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SHORT COMMUNICATION

Early stages of home range settlement in a newly reintroduced raptor on an island: Bonelli's eagle (*Aquila fasciata*) on Mallorca, Spain

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Abstract

Bonelli's eagle (*Aquila fasciata*) had become extirpated in parts of their Mediterranean distribution, such as on Mallorca Island (Balearic Islands, Spain). Thanks to reintroduction programs, a new breeding population was reintroduced to the island, between 2011 and 2017. To identify movement patterns within the island, we equipped each reintroduced individual with a GPS device before release to track their movements. Home range of reintroduced eagles were calculated using a KDE — kernel density estimation approach. Although we found that home range size differed for individuals among years and sex, we found a high degree of overlap in home range in the study population. The home range of each individual remained stable in size and shape and few explorative flights outside the delineated home range were observed. In conclusion, reintroduced Bonelli's eagles have adapted to Mallorca Island by breeding earlier than already established populations, reducing their dispersive behaviour, and accelerating establishment of home ranges.

Keywords Conservation management · Home range · GPS device · Raptor · Reintroduction · Satellite tracking

Introduction

One of the most widely used approaches for restoration of endangered species populations in recent decades is reintroduction to areas they had been extirpated or extinguished (Armstrong and Seddon 2008; Seddon et al. 2014). Raptors are among the most threatened taxa worldwide and are common targets of reintroduction projects (McClure et al. 2017; Schaub et al. 2009; Walters et al. 2010). Once a species has been reintroduced, it is important to monitoring released individuals to evaluate the success of the project (Armstrong and Seddon 2008). Key metrics to evaluate the success of a reintroduction program include the post-release survival rates and the establishment of stable home ranges (Armstrong and Seddon 2008; Morandini and Ferrer 2017).

Tracking of movement patterns with satellite telemetry has been a useful tool for ecological and behavioural studies (Aebischer 1993; Börger et al. 2008; Dray et al. 2012; McGarigal et al. 2016), particularly for the estimation of home ranges, which are areas where animals perform behaviours associated with survival and reproduction (Burt 1943). This tool has also been used to compare the sizes and shapes of individual home ranges or movement patterns (Martínez-Miranzo et al. 2016). However, few studies have used this information on home range establishment to evaluate the success of reintroduction programs (Egea-Casas et al. 2022).

Bonelli's eagle (*Aquila fasciata*) had experienced a considerable population decline across its distribution in recent decades, which has led to the species being classified as vulnerable in Spain (SEO/BirdLife 2021). The species is extirpated from some areas, such as the Mediterranean island of Mallorca, since the 1970s (Viada et al. 2015). As such, Bonelli's eagle has been used as a model species for reintroduction programs in Italy and Spain.

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The main objective of this work is to understand patterns in home range establishment of Bonelli's eagle reintroduced to the island of Mallorca. The absence of potential competitors may induce early home ranges settlements. We expected differences in home range size to be explained by sex before pairing. In addition to habitat configuration and prey availability, individual abilities and preferences may determine the shape and size of the home ranges. The location and size of each individual home range should remain stable over years, so we expected a high degree of overlap between years. Our study may support the stability on the island of Mallorca of a new reintroduced population of Bonelli's eagle.

Methods

The study was conducted on Mallorca, Spain, located in the Mediterranean, 220 km from the Iberian Peninsula. Mallorca is the biggest island in the Balearic archipelago (3640 km^2). The island is mountainous, including the Serra de Tramuntana and Serra de Llevant, which provides a suitable environment for the establishment of new territories by Bonelli's eagles.

We analysed data from 15 individual eagles in Mallorca, collected between 2013 and 2019. All reintroduced eagles were tagged with both a metal and a PVC ring and equipped with a GPS133 GSM satellite device (Table SI1). Transmitters were mounted following Garcelon (1985). The weight of all equipment (transmitter, harness and rings) represented a maximum of 3% of the total body weight (Kenward 2001). Not all transmitters were set to recorded location on the same time interval (its varies depend on the transmitter from every 5 min (minimum) to every 2 h (maximum). Therefore, to homogenize the data for analyses, one position every 2 h was used in the analyses for all individuals. We homogenized the data following the methodology of Martinez-Miranzo et al. (2016). We cleaned the dataset by removing spatial outliers. Also consecutively repeated locations in the early morning and late evening of inactive Eagles were excluded because they were considered to be non-independent.

