

Summer pre-breeding movements of Eleonora's Falcon *Falco eleonora* revealed by satellite telemetry: implications for conservation

UGO MELLONE, PASCUAL LÓPEZ-LÓPEZ, RUBÉN LIMIÑANA and VICENTE URIOS

Summary

Recent advances in bird tracking technologies are revealing that migratory birds use temporal staging sites other than breeding and wintering areas, and these areas deserve conservation efforts. Eleonora's Falcon *Falco eleonora* is a long-distance migratory raptor that breeds colonially on islands and is considered a priority species for conservation. Anecdotal observations indicate that during the pre-breeding period, Eleonora's Falcons stay in inland areas far away from the colonies, but, to date there are no detailed data concerning the connectivity between these areas and breeding colonies. Using satellite telemetry, we analysed data from four summering events belonging to three individuals breeding in two colonies in the Western Mediterranean (Spain). All of them made inland movements in areas up to c.400 km distant from the respective breeding colonies, visiting several habitats, from forests to arable lands, probably taking advantage of high densities of insects. Perturbations occurring in these areas could threaten Eleonora's Falcons with serious consequences at the population level. We suggest that conservation measures implemented at breeding and wintering grounds may not suffice and that temporary staging areas should be identified at a larger scale and deserve protection as well.

Introduction

In a traditional, simplified view, migratory birds alternate short-distance non-directional movements, occurring in breeding and wintering areas, with long-distance directional movements, namely spring and autumn migrations (Newton 2008). Recent advances in tracking technologies are revealing that this scenario is rather more complex (Klaassen *et al.* 2011), with species also performing pre-migratory movements, spending some weeks in staging areas away from breeding sites (Limiñana *et al.* 2008, Strandberg *et al.* 2008, Catry *et al.* 2011), using stop-over areas for relatively long periods (Chevallier *et al.* 2010, Kochert *et al.* 2011, Limiñana *et al.* 2012), or using staging areas different to breeding or wintering ranges before reaching sexual maturity (Mellone *et al.* 2011a). To date, pre-breeding movements have been described only for some seabirds (Phillips *et al.* 2007, Guilford *et al.* 2009, Bogdanova *et al.* 2011).

In this scenario, migratory species require conservation measures that are difficult to implement, since efforts carried out in one area can be jeopardised by threats occurring far away (Martin *et al.* 2007, Angelov *et al.* 2012). Therefore, the identification of the different areas used throughout the year is of utmost importance from a conservation point of view.

Eleonora's Falcon *Falco eleonora* is a long-distance migratory raptor, which breeds colonially almost exclusively in islands of the Mediterranean Sea (Walter 1979). The species is included in Annex I of the Directive 2009/147/EC on the conservation of wild birds and constitutes a priority species for conservation (BirdLife International 2004, 2010). The winter range of the species is

concentrated in Madagascar (Walter 1979, Mellone *et al.* 2012a) and migration routes have been recently mapped in detail (Gschweng *et al.* 2008, López-López *et al.* 2009, 2010, Mellone *et al.* 2011b, Kassara *et al.* 2012).

This species presents a unique adaptation, since it delays reproduction to late summer (August-September) in order to take advantage of the passage of migratory passerines en route to Africa, which form its main prey during the breeding season (Walter 1979). Nevertheless, timing of spring migration is similar to that of other Palearctic species, since Eleonora's Falcons normally arrive in Europe in May (Bernis and Castroviejo 1968, Walter 1979). Therefore, for these birds there is a time lapse of two months between the end of the spring migration and the beginning of the breeding season. There are some data indicating that during this period Eleonora's Falcons stay in inland areas far away from the breeding colonies (González *et al.* 1984, Ristow and Wink 1995, Cano 2001, Belenguer *et al.* 2004, Gregory 2007), but satellite tracking data concerning this behaviour are practically absent and therefore it has been impossible to unravel the connectivity between those staging areas and the breeding colonies (but see Gregory 2007). Here we analyse the pre-breeding movements of Eleonora's Falcons belonging to two different colonies in the western Mediterranean using Argos-based satellite telemetry.

