Pattern of non-breeding movements by the Stone-curlews *Burhinus oedicnemus* breeding in Northern Italy

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Abstract The identification of year-round geographical ranges and the quantification of the degree of migratory connectivity are fundamental for a successful conservation of migratory bird populations. The Stone-curlew *Burhinus oedicnemus* is a species of conservation concern in Europe, but its ecology and behaviour are relatively poorly investigated. In particular, its migratory behaviour and the location of the wintering ranges of most European populations are not known in details because of the lack of specific studies and scarcity of ringing recoveries. This study aimed to identify the wintering areas of a Stone-curlew population breeding in the Taro River Regional Park (Parma, northern Italy) by integrating the information belonging to ringing recoveries ($n = 2$), geolocators ($n = 7$), and GPS data loggers ($n = 2$). Furthermore, we compared two approaches to infer location of an assumed stationary bird using geolocator data. The different sources were quite coherent, indicating that tagged Stone-curlews did not leave the Mediterranean basin throughout the year and passed the winter in Sardinia or in Tunisia. The recorded wintering sites coincided with areas where breeding, possible resident, populations are reported, further emphasising the importance of these areas for the conservation of the species throughout the annual cycle. To our knowledge, our study represents the first thorough analysis aimed at understanding the movements of a Mediterranean population of Stone-curlews. Furthermore, it proves the great potential of the used tracking devices to provide information about migration and non-breeding sites for elusive species, for which mark-recapture/re-sighting techniques revealed profound limitations.

Keywords Migration – Geolocator – GPS – Ringing

Introduction

The understanding of bird migratory behaviour has been greatly improved in recent years thanks to the advances of tracking technologies. Nevertheless, the currently available devices differ consistently with respect to the type and quality of collected data and, consequently, for the range of research questions they can help to answer (Bridge et al 2011). The largest devices, satellite-tags (GPS and PTT), generally provide the most accurate location data but, for the moment, are still limited to larger birds (but see Wikelski et al 2007). The accuracy of one of the smallest devices, miniaturized light-based geolocation tags (geolocators), is far less, but these are the only devices currently suitable for tracking small birds on a continental scale (Bridge et al 2013). However, all tags represent an extra load for the tagged animal to carry, and the impact of any logger has to be considered (Costantini and Møller 2013). Although of lower accuracy, the information collected by geolocators is still useful, especially for species of conservation concern, since data on their winter distribution and ecology are strongly needed for successful conservation management and proper allocation of funds (Faaborg et al 2010). In particular, the possibility to tag significant numbers of birds, due to the relatively low costs of these devices, allows a proper understanding about how populations are geographically connected throughout the annual cycle, which is an important step to assess their vulnerability to environmental changes (Marra et al 2011; Fraser et al 2012; McKinnon et al 2013). The identification of year-round geographical ranges and the quantification of the degree of migratory connectivity are indeed fundamental to investigate the factors that govern population size of migratory birds (Webster et al 2002; Taylor and Norris 2010).

The Eurasian Stone-curlew *Burhinus oedicnemus* is the only member of Burhinidae in Europe and it is a species of European conservation concern (SPEC3, BirdLife International 2004). Its distribution is rather fragmented especially in Italy, where its main breeding areas are located in the South and in the major Islands (Sicily and Sardinia) (Brichetti and Fracasso 2004). The species is relatively poorly known both considering its ecology and behaviour, especially in the Southern part of its distribution range. With the exception of British populations (Green et al 1997), wintering ranges and routes are not well understood because of the lack of specific studies and the scarcity of ringing recoveries (Cramp and Simmons 1983; Vaughan and Vaughan Jennings 2005). According to the scant available information, the species is an intra-

Palaearctic migrant, but several populations are probably facultative migrant or even resident (see Vaughan and Vaughan Jennings 2005 and references therein).

This study aimed at identifying the pattern of movements of a Stone-curlew population breeding in Northern Italy by integrating the information belonging to ringing recoveries, geolocators and GPS data loggers.

Methods

Study area and bird ringing

Our study was carried out in the Taro River Regional Park (Parma, Italy; 44.74 N, 10.17 E), which hosts one of the largest populations of Stone-curlew in continental Italy (Giunchi et al 2009). In the period 1997-2012 a total of 555 chicks and adult birds were captured and most of them ringed with metal and colour rings both during the breeding and non-breeding season using different trapping methods (i.e. mist-nets, fall traps, dip nets and by hands).

