

Patterns of Orthoptera abundance and lesser kestrel conservation in arable landscapes

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Abstract The lesser kestrel *Falco naumanni* experienced a marked decline during the second half of the 20th century due to changes in land use that influenced breeding success by reducing the abundance and quality of prey. However, the factors governing spatial and temporal variation of prey abundance around lesser kestrel colonies has not yet been investigated. We sampled Orthoptera abundance in the main crop types and edge habitats surrounding six lesser kestrel colonies in southern Spain. Samplings focused on Orthoptera because they constitute the main prey during the nestling period. Only those Orthoptera species that are known to be preyed by lesser kestrels were considered in this study. We found differences in prey density among localities, and crop types. Semi-natural habitats such as grasslands, fallow land, and field margins held the highest densities. However, prey abundance showed a complex pattern that was not possible to explain solely on the basis of crop composition around colonies. Factors determining productivity in individual fields like soil type and productivity or biocide input, and mean size of agricultural fields contributed to explain this complex pattern of prey abundance. Our results highlight the key role of semi-natural and edge habitats in farmed landscapes as prey reservoirs and corridors. Higher conservation priorities for these habitats are suggested to benefit foraging lesser kestrels, but many other farmland species that also experienced steep population declines due to decreasing food supply resulting from modern agriculture.

Keywords Agri-environment schemes · *Falco naumanni* · Margins · Prey abundance · Prey biomass

Introduction

Modern agriculture is considered to be a major anthropogenic threat to biodiversity, comparable to climate change in its ability to affect vast areas (Donald et al. 2002). The populations of many farmland birds, including the lesser kestrel *Falco naumanni*, have

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experimented marked population declines in last decades across Europe (Fuller et al. 1995; Donald et al. 2001). There is compelling and extensive evidence to show that these declines have been driven by agriculture intensification (e.g. Gregory et al. 2004; Mattison and Norris 2005).

One of the most commonly argued process operating behind this negative relationship between farmland bird abundance and agricultural intensification is food availability (Newton 2004; Morris et al. 2005). However few studies have quantified the relationships between arthropod abundance and agricultural practices (but see McCracken et al. 1995; Wilson et al. 1999), especially at the scale of the home-range of the species involved (but see Potts 1986; Brickle et al. 2000; Hart et al. 2006). Understanding this relationship could be of enormous applied interest, because it constitutes the scientific basis for the development of new agri-environmental schemes that contrary to previous results (low to moderate success of these schemes; Kleijn and Sutherland 2003; Kleijn et al. 2006), can guarantee positive results on farmland biodiversity (see Aebischer and Ewald 2004). This is especially important in Mediterranean countries where agri-environmental schemes have been little used (Llusia and Oñate 2005), and their effectiveness remain almost unknown because of the lack of scientific evaluations (Kleijn and Sutherland 2003; but see Kleijn et al. 2006).

The lesser kestrel is a colonial migratory species associated to agricultural landscapes in Western Europe, breeding in holes of old buildings, such as churches or castles within urban areas, and also under tiled roofs of farmhouses (Negro 1997). For this species, the reduction in both the extent and quality of foraging habitats in its Western Palaearctic breeding range appears to be the primary cause of decline (Peet and Gallo-Orsi 2000). This is especially true for the Andalusian population (Southern Spain), where starvation is the main cause of nestling mortality (Negro et al. 1993). Both prey quality and availability have been demonstrated to be pivotal in determining breeding success (Rodríguez et al. 2006), which constitutes a keystone parameter for the stability of this population (Hiraldo et al. 1996). However, this is the first study providing detailed information on prey abundance in different crop types within lesser kestrel home-range, and to analyse the patterns, and factors involved in its spatial and temporal variation.

We examined the relative abundance of Orthoptera at six localities with arable land use holding lesser kestrel colonies. We used this group of arthropods because they constitute the bulk of lesser kestrel's diet during the chicks rearing period (78% of total biomass—Rodríguez 2004; Rodríguez et al. 2006). Our main aim is to identify those factors influencing prey abundance in lesser kestrel home-range during this period (when food demand is highest). This knowledge could be helpful in designing and implementing new management actions to be conducted in the lesser kestrel breeding range.

