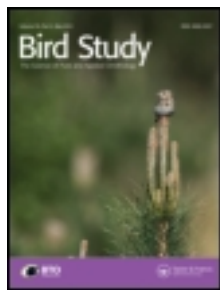


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Publisher: Taylor & Francis

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Bird Study

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tbis20>

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Published online: 16 Jan 2014.

To cite this article: Maurizio Sarà, Daniela Campobello, Laura Zanca & Bruno Massa, Bird Study (2014): Food for flight: pre-migratory dynamics of the Lesser Kestrel *Falco naumanni*, Bird Study, DOI: [10.1080/00063657.2013.867476](https://doi.org/10.1080/00063657.2013.867476)

To link to this article: <http://dx.doi.org/10.1080/00063657.2013.867476>

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Food for flight: pre-migratory dynamics of the Lesser Kestrel *Falco naumanni*

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Capsule The post-reproductive stage of Lesser Kestrel is crucial for migratory fuelling and survival.

Aims To describe the summer pre-migratory ecology of the Lesser Kestrel in Sicily and review existing data in Southern Europe.

Methods We identified the main summer roosts and then made roost counts every ten days from 2010 to 2012. We used case-sensitive modelling procedures to detect biases in counts (generalized linear mixed models), assess the annual population trends from 2005 to 2012 (Trends and Indices for Monitoring); and to model habitat preferences (generalized linear model). We sampled pellets to describe the birds' diet during the peak month prior to migration.

Results We discovered five roosts in Sicily with numbers of Lesser Kestrels varying annually (mean \pm sd: 2112 \pm 387; min–max: 1797–2544). Counts at the main roost were not biased by meteorological conditions and showed an August peak followed by persistent decline through October. Less urbanized and heterogeneous agricultural areas with large cereal fields were the most significant habitats preferred during summer. Within this landscape, Lesser Kestrels prey on seasonally high concentrations of the small cricket *Grylloderes brunneri*.

Conclusion Arable land not fragmented by agricultural intensification supports habitat rich with Orthopterans and attracts a large number of Lesser Kestrels fuelling before migration. Conservation of such pre-migratory habitats is as vital as conservation of breeding areas.

The evolution and maintenance of migratory behaviour is one of the most fascinating aspects of bird ecology (Alerstam 1990, Berthold 1996, Alerstam *et al.* 2003). Migration requires an increased amount of energy and so an accumulation of fat reserves. This can be achieved by maintaining a positive energetic balance between food consumption and the energetic cost of living during the pre-migratory period (Aparicio 1990a, Berthold 1996). All 38 of continental Europe's breeding raptors perform complete or partial migration (Zalles & Bildstein 2000). The Lesser Kestrel (*Falco naumanni*) is a small colonial falcon which breeds in Southern Europe and spends the winter in Africa (Cramp & Simmons 1980). It is considered as a partial migrant because a small proportion of the population occasionally overwinters in the breeding area (Cramp & Simmons 1980; Zalles & Bildstein 2000).

A considerable amount of research has been conducted in recent years on habitat selection and breeding ecology of Lesser Kestrels in the Iberian Peninsula and France with the aim of promoting concrete conservation actions for this species, which in turn have allowed the recovery of Lesser Kestrel populations (Iñigo & Barov 2011) resulting in its down-ranking from 'vulnerable' to a 'least concern' species (IUCN 2011). Outside the Iberian Peninsula, the ecology and distribution of the Lesser Kestrel is virtually unknown, despite the numerical importance of population in some other southern European (Italy, Greece) and Middle Eastern countries (Iñigo & Barov 2011). Consequently, we commenced a research project on Lesser Kestrel ecology and distribution in the Italian island of Sicily (Sarà 2010, Campobello *et al.* 2012, Sarà *et al.* 2012, Di Maggio *et al.* 2013) aimed at filling this gap.

Advances in tracking technologies, such as geolocators and satellite tags, have recently allowed more detailed

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investigations of the migratory ecology of Lesser Kestrels, prompting the discovery of wintering sites in Africa (Rodríguez *et al.* 2009, Catry *et al.* 2011, Limiñana *et al.* 2012). Several aspects of Lesser Kestrel migration, however, remain unknown. For example, in many species, birds of different sex and age classes may migrate different distances, by different routes, or on different schedules (Cristol *et al.* 1999), or they may show a pronounced pre-migratory behaviour, referred to as intermittent or intermediate migration, that is not directed towards the African overwintering quarters (Berthold 1996). In the Lesser Kestrel, although the sequential arrival of adult males, adult females and subadult birds to the breeding colonies has been recorded (Serrano *et al.* 2003), no data have been reported on whether there is an age or sex-related timing of departure to the wintering grounds and intermediate migration has been studied only in one Northern Spanish area (Olea 2001, Olea *et al.* 2004, De Frutos & Olea 2008). Therefore, we examined aspects of the pre-migratory ecology of Lesser Kestrels and compared the resulting patterns in one Mediterranean area to Temperate Spanish data in order to attempt to generalize for this biological stage for Lesser Kestrel across Southern Europe. Accordingly, the main aims of this investigation were: (i) to describe the temporal (i.e. annual, monthly and daily) pattern of roost use by Lesser Kestrels; (ii) to quantify their diet and habitat preference during the summer period; (iii) to assess the sex and age composition of the population in relation to migration timing; (iv) to assess the origin of the population gathering in the area by colour-ring readings; and finally (v) to highlight the conservation implications of these results for the pre-migration period.

METHODS

Counts and study area

The main study area (37°777'N; 13°118'E) was an agricultural landscape in North-western Sicily. Mainly devoted to cereal, forage and vineyard cultivation, it includes an artificial dam of some 500 ha, small seasonal streams with riparian vegetation and a karsts plateau: the Special Area of Conservation 'ITA 020042 – Rocche di Entella'. Remnants of natural vegetation, belonging to Thermo-Mediterranean shrub formations and Mediterranean xeric grasslands, are still present on the relief slopes. Most public land natural vegetation has been replaced by reforestation with *Eucalyptus* plantations.

