting results for REC and nest removal may be essentially a result of machinery efficiency, as supported by the negative relationship found between these two variables ($r = 0.66$, $p < 0.001$).

No issues on spatial autocorrelation were found in REC and nest removal global models.

Linking clutch destruction, bird mortality and haying management

The averaged models for CD and RWIS revealed weak relationships with haying variables and interactions tested and consequently poorly accurate averaged models (AUC < 0.75). However, the model averaging procedure for JAM yielded different results. As revealed by the interaction between mowing date and year, the probability of mortality events is significantly higher in fields mown earlier, but not in all years (Table 7). On the other hand, two-rotor rotary rakes

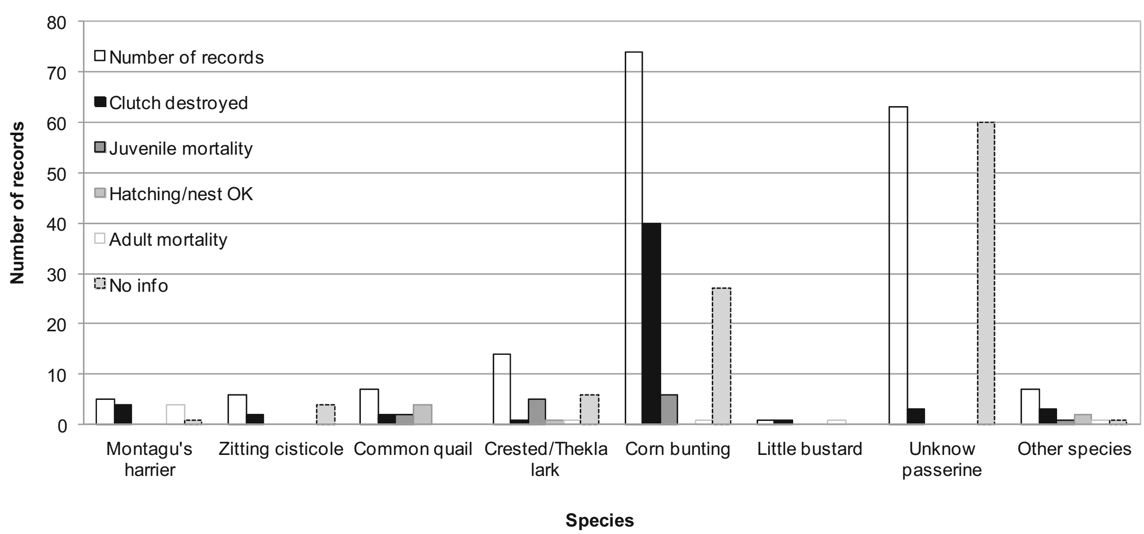

Fig. 1 Results of transect surveys in mown fields, grouped by bird species and observed events: (1) clutch destroyed, (2) juvenile mortality, (3) adult mortality, (4) hatching/nest OK (hatching successful for nidifugous species or nest active for nidicolous species) and (5) no info (records without information). The species included in the group "Other species" are: the common stonechat *Saxicola torquata*, the calandra lark *Melanocorypha calandra*, the reg-legged partridge *Alectoris rufa* and unidentified Anatidae *Anas* spp

