

Foraging activity and use of space by Lesser Kestrel *Falco naumanni* in relation to agrarian management in central Spain

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Summary

Arthropod abundance in most places across Europe has suffered a dramatic decline induced by modifications in agricultural practices, and this could induce changes in the selection of breeding habitat and foraging behaviour of several endangered raptor species. We studied a 6,500 ha Special Protection Area (SPA) in Spain created for the benefit of its important steppe bird populations and examined the patterns of land-use selection and use of vegetation structure by the Lesser Kestrel *Falco naumanni* in relation to prey-capture success. We also studied the spatial relationship between foraging sites and the location of colonies in that breeding area. The type of land-use most frequently used by foraging Lesser Kestrels was unploughed fallow (positively selected) while kestrels significantly avoided areas with cereal crops. The relationship between foraging sites and colonies (kestrels forage preferentially in areas close to the colonies) indicates that not only is farmland management important, but also the spatial relationships between foraging areas and breeding sites. Maintaining the Spanish traditional rotation of cultivation (called *barbechos*) may improve the correct habitat management for Lesser Kestrels in agricultural areas in Spain.

Introduction

The Lesser Kestrel *Falco naumanni* is a small falcon that usually breeds colonially in semi-deserts, steppes and extensively cultivated areas of the Palearctic Region, from Iberia and Morocco to east China and South Africa (Del Hoyo *et al.* 1994). In Western Europe it is mainly a summer visitor, migrating to Africa in winter. The species has declined markedly in the last decades over most of its range and is therefore considered as Vulnerable (BirdLife International 2004). Population decline has been induced mainly by recent agricultural changes that affect the birds' foraging habitats and food availability (Donázar *et al.* 1993, Parr *et al.* 1995, Bustamante 1997, Negro *et al.* 1997, Tella *et al.* 1998, 2004).

The diet of the Lesser Kestrel is based mainly on large arthropods such as orthoptera, coleoptera, *Scolopendridae* and spiders (Cramp and Simmons 1980, Negro *et al.* 1997), whose density in steppe habitats seems to be positively influenced by floristic composition (Wiens 1985, 1989). These prey are generally captured by Lesser Kestrels on the ground after a dive, following aerial detection by the bird while hovering. Consequently, foraging Lesser Kestrels can frequently be seen concentrated in varying numbers over habitat patches where prey access is presumed to be high

(Cramp and Simmons 1980, Negro *et al.* 1997, Tella *et al.* 1998). Extensive cereal fields, fallows, pasturelands and field margins in agricultural areas are the main habitats used by Lesser Kestrels for hunting (Cramp and Simmons 1980, Donázar *et al.* 1993, Tella *et al.* 1998). Arthropod abundance is usually higher in these types of land-use (Martínez 1994, Moreira 1999, Clere and Bretagnolle 2001), mainly due to their high floristic diversity (e.g. Tellería *et al.* 1988). On the other hand, for aerial hunters such as the Lesser Kestrel, access to prey must be affected by vegetation structure (Shrubb 1980, Bechard 1982, Toland 1987), notably cover which offers shelter to prey, and height which obstructs hunting manoeuvres. Consequently, capture success by Lesser Kestrels should be favoured in sites in which access to prey depends not only on its abundance but also on certain vegetation structure parameters. This may explain why the birds avoid hunting in habitat patches with taller vegetation cover, such as abandoned crop fields or scrublands (Tella *et al.* 1998).

In the present paper, we study the patterns of land-use type selection and use of vegetation structure by the Lesser Kestrel in relation to prey-capture success in an extensive agricultural pseudo-steppe of south-central Spain. We also study the spatial relationship between foraging sites and the location of colonies in that breeding area. This raptor species depends heavily on the abundance of their main prey, arthropods, whose populations have suffered a marked decline during recent decades due to modifications in agricultural practices (Potts 1991, Tucker and Heath 1994, Pain and Pienkowski 1997, Newton 1998). The current situation in many breeding areas of low prey availability for this raptor species may stress the effect of changes in land-use management and/or colonies on kestrel behaviour in the surroundings of a colony, especially hunting behaviour. Several habitat management recommendations based on our results are made for the conservation of this endangered species.

