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First evidence by satellite telemetry of Lanner Falcon's *Falco biarmicus feldeggii* natal dispersal outside Sicily, and a review of existing data

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Natal dispersal, the animals' movements from the birthplace to another living site (Bullock *et al.* 2002, Ronce 2007), encompasses patterns of movements associated with both quotidian needs (e.g. foraging, roosting) and the search for a new habitat where to establish and later reproduce (Bowler & Benton 2005, Van Dyck & Baguette 2005). This crucial moment of birds' life cycle regulates the survival of individuals, hence the future recruitment into the breeding population, with multi-level effects on the demography of populations and the permanence, evolution and conservation of species (Bullock *et al.* 2002, Kokko & Lopéz-Sepulcre 2006, Nevoux *et al.* 2013). Indeed, the spatial structure and connectivity of populations are directly linked to dispersal (Clobert *et al*. 2004).

Satellite biotelemetry (Cooke *et al*. 2004, Cagnacci *et al*. 2010), chiefly based on individual-tracking by GPS data-loggers, has opened new frontiers in the study of relevant aspects of animals' life history, including natal dispersal (Bowler & Benton 2005).

Information about natal dispersal and movements of Lanner Falcon juveniles is more available for the Afrotropical populations of *F. b. biarmicus* and *F. b. abyssinicus* (e.g. Herremans & Herremans-Tonnoeyer 1996, and rev. in Leonardi 2015). Lanner Falcons living in the Western Palaearctic (hence encompassing the *F. b. feldeggii*, *F. b. tanypterus* and *F. b. erlangeri* subspecies living in Europe, north Africa and Middle East) are considered to be 'partially migrant, or mostly so' (Porter & Beaman 1985, Zalles & Bildstein 2000), as well as mainly sedentary, with vagrant movements usually of juveniles and immatures (Ferguson-Lees & Christie 2001). Data and information about the movements of *F. b. tanypterus* across Israel and the Middle East, and of north African *F. b. erlangeri* to the Iberian Peninsula have been reviewed in Leonardi (2015). Currently, the previously rare records of *F. b. erlangeri* in Spain are currently increasing, besides occurring not only nearby the Gibraltar Strait area but also in the interior of the country (Gil-Velasco *et al*. 2019).

The European Lanner Falcon *Falco b. feldeggii* is considered an endangered species (BirdLife International 2015) and is of conservation priority in Italy (Andreotti & Leonardi 2007), being the subject of intense research aiming at its conservation (e.g. Amato *et al*. 2014, Sarà 2014, Allavena *et al*. 2015, Sarà *et al*. 2016, Di Vittorio *et al*. 2017). It is currently distributed in continental Italy (from Emilia Romagna to Calabria) and in the island of Sicily (Andreotti & Leonardi 2007). The Italian population is mainly sedentary too, with dispersal events and irregular wintering outside the breeding range (Brichetti & Fracasso 2003).

In 2013 we started a monitoring programme of the Lanner Falcon population residing in Sicily concerning mainly the investigation on spatial distribution and breeding biology of the species (e.g. Sarà 2014, Sarà *et al*. 2016, Mascara & Nardo 2018). In addition, the programme included the ringing of chicks, using metal and coloured dar-

vic rings with unique alphanumeric codes, and satellite telemetry to assess the natal dispersal. Ten GPS-GSM devices [4 Saker ultra-light in 2015, weight 20 g; plus 6 Crex xs (2 in 2017 and 4 in 2018), weight 12 g; Ecotone® – Poland] were deployed on juvenile Lanner Falcons (5 males, 5 females), about 32-35 days old. Sex was inferred by body biometrics and then confirmed by genetic analysis (Sarà *et al*. 2019). Transmitters were fixed as a backpack using a teflon harness and birds were released into their nest 45-60 minutes after capture. The complete backpack weighted about 21 g in the case of Saker and about 13 g in the case of Crex. The extra-weight respected the 3% limit of body mass (e.g. Fuller *et al*. 2005) and was on average 2.4±0.60% (range: 1.7-3.3%, N = 10). Tagged birds were monitored once a week for the first month after marking, to check both bird and tag conditions. The satellite transmitters had a solar battery and were programmed to collect a GPS position every 1-3 hours of signal reception after chicks have fledged out, although the satellite transmitter positions obtained less than 2 hours after the previous one were excluded from the analyses to minimize bias associated to the non-independence of the data (Limiñana *et al.* 2007). Bird locations and routes were retrieved in geographical coordinates and then converted to UTM WGS84 coordinates for further calculation by QGIS 2.16 (QGIS Development Team, 2016). An overall analysis of spatial movements of the ten individuals is currently going on (Sarà *et al*. pers. obs.). In this first paper, we report the natal dispersal outside Sicily regarding one juvenile male (hereafter Falc36, from the Crex code) and we reviewed the existing literature to comment and put this event in context.