Geolocators

Between April and July 2010 a total of 20 Stone-curlews (13 males and 7 females genetically sexed according to Griffiths et al 1998) were captured on their nests with a fall trap and fitted with geolocator tags (Mk18-L, 1.5 g, British Antarctic Survey) attached to Darvic rings placed on tibia (n = 10) or tarsus (n = 10). Two tagged birds belonged to the same breeding pair both in 2010 and in 2011 (see Table 1). In the year following the deployments, 12 individuals (5 tarsus-tagged and 7 tibia-tagged) were re-sighted and 10 of them were recaptured using fall traps or mist-nets and playback. Even though we have not performed a rigorous estimation of the re-sighting probability in our study area, a re-sighting rate of 60% was expected according to non systematic observations collected in previous years. While the legs of all re-trapped tarsus-tagged birds were in good conditions, one resighted and two recaptured tibia-tagged birds showed superficial wounds on the tarsus near the tibio-tarsal joint, probably due to the rubbing caused by the two pins of the devices that were not cut down before deployment. Being near the ground, the recovered tarsus-mounted loggers were rather worn, and two of them failed prior to the autumn migration. Another tibia-mounted logger gave inconsistent data due to a malfunction. Analyses were thus carried out on 7 individuals. We used BASTrak Decompressor software (British Antarctic Survey) to download light intensity data and the package *GeoLight* (Lisovski and Hahn 2012) within software R 3.0.1 (R Core Team 2013) to estimate daily latitude and longitude. Geolocator Mk18-L measured the intensity of visible light every minute on an arbitrary scale between 0 and 64 and recorded the maximum measurement every 5 minutes. Using a light threshold of 3, we manually checked all light transitions in order to identify dawn and dusk transitions. We rejected obvious shading events as well as data within 3 weeks around equinoxes (Hill 1994, Lisovski et al. 2012). Light data were corrected for internal clock drift using linear interpolation. While during the breeding season Stone-curlews are active both during the day and the night, during the non-breeding season birds are mainly active from sunset to sunrise (Cramp and Simmons 1983; Vaughan and Vaughan Jennings 2005). This behaviour, associated also to breeding duties (e.g. incubation), determined a lot of shading in our data, which produced a strong reduction of available fixes useful for the analysis.

Data were analysed using two different approaches. In the first method (*Method1*), loggers were calibrated using on-bird light data recorded during the 2010 nesting period (in-habitat calibration, Lisovski et al 2012), i.e. from the deployment date to 2010/08/15 (CAL period), when birds were at their breeding sites. Sun elevations angles (i.e. the angle of the sun above the horizon when the light intensity passed the threshold of 3) were individually calculated by minimizing the latitudinal distance between the deployment site and the median of latitudes of derived CAL fixes using the function *getElevation* from package *GeoLight* (Table 1). These values were used to estimate the locations throughout the year, given the expected short distance of migratory movements of Stone-curlews and the reported similarity of habitat types used during the breeding and non-breeding seasons (Vaughan and Vaughan Jennings 2005). We did not try to reconstruct the migratory routes and the location of stopover sites, because of the above-mentioned high level of shading causing high levels of uncertainty over short time periods, and the very low longitudinal component (see Results). For this reason, we only considered locations included in the period 2010/12/01-2011/02/28 (WINT period) when we expected that birds were in their wintering sites according to the available data on spring arrivals and autumn departures summarized by Vaughan and Vaughan Jennings (2005) or collected in our study area (Giunchi et al, unpublished data). During the WINT period we assumed that the birds were stationary for analysis purposes. Wintering ranges were determined using fixed normal kernel density estimation with reference smoothing parameter (h_{ref}), assuming a bivariate normal distribution (Worton 1995). We calculated kernel densities encompassing 50% (KDE50%) of the maximum density using the R-package *adehabitatHR* (Calenge 2006; Figure S1) and we assumed that the most likely location of the wintering site for each bird was the centroid of KDE50%. As a reference, we provide the results of the same approach applied on the fixes obtained during the nesting period (NEST period), from the deployment date to 2010/08/15 and from 2011/04/12 to recapture (Figures S2 and S3A, respectively).