Methods

Study area

Data were collected in the Guadalquivir river basin (south-western Spain), a predominantly flat pseudo-steppe (elevation range 20–240 m) where traditional agro-grazing systems have been replaced by a system of continuous cropping with full mechanization and high input of chemical fertilizers and biocides (Fernández et al. 1992; Donázar et al. 1993). In this area, six urban lesser kestrel colonies have been monitored since 1988 and their basic breeding parameters recorded annually (see Rodríguez and Bustamante 2003 for more

details). These colonies are located in the villages of Arahal, Lebrija, Mairena del Alcor, Manzanilla, Morón de la Frontera, and Palma del Condado (Fig. 1). The main crops in these localities are wheat, sunflower, and olive groves (Rodríguez et al. 2006). Grassy margins are used to separate individual fields.

Orthoptera sampling

Orthoptera were sampled in a radius of 3 km around the six above-mentioned colonies. Negro et al. (1993) found that about 75% of lesser kestrel foraging trips during the breeding season were within 3 km of the colony of Mairena, and Franco et al. (2004) also suggested this radius as critical foraging habitat for the species in Southern Portugal. Samplings were conducted almost daily during the nestling period (from late May to mid July; see Rodríguez and Bustamante 2003) in three consecutive years (1999–2001). Sampling dates were randomly distributed among colonies. We used two different sampling methods. The first consisted in transects of 30 min duration (Voisin 1980) randomly distributed within the 3-km radius, and thus including the most representative crop types of the study area (Table 1). We also conducted transects in non-arable land such as remaining patches of grassland and fallow land (hereafter semi-natural habitats). Minor crop types (e.g. sugar beet, chickpea, or maize) were grouped as others. Urban land was not considered. Transects were walked carrying a Global Positioning System (GPS) and trying to keep a constant speed. The distance covered in the 30-min transect was known from the GPS track. Belt width of transect (defined as the width of ground visible by the observer) was also recorded to allow estimates of Orthoptera density (range: 0.5 m in dense sunflower crops—2 m in olive groves with bare ground). We used densities instead of counts

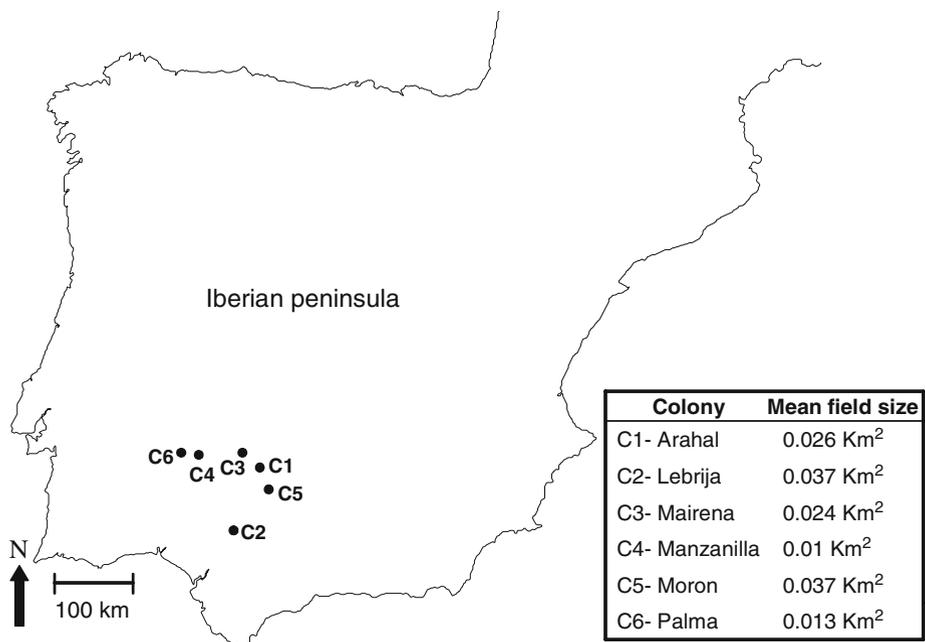


Fig. 1 Location of sampling localities and mean size of agricultural fields

Table 1 Mean density \pm SE (individuals per hectare) of prey species found in different crop types and localities during 30 min transects and ILAs (last column)

