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Brief report

New evidences confirm that during the breeding season Lesser Kestrel is not a strictly diurnal raptor

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Although Lesser Kestrel *Falco naumanni* is considered a typically diurnal species, in a previous study we have provided the first report on its nocturnal activity in Italy even in rural areas with no artificial illumination. In this study, using new, more complete and balanced data we provide further evidences that during the breeding season Lesser Kestrel is not a strictly diurnal species. Using accurate GPS data-loggers on Lesser Kestrels belonging to the two colonies of Gravina in Puglia and Altamura (Apulia region; Southern Italy), we have registered widespread nocturnal flights with distances from nests up to 15 km. At night, all of the surveyed Lesser Kestrels were active even in areas with no artificial illumination, and they were found in flight for about 25% of the tracking time. By comparing night-time and daytime periods, we found significant differences for three flight attributes: 1-minute flight length, distance from nest and distance from nearest roost. Instead, we found no significant differences in flight attributes between males and females and between the two colonies at night. We propose and discuss several plausible explanations for detected Lesser Kestrels' nocturnal flight activities.

1. Introduction

The Lesser Kestrel (*Falco naumanni*) is a colonial, small falcon which has declined markedly in the last decades, mainly because of agricultural intensification and use of pesticide which affect its foraging habitats and food availability (BirdLife International 2004).

The Lesser Kestrel is considered a typically diurnal species (Cramp & Simmons 1980), and little is known about its nocturnal activities. Liminñana *et al.* (2012) found that Lesser Kestrels migrated mainly during the day, although some travelling segments also occurred at night. In a posterior study, Limiñana *et al.* (2013) confirmed their previous results about nocturnal migration. Only two studies focussed on this topic at local scale (Andrada & Franco 1974, Negro *et al*. 2000), but they were conducted in an urban area (Seville, Southern Spain) with artificial lighting conditions,

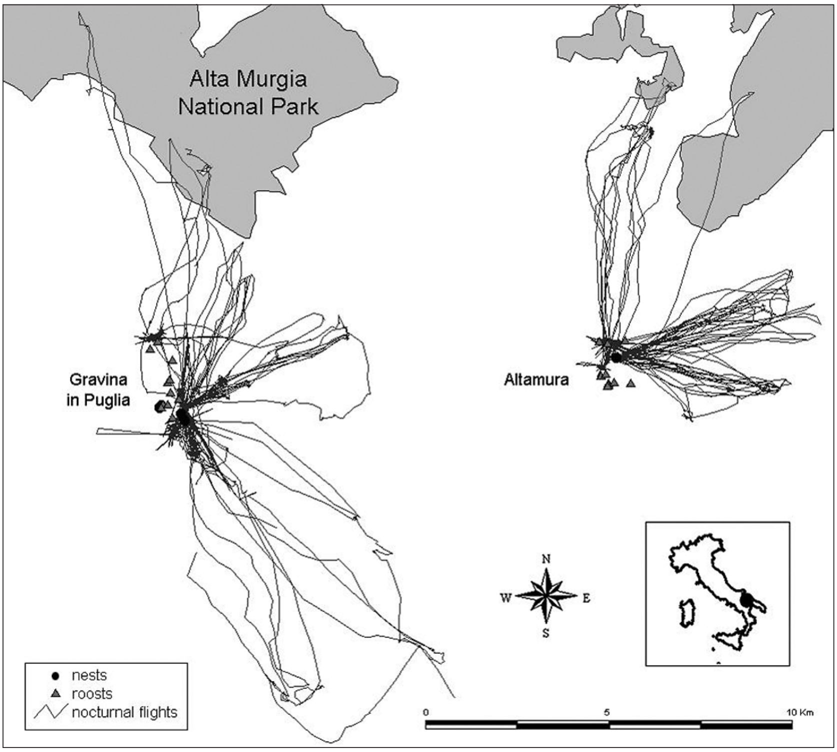

Fig. 1. Nocturnal trajectories followed by nine Lesser Kestrels surveyed for 23 consecutive days from June 15th to July 8th 2013. The tracking effort of nocturnal activities amounted to about 224 hours (13,420 GPS points) during which the tracked individuals totalled 1,108.2 km of flight.

hence not dealing with nocturnal flight activities in the countryside with no artificial illumination.

Gustin *et al.* (2014) provided the first report on the nocturnal activity of Lesser Kestrels in Italy even in rural areas with no artificial illumination. We argued that the need for food during the breeding season might impose also nocturnal activities to this typically diurnal species. However, that study was preliminary since the available amount of data was limited in size (3,728 GPS points), and not balanced among individuals and between the two colonies. In addition, nocturnal data were only available from 2:00 to 6:00 A.M. local time, and only for four Lesser Kestrels out of nine, thus we were not able to conclude if nocturnal activities were shared by all of the tracked individuals or were a notable exception.