During 2002–2004, concentrations of 100–150 Lesser Kestrels were reported in the main study area, where none or a few (1–10) breeding pairs were present in spring. In 2005, we began an intensive exploration of the area by car transects and were able to discover a large area used by Lesser Kestrels for foraging, some day perching sites and the roosting site (hereafter the 'main roost'). We also selected the best vantage point from which to count birds converging at dusk for the main roost, a large *Eucalyptus* wood bordering an artificial lake. During the surveys in 2005–2008, we made an average of 4 (min–max: 2–7) counts per year in August and September from the vantage point.

Seasonal and daily trends of roost use

To assess the seasonal and daily trends of roost use, in 2010–2012, we monitored the main roost every ten days from 20 June to 20 October. From the vantage point, we counted the Lesser Kestrels crossing over the lake to reach the main roost for 3–4 hours before sunset. Data were recorded every 5 minutes in the field but after were pooled into 30 minute bins to express the daily trend across the season. Our detection effort was constant over time and space (i.e. always the same two observers in the same place, at the same time of the day at ten day intervals). Nevertheless, barometric pressure, visibility or other meteorological conditions may have influenced bird behaviour and/or their detectability, therefore potentially biasing counts (Conroy & Carroll 2009). To control for counting errors due to field meteorological conditions, we performed a generalized linear mixed models (GLMM) analysis (McCullagh & Searle 2000). We modelled the response variable (the total number of birds counted every ten days) assuming a Gaussian distribution of error and an identity link function. We controlled for the potential non-independence of counts made within the same ten day interval, considering the Julian day as a random-effect factor, so producing a randomized complete block design to avoid pseudo-replication. The following meteorological conditions during the time of recording (namely, the focal conditions) were the covariates modelled as fixed-effect parameters: atmospheric pressure, relative humidity, wind speed and cloud cover. Nine daily measurements (every half hour from 16.20 to 20.20, from www.eurometeo.com) were averaged every date of counting to obtain quantitative data of focal meteorological conditions.

We discovered two perching sites (electric lines and single *Eucalyptus* trees), 3.9 and 5.7 km away from the main roosting site, where groups of Lesser Kestrels rested during the day. Every count-day we stopped, in rotation at either place, for 60–90 minutes to record from a hide the age class and sex of the perching Kestrels and search for individuals that had been colour-ringed during our long-term study on breeding populations (Sarà 2010, Di Maggio *et al.* 2013) and in Southern Italy (Sigismondi *et al.* 2003). Lesser Kestrels were sexed and aged (cf. Forsman 1999) according to their body and upper-wing feather colours as: male adults (cy, calendar year ≥ 3), males subadults (cy = 2), females (cy ≥ 2) and juveniles of the year (cy = 1). At each visit to the day perching sites, we quantified the sex ratio (M/F), the male age ratio (i.e. male subadults/male adults: MSAD/MAD) and the juvenile ratio (i.e. first cy juveniles/all adults plus subadults: [JUV/(AD + SAD)]). We then classified sexed and aged birds into two sample periods reflecting the two halves of the pre-migratory season (period 1 from the arrival in the area to the peak of numerical concentration = 1 July–20 August; period 2 from the peak period to departure = 21 August–20 October). Sampling at the day perching sites allowed us to determine the population origin of colour-ringed Lesser Kestrels and whether the sex and age class composition of the population changed during the pre-migratory stage and so whether departure sequence for autumnal migration was dependent on age or sex. Therefore, we performed three separate one-way ANOVA analyses with sample period (1/2) as fixed factor and sex, male age and juvenile ratios as dependent variables. The ANOVAs were conducted on only 14 visits during which at least ten Lesser Kestrels were recorded in one of the two perching sites used during the day.

Population annual trend

Counts performed in August–September of 2005–2008 provided Lesser Kestrel numbers comparable to those intensively recorded in similar dates of 2010–2012 (Wilcoxon Matched Pairs Test $Z = 1.2$; $P = 0.23$; $n = 7$). Therefore, we decided to use the highest counts of birds during the whole period 2005–2012 for assessing the population trend of Lesser Kestrels in the main study area. We used TRends and Indices for Monitoring (TRIM) data (Pannekoek & Van Strien 2005), software developed for the analysis of count data including missing observations (i.e. year 2009 with zero counts). The variances of these highest

counts were much larger than their means; therefore, they were normalized using a square root transformation. TRIM processes zero counts and replaces missing observations in the dataset with values derived by means of a log-linear Poisson regression, which is a statistical model employing an iteratively re-weighted least-squares algorithm (Ter Braak *et al.* 1994). After fitting the model by generalized estimating equations, the model and its estimated time-effects are used to predict the counts that were missing (Van Strien *et al.* 2004). Indices can then be calculated on the basis of a complete data set with the model-estimated counts replacing the missing counts. It is recommended that data with more than 20–50% missing counts are not to be used (Pannekoek & Van Strien 2005). In our case, only 1 (year 2009) out of 8 annual counts was missing (12.5%) and replaced using the TRIM method. We set the TRIM software options to work out a linear trend model considering the year 2005 as a baseline, in order to test for a trend in the annual highest counts of Lesser Kestrel in the main study area over the period 2005–2012 (Wretenberg *et al.* 2007, Fasola *et al.* 2010).