% Cover (range)	Cereal 23 (8–33)	Cereal stubble	Cotton 7 (0–10)	Olive 19 (0–46)	Others	Semi-natural 9 (4–22)	Sunflower 17 (5–30)	Vineyards 2 (0–3)	ILAs
Arahal	11.5 \pm 5.2	9.1 \pm 2.4	–	0.2 \pm 0.2	–	178.3 \pm 159.7	11.7 \pm 6.4	–	1117 \pm 316
Lebrija	10.5 \pm 10.5	1.0 \pm 0.5	4 \pm 3.2	–	0	49.8 \pm 26	1.2 \pm 0.7	–	135 \pm 40
Mairena	18.5 \pm 9.4	3.7 \pm 1.3	–	0	–	37.7 \pm 25.3	4.4 \pm 1.8	–	331 \pm 70
Manzanilla	18.7 \pm 6.6	31.5 \pm 8.8	–	1.2 \pm 0.8	35.8 \pm 20.2	25 \pm 8.4	11.2 \pm 3.6	36 \pm 15.5	624 \pm 122
Morón	9.1 \pm 4.7	11.9 \pm 4.7	–	1.2 \pm 0.6	–	15.4 \pm 6.1	6.2 \pm 4.4	–	544 \pm 198
Palma	80.3 \pm 69.2	17.7 \pm 11.0	17 \pm 7.1	–	–	350.1 \pm 200	4.7 \pm 1.4	6.8 \pm 3.2	674 \pm 150
SAMPLE	42	140	27	74	20	86	171	25	163

Values based on less than five samples were omitted. Mean cover of each crop type and range (between parentheses) in a three-km radius around the colonies is provided. For this calculation, absences were omitted

because the area covered in 30-min transects varied between samplings, and only densities allowed for comparison between them. In each field, transects were conducted at a minimum distance of 10 m from its limits to avoid the potential influence of neighbouring crops or margins (Badih et al. 1997). When field length was not enough for a 30-min transect, we conducted parallel transect within the same field separated a minimum distance of 10 m (Gottschalk et al. 2003). In order to prevent double counting, all Orthoptera specimens, except small larvae, were trapped with an entomological net. Occasionally, long flights of large Orthoptera prevented us to capture them and they were recorded with the generic name of “locust”. If their new position was in the sampling direction, this was considered to count them only once. When Orthoptera density was high the distance walked during the 30-min transect was short to be accurately measured with the GPS. In those instances, we used a 50 m fibre-glass tape to measure the distance covered.

Not only crops, but also field margins and edges conform the agricultural landscape, and the latter are known to be important for arthropods (Marshall and Moonen 2002). In margins, vegetation was too dense to be efficiently sampled with the previous method, so we used a second method exclusively applied to these linear habitats, where Orthoptera tend to hide behind broad leaves and stems more than to jump as they use to do in crops (Voisin 1980, 1986). This method consisted in a minimum of five 10×1 m quadrats where vegetation was carefully searched for Orthoptera specimens. Each set of quadrats was called Indice lineare d’abundance (ILA; see Voisin 1986 for details), and they were conducted during 2000 and 2001.