In this study, using new, balanced and more complete data we aimed to: a) analyse Lesser Kestrels' nocturnal flight activities during the breeding season in two main colonies in Italy, b) compare night-time and day-time activities, and c) propose and discuss several plausible explanations for detected nocturnal flights with reference to the landscape composition and structure of the study area.

2. Materials and methods

The study area lies within the SPA (Special Protection Area) "Murgia Alta" IT9120007 and is included within the IBA (Important Bird Area) "Murge". Although we surveyed twelve individuals, GPS provided data only for nine Lesser Kestrels (seven males and two females; five individuals at Gravina in Puglia and four at Altamura) that were surveyed from June 15th to July 8th 2013 (online Supplement A), corresponding to the almost complete nestling period (chick rearing period).

Surveys were conducted using TechnoSmart GiPSy-4 data-loggers (23 × 15 × 6 mm, 5 g weight), that provided information about date, time, latitude, longitude, altitude (meters a.s.l.) and instantaneous speed. We carefully chose only adult Lesser Kestrels in fit health conditions. Birds were captured and fitted with data loggers at their nest boxes when they were delivering food to their nestlings. In order to download the data from the data-loggers, Lesser Kestrels were recaptured at their nest boxes after batteries were exhausted (online Supplement B). *In situ* surveys allowed us to locate nests and roosts used by the tracked individuals.

Table 1. Time intervals (local time) and descriptive statistics about Lesser Kestrel's flight attributes with data from all individuals pooled, for both day (6:00 A.M.–9.00 P.M. local time) and night time (9:00 P.M.–6:00 A.M. local time).

Time interval	Daytime/ night-time	#GPS points	1-minute flight length (m)		Distance from nest (m)		Distance from nearest roost (m)	
			Mean	SD	Mean	SD	Mean	SD
0–1 A.M.	N	1,567	37.47	67.44	874.23	564.34	137.09	163.56
1–2 A.M.	N	1,534	35.50	61.08	886.99	564.61	148.74	200.81
2–3 A.M.	N	1,527	32.89	44.47	887.28	567.02	138.51	160.70
3–4 A.M.	N	1,537	30.19	43.49	878.04	569.78	134.86	160.53
4–5 A.M.	N	1,538	35.93	67.71	948.87	689.41	222.14	519.25
5–6 A.M.	N	1,530	113.39	174.75	1724.41	1770.67	1429.04	1547.65
6–7 A.M.	D	1,731	140.68	198.99	2174.27	2419.86	2093.07	2220.24
7–8 A.M.	D	1,541	188.93	217.57	2718.14	2784.61	2652.32	2682.04
8–9 A.M.	D	1,531	209.09	205.11	3052.82	2934.61	2958.14	2861.76
9–10 A.M.	D	1,523	269.23	217.50	2831.25	2516.28	2728.82	2423.46
10–11 A.M.	D	1,678	290.86	225.82	3334.20	2583.74	3231.46	2468.19
11–12 A.M.	D	1,747	269.88	219.07	3635.40	2756.06	3558.16	2636.41
0–1 P.M.	D	1,799	262.25	236.31	2983.56	2822.87	2967.01	2797.79
1–2 P.M.	D	1,785	271.91	235.24	3323.37	2658.22	3217.08	2609.22
2–3 P.M.	D	1,783	261.23	242.33	3106.56	2637.63	2966.88	2542.58
3–4 P.M.	D	1,802	271.51	235.54	3047.63	2356.99	2948.82	2340.15
4–5 P.M.	D	1,820	244.12	223.43	2960.60	2581.78	2935.84	2520.67
5–6 P.M.	D	1,814	233.00	209.00	3246.00	2618.49	3177.81	2582.87
6–7 P.M.	D	1,822	226.82	213.78	3674.20	2794.58	3502.17	2633.34
7–8 P.M.	D	1,874	196.21	214.87	3585.57	2896.15	3437.49	2739.35
8–9 P.M.	D	1,847	160.40	195.32	2340.20	2240.41	1904.80	2198.56
9–10 P.M.	N	1,754	44.17	94.43	852.67	566.59	185.57	211.27
10–11 P.M.	N	1,632	47.64	90.95	898.48	568.61	140.56	165.94
11–12 P.M.	N	1,634	43.12	79.14	900.32	564.06	138.16	168.10

GPS data were imported into GIS and superimposed on the terrain elevation of the study area (digitized at 1:2,000 scale by the authors from available topographic maps of Apulia Region) and on nest and roost locations. For each GPS point, flight height above ground level (in meters) was calculated by subtracting terrain elevation from altitude a.s.l. provided by data-loggers. Lesser Kestrels were considered in flight if instantaneous speed (provided by data-loggers for each GPS point) and flight height above ground level (calculated for each GPS point as described above) were simultaneously higher than 0. Lesser Kestrels' flight effort was measured using 1-minute flight length (i.e. length of flight between two successive GPS acquisitions). Distance from nest is a relevant metric during the chick rearing period when parental care is vital. Distance from the nearest roost is informative for a species whose roosting activity is elevated. Therefore, for each GPS point we calculated the distance in meters from the individual's nest and from the nearest roost.