Land use

In addition to the observations at the main study area, during the summers of 2010–2012, we visited the main artificial lakes in Western Sicily and other study areas in Central and South-eastern Sicily, where most of Lesser Kestrel population is known to breed (Sarà 2008), to search for other roost sites and concentrations of foraging Lesser Kestrels. We used the same protocol for car transects and counts from vantage points as at the main study area during this survey, providing the same sampling effort (e.g. the same observers did 2–4 annual visits per site and transects of 30–50 km at low speed per 10×10 UTM cell at each visit). The coordinates of the discovered roosts and of foraging groups of Lesser Kestrels were recorded in the field using a Garmin Geko 201 GPS, and then placed on 1:50 000-scale maps and assigned to a system of standardized grid cells of equal area based on the Universal Transverse Mercator (UTM) projection.

Predictive models investigating species' habitat preferences usually employ a multi-scale approach to identify the different factors affecting habitat preferences (Johnson 1980) and the choice of scale is dictated by the species' ecology or life history (Mackey & Lindenmayer 2001, Guisan & Thuiller 2005). In all

areas, 95% of Lesser Kestrel records were within 10 km of the roost (mean \pm sd: 4.58 ± 3.06 kms; min–max: 1–15.22; $n = 59$), similar to what De Frutos and Olea (2008) recorded when using radio-tracking techniques. Accordingly, the scale we used was matched to this by using 10×10 km UTM cells to assess the effect of bioclimatic variables and 5×5 km UTM cells to focus on the effects of topography, land use and habitat fragmentation on the presence of pre-migratory concentrations of Lesser Kestrels. We identified the presence of Lesser Kestrels in 16 of the 10×10 km UTM cells and their absence in 14 UTM cells with similar landscape (i.e. artificial lakes with artificial woods in a cereal agri-environment), corresponding to 39 presences and 81 absences in the 120 cells at the 5×5 km UTM scale. Presence and absence plots at both spatial scales were independently sampled to gather information on 17 variables using Geographical Information System (GIS) (Table 1). Land-use variables [three at the first and three at the second

Table 1. List of the 17 explanatory variables used to model the pre-migratory habitat preferences of Lesser Kestrel *Falco naumanni* in Sicily.

Scale	Predictor subset	Variable
10×10 km UTM cells	1. Bioclimatic; $n = 4$	De Martonne aridity index
		Annual ambient temperature (°C)
		Thermal annual excursion (°C)
		Annual accumulated rainfall (mm)
5×5 km UTM cells	2. Topographic and land use; $n = 9$	Range of slope
		Mean altitude a.s.l.
		Range of altitude a.s.l.
		Urban areas, artificial areas and infrastructures (1)
		Arable land (21)
		Permanent crops (22)
		Heterogeneous agricultural areas (24)
		Forests, shrubs, herbaceous vegetation. Open spaces with little/no vegetation (3)
		Wetlands and water bodies (41, 42 and 51)
		3. Habitat mosaic; $n = 4$
n of CLC in the UTM cell (CLC richness)		
n of Patches in the UTM cell (Patch richness)		
		Mean patch size

Note: The corresponding EEA (2000) Coordination of Information on the Environment (CORINE) land cover (CLC) class codes at first and second levels are reported in parentheses.

level of the Coordination of Information on the Environment (CORINE) land cover (CLC) class codes, European Environmental Agency (EEA 2000) were obtained from the APAT (2005) database. All plots were interpolated and processed with CORINE land-cover digital maps of Sicily at scale 1:25 000. Altitude and slope variables were obtained from a digital elevation model with 20-m pixels of horizontal and vertical resolution. Bioclimatic variables were obtained from SCIA (2008). Four variables: (i) land cover richness (i.e. the number of CORINE land covers in an UTM cell), (ii) land cover diversity as calculated by means of the Shannon index, (iii) patch richness (i.e. total number of patches present in a UTM cell), and (iv) mean patch size; redrawn from Forman (1995) represented the mosaic patterns and were extracted using a GIS (Table 1).

The low ratio between the number of statistical units (i.e. the 30 10×10 km UTM cells) with respect to candidate predictors ($n = 17$) would likely produce an inflated probability of detecting spurious correlations (Harrel 2001, Grosbois *et al.* 2008). To avoid over-parameterization and over-fitting problems in our modelling, we separated the whole set of candidate predictors into three subsets (bioclimatic, topographic-land use, mosaic, Table 1) and performed three independent statistical modelling procedures. In addition, interdependence among explanatory variables (multi-collinearity) may hamper model selection, parameter estimation and interpretation of results in regression analyses (Grosbois *et al.* 2008). We therefore checked for multi-collinearity by performing a preliminary analysis of multiple correlations among the candidate variables in each subset and excluding all variables with a Variance Inflation Factor > 7 (i.e. $R^2 > 0.85$). The multi-collinearity test removed 9 variables (3 bioclimatic, 3 topographic-land use, 3 mosaic: not reported in Table 1) from a former set of 26 potential candidates.

The remaining 17 variables, therefore, represent scaled and independent measures of the type and predominance of the environment in the study area. Accordingly, we assumed that they correspond to adequate proxies for modelling the effects of the environmental variables on the Lesser Kestrel pre-migratory habitat preferences in the study area. We used a generalized linear model (GLM; McCullagh & Searle 2000) to build a model in which the response variables were the presence of Lesser Kestrels in the 10×10 and 5×5 km UTM cells respectively, as ranked: 0 = absence in UTM cells at both scales; 1 =

presence of Lesser Kestrels in a 10×10 km cell or of 1–5 records in a 5×5 km cell; 2 = presence of Lesser Kestrels in a 10×10 km cell or > 5 records in a 5×5 km cell.