The second approach of data analysis (*Method2*) partly follows Porter and Smith (2013). These authors emphasized that, while longitude estimations are expected not to be biased in one direction provided that shading events equally influence dusk and dawn transitions, the same is not true for latitude estimation. In this last case shading leads to a shorter estimate of daylight duration, which translates in a systematic displacement of points northwards when daylight duration is shorter at more northerly latitudes (after September equinox and before March equinox) and southwards when daylight duration is shorter at more southerly latitudes (after March equinox and before September equinox). Assuming that geolocator tags cannot record more light than direct sunlight with nil cloud and nil shading, it follows that the latitude of breeding locations of tagged Stone-curlews should be best approximated by the northernmost latitude estimate, while the southernmost location should best approximate the latitude of wintering location. These locations should represent the reading from perfectly clear and bright sky. Given the above and in order to buffer possible light reading errors of the tag, we determined the sun elevation by minimising the latitude distance between the deployment site and the average of the three northernmost locations recorded during the NEST period for each geolocator tag (Table 1). This approach assumes the occurrence of at least three perfectly clear unshaded transition pairs (i.e. dawn-dusk or dusk-dawn) during the NEST period. As the normality assumption for longitudes distribution was reasonably satisfied, the corresponding longitude was calculated as the average of the longitudes of all NEST fixes. The resulting locations are reported in Figure S3B. The most likely WINT locations were then calculated using the same philosophy: longitudes were estimated as averages of longitudes of all WINT fixes available for each bird, while latitudes were obtained by considering the average among the three southernmost available WINT latitudes.

GPS

In September 2012 two female Stone-curlews, trapped in a pre-migratory roost-site by means of mist-nets, were fitted with GPS data loggers with solar power and radio download (Harrier GPS logger, ca. 16 g, Ecotone, Poland). The weight of the GPS corresponded to ca. 3.5% of birds body weight. GPS were fitted using the leg-loop harness method (Rappole and Tipton 1991) with loop length determined according to the allometric function reported by (Naef-Daenzer 2007). GPS were set to record one fix every 30 minutes. Birds were followed for a few weeks before their departure. Both birds appeared in good conditions after the release, running and flying without impediments. In spring 2013 the two tagged Stone-curlews were recorded in the study area and we were able to download the wintering data at the beginning of April. As the sample size was rather small, we did not attempt to test statistically the side effects of the GPS. However, for both birds we were able to document at least one breeding attempt and, in one case, we recorded successful hatching by observing one chick about one-week old. Unfortunately, for unknown reasons (possibly for insufficient sunlight due to cloud cover or temporary feather obstruction), both GPS did not record/store locations from the period October-December 2012 and thus we have no data regarding the autumn migration. Given the scale and the aims of this paper, we do not provide any detailed analyses of the winter home ranges and of spring migratory routes.

Results

Ringing recoveries

As reported in Figure 1, only two ringing recoveries belonging to the non-breeding seasons are available for the study area. Both birds were ringed as chicks in the Taro Park and were found dead during the winter in Sardinia in the following year or in Corsica after three years.

Geolocators

Table 1 summarises the collected data. As anticipated in the Methods, the number of available fixes was relatively low due to the significant amount of shading caused by the behaviour of the studied species. The most likely wintering locations estimated by means of *Method1* and *Method2* are reported in Figure 1. Winter locations calculated according to *Method2* were relatively less dispersed and, as expected, generally displaced southward with respect to those obtained by *Method1* (distance between wintering sites: mean±SD = 77.7±56.8 km; bearing from *Method1* to *Method2* wintering site: alpha=180°, r=0.72, *n*=7). The patterns obtained by the two approaches were however quite consistent. Winter locations were clearly distributed along a North-South axis which connects the study area to Tunisia, passing through Corsica and Sardinia. Two groups of birds could be identified in both analyses: 1) birds wintering within the Mediterranean basin (mainly in Sardinia); 2) birds passing the winter in Tunisia (two individuals according to both methods). While the paired distances between breeding sites were quite small (mean±SD = 4.8±2.9 km, *n*=21; nearest neighbour distance = 1.3±1.2 km, *n*=7), the paired distances between wintering sites were of two order of magnitude higher (*Method1*: paired distance = 438.9±341.9 km, nearest neighbour distance = 113.4±113.1 km; *Method2*: paired distance = 375.8±313.4 km, nearest neighbour distance = 95.0±84.8 km) and roughly comparable to the scale of migratory movements (average distance between capture and wintering sites: *Method1* = 707.7 ± 381.6 km; *Method2* = 778.7 ± 335.5 km). Both birds belonging to the same breeding pair spent the winter between Sardinia and Corsica according to *Method1* or both in Sardinia according to *Method2.* The distances between the estimated WINT locations were one order of magnitude higher than those calculated between the estimated NEST locations (*Method1*: NEST distance = 54.1 km, WINT distance = 213.6 km; *Method2*: NEST distance = 26.2 km, WINT distance = 181.5 km).