Methods

Study area

Fieldwork was carried out in the agricultural pseudo-steppes of Campo de Calatrava (central-southern Spain, 38°35' N/3°55' W, 650 m a.s.l.). This is a 6,500 ha Special Protection Area (SPA) created for the benefit of its important steppe bird populations (mainly Lesser Kestrel, Little Bustard *Tetrax tetrax*, Great Bustard *Otis tarda*, Black-bellied Sandgrouse *Pterocles orientalis* and Pin-tailed Sandgrouse *P. alchata*). The climate is typically Continental-Mediterranean with relatively cold wet winters and dry hot summers. Its flat to gently undulating landscape is dominated by a mosaic of dry winter cereal crops (wheat, and especially barley), fallows of variable ages, dry pastures (grazed by sheep and sometimes including low shrubs such as *Thymus* spp.), olive groves, vineyards and a few patches of dry annual legume crops (mainly vetch *Vicia sativa*). During the study period, cereal crops occupied up to 2,885 ha (54% of the total area), fallows occupied 1,362 ha (13%), while old fallows accounted for only 70 ha (1.3%). Dry pastures occupied 414 ha (8% of total area), vineyards covered 261 ha (5%) and olive groves extended over 193 ha (4%). The remaining area corresponded to minor crops (mainly fruit trees), river vegetation and villages. Although it was not quantified, the area occupied by field margins can be considered important in the study area, given the relatively small average field size (3.42 ha, SD = 7.32). Vegetation structure and composition of these field margins are very similar to those of unploughed fallows.

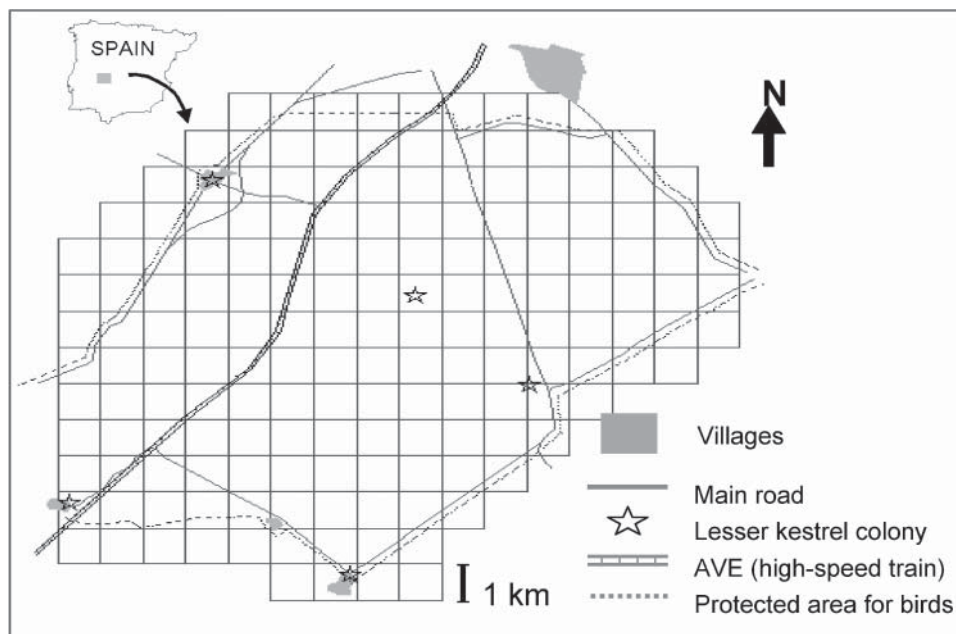


Figure 1. Map of the Iberian Peninsula showing the location of the study area, and the 1 km² grid squares where Lesser Kestrel foraging observations were recorded. The principal villages of the study area are shown in grey.

Most of the Lesser Kestrels observed in the study area breed in five main colonies (Martínez 1999; see Figure 1), three of which are located within the SPA (in the village of Ballesteros de Calatrava and the farmhouses of La Puebla and Casas de Ciruela), while the remaining two are found in villages outside the SPA but close to its limits (Cañada de Calatrava and Poblete). The total population reaches 74 pairs (Martínez 1999); the largest colony is Cañada de Calatrava, with 36 pairs, while the smallest one is that of Casas de Ciruela, with only 2 pairs.