Based on previous studies with Bonelli's eagle (Martínez-Miranzo et al. 2016), we estimated four spatial parameters for each breeding pair ($n=6$), where K = the percentage of Isopleths at different levels). We defined the nesting area (K5) as the area of preferential use or where the largest number of locations were concentrated within the home range. The core area (K50) was defined as the area selected for hunting and roosting. The critical area (K75) and the total home range (K95) were defined as the territory. We used the 'adehabitatHR' package in Rstudio 1.3.1056 using the estimation of kernel home-range function (kernelUD; Calenge 2006). These parameters were plotted with the program QGIS 1.18.13. We used an overlap analysis in the 'vector' function for QGIS 3.14 to assess the degree of home range overlap. We calculated the overlap between individuals which were tracked for > 2 years (Martínez-Miranzo et al. 2016). We used the total of years tracked for each individual and compared the degree of overlap between consecutive years. In addition, we calculated the degree of overlap between individuals of the same breeding pair.

Analysis of variance (ANOVA) was conducted to analyse variations in home range according to individuals, sex, and year. We first checked our spatial parameters (K5, K50, K75, K95) for normality using a Shapiro–Wilk test. Statistical analyses were carried out using RStudio 1.3.1056 with stats R package.

Results

A total of 53,471 locations from 15 eagles were obtained and analysed in this study. When a possible breeding pair settled in an area, it was considered the first year of home range establishment (Table SI1).

We considered 6 home ranges in this study (Table SI1). The parameters related to the spatial use of 15 individuals were estimated for those individuals with more than 1 year of monitoring. In addition, data from individuals whose GPS failed were not included in these analyses (Table SI1). Area values (km^2) between the different years were obtained for the spatial parameters (K95, K75, K50, and K5; Table 1). The mean home range size (K95) of Bonelli's Eagles in Mallorca was 56.3 km^2, with a range of 26.3–98.7 km^2.

Table 1 Coefficient table for ANOVA for all spatial parameters (nesting area [K5], core area [K50], critical area [K75], and total home range [K95]) of Bonelli's eagles (*Aquila fasciata*; $n=15$ [6 pairs]) reintroduced to the island of Mallorca. Significants ($p<0.05$) are represented with *

Variables	Spatial parameters	Sum Sq	Mean Sq	F value	*P* value
Individuals	K5	0.0218	0.02729	0.89	0.55
	K50	158.5	19.81	4.31	0.0072*
	K75	562	70.3	2.69	0.047*
	K95	9469	1187	2.58	0.054
Sex	K5	0.004	0.00351	0.11	0.74
	K50	7.9	7.87	1.71	0.2102
	K75	199	199.3	7.62	0.015*
	K95	2358	2358	5.12	0.039*
Years	K5	0.038	0.00637	0.21	0.97
	K50	94.1	15.68	3.41	0.025*
	K75	626	104.3	3.99	0.014*
	K95	3149	525	1.14	0.387

We found significant differences in core area (K50) and critical areas (K75) for individuals ($p < 0.05$), both related to the spatial use inside the home range and were dependent on the individual. Bonelli's eagles on the island of Mallorca showed a different pattern of spatial parameters between sex and years. We found significant differences in critical area (K75) and home range size (K95) between sexes. However, we did not find any differences in home range size between years (Table 1), but they were significantly different in core (K50) and critical areas (K75; Table 1).

Female 1, female 2a, and male 6 (Table 2) were excluded from the overlap analysis because only 1 year of monitoring was available for these individuals. Eagles in Mallorca showed a high degree of overlap in the total size of the home range (K95) between years and within individuals. The home range size decreased over the years but with different individual patterns, typical of home range stabilization. The only individual that increased the size of its home range was male 2, likely induced by a change in a breeding pair (Table 2). The average degree of overlap between individuals of the same breeding pair was 92%. Pairs 2, 3, 4, and 6 showed 100% overlap, pair 1 showed 72%, and pair 5 showed 85% of overlap.

Discussion

For the reintroduced population of Bonelli's eagle on Mallorca, home range size tended to stabilize and minimize in order to optimize the use of the home range by individuals. The use of space that individuals made within their home ranges appeared to vary in core and critical areas (K75, K50) and was different between sexes, despite individuals within breeding pairs having a high degree of home range overlap. The fact this was a new population on an island seemed to determine both the home range establishment and the age of reproduction. The individuals occupied the mountainous areas of the Tramuntana first, then colonized the rest of the island according to availability. Individuals were younger at their first breeding attempt compared to already established populations.