GPS

As reported in Figure 1, the two GPS-tagged birds spent at least part of the winter in the North of Tunisia, about 900 km from the ringing area. Interestingly, the two wintering areas were relatively near (distance between the centre of mass of winter fixes = 80.0 km) and located not far from the coast. Since GPS dataset was not complete, we do not know whether the two birds migrated together in autumn. In spring they migrated independently, starting their migration on different days (March 9th and 19th) and following different routes, even though both birds headed toward the Italian peninsula and reached their breeding area flying over the mainland (Figure 1). In 2013 the distance between their nests sites was 4.3 km.

Discussion

To our knowledge, this study represents the first thorough analysis aimed at understanding the movements of a Mediterranean population of Stone-curlew and one of the few ever reported for the species. Indeed, up to now the only available data belonged to a handful of relatively small ringing recovery datasets (e.g. Spina and Volponi 2008; SEO/BirdLife 2012), which did not allow any satisfactory inference about the movement pattern of European populations, except for the British one (Green et al 1997).

The different sources of information we combined were quite coherent. Our results show good performance of geolocator tags on a short distance migrant species mainly active during the night. Most other geolocator shorebird studies have involved long distance movement (e.g Minton et al 2011; Klaassen et al 2011; Johnson et al 2012; Smith et al 2014). The two kinds of analysis of geolocator data produced comparable results. It should be noted, however, that: 1) data from *Method2* were relatively more homogeneous and 2) the pattern of sun elevation angles estimated by *Method2* (generally higher sun elevation angles for tibia than for tarsus loggers) was expected due the higher body shading experienced by tibia loggers (for *Method1* no pattern was evident). These considerations suggest that *Method2* is a reliable simple method to infer latitude of an assumed stationary bird (e.g. during wintering or at stopover site; see also Porter and Smith 2013), while *Method1* is more suitable for temporal movement information. As some shading variation will invariably be present in a significant dataset, *Method1* is likely to produce a greater error than *Method2* when used to determine the unknown static location.

Our results confirmed the expected short-range movements by the Stone-curlew (Cramp and Simmons 1983, Vaughan and Vaughan Jennings 2005). No tagged birds reached sub-Saharan Africa, contrary to what has been suggested by some Authors (e.g. Brichetti and Fracasso 2004). As we marked only adults, this particularly short migration range could be explained by considering the hypothesis put forward by Green et al (1997) that mostly first year birds moved to northern sub-Saharan regions. However, the possible effect of climate change should not be neglected, as a lot of studies have documented a recent northern shift of wintering ranges of several birds species, especially short-distance migrants, which has led to decreased migratory distances and sometimes even to residency (Fiedler et al 2004; Newton 2008; Doswald et al 2009; Knudsen et al 2011). Unfortunately, this second hypothesis cannot be tested, because of the lack of historical data on the migratory behaviour of the species.

It is worth mentioning that all birds captured in the same place (the two paired geolocator-tagged birds and the two GPS-tagged birds trapped in the same roost site) showed a noticeable latitudinal separation in winter, which suggests that the Stone-curlews belonging to the same breeding population tend to disperse over a relatively wide area during the non-breeding season. As almost all recorded wintering areas of tagged Stone-curlews occurred in regions where resident populations are reported/suggested (del Hoyo et al. 1996), it can be speculated that the observed distribution of birds during winter could be due to competition with local residents, which could force immigrant birds to use less favourable habitats and/or to spread over a wide area, as documented for other species (see Newton 2008 for references).