Data collection

During April 2003, the study area was surveyed weekly by car using all available tracks and thus achieving complete coverage of the study area. Surveys began 1 hour after dawn and finished 1 hour before dusk in order to encompass the whole foraging activity period of the species at that time of year, prior to chick-rearing (Negro *et al.* 1991). Each time a Lesser Kestrel was detected foraging over a field, it was observed for 5 minutes using telescopes. During this time, the numbers of prey strike attempts and successful captures were recorded. Strikes and captures were fairly unambiguous. Strike attempts were defined as those strikes in which the bird landed on the ground. Captures were usually obvious from the kestrel's subsequent behaviour. Failed strikes were generally followed by the immediate resumption of foraging, whereas captures resulted in kestrels eating the prey at or near the capture site, or flying with it to the nest. The land-use type in which the capture took place was also recorded. After a

5 minute period, maximum vegetation height (in cm) and cover in a 1×1 m square (%) were measured as close as possible to the exact location of the strike attempt. Simultaneously with Lesser Kestrel observations, a series of 152 random points distributed over the study area were visited. At each random point, vegetation height and cover were measured following the same procedure used at the observation points. The land-use was also recorded and classified into the following types: cereal, unploughed fallow (over-winter stubbles and 2-year or older fallows), ploughed fallow (some fields may be ploughed several times during the breeding season), legume, pasture, olive grove and vineyard. Field margins were included in the unploughed fallow category.

Data treatment and analysis procedure

In order to determine which types of land-use were preferentially used by foraging Lesser Kestrels, we considered only birds observed during hunting activities (hovering or hunting from perches) and excluded birds making directional flights. To avoid the assignment of different habitats to the same kestrel record, each bird observed was attributed only once to the habitat where it was first sighted, irrespective of the habitat types subsequently used by that individual. To analyse the selection by kestrels of foraging habitats we used the Savage selectivity index, $w_i = U_i/p_i$, where U_i is the proportion of kestrels hunting in any one habitat and p_i is the proportion of that habitat in the overall study area. The proportion of each habitat type was derived from random points. This index ranges from 0 (maximum negative selection) to infinity (maximum positive selection), 1 indicating no selection (Manly *et al.* 1993). The statistical significance of the results is obtained by comparing the statistic $(w_i - 1)^2/S.E(w_i)^2$ with the corresponding critical value of a chi-square distribution with one degree of freedom. The null hypothesis is that birds use the foraging habitat in proportion to availability. The standard error of the index (SE) was calculated as $\sqrt{(1 - p_i)/(u \times p_i)}$, where u is the total number of foraging records sampled (Manly *et al.* 1993). This index was applied by Tella and Forero (2000) in a similar foraging study on wintering kestrels.

We used a generalized linear model (GLM) to search for differences in vegetation cover and height between observed foraging sites and random points, with land-use (cereal, unploughed fallow, ploughed, legume, pasture, olive grove and vineyard) and type of observation (random vs kestrel sightings) as categorical factors. GLMs allowed us to identify differences in vegetation structure of each land-use type that might explain selection of foraging sites by kestrels.

To examine variations in strike rates and effectiveness in relation to land-use we used a GLM with land-use as a categorical factor and the number of strikes per unit time (in seconds) or success rate as a dependent variable with Poisson error and log link function. Success rate was defined as number of captures/number of strikes.

We analysed the potential effect of distance to the colony on the kestrels' foraging activity in more detail by using a GLM to identify the factors that determine the probability of observing a kestrel hunting in the colony surroundings. Each Lesser Kestrel observation was assigned to a 1×1 km square throughout the study area and incorporated into a Geographical Information System (GIS; ArcView 3.2). The location of each colony was also plotted in the GIS. For each quadrat of the grid, we calculated the