Descriptive statistics on the three flight attributes (1-minute flight length, distance from nest and distance from the nearest roost) were extracted from GIS data and used in inferential tests. As the data points from the same individuals could not be treated as independent (uncorrelated) observations, we compared the averaged attributes for all the individuals using a classic two sample *t*-test. All the descriptive and inferential analyses were performed using R (R Development Core Team 2010). Tests were considered significant for $p < 0.05$.

3. Results

The nocturnal tracking effort for the nine individuals amounted to almost 224 hours (N_1 = 13,420

GPS points), while the diurnal one was about 462 hours (N_2 = 27,706 GPS points).

We found evidence of Lesser Kestrels' nocturnal flights in both Gravina in Puglia and Altamura colonies (Fig. 1). All of the individuals showed nocturnal flight activities, during which they totalled 1108.2 km of flight. At night they were found in flight for 25.09% (3,368 GPS points out of 13,420) of the tracking time (36.58% during daytime), both in low-light (i.e. close to sunset and close to sunrise) and no-light conditions (Table 1).

The five individuals of Gravina had an average per-individual nocturnal flight activity of 127.38 km, and an average per-hour nocturnal activity equal to 4.6 km. The four individuals of Altamura had an average per-individual nocturnal activity of 117.82 km and an average per-hour flight activity equal to 5.5 km.

All of the flight attributes (1-minute flight length, distance from nest and distance from the nearest roost) were significantly higher for the diurnal period than for the nocturnal one (upper-tailed paired t; $p < 0.05$; online Supplement C). Instead, we found no significant differences between males and females and between the two colonies at night (two-tailed independent 2-sample t; $p > 0.05$; online Supplements D and E).

4. Discussion

Our work confirms regular nocturnal activities of Lesser Kestrels during the breeding period in two main colonies in Italy. At night they were found in flight for about one-fourth of the tracking time, and we registered widespread nocturnal flights up to almost 15 km from nest sites even in areas with no artificial illumination. In fact, at night the study area is almost completely unilluminated, with the exception of Gravina in Puglia, Altamura and few farmhouses in the countryside. Although in the study area harvesting activities can sometimes occur at night using artificial illumination, this was not our case at least during the tracking period.

The Lesser Kestrel is primarily insectivorous, feeding mainly on beetles, myriapods and grasshoppers (Franco & Andrada 1977) and, clearly, foraging activities for insectivores are more comfortable during the daytime, in particular in rural areas with no artificial illumination. Thus, our results raise one main question: why do Lesser Kestrels, usually considered a strictly diurnal species, show widespread nocturnal activities?

Cloudy conditions at night for almost all of the tracking period (data from the meteorological office of Apulia Region) did not allow us to test for correlation between visibility at night due to moonlight and Lesser Kestrels' flight activities. However, we are reasonably confident that moon visibility can be discarded as driver of nocturnal activities, as in 2012 it resulted negatively and significantly correlated to nocturnal flight lengths (Gustin *et al.* 2014). One possible reason could be that the average difference in temperature between day and night was elevated in the study area during the tracking period (16.8 °C; data from the meteorological office of Apulia Region), and thus it could be energetically more profitable for Lesser Kestrels to hunt at night. However this explanation can be discarded too, because it would be contradictory with the evidence that Lesser Kestrels' flight activity was considerably more elevated during daytime than at night (Table 1 and online Supplement C).

We hypothesise that the explanation of Lesser Kestrels' nocturnal activity might rely on the landscape composition and structure of the study area. Pseudo-steppes are the most important habitat for the maintenance of this species (Gustin *et al.* 2014b). In the study area, these dry grasslands remain uncultivated for one or several years, and are grazed by livestock herds that produce optimal conditions for Lesser Kestrels by making vegetation shorter and less dense, thus facilitating the access to prey.