Since response categories were ordered with respect to an increasing degree of species' presence, we assumed an ordinal multinomial error distribution and a logit link function and performed a GLM for each subset of continuous predictors as reported in Table 1. In order to evaluate the explanatory power of each logistic regression model, we identified the best set of variables contributing to the occupancy of Lesser Kestrel in an UTM cell by the Akaike's information criterion (AIC; Akaike 1973). All possible models were evaluated by ranking them from the lowest to the highest and computing the difference between each model's AIC value and the best model the (Δ AIC). Finally, the Akaike model weight (AICw) was obtained by averaging the first 30 ranked models so that the sum of weights over the set of candidate models was 1 (Burnham & Anderson 2002, Conroy & Carroll 2009). Models were then compared by the Likelihood Ratio (LR; χ^2 test) and AIC values. Differences in AIC values were interpreted in terms of their relative support to the data following a simple rule of thumb (Burnham & Anderson 2002). If two models differed by less than two AIC points, they were considered as getting nearly identical support from the data. To check whether ecologically relevant interactions between predictors could have a meaningful influence on the occupancy of Lesser Kestrels, we also considered second-degree and third-degree factorial regression design introducing the terms: accumulated rainfall \times annual ambient temperature in the bioclimatic model; altitude range \times slope range and arable land \times forest \times wetlands in the topographic-land use model. The first-ranked variables (i.e. all those within the two AIC points drop) in each logistic model were then selected and the same procedure was repeated to obtain the final best set of models predicting the occupancy of Lesser Kestrels.

Environmental variables were standardized (to mean 0 and variance 1) to eliminate the effect of differences in the original scale of measurement. Statistical significance was set in all analyses at $P < 0.05$, and means \pm standard errors (se) are reported. Statistics were computed in STATISTICA 8.0 (www.statsoft.com)

Diet

At the main roost site, at the end of July of 2010 and 2012, we cleaned patches of ground below the roosting

trees and collected samples of unbroken pellets (>100) putting them in separate plastic bags to avoid mixing the material, until the end of August 2010 and 2012. The samples thus correspond to the diet of individuals during August and include the peak period of presence in the area. For assessing a sample of pellets representative of diet in both years, we used explicit statistical sample modelling based on species accumulation curves (Colwell *et al.* 2012). Pellets are sampling units, similar to plots and quadrats, within which the number of prey for each species can be estimated. Therefore, we used the approach referred to as 'sample-based abundance of data' for interpolation and extrapolation of data from the empirical reference samples (Colwell *et al.* 2012). To estimate the form of the underlying species accumulation curves and the related parameters, we used iNEXT (Hsieh *et al.* 2013). In particular, we used C_t that is the estimated rarefaction sample coverage value for a function with sample size t , where t goes from 1 to 100 pellets, and LCL and UCL are the 95% bootstrap confidence lower and upper limits for C_t . In the context of a rarefaction curve, lack of overlap between the C_t 95% confidence limits can be used as a simple but conservative criterion of statistical difference at $P \leq 0.05$ (page 19 in Colwell *et al.* 2012).

Identification of prey from pellets of kestrel species is difficult because these raptors dissect their prey. Insect fragments may be identified at the species level only by comparison of the small chitinous pieces with entomological collections (Rizzo & Massa 1995) and with dissected sample collections of the species commonly present in the study area (Massa 2011). Pellets were dry-dissected in laboratory under magnification using a Wild M5 Stereomicroscope. Every mandible was paired with its partner, and each head, fragment of legs and aedeagus was isolated, so that it was possible to count the total number of specimens in every pellet. Although identification was possible in many cases, some fragments remained unidentified. These were photographed with different focal planes using a Nikon Coolpix 4500 digital camera, mounted on the Wild M5 Stereomicroscope and integrated from the in-focus areas of each image, using the freeware Combine ZP (Hadley 2008). The procedure created a composite image with an extended depth of field that facilitated the classification of unidentified fragments. Such photographs were then posted to the forum Entomologistaliani.it, where the specimens were identified.

RESULTS

Counts and population trends

Counts from the vantage point of birds flying to the main roost were normally distributed (Shapiro-Wilk = 1.0; $df = 33$; $P = 0.30$) and the GLMM test of the whole model did not reveal any significant effect of meteorological conditions during field counts ($F_{5,37} = 0.4$; $P = 0.84$), or significant effects of any of the single focal covariate (air pressure: $P = 0.96$; relative humidity: $P = 0.94$; wind speed: $P = 0.23$; cloud cover: $P = 0.88$) or the random effect (Julian day: $P = 0.73$).

Counts at the main roost were 2261 Lesser Kestrels in 2010; 1665 in 2011; and 1692 in 2012. At the newly discovered four additional small roosts, we recorded a variable annual number of Lesser Kestrels (283 in 2010, 330 in 2011 and 105 in 2012). Total maximum counts of Lesser Kestrels among all five roosts over this period ranged therefore from 2544 birds in 2010 to 1797 in 2012.

In 2010–2012, the cumulative number of birds flying to the main roost-site over the ten day periods showed considerable seasonal variation (Fig. 1). First arrivals were in July and then Lesser Kestrel numbers increased in August, with a maximum concentration of individuals mid-August, after which, the population began to decline and the last individuals (< 100) left the area by the 20th October (Fig. 1). As day-length shortened, birds gathered and flew earlier to the roost at a set time before sunset, with a 30-minute peak

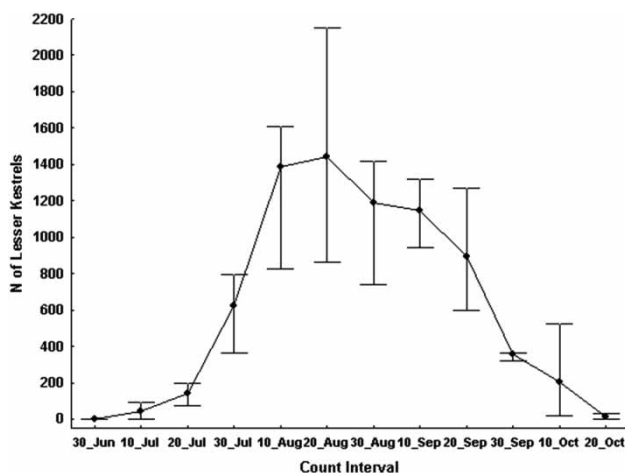


Figure 1. Average number of Lesser Kestrels counted at the main roost site through the period 2010–2012 from the third ten day interval of June (30 June) to the second ten day interval of October (20 October). Vertical bars denote upper and lower confidence limits.

passage about 1.5 hours before darkness (i.e. from 19:30 in early August to 17:30 in early October).