Falc36 was ringed and provided with a GPS-GSM tag on 13 of May 2017, when some 33-34 days old, in a nest-site of eastern Sicily. His weight at ringing was 630 g and the tag plus harness added a 2.06% extra-weight. He decidedly fledged the 25 of May, after two days of very short flights and perching around the eyrie. The post-fledging dependence period (hereafter PFDP), is the crucial stage (also called 'start phase' in Penteriani & Delgado 2009) when juveniles are still dependent from parents and move around the nest-site with the family (Newton 1979, Morrison & Wood 2009), which usually occurs from the fledging day to the first day of leaving the natal area (wandering phase: Morrison & Wood 2009, Penteriani & Delgado 2009). To establish the end of PFDP and the start of wandering phase, we used both a visual observation of QGIS maps, and two standardized and quantitative methods, the net displacement (hereafter ND, Turchin 1998), and the cumulated coefficient of variation (hereafter ΔCV, Limiñana *et al.* 2008), see details in Bondì *et al*. (2018) and Fig. 1. The PFDP lasted 35 days, until the 28 of June and during this period Falc36 moved very little. On average the NDs were 0.36 km (±0.72 SD, range: 0.01-4.84 km) far from the natal cliff, and covered a small area of 0.45 km^2 around the natal cliff. The 29 of June Falc36 started a first wandering phase (Fig. 1) with a long flight of some 57 km, and in two days explored an area of some 420 km^2 in the north-east Sicily between the Nebrodi and the Aetna, with mean NDs of 22.93 (±20.52 SD, range: 1.08–56.72 km). Such a wandering period was rapidly over, since Falc36 returned home the 30 of June, and for the 10 following days repeated explorations around the natal cliff. The NDs during these 10 days were still short, on average 2.05 km (±4.88 SD; range: 0.01-22.26 km), although significantly longer (t_{170} = 3.88, P = 0.0001) than in previous PFDP. July 10th at 06:00 am, Falc36 left definitely the natal area and at 12:00 am was flying over the Messina Strait. Then he crossed the Aspromonte mountains directed toward the Ionian side of Calabria (Fig. 2), where he stopped to spend the night in an open wooded area, some 5 km far from the Ionian coast. The day after at 06:00 am, he left again heading northbound and arrived in Apulia at 18:00 pm stopping in an open agricultural area west of the Gravina di Puglia town (Fig. 2). Excluding the night stop-over in Calabria, the total trip lasted 30 hours and 448 km, with a gross speed of 15 km/hr. Falc36 moved some 20 km further north the 12 of July, and settled for 42 days in a large area north of Altamura and Gravina di Puglia, mostly moving in open habitats (arable land and heterogeneous agricultural areas) with small daily NDs averaging 3.51 km (±3.35 SD; range: 0.12-20.09 km), and settling in a core area of 44.5 km^2 (as calculated using 95% kernel density estimation, hereafter KDE95). These short movements back and forward a delimited area and far from the natal site (Fig. 2) recall the 'stop phase' in Penteriani & Delgado (2009). Nonetheless, on 24 of August at 06:00 am, he flew westbound and began to frequent a larger area of 247.5 km^2 until the end of November. This second stop area was always composed of arable land and heterogeneous agricultural habitats between Cerignola, Ascoli Satriano and Candela towns (Fig. 2). There, the KDE95 revealed only two small areas corresponding to the two preferred nocturnal roosts (21 and 16 midnight positions, respectively) distant 14.64 km each other, both in single trees in the middle of corn fields. Yet, Falc36 got around in this new agricultural area with mean daily NDs comparable to those in the former area (3.23 km±6.95 SD, range: 0.00–90.69 km) and changing often the night roost (1-5 midnight positions, N=27). Overall, we were able to collect 111 midnight positions since the date of leaving Sicily, 96.4% of them were on single trees in arable plots, as well as on trees inside olive orchards, wood-