However, in the study area pseudo-steppes are almost exclusively within the boundaries of the Alta Murgia National Park (Gustin *et al.* 2014b), i.e. more than 6 km distant from the two colonies. In the remaining portion of the study area, pseudo-steppes have been almost completely replaced in the recent past by non-irrigated arable lands, broad-leaved forests, coniferous forests, mixed forests and ligneous crops. In addition, in the neighbourhood of the two colonies, intensive agriculture made harvested patches a short-lived habitat, as cereals are converted into low-quality stubbles with consequent decline in prey abundance (Catry & Franco 2014).

The reduction in both the extent and quality of foraging habitats might have forced Lesser Kestrels to flight long distances even at night. When favourable habitat is available in the surroundings of the colony, foraging distances are modest (Bustamante 1997, Tella *et al.* 1998, Catry *et al.* 2013). Instead, if foraging resources are limited, it is reasonable that Lesser Kestrels are forced to flight more frequently, for longer distances and for longer time periods, which might include night-time. The two colonies under study present the highest number of individuals in Italy (in 2013, about 2,600 Lesser Kestrels at Gravina in Puglia and about 2,500 individuals at Altamura; Gustin *et al.* 2013) and probably the most elevated density of Lesser Kestrels in urban areas worldwide, which is likely to determine extreme competition for trophic resources, as the foraging requirements of these two large populations are hardly supported by a man-dominated landscape. This trend has already been registered elsewhere. Hiraldo *et al.* (1996) found that nestling mortality due to starvation might be an important reason of Lesser Kestrel's population decline in southern Spain. Liven-schulman *et al.* (2004) found similar results in Israel.

Negro *et al.* (2000) observed that, compared to the daytime, chick provisioning is minor at night, therefore the main purpose of the adult birds' flights at night is probably to feed themselves. On average, the tracked individuals had 3.68 ± 1.12 std. dev. chicks into the nest (online Supplement A). It is plausible that there was insufficient time during the daylight hours to find enough prey to both feed offspring and parents due to the need to travel longer distances to pseudo-steppe habitat (and/or to take inferior quality prey at shorter distances). In fact, Lesser Kestrels spent substantial portions of the daylight off the nest (Table 1), which supports a plausible argument that they might not be able to complete the foraging activities during the day, but instead had to forage at night as well. This explanation holds for both sexes and both colonies, and might explain why we found no significant differences in nocturnal flight attributes between males and females and between the two colonies (online Supplements D and E).

We have provided here further evidence that during the breeding season Lesser Kestrel is not a strictly diurnal species. However, our study is not conclusive. At this stage of our research we are not able to exclude further competing explanations. Although we have not evidence of an outbreak of some nocturnal prey during the tracking period, only a systematic field study could discard this possible reason for Lesser Kestrel's nocturnal activity. We can't exclude that the behaviour and availability of potential prey animals might be different between day and night. Last, given the habitat changes occurred in the area, it is not impossible that changes in prey have occurred as well (or shifts in what Lesser Kestrels consider suitable prey, small bats for example) that could drive nocturnal flights. The exclusion of these alternative explanations will require further field surveys.

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Pikkutuulihaukan pesimäaikaisesta yöaktiivisuudesta

Perinteisesti pikkutuulihaukan on ajateltu olevan päiväaktiivinen laji. Aiemmassa tutkimuksessa esitettiin ensimmäiset havainnot yöaktiivisuudesta maaseudulla, missä keinovaloa ei ole saatavilla. Tässä tutkimuksessa selvitimme yöaktiivisuutta tarkkojen GPS-loggereiden avulla kahdessa pikkutuulihaukkakoloniassa (Gravina ja Altamura, Etelä-Italia).

Havaitsimme että yöaktiivisuus oli yleistä, ja haukkoja tavattiin jopa 15 km päässä pesiltä. Kaikki seuratuista haukoista olivat aktiivisia yöaikaan, ja ne havaittiin lennossa keskimäärin 25 % seuranta-ajasta, jopa alueilla joilla ei ole keinovaloa. Vertasimme päivä- ja yöajan aktivisuutta kolmella mittarilla: lennon pituus 1-min jaksossa, etäisyys pesästä ja etäisyys levähdyspaikasta.Nämä olivat kaikki pidempiä päiväaikaan verrattuna yöaikaan. Koiraiden ja naaraiden välillä ei ollut eroja kyseisissä parametreissa. Havaittuun yöaktiivisuuteen on useita mahdollisia tulkintoja, joita lisätutkimukset voivat valottaa.

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Online supplementary material

Supplementary Table A. Description of the tracked Lesser Kestrels.
Supplementary Table B. The deployment of transmitters.
Supplementary Table C. Lesser Kestrels' flight attributes: daytime versus night-time.
Supplementary Table D. Lesser Kestrels' nocturnal flight attributes: females versus males.
Supplementary Table E. Lesser Kestrels' nocturnal flight attributes:
Gravina colony versus Altamura colony.