At the day perching sites of the main study area, we recorded 890 birds, accounting for 4% of the total birds ($n = 22\,804$) counted at the vantage point. The number of males was always slightly higher than females (Table 2), but we did not record any significant effect of period on sex ratio ($F_{1,11} = 0.01$; $P = 0.94$). Nearly 90% of the males censused were adults (Table 2), with no statistically significant change ($F_{1,12} = 1.9$; $P = 0.20$) in the ratio of subadults to adults from the first (1 July–20 August) to the second (21 August–20 October) period of observation. The representation of first cy birds relative to the number of adults and subadults decreased in the second period of observation, close to statistical significance ($F_{1,11} = 3.7$; $P = 0.08$). At the perching sites we read nine rings belonging to seven adult males, one adult female and one first cy bird, all of which were ringed in our study area in Southern Sicily. Three ringed males were repeatedly seen within the seasons in 2010 and 2012 (min–max: 15–28 days) indicating that at least some individuals were using the area for most of the pre-migratory period.

Annual variation in the 2005–2012 maximum counts of birds had an acceptable estimated overdispersion (0.7; good if values < 4) and serial correlation (–0.2; good if < 0.4). Model data fitted a log-linear Poisson distribution ($\chi^2 = 3.6$; $df = 5$; $P = 0.60$) and LR (LR = 5.2; $df = 1$; $P = 0.40$). The overall slope of the model was 1.03 ± 0.02 , corresponding to a slight increase of 2.8% for the population gathering in the main study area from 2005 to 2012.

Land use

The analysis of bioclimatic data at the 10×10 km scale yielded no significant combinations (χ^2 with $P > 0.05$) of the five bioclimatic variables, which were ranked in seven models within the two AIC points drop and had equivalent AIC weights (Table 3). This revealed that climate predictors did not determine the probability of finding a UTM cell occupied by a roost or a summer concentration of Lesser Kestrels. At the 5×5 km scale, the extent of urban, artificial areas plus arable lands and the extent of the former uses plus heterogeneous agricultural areas have both more support from the data and significantly predicted the occupancy of Lesser Kestrels in the topographic and land use subset (Table 3). Interestingly, the concomitant presence in

Table 2. Sex and age composition of the sample of Lesser Kestrels observed in the daily temporary roosts of the main study area (Rocca d'Entella, Sicily) during the two halves of the pre-migratory period.

	First period (1 July–20 August)	Second period (21 August–10 October)	Total season	<i>n</i>
Sex ratio (M/F)	1.2 ± 0.3	1.2 ± 0.2	1.2 ± 0.1	607
Male age ratio (MSAD/MAD)	0.1 ± 0.1	0.1 ± 0.1	0.2 ± 0.1	337
Juvenile ratio [JUV/(AD+SAD)]	0.6 ± 0.1	0.3 ± 0.1	0.5 ± 0.8	890

Notes: MSAD, subadult male; MAD, adult male.

three out of the five pre-migratory concentration areas, of arable land, artificial lake and *Eucalyptus* wood was ruled out by modelling, because the additive effect of arable land, forests and water bodies ranked at 157th place ($\Delta\text{AIC} = 7.5$; $\text{AICw} = 0$), while the interaction among the three variable had an even worse performance (rank = 212; $\Delta\text{AIC} = 10.4$; $\text{AICw} = 0$). In the third subset, summarizing the pattern of land uses and habitat patches in the 5×5 km UTM cells, four additive combinations of three variables were selected as getting more support from the data. The first ranked and with the largest AICw model included the number of CORINE land uses (CLC richness) plus the CLC diversity, this latter as expressed by the Shannon index. The second model encompassed also the patch

richness, i.e. the total number of patches in a 5×5 UTM cell. CLC diversity plus patch richness and CLC diversity alone ranked, respectively, as the third and fourth models (Table 3).

Further modelling including all the six first-ranked variables resulted in a final model which selected the extension of arable and artificial areas and the CLC richness as the very best model (Table 3). The highest concentrations of foraging Lesser Kestrels were found in 5×5 km UTM cells with lesser extensive artificial areas, more extensive arable land and fewer land uses (Fig. 2).

Within the agro-environments of Sicily, Lesser Kestrels used thickets or large *Eucalyptus* reforestation and electric lines crossing the fields, similar to other

Table 3. The best sets of variables which had the highest explanatory power for predicting the habitat preference of Lesser Kestrel during the pre-migratory season.

Rank	Variable	df	AIC	ΔAIC	AICw	χ^2	<i>P</i>
<i>10 × 10 km scale</i>							
Bioclimatic subset							
1	Temperature × rainfall	1	68.0	0	0.16	2.7	0.26
2	Aridity index	1	68.5	0.5	0.12	2.1	0.35
...
7	Thermal excursion + temperature × rainfall	2	69.9	1.9	0.06	4.8	0.31
<i>5 × 5 km scale</i>							
Topographic and land use subset							
1	Artificial + arable areas	2	157.3	0	0.22	58.8	<0.001
2	Artificial + arable + heterogeneous areas	3	159.4	2.0	0.08	60.8	<0.001
Habitat mosaic subset							
1	CLC richness + CLC diversity	2	175.6	0	0.32	40.5	<0.001
2	CLC richness + CLC diversity + patch richness	3	177.0	1.4	0.16	43.1	<0.001
3	CLC diversity + patch richness	2	177.4	1.8	0.13	38.7	<0.001
4	CLC diversity	1	177.6	2.0	0.12	34.5	<0.001
Final subset							
1	Arable + artificial areas + CLC richness	3	151.2	0.0	0.17	62.9	<0.001
2	Arable + artificial areas + CLC richness + CLC diversity	4	151.8	0.6	0.13	64.3	<0.001
3	Arable + CLC richness	2	152.8	1.6	0.08	59.3	<0.001
4	Arable + artificial areas + CLC richness + patch richness	4	153.1	1.9	0.07	63.0	<0.001
5	Arable + artificial + heterogeneous areas + CLC richness	4	153.2	2.0	0.06	63.0	<0.001