For both methods, samplings were made from 10 am to 8 pm (local times), when temperatures in the study area are warm enough (above 20°C) for insect activity (Willott 1997). In each individual sampling we noted as potentially explaining factors of Orthoptera abundance: crop type, crop development, crop cover, wind speed, and temperature (see Voisin 1980; Willott 1997; Gottschalk et al. 2003). All of them were estimated by eye and categorized. Categories for crop development and cover were grouped into five categories: 0 = 0% (recently sown fields or no vegetation cover); 1 = 1–20%; 2 = 21–40%; 3 = 41–60%; 4 = 61–80%; 5 = 81–100% (crops fully developed or no bare ground from above view). Wind speed was relatively low in the study area (98% out of 2,702 observations were below 20 knots— 37 km h^{-1} ; Spanish Instituto Nacional de Meteorologia), and then we considered wind as a logical variable (true/false). Using the entomological net as windsock, we considered windy days when the wind was able to fill the net (categories 3, 4, and 5 in Beaufort wind scale, approximately). Mean temperature during sampling dates averaged 25.1°C with low variation among days ($\text{SD} = 2.9^{\circ}\text{C}$), and among localities ($\text{SD} = 1.3^{\circ}\text{C}$). All individuals captured were counted, and released in the field immediately after sampling, except a sub-sample of one individual for each combination of species, size and sex found in each sampling location. This sub-sample was brought to the lab and weighted fresh (to the nearest 10^{-2} g) to obtain estimates of Orthoptera biomass.

Orthoptera specimens were identified to the genus or species levels using dichotomic keys (Harz 1969; Clemente et al. 1987), and with the help of Orthoptera experts (Dr. A. Badih. University of Granada, Spain, and S. Gadoum. Parc Naturel Régional du Vexin français, France). All sampled individuals belong to common Orthoptera species, and they were not included in any category of conservation concern (IUCN 1983; Gangwere et al. 1985). From the whole set of specimens sampled, we only considered those belonging to species actually consumed by the lesser kestrel as identified in a three-year dietary study on the same six colonies of this study (Rodriguez 2004; see Rodriguez et al. 2006 for a summary). This included the tree locust *Anacridium aegyptium*, the desert locust *Calliptamus* sp., the white-faced bush cricket *Decticus albifrons*, the saddle-backed

bush cricket *Ephippiger ephippiger*, the migratory locust *Locusta migratoria*, and grey bush crickets *Platypleis* spp. (all of them referred as prey or prey species hereafter). Large, unidentified locusts (see above) were also considered as lesser kestrel's prey.

Statistical analyses

To identify whether there were differences in the density of prey and prey biomass among localities holding lesser kestrel colonies, we used generalized linear models GLMs (see Crawley 2002) where the locality was introduced as factor. To ascertain which variables determined the density of prey and prey abundance in the two sampling methods, colony and year were introduced as random factors in Generalized mixed linear models (GLMMs) fitted by restricted maximum likelihood (see Pinheiro and Bates 2002). Crop type, crop cover, crop development, wind, and temperature were introduced as potential explanatory variables (fixed factors). Date (as the number of days from the first of January) was introduced as continuous variable. We also tested second degree polynomials fitted to variable date to check for potential curvilinear responses. Because the aggregation of fields is one of the main processes in agricultural intensification (Donald et al. 2002) and mean size of fields has demonstrated to be one of the best structural correlates of farmland biodiversity (Baessler and Klotz 2006), we also included mean field size (continuous) in our analyses. Mean field size was calculated by dividing municipality surface by the number of agricultural fields in the municipality. Original data were log transformed to achieve normality of errors. When necessary, heteroscedasticity was corrected by fitting different variance structure for each factor using the weight function of S-plus (see Pinheiro and Bates 2002 for details). Statistical assumptions were checked using Tukey-Anscombe and Normal/QQ diagrams (see Crawley 2002; Pinheiro and Bates 2002). Models started by sequentially including each predictor, using a forward-stepwise search of the best model. In every step, we tested the significance of variables by comparing the current full model versus the reduced model without each particular variable using $P < 0.05$ and AIC values as criteria. This process stopped when no additional variables contributed to increase significantly the explanatory ability of the model. All models were run with S-plus 2000 (MathSoft 2000).

Results

We conducted a total of 585 transects, and 163 ILAs. The distribution of samplings per locality and year is provided in Table 2.