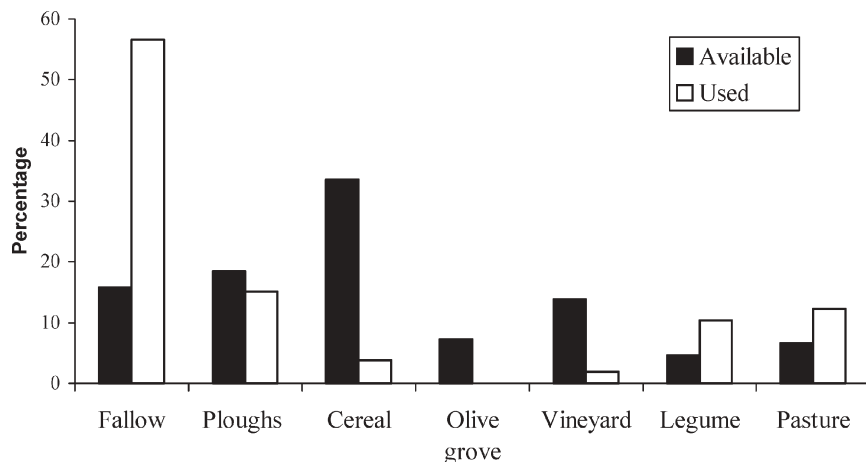


Figure 2. Percentage of habitat available and used by hunting Lesser Kestrels in the study area.

number of sights (foraging attempts). GLMs make it possible to search for linear and non-linear relationships between an ordinal response variable (e.g. number of hunting kestrels), and continuous predictor variables (e.g. distance to the colony and geographic coordinates such as longitude and latitude). We fitted an ordinal logit regression model with significance levels corrected for overparameterization. Variables were included in the model by selecting the best of all predictive variable subsets according to Akaike Information Criteria (AIC) minimization. Spatial correlation of kestrel sightings due to their spatial distribution in the 1 km² cells was included in the analyses with a second-order polynomial of the geographic coordinates (i.e. longitude X , latitude Y , $X \times Y$, X^2 , Y^2 ; see Legendre 1993). Latitude and longitude ranges were standardized before calculating the polynomial.

Results

Habitat use

A total of 106 observations of foraging kestrels were made and considered for analysis. The type of land-use most frequently utilized by foraging Lesser Kestrels was unploughed fallow (56.60%), followed by ploughed (15.09%), pasture (12.26%), legume (10.37%), cereal (3.77%) and, finally, vineyard (1.88%). No Lesser Kestrel was detected hunting in olive groves. These differences between the number of foraging attempts in relation to land-use types were statistically significant ($\chi^2 = 182.6$, d.f. = 6, $P < 0.0001$).

Among the land-uses considered, ploughed, legume and pasture were used in proportion to their availability (Figure 2, Table 1) breeding kestrels positively selected unploughed fallow, while significantly avoiding cereal, olive grove and vineyard. According to the values of the Savage selectivity index (w_i) obtained for each habitat type (Table 1), breeding Lesser Kestrels showed the following rank of preferences (the sign of the selection is in parentheses): unploughed fallow (+) > legume (o) > pasture (o) > ploughed (o) > vineyard (-) > cereal (-) > olive grove (-).

Table 1. Values of the Savage selectivity index (w_i) for each habitat used by kestrels, standard error of the index (SE) and P values.

Habitat	w_i	SE	P
Unploughed fallow	3.58	0.22	<0.01
Ploughs	0.81	0.20	n.s
Cereal	0.11	0.14	<0.0001
Olive grove	0	0.35	<0.0001
Vineyard	0.13	0.24	<0.0001
Legume	2.25	0.44	n.s
Pasture	1.86	0.37	n.s

Substrate features and hunting behaviour

Vegetation cover differed significantly between land-use types (GLM, Land-use: $F_{5,235} = 11.85$, $P < 0.0001$) and also differed between kestrel sightings and random points when substrate type was controlled, being lower in kestrel foraging sites than in random points (GLM, Type of observation (sightings vs random): $F_{1,235} = 11.89$, $P < 0.001$). The maximum differences were observed in the densest habitats (cereal and pasture; see Figure 3). In contrast, no significant differences were found with respect to vegetation height between kestrel sightings and random points (GLM, Type of observation: $F_{1,235} = 0.56$, $P > 0.05$; Figure 4), despite their variation in relation to