Notes: Models were ranked by lower ΔAIC and greater Akaike weight (AICw) and the statistical significance of their effects was expressed by the likelihood ratio test (χ^2). All significant ($P \leq 0.05$) models differing less than two AIC points ($\Delta\text{AIC} \leq 2$) have been reported, since they have identical support from the data. Seven bioclimatic models have been ranked within two AIC points, but all proved to be not significant ($P > 0.05$) and for brevity only the extreme models have been reported. Short forms of variables listed in Table 1 have been used; CLC = CORINE land cover.

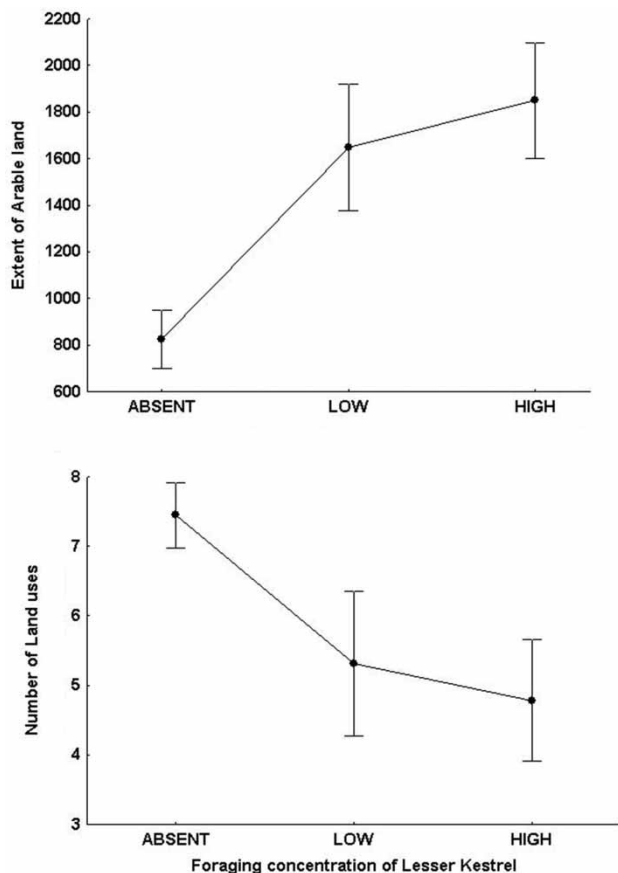


Figure 2. The opposite effect of two of the variables with the largest explanatory power in modelling the summer habitat preferences of Lesser Kestrels. Foraging concentrations increase with the extent of arable land (above) and decrease with the number of CORINE land uses in a 5×5 km UTM cell (below). Other significant variables not reported here (e.g. extent of artificial areas, see text and Table 3) have a negative effect like the number of CORINE land uses. Low = 1–5 records, High = >5 records of Lesser Kestrel flocks in a UTM cell.

populations in France, Spain, Albania and continental Italy (Table 4).

Diet

In 2010, the C_t estimated rarefaction sample coverage value for a function with sample size of 50 pellets was $C_{t50} = 0.92$ (LCL–UCL: 0.87–0.96), whereas for 100 pellets the C_t sample coverage reached the value of $C_{t100} = 0.95$ (LCL–UCL: 0.90–1.00). A similar figure occurred in 2012, with $C_{t50} = 0.93$ (LCL–UCL: 0.82–0.98) and $C_{t100} = 0.95$ (LCL–UCL: 0.90–0.99). Furthermore, in both years the C_{t50} and C_{t100} confidence limits overlapped. Therefore, we considered 50 pellets per year as a representative sample of Lesser

Kestrel diet, because continuing sampling until 100 pellets would have added a negligible 3.3% and 2% of information in 2010 (i.e. from 0.92 to 0.95) and 2012, respectively. From the analyses of the two 50-pellet samples, we obtained 1211 prey in 2010 and 958 in 2012 (Table 5). During August, Lesser Kestrels had a very homogeneous diet. Insects proved to be the most abundant items in the pellet samples, of which Orthoptera were the main prey, accounting for 99.0% in 2010 and 98.6% of the prey in 2012. Apart from some species of grasshoppers represented by tens of specimens (i.e. *Aiolopus strepens*), the diet of Lesser Kestrels consisted of large numbers of the small cricket *Grylloderes brunneri* (total length 19–21.7 mm, dry weight 0.22 ± 0.08 g, Massa *et al.* 2012). This was the main prey in both years (Table 5) with an average of 22.5 ± 6.0 (0–32) individuals per pellet in 2010 and 17.7 ± 8.4 (0–31) in 2012. Considering on average 1870 Lesser Kestrels present in the main study area during August of 2010 and 2012, and an average daily production of 1.8 pellets (Aparicio 1990b), every one containing an average meal of 20 *G. brunneri*, we could extrapolate our results to a gross estimate of >2 million (around 450 kg in dry weight) *G. brunneri* crickets consumed in one month.

DISCUSSION

Few studies have investigated the pre-migratory stage in birds (Fliege 1984, Van der Winden *et al.* 2010, 2012, Portugal *et al.* 2012), and particularly in colonial raptors (but see Limiñana *et al.* 2008). Summer concentrations of Lesser Kestrels were documented in Northern Spain (Olea 2001, Olea *et al.* 2004), but we have found them as a broad phenomenon occurring across the species' Southern European range (cf. Table 4). We identified five late summer roosts in Sicily. Counts were reliable because we standardized the sampling method and their variability was not affected by weather conditions. Nonetheless, counts likely underestimated the population, because Lesser Kestrels are able to fly in darkness (Limiñana *et al.* 2012) and hence could arrive at the roosts well after the sunset (Kopji 2002), long after our observations ceased.