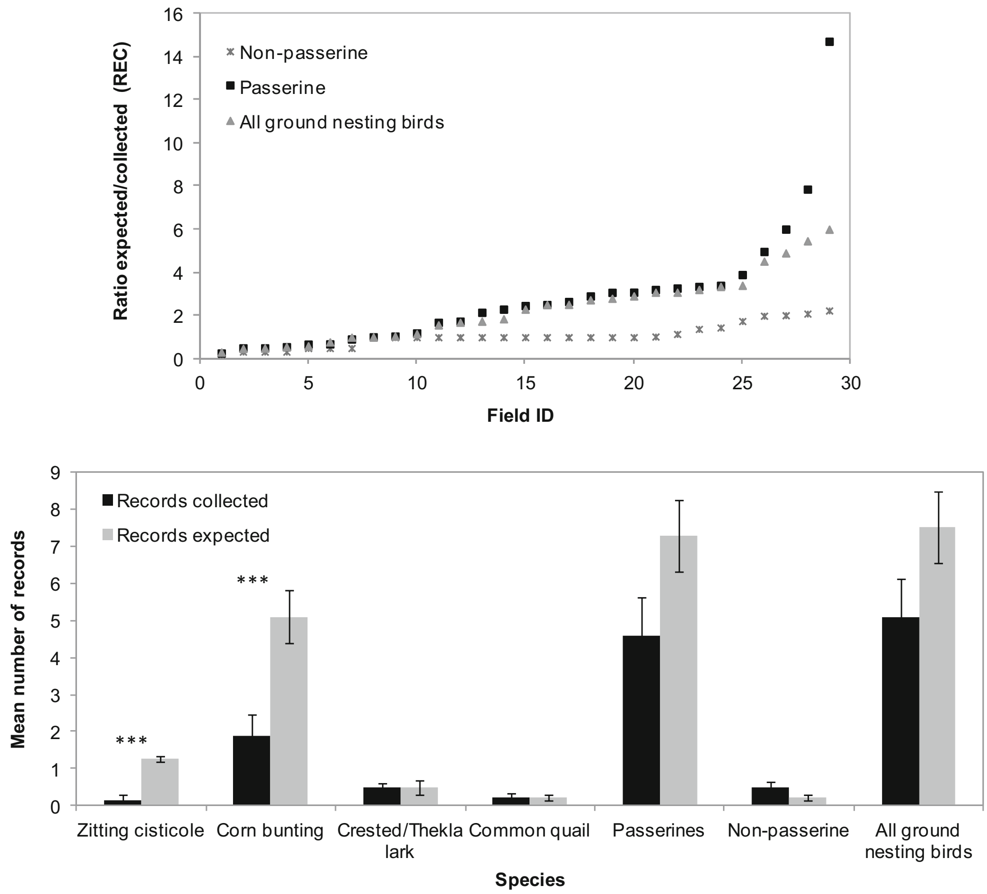

Fig. 2 Comparative results by field of REC for passerine species, non-passerine species and all ground nesting grassland birds (*above*) and comparison between the number of records collected during transects in mown fields and the expected number of records obtained from point counts (*below*) for the most representative species and groups. Standard errors and significant differences for the means (Student's *t* tests) are presented

produce significantly lower bird mortality, at least when compared with one-rotor rotary rakes. The AUC values for the averaged model revealed rather satisfactory accuracy for our data (averaged AUC = 0.81). No issues on spatial autocorrelation were found in JAM models.

Discussion

The results here presented suggest important losses for grassland bird populations in the Évora region due to haying, showing thus concordance with similar studies elsewhere (Perlut et al. 2006; Masse et al. 2008). We must acknowledge that the results involving a comparison between expected records and collected records could be highly dependent on the accuracy of the determined expected records, which is based on estimates of breeding pairs something that is not easy to determinate in grassland habitat and for grassland birds. However, some underestimation for the number of expected records of non-passerine species may exist in our data. The reasons for this underestimation are related to the fact that, in late April, the territories of non-passerines may not yet be fully established. Furthermore, for some polygamous species, male displaying locations can differ markedly from nesting sites.

Table 4 Linear models for the relationship between REC and vegetation variables prior haying works (biomass and percentage of cover). The coefficients of each variable and the AICc for each model are provided

Model	Vbiomass	Vcover	R^2	AICc	ΔAICc	Weight
1	−1.63		0.17	94.40	0.00	0.49
2			0.00	96.50	2.06	0.18
3	−1.36	−0.03	0.19	96.50	2.13	0.17
4		−0.05	0.10	96.60	2.14	0.17

Table 5 Linear models for the relationship between REC and the machinery type used for haying. The coefficients of each variable and the R^2, AICc, ΔAICc and Akaike weights for each model are provided. See Table 2 for a description on the categories of factor variables (*Rake* and *Mower*)

Model	Mower		Rake		R^2	AICc	ΔAICc	Weight
	SB	M	R^2	W				
1	1.85	0.28	−0.90	−0.20	0.44	105.50	0.00	0.66
2			−1.72	−1.78	0.26	107.30	1.84	0.26
3	1.29	0.28			0.17	111.00	5.46	0.04
4					0.00	111.00	5.54	0.04

Table 6 GLM models for the relationship between nest removal and machinery type used for haying. The coefficients of each variable and the R^2, AICc, ΔAICc and Akaike weights for each model are provided. See Table 2 for a description on the categories of factor variables (*Rake* and *Mower*)

Model	Mower		Rake		pseudo-R^2	AICc	ΔAICc	Weight
	SB	M	R^2	W				
1			−0.09	1.59	0.10	228.10	0.00	0.51
2	−1.00	−0.12	−0.05	2.23	0.12	228.20	0.10	0.49
3					0.00	241.90	13.82	0.00
4	0.16	−0.35			0.01	245.00	16.90	0.00

This is true, for instance, for the little bustard and the common quail, where males may be seen display in fields with little vegetation, but females nest in fields with tall vegetation most favourable for the production of hay.