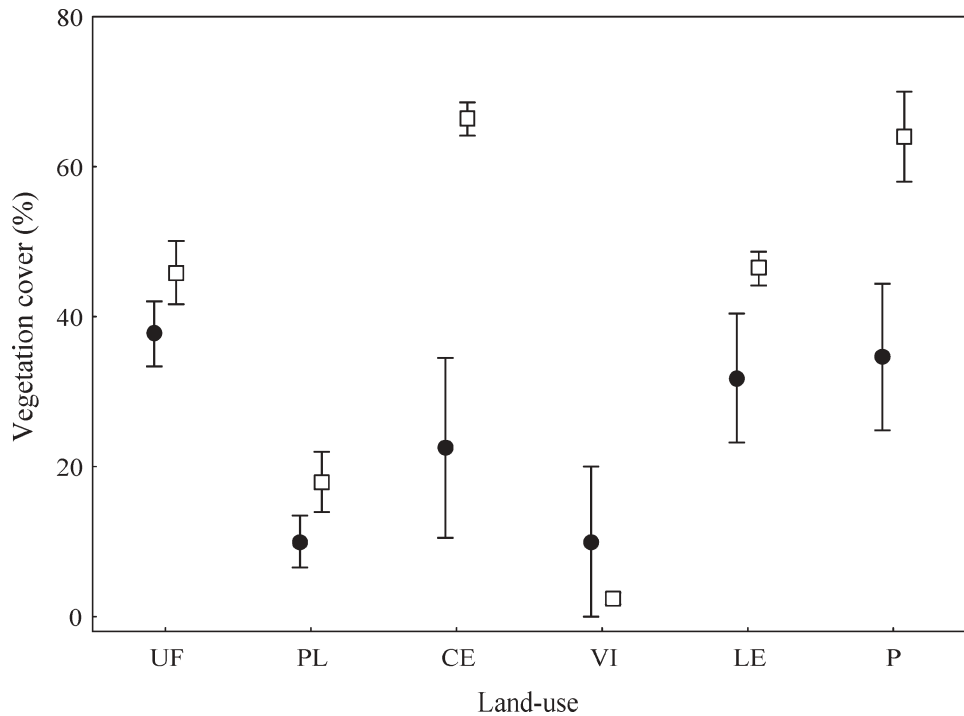


Figure 3. Differences (mean ± SE) in vegetation cover (%) between kestrel sightings (black circles) and random points (white squares). UF, unploughed fallow; PL, ploughed; CE, cereal fields; VI, vineyard; LE, legume; P, pasture.