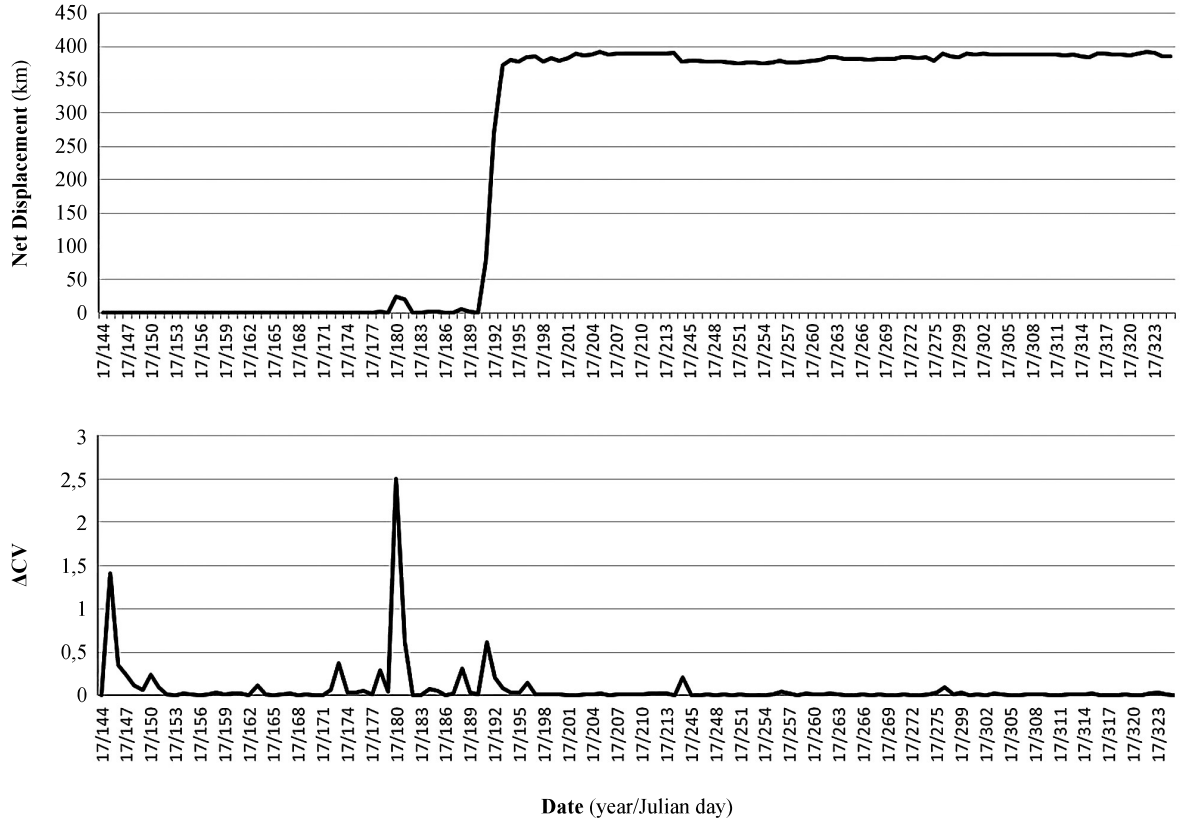

Figure 1. The end of Falc36 post-fledging dependence period (PFDP) and the start of wandering as calculated by the methodology followed to distinguish between the two phases. Above the movements from the natal cliff (Net Displacement). Below the highest increment of coefficient of variation (ΔCV) between the means of two consecutive daily displacements. Both methods indicate that wandering occurred on day 28 June 2017 (17/180), after 35 days of PFDP. Besides both graphs show some later phases (see text), as the return to natal site for 10 days and the start of dispersal to Apulia (flat net displacements between 17/180 and 17/190, with relatively small ΔCV daily increments), and the constancy (always relative to the distance from the natal site) of net displacements and ΔCV daily increments in Apulia.

lots and lines of trees. Only 1.8% were on electric pylons and 1.8% on rocks.