The recorded winter distribution of tagged Stone-curlews has significant management implication. Indeed, the majority of birds seem to spend the winter in Sardinia which indicates that the conservation of the species throughout its full annual cycle is a Mediterranean and, especially, an Italian/European issue. In particular, Sardinia, which also hosts the main Italian breeding population (Brichetti and Fracasso 2004, Tinarelli et al. 2009), has to be considered crucial for the conservation of the species in Italy, both during the breeding and the non-breeding seasons. It is important to notice that in *Method1* even though the centroid of kernel densities distribution of most birds was located in Sardinia or near the Sardinian coasts, it is actually difficult to decide whether these birds spent the winter in Corsica or Sardinia, given the low accuracy of geolocator fixes (see Figure S2). In Sardinia the winter presence of Stone-curlews is well known (Brichetti and Fracasso 2004; Tinarelli et al 2009), while very few winter records are reported for Corsica (Thibault and Bonaccorsi 1999). For this reason, Corsica seems to be less likely a significant wintering area, even though recent investigations indicate that the species is rather more widespread than previously thought at least during the breeding season (Seguin 2011).

While we do not have any information regarding the autumn migratory routes, in spring GPS-tagged birds did not fly over Sardinia and Corsica, but headed toward the Italian peninsula. However, no tagged birds passed the winter in the Italian peninsula, even though wintering populations of the species are reported from Central/Southern Italy and from Sicily (Brichetti and Fracasso 2004; Tinarelli et al 2009; Dragonetti et al 2014).

The presented data prove the great potential of tracking devices for understanding the movement pattern by the Stone-curlew. This information is extremely important for designing an effective conservation plan for the species, especially considering the recently revealed unexpected gene flow among Mediterranean populations of the species (Mori et al 2014).

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Figure captions

Fig. 1 Maps reporting the distribution of ringing recoveries available for the study area (filled triangles), of winter locations (filled dots) and spring migratory routes (black and grey thick lines) of the two GPS-tagged birds and of winter locations of geolocator-tagged birds (squares and diamonds) estimated by means of *Method1* (**A**, centroid of KDE 50%) or *Method2* (**B**, latitude = the latitude of the southernmost available WINT fix; longitude = average of all available WINT fixes). Open square and diamond indicate the two members of the same breeding pair. In Figure 1B horizontal bars indicate the SD of the distribution of WINT longitudes, while vertical error bars are equal to the range of the three southernmost WINT fixes considered in the analysis (see Methods).

Fig. S1. Maps reporting the filtered WINT fixes (filled dots) of geolocator-tagged birds estimated by means of *Method1* along with kernel densities encompassing 50% (KDE 50%) of the maximum density.

Fig. S2. Maps reporting the filtered NEST fixes (filled dots) of geolocator-tagged birds estimated by means of *Method1* along with kernel densities encompassing 50% (KDE 50%) of the maximum density.

Fig. S3. Distributions of the most likely NEST locations of geolocator-tagged birds estimated by means of *Method1* (**A**, centroid of KDE 50%) or *Method2* (**B**, latitude = average and range of the three northernmost available NEST fixes; longitude = average±SD of all available NEST fixes). Open square and diamond indicate the two members of the same breeding pair. Deployment and recapture sites of each bird were considered coincident (Nest site in the figure) because their distance was always less than 150 m.

Table 1 Summary of the data collected with geolocators.

									Sun elevation angle	
Animal ID	Sex	Deployment	Mount	Tracking days	Available fixes	CAL fixes*	NEST fixes**	WINT fixes***	*Method1*	*Method2*
IAAX	M	2010-06-04	Tarsus	365	181	24	33	76	-4.4°	-5.3°
IAFP	M	2010-05-01	Tarsus	362	87	16	16	32	-4.3°	-5.1°
IBFA†	M	2010-04-30	Tarsus	347	138	28	28	58	-5.2°	-5.7°
IBFC	M	2010-05-29	Tibia	337	128	18	27	28	-3.6°	-4.5°
IBFF	F	2010-06-04	Tibia	360	148	20	52	80	-4.4°	-5.0°
IBFK†	F	2010-07-09	Tibia	316	143	21	48	34	-4.2°	-4.6°
IBHP	F	2010-06-03	Tibia	344	236	55	77	73	-4.5°	-5.3°

† Members of the same breeding pair

* Considered period: [deployment, 2010/08/15]