The abundance of grassland birds was considerably higher in 2014 and 2013, and this is certainly one of the explanations for the annual variation in the number of records found. However, the abundance of grassland birds by itself fails to explain the magnitude of this variation, particularly between 2012 and 2014 (the maximum variation between years in bird abundance was only 43 %). This variation can be further explained by vegetation structure prior to mowing since the farms sampled and the machinery used in each farm every year were mostly the same. Dry years produce sparser swards with lower biomass, therefore reducing nest removal resistance both during mowing and raking. Dry years have the advantage of having less mown area, but the few areas mown can act as ecological traps for some rare species such as the great or the little bustards, which often prefer medium-tall moderately dense vegetation (Morales and Martin 2002; Faria et al. 2012). Indeed, two out of eight little bustard females tracked in this region by our team since 2003 nested in fields with potential for being mown, in very dry years (one of these females lost her brood due to haying works).

Transects on mown fields globally revealed low adult mortality for passerine species. Grüebler et al. (2008) estimated overall low-moderate (11.3%) female mortality due to haying for the Whinchat (*Saxicola rubetra*) in temperate grasslands. The situation may be quite different for non-passerines, particularly for the Montagu's harrier. Our estimates on the breeding population of this species in 2013 indicate that no more than 10 breeding pairs existed in Évora region (own unpublished data). This suggests that our four mortality records for this species represent at least 20 % of adult individuals of this population and may help explain the decline for just one breeding pair in 2014 and 2015.

Bird mortality in mown fields was dependent on the timing of mowing as well as on bird phenology and yearly weather conditions which is consistent with the findings of other studies in temperate regions (Perlut et al. 2006; Grüebler et al. 2008; Buckingham et al. 2015). In 2014, favourable nesting conditions effectively started in the second week of March, when 2 weeks with temperatures around 20 °C and no rain led to early clutches in most of the passerine assemblage. As a result, we detected several fledging juveniles in early May just before mowing took place so that bird mortality was less probable to occur in late mown fields as revealed by our averaged model. On the contrary, due to severe winter drought in 2012 and persistent early spring rains in 2013, the nesting season started late and therefore, all nests could have been evenly affected over the haying season. As seen for temperate regions, delaying mowing for hay may highly penalize farmers, due to an important loss of grass protein content (Nocera et al. 2005). Under Mediterranean climate,

Table 7 Summary results for the averaged GLM model on grassland bird mortality in mown fields. The variables and factors included in each model, the AICc, ΔAICc, Akaike weights and model selection probabilities are provided. The models shown represent ΔAICc < 4. See Table 2 for a description on the categories of factor variables included in models

Model	Year		Mower		Rake		Dmow	Dmow:fac (Year)		AICc	ΔAICc	Weight
1	+				+		0.13	+		120.40	0.00	0.51
2	+						0.26	+		121.50	1.16	0.29
3	+		+		+		0.21	+		123.50	3.17	0.10
	2013	2014	SB	M	R2	W		Dmow:Year (2013)	Dmow:Year (2014)			
Averaged β	3.91	5.96	−0.17	0.71	−1.61	−0.28	0.18	−0.20	−0.43			
SE (adj.)	4.37	4.30	1.03	0.82	0.77	1.22	0.17	0.18	0.18			
P-value	0.37	0.17	0.87	0.39	0.04	0.82	0.28	0.25	0.02			
Selection probability	1.00		0.15		0.65		1.00	1.00				

the loss of grass protein content is expected to occur even in a smaller time window since vegetation rapidly dries as soon as high temperatures arrive in May.

The confounding factors acting in hayed fields are likely to affect the reliability of models, notably egg and dead bird removal by scavengers as seen in other related studies (Prosser et al. 2008; Guinard et al. 2012).