Methods

Eighteen Eleonora's Falcons were trapped in Balearic and Columbretes Islands (Spain) in autumn between 2007 and 2010 (Fig. 1; details in López-López *et al.* 2009, 2010). Birds were sexed by molecular methods and equipped with Microwave Telemetry Inc. 9.5-g solar-powered satellite transmitters using Teflon ribbon. During the summer season, transmitters were programmed to collect data on a duty cycle of 12 h on/58 h off, apart from bird #92532 that partly transmitted with a cycle of 12 h on/18 h off. Here, we only used summer data from those individuals for which we recorded the complete summering event (since arriving in the Mediterranean basin until the onset of the following autumn migration). Overall, we used data from four summering

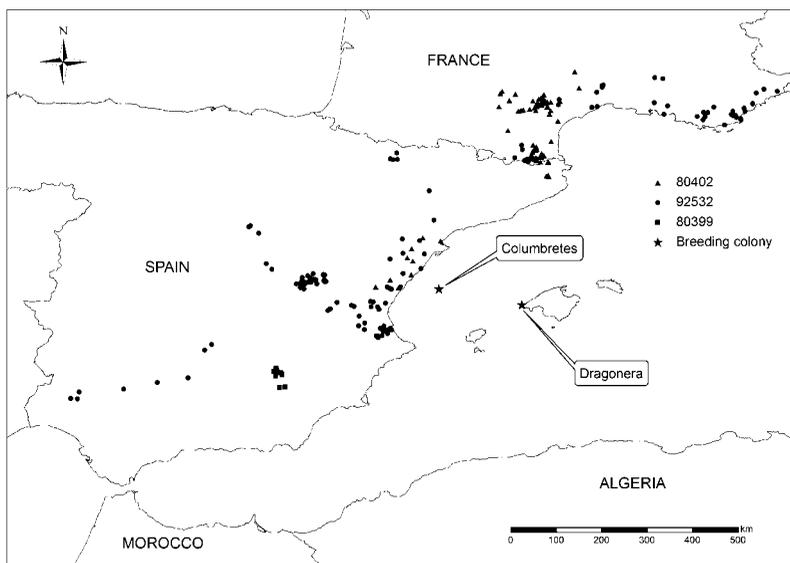


Figure 1. Locations outside the colonies of three Eleonora's Falcons during four summering events occurring between 2009 and 2011. Bird #80399: $n = 10$ locations; bird #80402: $n = 49$ (2009) / $n = 28$ (2010); bird #92532: $n = 153$.

events belonging to three individuals: two adult females captured in 2008 (#80399 from Dragonera, Mallorca and #80402 from Columbretes islands) and one immature (2nd calendar-year) male born in Columbretes Islands in 2010 (#92532). Bird #80402 was tracked for two consecutive summers. For the remaining tagged individuals, the transmitters did not work properly or birds died during migration (López-López *et al.* 2010, Mellone *et al.* 2012a). Locations were collected using the Argos system. The locations are coded for accuracy and grouped into location classes (l.c. hereafter). In order of decreasing accuracy these classes are 3, 2, 1, 0, A, B and Z. Initially all data apart from those with a l.c. of were included. Data were then filtered to exclude locations obtained in the same hour (retaining the highest quality one) and locations resulting in unrealistic values of speed and direction (e.g. > 80 km/h during the day and > 5 km/h at night).

In order to identify the centroid of the areas used during summer outside the breeding colonies and to calculate its distance from colonies, we selected all the locations occurring on the mainland and calculated 50% fixed kernel density contours (Worton 1989) for every summering event, using the Animal Movement Extension for ArcView 3.2 (Hooge and Eichenlaub 2000) and the least squares cross validation (LSCV) procedure (Silverman 1986).

In order to describe habitat composition, we followed a conservative approach, excluding data with l.c. A and B, and applying to the remaining data (l.c. 3, 2, 1 and 0; $n = 86$) a buffer whose radius was the nominal accuracy of each location (l.c. 3: 250 m; l.c. 2: 500 m; l.c. 1: 1,500 m; Argos 1996). For data with l.c. 0, nominal accuracy is higher than 1,500 m, therefore we conservatively applied an arbitrary buffer of 5,000 m. In our experience, after filtering for direction and speed (see above), those data are reasonably accurate (Soutullo *et al.* 2007, López-López *et al.* 2010, Mellone *et al.* 2011b, Limiñana *et al.* 2012). Within each buffer, we calculated the area of the different habitat categories, using the GIS layers of Corine Land Cover (<http://www.eea.europa.eu/publications/CORO-landcover>). Since the buffer area differed according to the l.c. (e.g. a buffer whose centre was a l.c. 3 was smaller than a buffer with l.c. 2), we weighted the obtained surfaces according to the location class, in order to avoid a bias towards more inaccurate data. We compiled those percentages in Table 1.

Results

All individuals performed pre-breeding inland movements in areas hundreds of kilometres from the respective breeding colonies (Figure 1).