Table 2 Number of samplings per locality and year

	Arahal	Lebrija	Mairena	Manzanilla	Moron	Palma
Transects						
1999	21	20	30	26	21	15
2000	31	31	34	32	32	32
2001	44	45	44	42	42	43
ILAs						
2000	7	7	7	8	8	8
2001	22	19	21	22	16	18

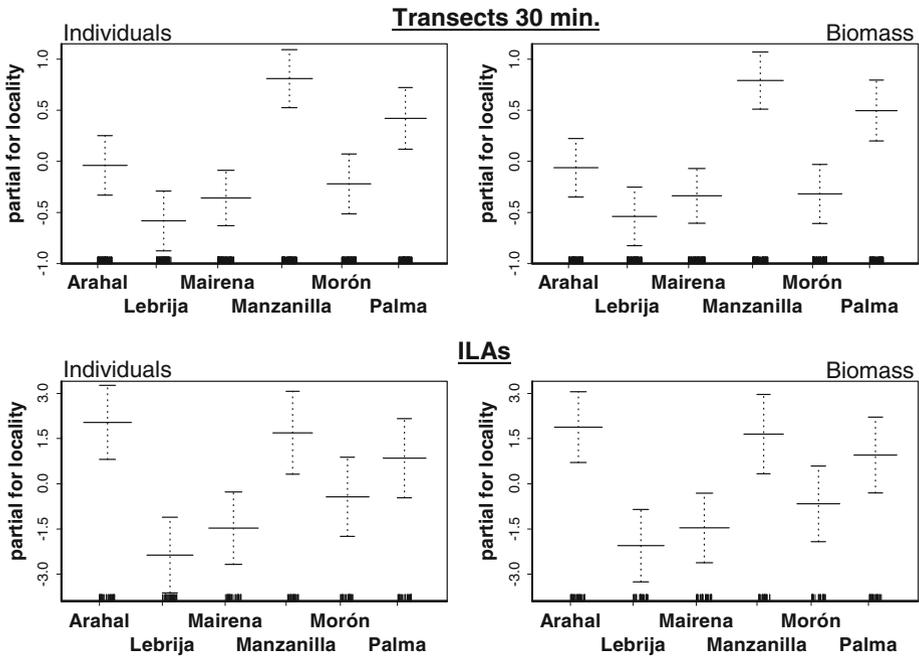


Fig. 2 Mean partial effect of factor locality on the density of prey and prey biomass in both 30-min transects (on top) and ILAs (bottom plots). Broken lines indicate the SE of the mean. The rugplot on the x-axes indicates the density of data points

In both methods, the density of prey and prey biomass varied among localities holding lesser kestrel colonies ($P < 0.0001$ in all cases), being Arahal, Manzanilla, and Palma those with higher densities in all cases (Fig. 2).

The minimum adequate GLMM built for the density of prey individuals in 30-min transects included locality and year as random factors, and crop type ($P < 0.0001$), crop development ($P = 0.0006$) and mean field size ($P = 0.01$) as explanatory variables. Parameter estimates indicated that the density of prey follows the sequence: semi-natural habitats > cereal crops > cotton crops > vineyards > others > sunflower crops > olive groves. Nonetheless, there were some variations among localities (see Table 1) that according to the model could be due to differences in crop development (positive effect), and mean field size among localities (negative effect). It was not possible to build the GLMM including the interaction between crop type and development, so we built a GLM including the same fixed factors than the GLMM. This interaction was not significant ($P = 0.2$).

The best GLMM built for density of prey biomass in 30-min transects was very similar to the model for prey density. It included locality and year as random factors and crop type ($P < 0.0001$), crop development ($P = 0.0002$) and mean field size ($P = 0.007$) as explanatory variables. Parameter estimates indicated that the prey biomass follows the sequence: semi-natural habitats > cotton crops > vineyards > cereal crops > others > sunflower crops > olive groves. Prey biomass was positively influenced by crop development, and negatively influenced by mean field size in each locality. It was not possible to build the GLMM model including the interaction between crop type and

development, but this interaction was not significant ($P = 0.2$) in a GLM including the same fixed factors than the GLMM.