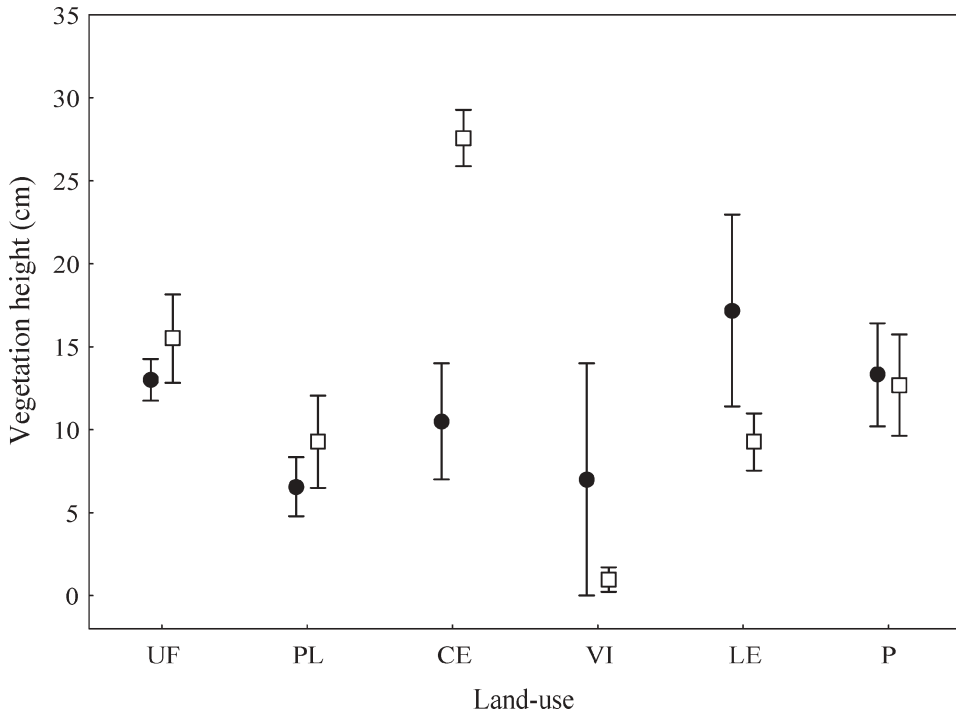


Figure 4. Differences (mean \pm SE) in vegetation height (cm) between kestrel sightings (black circles) and random points (white squares). UF, unploughed fallow; PL, ploughed; CE, cereal fields; VI, vineyard; LE, legume; P, pasture.

land-use among selected sites for hunting (interaction Type of observation \times Land-use: $F_{5,235} = 0.33$, $P < 0.01$). In this respect, selected sites in cereal fields consistently showed significantly lower height and cover than random points (Tukey's *post-hoc* test, $P < 0.01$ for both variables), whereas they showed significantly lower cover but greater vegetation height in legume fields (Tukey's *post-hoc* test, $P < 0.05$ in both cases).

Strike and success rates (number of successes in relation to number of strikes) did not vary significantly in relation to land-use (strikes: $F_{5,99} = 0.49$, n.s.; captures/strikes: $F_{5,62} = 0.29$, n.s.). There was no significant relationship between the distance from colonies of each kestrel observation and the rate at which kestrels struck at prey (Spearman correlation, $r_s = 0.04$, $P = 0.67$; $N = 106$) nor with success rate ($r_s = -0.03$, $P = 0.71$; $N = 106$).

Distance from colony

The best significant GLM obtained accounted for 7.56% of the deviance (Table 2). Distance featured significantly in this model, indicating that the probability of observing a kestrel hunting was significantly determined by the distance from the colony (Table 2). This model showed that kestrels more frequently used areas close to the colonies and that the probability of observing individuals hunting decreased with distance (Figure 5; see also the negative sign of the relationship in the model in Table 2).

Table 2. GLM model for the probability of observing a kestrel hunting in the study area. Variables were included in the model by selecting the best of all predictive variables subsets (AIC). Sample size = 106 observations.

Change in deviance		Variables included in the model ^a	Variables not included
% D ²	P		
7.56	<0.01	-0.94 * Dist. -0.93 * Y -5.46	X, X ² , Y ² , X × Y

^aDistance to nearest colony (Dist), longitude (X), latitude (Y), longitude × latitude (X × Y), longitude² (X²), and latitude² (Y²). The intercept was included in the model.