The GPS-GSM tag had started to give intermittent transmissions in August, and later did not transmit data from 3 to 23 October. It definitely ceased transmissions the 21 November, after 180 days from the fledging date. We had a single final signal north of Cerignola the 7 of December before the tag totally broke up. We ignore the actual fate of Falc36, and we are not able to assess whether, approaching the winter, the stop phase was definitely achieved in the Cerignola-Ascoli Satriano-Candela area, or Falc36 moved away.

Despite the short period of transmission, the information that Falc36 was able to provide us is consistent to what we mostly know about habitat use during natal dispersal. A complex interaction between genetic and condition-dependent environmental forces complements with individuals' behavioural characteristics to shape flexible dispersal strategies (Bowler & Benton 2005, Penteriani & Delgado 2009), with the ultimate purpose of settling in areas similar to the natal site (Doligez *et al*. 2002). Individuals may prefer to settle in habitats similar to their natal habitats either for cutting the costs of examining the suitability of new habitats, or because previous experience improves the performance of settling in the same habitats (Stamps 2001). Accordingly, during his five-months permanence in Apulia, Falc36 used open habitats very similar to those travelled around the natal area during the PFDP. Exploration of new habitats (e.g. forest areas and highlands between Nebrodi and Aetna) was kept at minimum and occurred only during the first short wandering of 29-30 June. Indeed, we had another Lanner Falcon moving outside Sicily, that is worth briefly mentioning. Falc43, a female fledged out the 17 of May 2018, which ended the PFDP after moving in an area of some 21 km^2 for 42 days, and undertook a first wandering flight the 29 of June directed

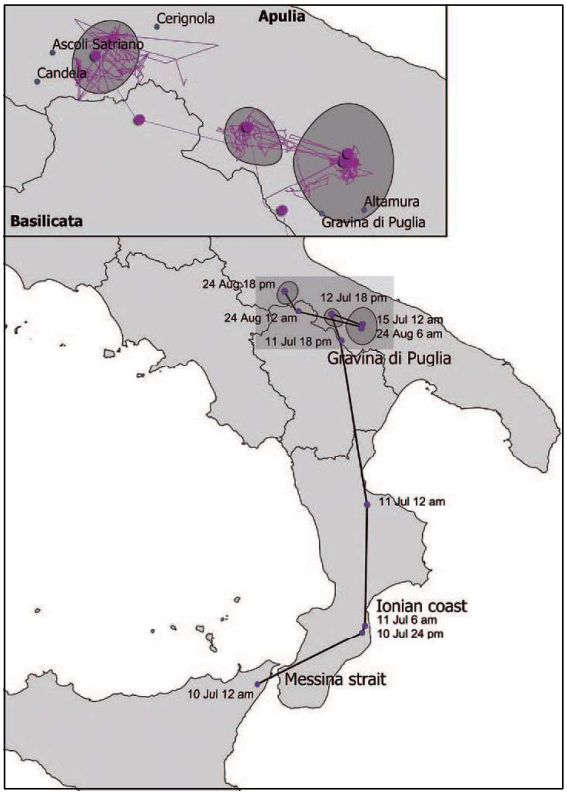

Figure 2. Map of Falc36 natal dispersal outside Sicily and until his final destination in Apulia (Southern Italy). The most significant fixes (localities and dots with date and hour) have been reported, see text for further details. The late summer/autumn movements in Apulia inside and outside the main wandering/settling areas (dark grey), with surrounding towns and significant fixes (dots) are detailed in the upper inset. The initial movement from the natal site to Messina Strait not showed for caution about the natal site identification.

straight to Aeolian islands, where she stayed just 9 hours (from 06:00 am to 15:00 pm) in Vulcano and Salina, before coming back to Sicily. She was continuing her wandering inside Sicily after that, and is now settling in a residency area without leaving anymore the island (Sarà *et al*. pers. obs.).