The best GLMM models for prey density and prey biomass in ILAs included locality and year as random factors and vegetation cover ($P = 0.002$; $P < 0.0001$, respectively) as the main explanatory factor. The model built for prey density also included wind ($P = 0.02$), while the model for prey biomass also included mean field size ($P = 0.04$) as additional explanatory variables. Parameter estimates indicated a positive effect of cover and a negative influence of wind and mean field size.

Discussion

A high variability of Orthoptera densities was found among different crop types and localities in Southern Spain. Because we only focused on those species that are known to be part of lesser kestrel's diet during the chick-rearing period (see Rodríguez 2004), our results point out to the main factors determining prey abundance for this endangered species in the study area.

In a first, simple approach we found differences in prey abundance and prey biomass between localities, with Palma and Manzanilla showing the highest densities and Lebrija and Mairena the lowest. Although this did not account for differences in composition of crop types among these localities, samplings in both crops and field-margins were consistent in this result (with the exception of Arahal, which showed intermediate densities of prey and prey biomass in crops, but the highest in margins). This suggests generalized differences in prey abundance among localities.

Once random variability belonging to locality and year was included in GLMM, crop type was the most influential variable on prey density and prey biomass in transects. We found that small remaining patches of semi-natural habitats such as fallow lands and grasslands held the highest densities of prey and prey biomass, while the lowest densities were found in olive groves. The main crops in the area, cereals and sunflowers, showed intermediate values of prey density and biomass, but cereals had higher prey densities than sunflowers, and prey accessibility is probably much lower in the latter (because of greater vegetation cover and height; see Table 3). These results confirm the indirect evidences of a previous study on lesser kestrel also suggesting that high prey densities in semi-natural habitats would explain their positive selection by foraging lesser kestrels, as well as the negative selection of other crops such as sunflower and olive groves (Donázar et al. 1993). In fact, our results indicate that crop preference for foraging by lesser kestrels (grasslands > cereals > sunflowers and olive groves) as found in a radio-tracking study by

Table 3 Vegetation cover (in %) and median development (categories 0–5) of sampled crop types

Crop type	Cover (%)	Median development
Cereal	56	1 (<20 cm. Stubbles)
Cotton	54	3 (50–100 cm)
Olive	22	5 (>150 cm. Adult trees)
Others	50	2 (20–50 cm)
Semi-natural	50	3 (50–100 cm)
Sunflower	58	4 (100–150 cm)
Vineyards	46	4 (100–150 cm. Adult plants)

Donázar et al. (1993) in one of our study localities (Mairena) is in accordance with mean relative prey abundance (Table 1), but also with parameter estimates of GLMM for these crops. Although our sample size prevents us to evaluate whether other locally important crops such as traditional vineyards or cotton crops could be suitable for foraging kestrels, our results pointed in this direction (see also Isenmann and Debout 2000). Nonetheless further studies should explore in detail these preliminary results.

Crop development also explained differences in densities of prey and prey biomass in transects. In the study area, cotton was the only crop still growing at the time of sampling. For the others, crop development constitutes a measure of their previous growth. Although all localities belong to the second best category (out of 8) of soil productivity (except Morón that was in the third; Andalusian Government), different soil types, slopes and past agricultural practices (nitrification, crop rotation, etc.) probably determine differences in individual field productivity. Thus, the positive association of prey and prey biomass with crop development was probably due to higher productivity of those fields showing more developed crops considering the generalized herbivore diet of Orthoptera (Hendriks et al. 1999; Olmo 2002).