The maximum concentration of birds in our sample area varied among years without an evident population trend in the 2005–2012 period. Annual variability in the abundance of birds gathering at the roosts and the duration of their pre-migratory stage across years is a pattern common to other study sites (Olea *et al.* 2004, Lelong & Riols 2009) and might be related to the

Table 4. Type of roost and estimated number of Lesser Kestrels observed during the intermittent migration in the Southern Palaearctic areas.

Geographic site	<i>n</i> Birds	Type of roost	Notes and references
Drino valley (Albania)	4000–6000	Trees and electric lines	July 2008. Minas <i>et al.</i> (2009)
Boulquère, Eastern Pyrenees (France)	33–220	Electric pylons	Site known since 2005. Lelong and Riols (2009)
Boulquère, Eastern Pyrenees (France)	1500–1600	Electric pylons	August–September 2012. Debois <i>in verbis</i>
11 localities in Southern (France)	153–1200	Trees and electric lines	Site known since 2005. Lelong and Riols (2009)
Matera, Basilicata (Italy)	1200–2100	Pine trees	Site known since 1990. Palumbo (1997), Visceglia <i>in verbis</i>
Matera and four others localities in Apulia and Basilicata (Italy)	10 138–16 764	Pine trees	Site known since 1993, Sigismondi <i>et al.</i> (2003)
Passo del Cornello, Umbria (Italy)	>100	<i>Pinus nigra</i> reforestation wood	September 2000. Gaggi and Paci (2008)
Rubino and three others localities in western and central Sicily (Italy)	110–350	<i>Eucalyptus</i> spp. thickets and electric lines	This study, 2010–2012
Rocca D'Entella, western Sicily (Italy)	1100–2200	<i>Eucalyptus</i> spp. woods and electric lines	This study, 2005–2012
Santas Martas y Sahagun, León (Spain)	761–925	Trees or electric pylons	4–5 roosts in 2001. Olea <i>et al.</i> (2004)
2 localities in Navarra (Spain)	≈3000	Electric pylons	Late September 2000. Ursúa & Tella (2001)
Badajoz, Extremadura (Spain)	3500–4000		Late August 2011. Sanchez <i>in</i> Molina <i>et al.</i> (2011)
La Vera, Extremadura (Spain)	595–1000	Electric lines	Late August 2009 and 2011. Gómez <i>in</i> Molina <i>et al.</i> (2009, 2011)

Table 5. Lesser Kestrel diet during August 2010 and 2012 as determined by 50 pellets collected per year in the main study area.

	2010		2012	
	<i>n</i>	%	<i>n</i>	%
<i>Microtus savii</i>	2	0.2	2	0.2
MAMMALIA	2	0.2	2	0.2
<i>Trochoidea trochoides</i>	0	0.0	2	0.2
MOLLUSCA GASTROPODA	0	0.0	2	0.2
Tenebrionidae	1	0.1	0	0.0
Coleoptera spp.	6	0.5	1	0.1
<i>Thorectes intermedius</i>	1	0.1	1	0.1
<i>Pentodon bidens</i>	1	0.1	3	0.3
Curculionidae Cleoninae	0	0.0	2	0.2
Carabidae	1	0.1	0	0.0
COLEOPTERA	10	0.8	7	0.7
<i>Calliptamus barbarus</i>	0	0.0	10	1.0
<i>Aiolopus strepens</i>	62	5.1	35	3.6
<i>Oedipoda miniata</i>	4	0.3	4	0.4
<i>Chorthippus</i> sp.	1	0.1	3	0.3
<i>Locusta migratoria</i>	0	0.0	5	0.5
<i>Acrida</i> sp.	1	0.1	0	0.0
<i>Grylloderes brunneri</i>	1126	93.0	884	92.3
<i>Eyprepocnemis plorans</i>	4	0.3	1	0.1
<i>Platycleis</i> sp.	0	0.1	5	0.5
ORTHOPTERA	1198	99.0	947	98.5
TOTAL PREY	1211		958	

Notes: *n*, total number of items found in a sample of 50 pellets; %, percentage of specific prey items on the total prey items.

birds' body condition and performance during the preceding breeding seasons. For example, early breeders, failed pairs or non-breeding subadults are likely to leave the breeding area in advance of later successful breeders. A seasonal trend, however, is consistent across geographical regions, despite potential biases in data collection due to variability of methods, sampling efforts and number of observers employed in different study areas. First arrivals in the pre-migratory areas and occupancy of the roost-sites occur in mid-through end-July. The bulk of the population arrives later, with the highest concentrations occurring between 1 August and mid-September. In southern France, the peak period lasted only 5–7 days (Lelong & Riols 2009), thus is much shorter than the 40–45 days recorded near León (Spain, Olea *et al.* 2004) or the 20–30 days now documented for Sicily. After the annual peak, the number of individuals at the roost-sites declines. In Spain, the last Lesser Kestrels were recorded at the end of September, whereas in Sicily they stayed until 11–20 October. All such departure dates are consistent with the migration timing of Lesser Kestrels whose movements were tracked by geolocators and satellite tags (Cstry *et al.* 2011, Limiñana *et al.* 2012). Lesser Kestrels irregularly overwinter in Sicily (Lo Valvo *et al.* 1993), thus in

some years, the few tens of individuals detected in October could possibly be birds that spend the winter on the island. The sex and age composition of the sampled population did not differ significantly between the first and second parts of the pre-migratory period. It is thus likely that all departing flocks are composed of a comparable quantity of birds of different sex and ages. This result contrasts the earlier mass departures towards overwintering grounds of juvenile birds recorded among other species of short distance and partially migrant raptors (Newton 1979, Kjellén 1992). If this is the case also in our study area, it may require more intensive sampling to detect an age effect on departure timing from late August onwards.