** Considered period: [deployment, 2010/08/15] and [2011/04/12, recapture]

*** Considered period: [2010/12/01, 2011/02/28]

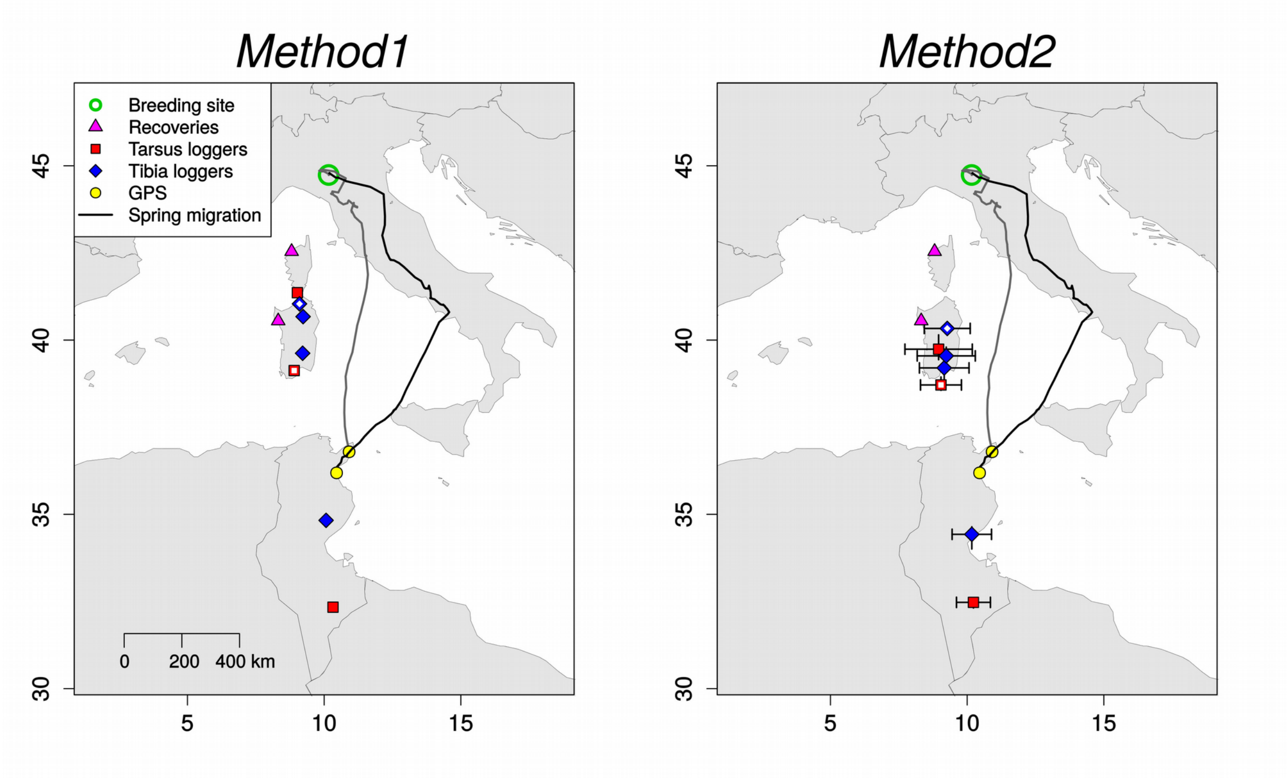
Method1
Method2
Breeding site
Recoveries
Tarsus loggers
Tibia loggers
GPS
Spring migration
0
200
400 km
30
35
40
45
5
10
15