Bird #80399 first visited the breeding colony located in Dragonera (Mallorca, Balearic Islands), between 20 May 2009 and 13 June 2009. It then spent 16 days in southern Spain, in the Sierra de Segura mountain range (Sierras de Cazorra, Segura y Las Villas Natural Park), 444 km from its breeding colony. Afterwards, it came back to the colony, where it stayed until the beginning of the autumn migration.

Bird #80402 showed more complex movements during both summers that it was tracked. Its inland movements ranged from southern France to north-eastern Spain. During 2009 the first location within the Mediterranean basin was a low quality one in the Tyrrhenian Sea, close to central Italy (15 May). Then the falcon visited southern France (18 May), and before finally settling in the breeding colony (17 July) it alternated short visits to the colony (twice, of one and four days each) with inland movements to France (maximum period away from the colony of 31 days: 18 May to 17 June; 395 km away from the colony).

During 2010 it again first visited central Italy (16–18 May) and Corsica (20–24 May), then from 26 May, it stayed mainly in southern France, including a first short visit (15–17 June) to the breeding colony. It finally settled in the colony on 1 July, but between the 23 and 27 July stayed inland in Castellón province (eastern Spain), the closest mainland area to the colony. During this year two core areas were identified (Figure 1), completely overlapping with the core area of the previous year, and located 440 and 331 km respectively from the breeding colony in Columbretes Islands.

The immature bird (#92532) reached Spain on 24 June 2011, after having spent 10 days in northern Algeria, at the end of spring migration. Apart from two “trips” of four days each, one to northern Spain (central Pyrenees) and the other to southern Spain (Sierra Morena), it stayed in

Table 1. Percentages of CORINE land cover classes included within the buffer areas of satellite fixes with l.c. 3–0 (see methods) for each summering event of Eleonora’s Falcons. “Others” includes: beaches, bare rocks, agro-forestry, sparsely vegetated and burnt areas, rice fields, inland and coastal water bodies.

	80399	80492 (2009)	80402 (2010)	92532	average
Artificial and urban surfaces	0.00	0.39	0.36	4.44	1.30
Non-irrigated arable land	0.00	8.09	1.03	3.90	3.25
Permanently irrigated land	0.84	0.00	0.00	1.01	0.46
Rice fields	0.00	0.00	0.00	0.14	0.04
Vineyards	0.00	1.45	4.92	5.19	2.89
Fruit trees and berry plantations	0.00	7.06	0.13	10.10	4.32
Olive groves	0.67	0.42	0.00	1.53	0.65
Pastures	0.00	0.92	5.27	0.10	1.57
Annual crops associated with permanent crops	0.00	0.00	0.00	0.09	0.02
Complex cultivation patterns	0.37	2.26	2.79	5.57	2.75
Land principally occupied by agriculture, with significant areas of natural vegetation	0.27	1.37	3.57	2.67	1.97
Agro-forestry areas	0.00	0.00	0.00	1.45	0.36
Broad-leaved forest	0.00	45.87	49.60	8.50	25.99
Coniferous forest	84.25	9.14	11.89	16.69	30.49
Mixed forest	0.00	6.74	4.11	3.59	3.61
Natural grasslands	1.98	1.03	5.80	2.16	2.74
Moors and heathland	0.00	0.00	0.25	0.00	0.06
Sclerophyllous vegetation	3.02	13.16	2.78	16.79	8.94
Transitional woodland-shrub	8.59	0.68	6.00	13.34	7.15
Others	0.00	1.28	1.50	1.54	1.08
Sea	0.00	0.13	0.00	1.21	0.33
Total	100.00	100.00	100.00	100.00	100.00

eastern Spain until 9 August, when it began to move northwards, stopping for 10 days in the eastern pre-Pyrenees and then for 12 days in a coastal areas of southern France. On 22 September, for the first time, it went back to its natal colony (Columbretes Islands), where it remained for roughly one month before beginning the autumn migration (25 October), including two short daily trips to inland areas (Castellón province). The centroid of its core area was located 173 km from the colony.

Concerning land cover, the main habitats were coniferous and broad-leaved forests, followed by areas covered by sclerophyllous vegetation, transitional woodland-shrub, and cultivated areas such as fruit plantations and vineyards (Table 1).

Discussion

Overall, during the summer pre-breeding season Eleonora’s Falcons visited a highly varying range of environments, spanning mountains (#80399) to lower hilly areas (#80402, #92532), to coastal areas (#92532), as well as the breeding colonies. The main habitats represented within the core areas were forests, shrubland, arable lands and vineyards (Table 1).