What predation or scavenging cannot explain is why so few nests were found in fields where bird density was high. This is particularly true for passerine species which hold relatively small territories and therefore are not expected to show significant differences between the location of territories determined at counting buffers and the real location of the nest. Haying machinery is likely to be the responsible for this nest disappearance and, together with scavengers, also for some unquantifiable dead bird removal. Indeed, according to local farmers, the presence of dead animals inside bales is not rare (some lizards and snakes were actually seen in bales during field works). The analysis of bale contents may thus return interesting information. Rotz and Shinners (2007) refer that disc mowers may at times cause slightly greater loss of biomass than do sickle bar mowers. In fact, some farmers of our study area prefer to use sickle bar mowers arguing that they can mow closer to the ground. Sickle bar mowers can easily remove the nests placed above ground level (such as those of the zitting cisticola) and reduce the resistance of remaining nests to being removed during raking. On the other hand, rotary rakes with two rotors are reported by farmers as more stable than rotary rakes with one rotor, hitting the ground less frequently and causing less trampling by the tractors, potentially decreasing nest removal and bird casualties.

Conclusions

A systematic planning where the most valuable areas for grassland birds are looked after and a contract with specific management prescriptions, including commitments such as delayed mowing or uncut refuges, should be established between the farmers and the environmental authorities, while the remaining areas can be used, for instance, for hay to be mown on optimal dates or silage production using temporary crops. Although the effects of silage have not been addressed in the present study, we suppose that grassland management intensification due to silage production is unlikely to occur on a large scale (*e.g.* regional) since water availability in our region is strongly limited. Silage field works normally occur until the end of April what might be of great help in reducing mortality of those non-passerines which by this time have not yet started their clutches.

Finally, unless May is unusually rainy in southwest Iberia, haying can be scheduled in order to rake right after mowing. Therefore, the use of machinery enabling simultaneously mowing and gathering hay in lines, avoiding the use of rakes as happens with cereal harvesters, may be an important complementary measure to reduce bird casualties.

Acknowledgments We thank Carolina Bloise, Hevana Lima, Ana Teresa Pereira and André Carrilho for their contributions to our field work and to all land managers that kindly supplied information on haying and for allowing us to work on their lands. Nuno Faria was funded by grant SFRH/BD/74840/2010 from Portuguese Science and Technology Foundation (FCT- Fundação para a Ciência e a Tecnologia), supported by funding POPH/FSE.

References

Bartoń, K (2015) MuMIn - Model selection and model averaging based on information criteria (AICc and alike). R package version 1.15.1. https://CRAN.R-project.org/package=MuMIn)

Bates D, Maechler M, Bolker B, Walker S (2015) lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-9. https://CRAN.R-project.org/package=lme4

Bivand RS, Hauke J, Kossowski T (2013) Computing the Jacobian in gaussian spatial autoregressive models: an illustrated comparison of available methods. Geogr Anal 45:150–179

Broyer J (2003) Unmown refuge areas and their influence on the survival of grassland birds in the Saône valley (France). Biodiv Conserv 12: 1219–1237

Buckingham DL, Giovannini P, Peach WJ (2015) Manipulating grass silage management to boost reproductive output of a ground-nesting farmland bird. Agr Ecosyst Environ 208:21–28. doi:10.1016/j.agee.2015.04.018

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practice information-theoretic approach. Springer Verlag, New York

Carpintero C, Suárez A, Pascual YMR (1991) Producción y calidad de varias gramíneas en cultivo monofito y en asociación. Pastos 20–21:3–17

Cliff AD, Ord JK (1981) Spatial processes: models & applications. Pion Ltd, London

Development Core Team R (2007) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, http://www.R-project.org. Accessed December 2014

Faria N, Rabaça J, Morales MB (2012) The importance of grazing regime in the provision of breeding habitat for grassland birds: the case of the endangered little bustard (*Tetrax tetrax*). J Nat Conserv 20:211–218

Fielding AH, Bell JF (1997) A review of methods for the assessment of prediction errors in conservation presence/absence models. Environ Conserv 24:38–49

Green RE, Tyler GA, Stowe TJ, Newton AV (1997) A simulation model of the effect of mowing of agricultural grassland on the breeding success of the corncrake *Crex crex*. J Zool 243:81–115

Grüebler MU, Schuler H, Müller M, Spaar R, Horch P, Naef-Daenzer B (2008) Female biased mortality caused by anthropogenic nest loss contributes to population decline and adult sex ratio of a meadow bird. Biol Conserv 141:3040–3049