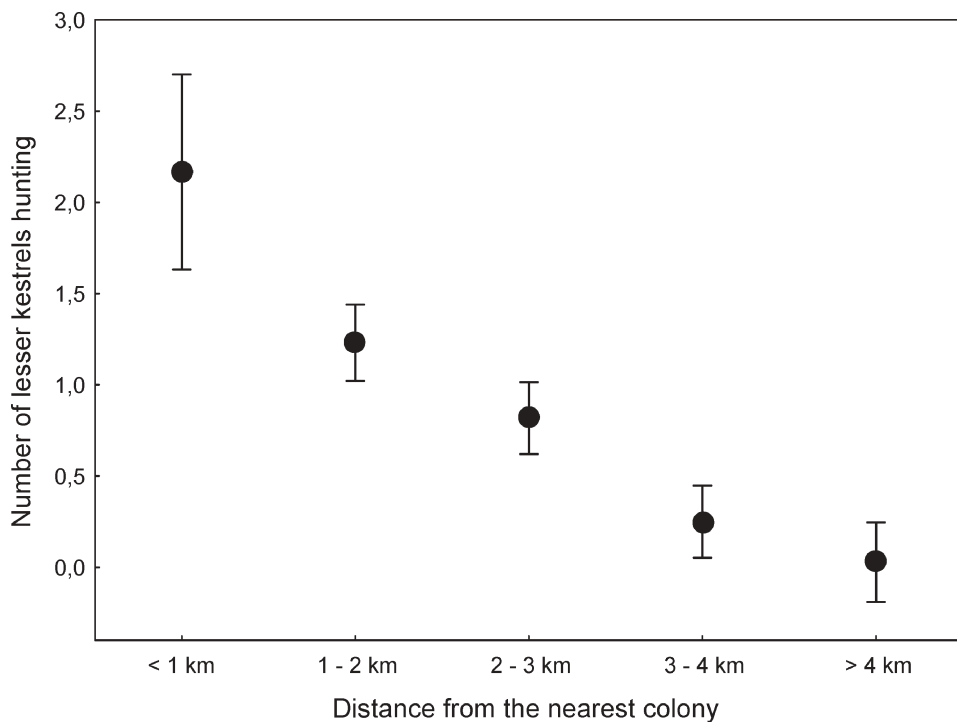


Figure 5. Number of Lesser Kestrel foraging attempts per square kilometre (mean ± SE) in relation to the distance from the nearest colony in Ciudad Real.

In addition, latitude coordinates were included in the model, as expected because the denser colonies were concentrated at one side of the study area (the southern side). Thus, the probability of observing a kestrel hunting decreased as latitude increased. No other variables or interactions featured significantly in the model.

Discussion

Kestrels positively selected unploughed fallows as hunting grounds, while they avoided cereal fields vineyards, and olive groves, suggesting that prey should be more available in the former habitat than elsewhere. More than half of the kestrels observed

were sighted at unploughed fallows, even when this kind of habitat represented only the 15% of the total surface of that area. Other habitat types were used with a frequency not significantly different from their availability in the landscape (ploughed fields, legume and pasture). Our results partially agree with previous studies in which ploughed fields were non-preferred or strongly avoided and Lesser Kestrels strongly depended on unploughed fields (stubble and fallow) for hunting during winter (Tella and Forero 2000).

Avoidance of olive groves and vineyards by foraging birds could be expected in an open-habitat raptor such as the Lesser Kestrel, as it has been shown previously that this species avoids scrubland (Tella *et al.* 1998). However, we also found that cereal fields were significantly avoided, while this type of habitat has been found to be a good predictor of the presence of colonies (Bustamante 1997), and was positively selected for hunting during the laying and chick-rearing periods in other study areas (Tella *et al.* 1998, Ursúa *et al.* 2004). Avoidance of cereals during the pre-laying period was also found by Ursúa *et al.* (2004) in the Ebro valley (north-east Spain). Therefore, our results confirm this behaviour as a general pattern in the species. One possible explanation is that vegetation structure of cereals precluded Lesser Kestrels foraging in this habitat at this time of year, since it was denser and taller than other habitats, and it might have offered shelter to prey and/or obstructed hunting manoeuvres (Shrubb 1980, Toland 1987), reducing access to prey for kestrels. In this respect, we found that observations of kestrels hunting in cereals corresponded to fields with less vegetation cover and lower height with respect to random expectation, which supports the latter hypothesis. Nevertheless, in our study area, the use of biocides and fertilizers was high (several times during the season in some areas; pers. obs.), which could have a large affect on the abundance of insect prey (Fan *et al.* 1993, Krooss and Schaefer 1998, Moreby and Southway 1999), making this habitat unsuitable as hunting grounds for kestrels.

The main conservation conclusion from our results is basically in agreement with that reached by Tella *et al.* (1998) and, more recently, by Franco *et al.* (2004): traditional agriculture may favour this species. Moreover, our results suggest that fallow fields (or *barbechos*, a typical component of traditional agriculture in Spain) may indeed be a key habitat for Lesser Kestrels, acting as the main foraging habitat previous to cereal harvesting, when stubble becomes the preferred hunting ground, as shown by previous studies (Tella *et al.* 1998, Ursúa *et al.* 2004, Franco *et al.* 2004). Consequently, although landscape dominance by cereals is a good indicator of habitat suitability on a large spatial scale (Bustamante 1997), local landscape heterogeneity generated by the presence of fallows seems critical for satisfying the important energy requirements of Lesser Kestrels in the pre-laying phase. Thus, correct habitat management for Lesser Kestrels in agricultural areas should not be based exclusively on reducing biocides or preserving field margins (Tella *et al.* 1998): it could be even more effective to maintain the mosaic landscape resulting from traditional culture rotation. It is important to note that one of the management techniques promoted by agri-environmental measures in Europe, long-term set-asides, may not be favourable for Lesser Kestrels, because they promote thick vegetation patches probably unsuitable as hunting grounds.