Figure 1

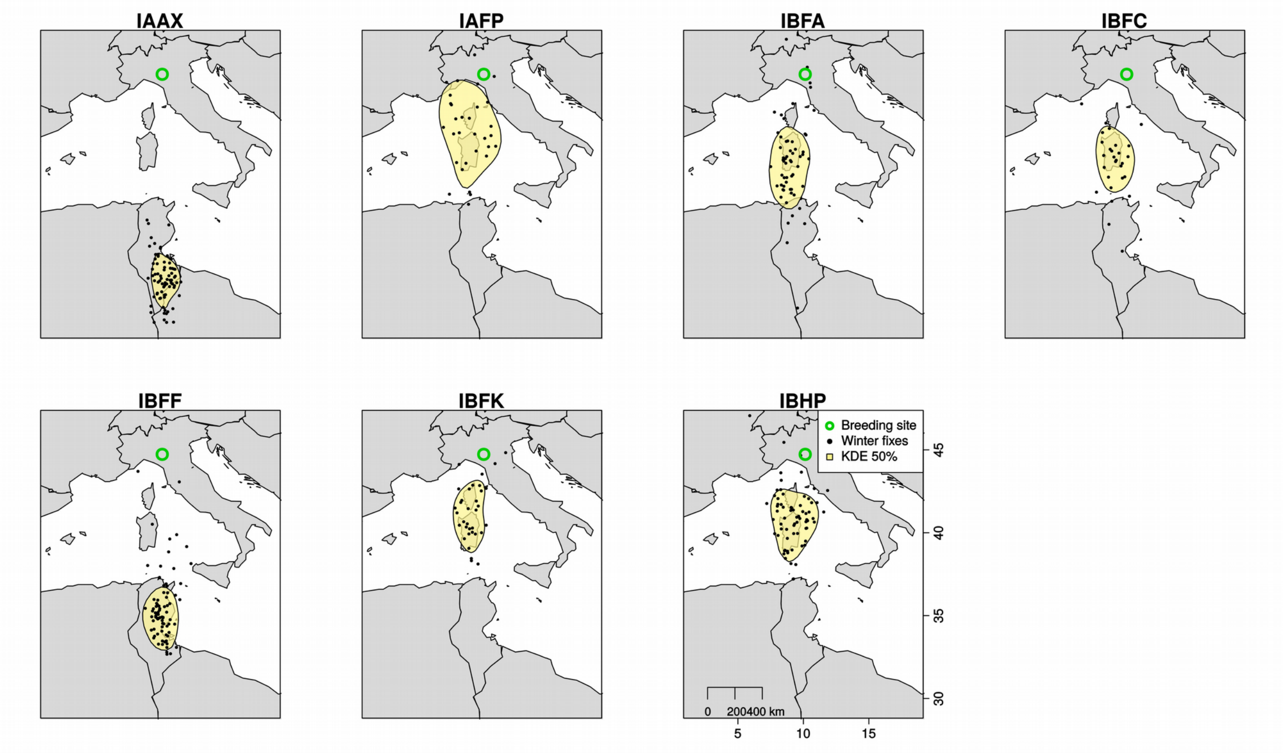
IAAX
IAFP
IBFA
IBFC
IBFF
IBFK
IBHP
Breeding site
Winter fixes
KDE 50%
45
40
35
30
0 200400 km
5
10
15

Figure S1

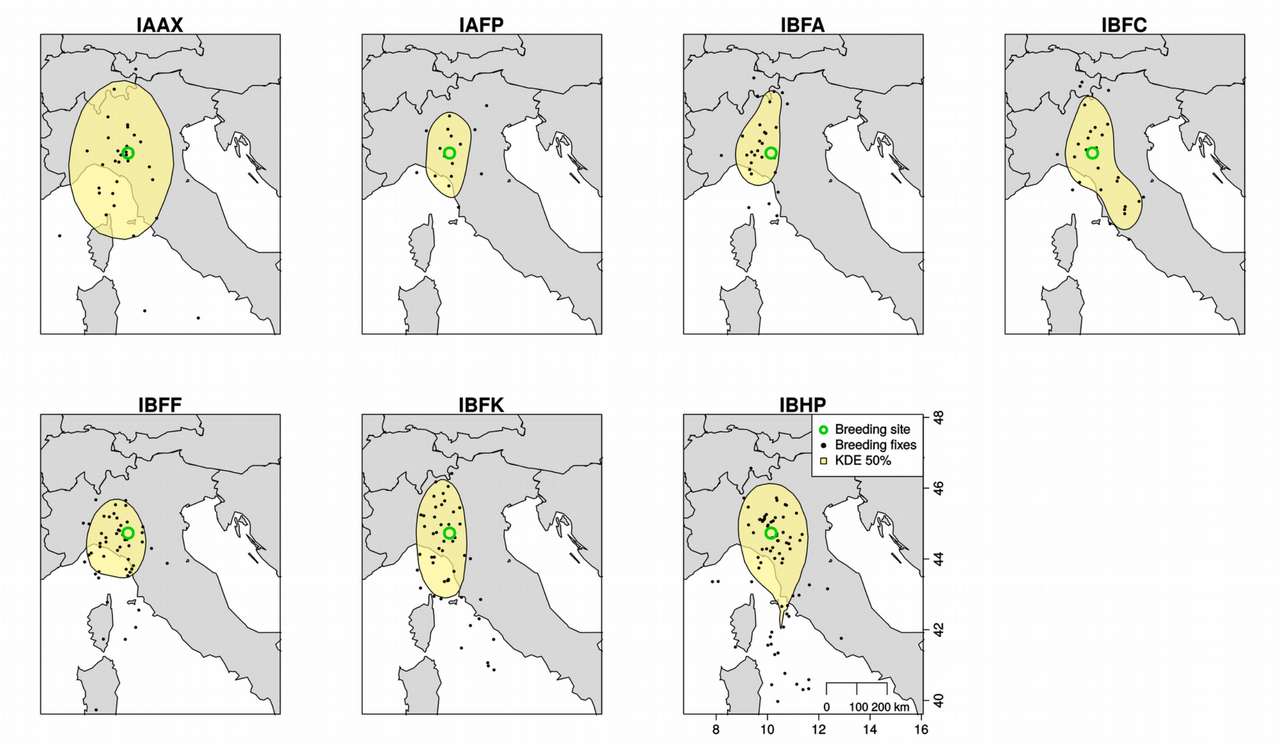
IAAX
IAFP
IBFA
IBFC
IBFF
IBFK
IBHP
Breeding site
Breeding fixes
KDE 50%
48
46
44
42
40
0
100 200 km
8
10
12
14
16