After considering the effect of crop type and development, the mean size of fields in each locality explains part of the remaining variability in prey density and biomass. Although crop types composition differs between localities and some crop types may potentially contribute more than others to mean field size, digitalized maps of arable fields in the area suggest that there are generalized differences in field size among the study localities. The increase in mean field size has taken place mainly by the aggregation of small fields, which reduces edges and linear elements associated to field limits, but also removes small patches of non-arable land previously present in the landscape (Fernández et al. 1992; Baessler and Klotz 2006). Thus, the negative influence of increasing mean field size on the density of prey and prey biomass in 30-min transects suggest a positive effect of habitat heterogeneity and higher availability of margins on prey abundance in arable landscapes (Marshall and Moonen 2002; Benton et al. 2003). This is probably because margins act as prey reservoirs (Donázar et al. 1993; Brickle et al. 2000; Weibull et al. 2003) and corridors that allow for the recolonization of locally extinct patches in the farmed landscape (Berggren et al. 2002). They also buffer the harmful effects of biocide applications on arthropod populations (Lemke and Poehling 2002; see also Ursúa et al. 2005). In addition, models for ILAs indicated that not only in crops, but also in margins, prey species were negatively influenced by increasing field sizes. Higher connectivity margin-field-margin in localities with smaller fields, could explain this result (Berggren et al. 2002).

The main factor explaining prey density and especially prey biomass in margins and edges was vegetation cover, probably enhanced by more productive soils (Kleijn et al. 2006), less herbicide application (Hart et al. 2006) and/or better conservation of these habitats. After introducing vegetation cover, only a negative influence of mean field-size and some correction for windy days (probably because the reduced ability of the observer to detect Orthoptera with wind) were found.

Conclusions and management implications

Prey abundance for lesser kestrels in arable landscapes shows a complex pattern accounting for the already deduced influence of crop type composition (Bustamante 1997; Franco et al. 2004), also highlighting the importance of crop development, spatial features

of the landscape (mean field size), and quality of margins (vegetation cover). This suggests that relying solely on the composition of crop types in a given locality as a measure of its suitability for the lesser kestrel may render confusing results. Values of prey and prey biomass found in Arahal exemplify the importance of these factors. In this locality only 25% of the surface within the 3-km radius is suitable for foraging (due to the high proportion of unsuitable olive groves and sunflowers occupying the rest). In addition, mean field size was relatively high (Fig 1) so margins are not especially abundant. However, field margins in this locality showed the highest densities of prey and prey biomass, probably due to their high development or conservation status. Although vegetation in well developed margins may decrease prey accessibility, high selection of margins by foraging lesser kestrels in different areas (Donázar et al. 1993; Ursúa et al. 2005) suggest that they are able to circumvent these hunting difficulties. Nonetheless, prey accessibility could be an important issue for foraging kestrels that should be considered. For instance, Donázar et al. (1993) reported higher foraging efficiency of kestrels in stubbles than in cereal fields, and although the majority of cereal fields were already harvested when sampled (141 out of 182; see Table 3), our results indicate higher prey density in cereal fields than in stubble (Wilcoxon rank test $Z = -2.5626$, $P = 0.0104$). Similarly, lesser kestrels showed higher hunting preferences for grazed fallows in Southern Portugal (Franco et al. 2004) because of the higher prey accessibility. In this respect, rearing livestock (mainly sheep and goats) is a minor activity in our study localities (range = 0–0.23 animals per ha; INE 1999) and its influence on the sampled grasslands and fallows is minimal.

The positive effect of both quantity and quality of margins on prey abundance and biomass for the endangered lesser kestrel highlights their role as key-component of the farmed landscape as previous studies also suggested (e.g. Wilson et al. 1999; Marshall and Moonen 2002; Ursúa et al. 2005). Thus, we encourage managers to increase the conservation efforts oriented to ensure the long-term persistence of semi-natural habitats in the farmed landscape. This should include the recovery and enhancement of grassy margins, which in the study area have disappeared between many individual fields. This measure (creating new field borders or increasing their width) has been identified as a desirable agricultural practice to benefit pseudo-steppe birds that has never been applied in Spain (Llusia and Oñate 2005). Nonetheless, further research efforts should be carried out to evaluate the importance of cover, and spatial distribution of these environmental-friendly measures (margins, in-field strips, etc.), their effects on farmland biodiversity, and their cost for farmers. Such kind of scientific, multidisciplinary evaluations are required to determine whether agri-environmental schemes are really useful and cost-effective (Kleijn et al. 2006; Watzold et al. 2006).

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