Lesser Kestrels seem to prefer unploughed fallow for hunting activities, suggesting that prey are more accessible in this land-use category. This may be due to the fact that either arthropod prey density is higher in this land-use type (e.g. because they

may be free of the effect of biocides), or vegetation structure differs between substrates, unploughed fallow being the most suitable one for arthropod hunting by Lesser Kestrels. Therefore, one would expect higher strike or success rates in those habitats showing greater access to prey. For example, sites with cereal crops selected for hunting were always lower and less dense than random expectation (Figures 3 and 4). However, despite the great variation in vegetation structure between land-use categories found in this study, both among sites used by kestrels and non-selected random points, we found no evidence that habitat characteristics influenced the likelihood of capture. This suggests either that prey abundance did not vary in relation to land-use among sites selected for hunting, or that strike or capture rates reflect changes in behaviour of hunting kestrels. For example, individuals may adjust strike rates to abundance of prey, being selective in sites with a high abundance of prey but forced to strike at any prey in sites where prey is scarce (Redpath *et al.* 2002). That would be consistent with the results of Tella *et al.* (1998) for southern Spain, where capture success did not differ between land-use types even though prey size was significantly different between them. Alternatively, and interestingly, perhaps kestrels are able to select optimal patches for hunting in non-optimal habitats, as supported by the differences in habitat structure between cereal patches used by kestrels and those that were randomly selected. Tella *et al.* (1998) also reported that, in areas with intensive agriculture and less suitable habitat, kestrels concentrated their hunting efforts in a lower number of smaller patches.

On the other hand, the distance to the nearest colony significantly influenced the probability of finding a kestrel hunting. In some breeding areas, changes in agro-system management have reduced the extent of foraging areas close to colonies, and kestrels are forced to fly long distances from the colony (>16 km) to forage, while in areas with non-intensive agriculture individuals tend to forage close to the colony (<3 km), as would be expected from a central foraging species (Bustamante 1997, Tella *et al.* 1998, Franco and Sutherland 2004). In our study area kestrels foraged close to the colony (<5 km), suggesting that the quality of the surrounding foraging habitats is sufficient at present to maintain the current population size. Consequently habitat management aimed at maintaining colony viability should be concentrated mainly within that radius, as has also been recommended in other study areas (Franco *et al.* 2004). However, this would not ensure the future of Lesser Kestrel colonies in the area studied, which will undergo imminent changes in land-use, including the construction of an airport on the southern limit of the SPA. Our results, showing an inverse relationship between distance from colonies and foraging activity, lead to one conclusion of great relevance for conservation strategies: not only is farmland management important, but also the spatial relationships between foraging areas and breeding sites. Consequently, while the habitat requirements of threatened species such as the Lesser Kestrel can be satisfied by means of changes in habitat composition or structure, it is also necessary to take into account the spatial relationships between foraging areas and colonies. This is important when designing compensatory measures directed to reduce the impact on Lesser Kestrel populations of actions such as the above-mentioned airport or radical agricultural changes (e.g. irrigation plans), since the improvement or maintenance of habitat in areas distant from colonies through, for example, the implementation of agri-environmental measures, may be largely useless if suitable foraging habitat around nesting sites is removed.

In summary, our results support the dependence of Lesser Kestrels on extensive and heterogeneous cereal farmland found in other study areas, thus helping to

generalize their conservation implications for the European range of the species. Moreover, our findings show a dependence of Lesser Kestrels on those foraging substrates with vegetation structure promoting prey accessibility. In our study area these are mainly unploughed fallows and, to a lesser extent, legumes. These requirements coincide to a large extent with those of other insectivorous (or partly insectivorous) farmland and steppe birds (e.g. Suárez et al. 1997). We have also shown how Lesser Kestrels preferentially use areas close to their colonies, a factor which should be addressed in any management plan for the species.

Acknowledgements

We are grateful to A. Linares who collected part of the field data, and Z. O. Codover for clarifying our ideas on habitat selection. We wish to thank J. L. Tella and an anonymous referee, whose comments and suggestions improved the manuscript.

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Received 15 August 2004; revision accepted 21 June 2005