Guinard E, Julliard R, Barbraud C (2012) Motorways and bird traffic casualties: carcasses surveys and scavenging bias. Biol Conserv 147:40–51

Herkert JR (1997) Bobolink dolichonyx oryzivorus population decline in agricultural landscapes in the midwestern USA. Biol Conserv 80:107–112

Hernández AJ, Pastor J, Benayas JMR et al (1994) Forage production under suboptimal conditions: an overview of drought problems in Mediterranean-type ecosystems. In: Mannetje L, Frame J (eds) Grassland and society, pp. 539–548. Wageningen Pers, Wageningen, Proceedings of the 15th General Meeting of the European Grassland Federation

Humbert JH, Ghazoul J, Walter T (2009) Meadow harvesting techniques and their impacts on field fauna. Agr Ecosyst Environ 130:1–8

INE (2014) Statistical data: Database. Lisbon, Portugal: Instituto Nacional de Estatística. http://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_base_dados. Accessed online at December 2014.

IPMA (2014) Climate normals - 1981–2010 – Évora. Instituto Português do Mar e da Atmosfera, Lisboa, Portugal. http://www.ipma.pt/en/oclima/normais.clima/1981-2010/007/. Accessed online at December 2014.

Kruk M, Noordervliet MAW, ter Keurs WJ (1997) Survival of black-tailed godwit chicks Limosa limosa in intensively exploited grassland areas in The Netherlands. Biol Conserv 80:127–133

Masse RJ, Strong AM, Perlut NG (2008) The potential of uncut patches to increase the nesting success of grassland songbirds in intensively managed hayfields: a preliminary study from the Champlain valley of Vermont. Northeast Nat 15:445–452

McCullagh P, Nelder JA (1989) Generalized linear models. Chapman and Hall, London

Morales MB, Martin CA (2002) Great Bustard Otis tarda. Birds of Western Paleartic update 4. Oxford University Press, Oxford, pp 217–232

Nocera JJ, Parsons GJ, Milton GR, Fredeen AH (2005) Compatibility of delayed cutting regime with bird breeding and hay nutritional quality. Agr Ecosyst Environ 107:245–253

Pearce J, Ferrier S (2000) Evaluating the predictive performance of habitat models developed using logistic regression. Ecol Model 133:225–245

Perkins AJ, Maggs HE, Wilson JD, Watson A (2013) Delayed mowing increases corn bunting *Emberiza calandra* nest success in an agri-environment scheme trial. Agr Ecosyst Environ 181:80–89

Perlut NG, Strong AM, Donovan TM, Buckley NJ (2006) Grassland songbirds in a dynamic management landscape: behavioral responses and management strategies. Ecol Appl 16:2235–2247

Pinheiro J, Bates D, DebRoy S, Sarkar D, R Core Team (2015) nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-122. http://CRAN.R-project.org/package=nlme

Prosser P, Nattrass C, Prosser C (2008) Rate of removal of bird carcasses in arable farmland by predators and scavengers. Ecotoxicol Environ Saf 71:601–608

Rivas-Martínez S, Penas A, Díaz TE (2004) Bioclimatic Map of Europe. Thermoclimatic Belts. Léon, España: Servicio Cartográfico de la Universidad de León. http://www.globalbioclimatics.org/form/maps.htm. Accessed December 2014.

Rodríguez MES, Morales AM, Álvarez ML (2006) Estudio fitosociológico y bromatológico de los pastizales con interés ganadero en la provincia de Salamanca. Studia Botanica 6:9–61

Rotz CA, Shinners K (2007) Hay harvest and storage. In: Barnes RF, Nelson CJ, Moore KJ, Collins M (eds) Forages: the science of grassland agriculture, 6th edn. Blackwell Publishing, Iowa, pp 601–616

San Miguel A (2009) Los pastos de la comunidad de Madrid. Tipología, cartografía y evaluación. Serie técnica de medio ambiente n° 4. Consejería de Medio Ambiente, Madrid

Vickery JA, Tallowin JR, Feber RE, Asteraki EJ, Atkinson PW, Fuller RJ, Brown VK (2001) The management of lowland neutral grasslands in Britain: effects of agricultural practices on birds and their food resources. J Appl Ecol 38:647–664