Spatial behaviour of Bonelli's eagle population on Mallorca seems to follow the same pattern of the mainland population (Martínez-Miranzo et al. 2016; Pérez-García et al. 2012; Real et al. 2016). Individuals establish their home range (K95) and maintain it between years, with a high degree of overlap (98% per individual in some cases).

Individuals usually reduce the size of their home range year after year, for optimization of the home range usage to cover their basic needs (nest location and prey availability), while minimizing overlap with other individuals of the same species to avoid intraspecific competition (Ritchie and Johnson, 2009). Unless females maintain larger home range (K95) and critical areas (K75) than males, due to sexual size dimorphism in raptors, overlapping home ranges of the same breeding pair is almost 92%. Individual differences in the degree of overlap were caused by the loss of one of the members of the breeding pair.

The insularity effect of the Mallorca Island for a new population of long-live raptor should play an important role in establishing their home range. Reintroduced individuals breeding earlier than already established populations should play a critical role in the success of reintroductions of such long-lived birds (Morandini et al. 2019). It decreases the probability of mortality in dispersing juveniles, which is critical for this species. Additionally, individuals that recruited into the population at a young age had both higher breeding performance and higher adult survival than those that recruited at advanced ages over the individual life span. Finally, selecting a quality home range is crucial for higher breeding performance (Ferrer et al. 2011), which may be a challenge in a closed system, such as an island. In fact, this species preference for cliffs and rocks as nesting sites has made them almost

Table 2 Total size of the home range (K95) in km^2 and overlapping percentage (%) of the area in relation to the previous year (in parentheses) of Bonelli's eagles (*Aquila fasciata*; $n = 15$ [6 pairs]) reintroduced to the island of Mallorca. In the last column, the difference in size in km^2 between the first and the last year for each individual and the percentage of overlap between the two (in parentheses). Signs +/− indicate an increase/decrease in home range size. The only individual that increases the size of its home range is male 2 and it is due to a change of breeding partner. *Indicated the GPS device failed after deployment

Pair	Sex	2013	2014	2015	2016	2017	2018	2019	Change rate
1	♂	49.76	46.76 (85%)	50.70 (80%)	43.34 (98%)	*	28.09 (86%)	36.81 (90%)	− 12.95 (91%)
2	♀*b*				60.31	41.08 (100%)	*		− 19.23 (100%)
	♂					39.81	49.27 (95%)	98.60 (100%)	+ 58.79 (100%)
3	♀			69.69	33.01 (100%)	*	*	35.00 (80%)	− 34.69 (100%)
	♂			68.90	46.90 (99%)	*	26.34 (100%)		− 42.56 (100%)
4	♀*a*				81.53	71.62 (98%)	44.84 (95%)	*	− 36.69 (98%)
	♂				78.95	65.31 (99%)	*	28.81 (100%)	− 50.14 (100%)
5	♂				78.69	62.28 (97%)	*		− 16.41 (97%)

completely occupy the Serra de Tramuntana, where the first breeding pairs settled.

To avoid overlap of home ranges, the selection of alternative habitats for nesting may be necessary, such as the secondary occupation of trees that we recorded in some of the breeding pairs we monitored (e.g. pairs 2 and 6). This will be relevant for the establishment of future breeding pairs in Mallorca because the lack of space will force individuals to search for alternative habitats to establish new territories, as the most optimal habitats become fully occupied.

In conclusion, reintroduced Bonelli's eagle appear to adapt to life on the island of Mallorca by accelerating the establishment of home ranges and reducing, both in time and space, its dispersive behaviour in comparison to its peninsular neighbours. Of the studied factors, only sex affected the size of home range estimate (K95). Additionally, the absence of interspecific competitors such as the golden eagle (*Aquila chrysaetos*), which became locally extinct on Mallorca since the 1950s, has allowed the Bonelli's eagle to quickly settle and take its place as a top predator. Additional data and monitoring of newly released or hatched individuals on the island will help to track the long-term success of the reintroduction project and implement future conservation measures to preserve the species on Mallorca.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10344-022-01633-3.

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Data availability Due that Bonelli´s eagle is a endagered species, data from the study can be request to the corresponding author if this is a suitable proposal.

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