After performing these large-range movements, adult individuals settled in the breeding colonies in July, and after that they no longer visited inland areas, beginning the southward migration from the colonies in October. Apart from the last wave of spring migrant passerines that occurs in May, in late spring-early summer, small Mediterranean islands cannot offer enough food to support hundreds of falcons, and therefore birds are forced to look for areas where feeding opportunities are more favourable (Ristow and Wink 1995). It is remarkable that the peak of insect

abundance, particularly beetles (Order Coleoptera) as well as dragonflies and damselflies (Odonata), occurs in the inland areas visited by Eleonora's Falcons just during the pre-breeding period (Cano 2001, Belenguier *et al.* 2004), providing an adequate food supply until the beginning of the autumn migration of passerines that form their main resource during breeding (Walter 1979). It has been reported that Eleonora's Falcons prey particularly upon the Common Cockchafer *Melolontha melolontha* (Cano 2001, Belenguier *et al.* 2004), an abundant insect that shows demographic explosions in June in some years.

Inland observations of Eleonora's Falcons occurring in August-September, during chick rearing, involve mainly immature, non-breeding individuals (Ristow and Wink 1995; authors' unpubl. data). The pattern shown by our immature bird (#92532) fits well in this scenario, and its behaviour during the stay in the coastal area of southern France (movements over the open sea during early morning) might suggest that it was already chasing migrating passerines.

Field observations confirm the importance of the areas identified in this study, suggesting that our findings may apply to a larger proportion of individuals. For example, within the mountain range of Sierra de Segura (southern Spain) a maximum of 11 Eleonora's Falcons were observed together in early July 2009, and six were recorded in the same period the previous year (C. Ruiz pers. comm. 2011). In addition, the species is regularly observed in southern France and Corsica (Carp and Cheylan 1979, Mayol 1996). Finally, bird #80402 briefly visited Tolfa hills (central Italy) in 2010 (and probably also in 2009, but not enough data were obtained). This area is the most important one in inland Italy concerning the number of Eleonora's Falcons regularly observed, with up to 18 individuals observed hunting insects together (Celletti and Meschini 1992). In inland areas of Mallorca (Spain), close to the colony of bird #80399, up to 49 individuals have been observed hunting insects in the Albufera wetland in May (Ristow and Wink 1995), and the species is usually observed year after year in particular areas of the Serra de Tramuntana (Mayol 1977, 1996). Unfortunately no satellite locations have been obtained from our tracked individuals that could confirm movements to this area.

Other areas where Eleonora's Falcons are regularly observed far away from the colonies occur elsewhere within its breeding range and in a wide range of habitats and altitudes (reviewed by Ristow and Wink 1995, see also Premuda and Mellone 2007, Díaz-Portero *et al.* 2009). Not surprisingly, the highest numbers have been reported in mainland Greece and Crete (up to 120 individuals hunting insects together, Ristow and Wink 1995), the region where the breeding density is the highest worldwide (Dimalexis *et al.* 2007). The use of cultivated areas by Eleonora's Falcons could be a cause for concern, given the widespread use of pesticides in Spain and France (Geiger *et al.* 2010). Ristow (2001) showed that poison ingested by Eleonora's Falcons through drinking at polluted pools inland in Crete caused several deaths and a strong decline in a close-by breeding colony. It has been also shown that insect availability prior to egg-laying, even near the colonies, can affect clutch size (Xirouchakis *et al.* 2012). Therefore, events occurring in the pre-breeding staging areas could have serious consequences at the population level and it is thus of paramount importance to identify and protect at least the areas where the highest concentrations of Eleonora's Falcons occur. Our results highlight that conservation schemes for migratory species should be focused not only at breeding and wintering grounds, but should also take into account temporary staging areas. Similar processes have been described for non-migratory species, when juveniles disperse and settle in temporary staging areas (see Penteriani *et al.* 2005, Soutullo *et al.* 2008, Cadahia *et al.* 2010, Caro *et al.* 2011). However, it is very difficult to obtain these data and only recently, transmitters lasting more time than just one or two years, are allowing gain new insights into hitherto unknown processes such as the pre-breeding movements, as shown here.

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UGO MELLONE*, PASCUAL LÓPEZ-LÓPEZ, RUBÉN LIMIÑANA, VICENTE URIOS
 Vertebrates Zoology Research Group, CIBIO, University of Alicante, Edificio Ciencias III,
 Campus San Vicente del Raspeig s/n, Apdo. 99, E-03080, Alicante, Spain.

RUBÉN LIMIÑANA

Instituto de Investigación en Recursos Cinegéticos (IREC). CSIC-UCLM-JCCM. Ronda de
 Toledo, s/n. E-13005 Ciudad Real Spain.

*Author for correspondence; e-mail: ugomellone@libero.it

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