Ringed records and geolocators confirmed a pre-migratory journey of Portuguese birds towards Southern France (Lelong & Riols 2009, Catry *et al.* 2011). In continental Italy, Lesser Kestrels spend the summer in the *Festuco-Brometalia* highlands of central and northern Apennines where they are absent for the rest of the year (Papa 1997, Gaggi & Paci 2009). Two of our ring recoveries showed that at least some Sicilian Lesser Kestrels also carried out a northward migration to these highlands. If the recovery of one of our rings in Senegal is indicative of the wintering grounds of our population (Pilard *et al.* 2009), the Sicilian population may leave the island in two main directions by crossing: (i) the Sicily Channel to Tunisia (Massa 1992); and, (ii) the Messina Strait to central Italy. Whether they reach the south-eastern coast of Spain from this latter area and then cross the Mediterranean to northern Africa (Limiñana *et al.* 2012), or alternatively, they come back to Sicily before crossing the Sicily Channel still remains an open question.

According to our models, during their summer pre-migratory periods, Lesser Kestrel preference was best predicted by a few environmental variables mostly related to an open agro-environment with flat lowlands and large cereal fields. This result is in accordance to preferences shown by Spanish populations that selected farmland and, at finer scale, cereal stubbles, but that avoided ploughed fields and irrigated crops (De Frutos & Olea 2008). In addition, our Lesser Kestrels avoided the excessive fragmentation, typical of intensively cultivated open landscapes (EEA 2011), as shown by the negative estimates of both the CLC Shannon diversity index and of the number of CLC classes in the UTM cells. Food availability has commonly been argued to be the factor underlying the negative relationship between

farmland bird abundance and agricultural intensification (Benton *et al.* 2002, Newton 2004). This latter often goes hand in hand with degradation of the quality of the remaining habitat due to landscape fragmentation and the removal of diverse typical landscape features (EEA 2011). Therefore, the preference for less fragmented habitat among Lesser Kestrels in our study area is possibly related to the availability of prey, and thus to the quality of the foraging grounds. The massive predation of Lesser Kestrels upon *G. brunneri* would be consistent with this. The availability of very large numbers of flightless crickets seems likely to be the reason for the extended Lesser Kestrel presence in the study area. The summer phenology of Lesser Kestrels thus allows them to capitalize on this abundant cricket prey within a localized area of Sicily to gain the energy necessary to fuel their trans-Saharan migration. The exploitation of seasonal and local Orthopteran outbreaks, including that of the Italian locust (*Calliptamus italicus*; Lelong & Riols 2009), or the mole cricket (*Gryllotalpa gryllotalpa*; Gaggi & Paci 2009) is perhaps a common foraging strategy for Lesser Kestrels during the pre-migratory stage. The foraging strategy used in summer is consistent with findings showing a specialist predator-prey relationship between Lesser Kestrels and Orthoptera during the breeding season (Rodríguez & Bustamante 2008).

Two non-mutually exclusive explanations have been put forward to explain the importance of intermittent migration for Lesser Kestrels in Southern Europe. The primary reason for intermittent migration of Lesser Kestrels in the Southern Palaearctic seems likely then to be the search for favourable feeding grounds that leads birds to climatically advantageous areas with plentiful and predictable food resources for migratory fuelling (Olea 2001, Barlein & Hüppop 2006). Another hypothesis suggests that prospective suitable living space or future breeding sites might be other resources searched for during intermittent migration by Lesser Kestrels (Olea 2001) and other raptors (cf. Limiñana *et al.* 2008).

It has been already argued that conservation efforts addressed only to part of the life-cycle of migratory species may be inefficient, since pressures occurring in areas or stages different from the breeding ones may severely affect a population (Sutherland 1996, Martin *et al.* 2007). In the case of the Lesser Kestrel, the pre-migratory stage involves the mass aggregation of thousands of birds in small and peculiar habitats within the species' range. Therefore, a sort of

population bottleneck could potentially limit Lesser Kestrels to a few hotspots exposing populations to a variety of threats such as extreme climatic events (Taljaard & Anderson 1994) or habitat destruction (DEMA 2005). As regards to habitats used during summer in Southern Europe, other than traditional arable land, most are semi-natural habitats like Mediterranean xeric grasslands (EUNIS Classification: E1.3) and *Festuco-Brometalia* calcareous grasslands (EUNIS Classification: E1.2). Both are priority and high biodiversity habitats, threatened by several anthropogenic impacts (Wallis De Vries *et al.* 2002, Bota *et al.* 2005, Calaciura & Spinelli 2008, San Miguel 2008). For instance, the management of calcareous grasslands affects Orthopteran diversity, with a 50% decrease in very intensively managed meadows (Marini *et al.* 2008, 2012). Thus, temporary pre-migratory areas could represent the Achilles' heel of the Lesser Kestrel, negating years of positive conservation actions in the breeding range (Iñigo & Barov 2011). Conservation of the species clearly requires measures to identify and maintain an ecologically coherent network of both breeding and summering areas.

ACKNOWLEDGEMENTS

We greatly thank Marcello Romano, manager of the forum Entomologicaliani.it, for his assistance during the identification of some prey remains posted in the forum web page. Stefano Triolo helped with GIS analyses and field work. James Hare provided valuable comments and revised the English of the manuscript. Two anonymous referees made valuable suggestions for improving an earlier version of the manuscript.

FUNDING

This project was supported by the Italian Ministry of Education, University and Research [PRIN 2010/2011, 20108 TZKHC].

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(MS received 13 August 2013; revised MS accepted 31 October 2013)