Figure S2

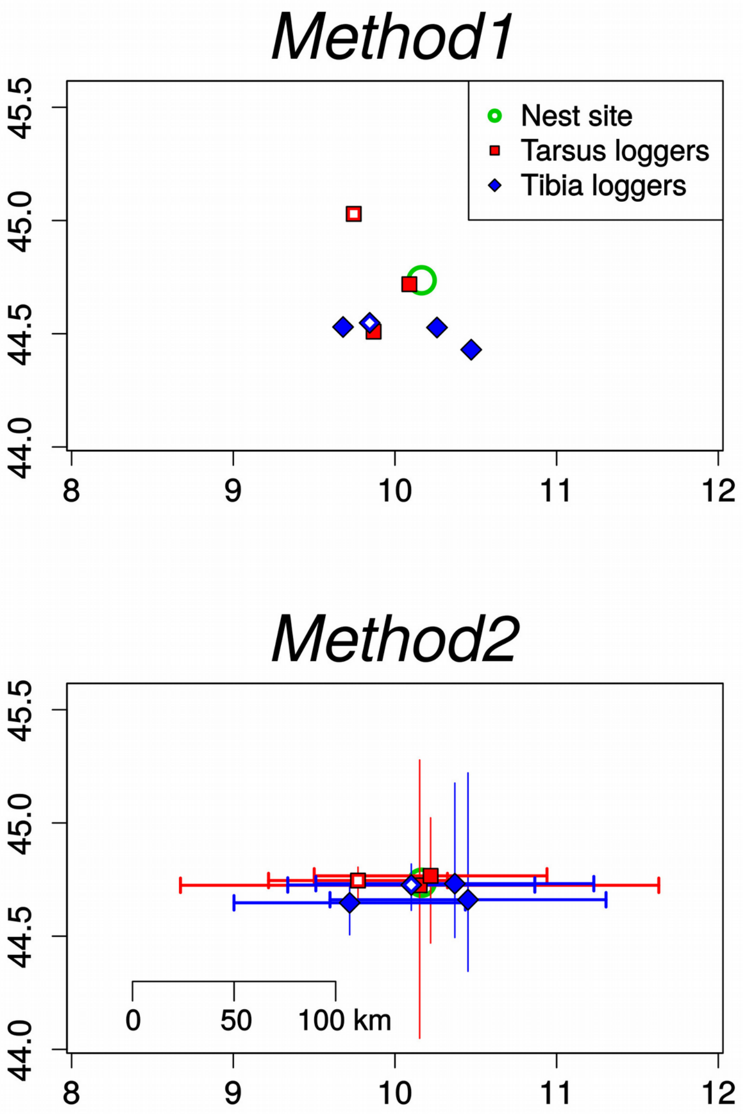
Method1
Nest site
Tarsus loggers
Tibia loggers
45.5
45.0
44.5
44.0
8
9
10
11
12
Method2
0
50
100 km
45.5
45.0
44.5
44.0
8
9
10
11
12

Figure S3