These first data we report, although mainly related to a single individual, shed some more light on European Lanner Falcon dispersal. A small quota of Sicilian population should leave the island to carry on natal dispersal in continental Italy. Departures can start in early summer, thus migratory watch-points at the Messina Strait (e.g. www.straitobservatory.com) active from midsummer (from 10-12 August in 2015-2018) could miss these infrequent species' crossings. Interestingly, there are some observations consistent with the Falc36 movements in Piedmont [1 immature at Maritimes Alps in late August 2005 (Toffoli & Giraudo 2005), and 1 juvenile at Turin hills in early October 2006 (Assandri & Marotto 2006)] plus at least 8 more observations of 1-2 individuals in Liguria and south-eastern France from early August to early November (www.migraction.net). In addition, *F. b. feldeggii* juveniles, immatures (and adults) occur regularly during the boreal winter in the French Camargue (Kayser *et al.* 2008). All these records combined could suggest indeed a dispersal of individuals from the small continental Italian populations. Another record similar to that of our Falc43 visiting the Aeolian islands could have occurred in mid-September 2006 at the Elba island (Paesani & Vanni 2006), involving probably one juvenile from the Tuscany population.

The records of the Lanner Falcons observed in spring time at the watch-points are trickiest to weigh up for at least three reasons (i.e. the possible confusion with *Falco cherrug*, or with resident European Lanner Falcons living nearby the watch-points, as well as the odd phenology of adults leaving Sicily in spring). The spring passage across the Messina Strait has been often considered doubtful, and records at this watch-point have been better referred to resident individuals (cf. Iapichino & Dimarca 1984, Giordano 1991, Giordano *et al*. 2013). Nonetheless, at least three observations belonging to European Lanner Falcons have been certainly recorded at the Calabrian side of the Messina Strait (1 adult male mid May 2015, 1 adult female mid May 2016 and 1 immature end of March 2019, www.straitobservatory.com and M. Panuccio *pers. com.*). In addition, Galea & Massa (1985) reported that a few immatures migrate across Sicily (Peloritani) from February to March, and single individuals have been also reported at the Messina Strait without either sex/age and direction indications (e.g. Gustin 2006, Giordano *et al*. 2012).

In other migratory watch-points of the southern Mediterranean area, the Lanner Falcon is absent (e.g. Agostini & Logozzo 1997, Agostini *et al*. 2004, Mellone *et al*. 2013) and vagrant at Malta [3 records in 1948-1978, but one supposed to be *F. b. tanypterus* (Sultana & Gauci 1982), and no more recently recorded (e.g. Sammut & Bonavia 2004, Raine 2007, 2008, Raine & Vella 2009, 2010)]. Few other spring records occurred at migratory watch-points along the Adriatic Sea [1 individual at the Pesaro hills in 2007 and 1 in 2009 (Sonet 2007, Sonet *et al*. 2009); 1 at Cape Otranto in 2005 (La Gioia 2009); and 1-3 at Mount Conero (Borioni & Baldoni 2011, Fusari 2012)] despite the annual regularity of observations in these areas during the 2005-2018 period (see Infomigrans nn. 15-41 at http://www.areeprotettealpimarittime.it). It is not clear whether they were local individuals approaching the watch-sites or dispersing birds crossing the Adriatic Sea to return in the Balkans. A consistent trans-Adriatic movement of Lanner

Falcons arriving from the Balkan areas to spend the winter in Central and Southern Italy was supposed in the past (Orlando 1957, Valentini 1957).

In conclusion, satellite telemetry confirmed natal dispersal outside Sicily, and we assembled also substantial data about dispersal movements along north-western Italy. Certainly, these events are rare and happen irregularly. However, it might be the case that the strong population decline in Italy and the Balkan area (BirdLife International 2017) has concealed the dispersal of the European Lanner Falcon, greatly reducing the cohorts of individuals potentially involved every year.

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