Revised for Ostrich

Ranging behaviour of Long-crested Eagles *Lophaetus occipitalis* in human-modified landscapes of KwaZulu-Natal, South Africa

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Abstract

The ranging behaviour of raptors in human-altered environments such as agricultural and suburban landscapes are becoming increasingly important for conservationists in the context of unprecedented high rates of anthropogenic land use change. We studied the movement ecology of adult Long-crested Eagles (*Lophaetus occipitalis*) fitted with geographic positioning system transmitters in an agricultural landscape in KwaZulu-Natal Province, South Africa. Mean home ranges (± SD) of males and females estimated using the autocorrelated kernel density estimator (AKDE) method were 608 ± 552 ha (n = 5) and 664 ± 844 ha (n = 4), respectively. Core areas (KDE h_{ref} 50%) were estimated to be 80 ± 38 ha and 39 ± 20 ha for males and females, respectively. We also recorded exploratory behaviour (in the form of long excursions) in two of the birds, of up to 49 km from the centre of their home range. The relatively small home ranges reported in this study are suggestive of productive foraging habitats whereby Long-crested Eagles can meet their energy requirements without having to travel long distances to obtain resources. Consistent with predictions, non-breeding male and female Long-crested Eagles showed similar ranging behaviour which includes occasional exploratory behaviour.

Keywords: Long-crested Eagle, home range estimate, agricultural landscapes, raptor, GPS transmitter

Introduction

The ranging behaviour of raptors in transformed habitats such as agricultural landscapes is becoming an increasingly important topic to conservationists because of the unprecedented high rate of land use change in recent years. Foraging habitats in transformed and natural habitats may differ in the quality and quantity of the food resources they offer resulting in different home range sizes in these habitats (Buij et al. 2014, Morrison et al. 2016). The area where an animal obtains its food and breeds is known as its home range (Burt 1943).

Factors affecting the size of this area (home range) are not fully understood for most species (Börger et al. 2006) but habitat productivity, vegetation structure and foraging habits of a species are expected to contribute significantly to home range size as they relate to foraging success (Buij et al. 2014). In general, diurnal raptors tend to have larger home ranges in habitats with lower food availability (Newton 1979; McPherson et al. 2019), and those species that feed on sparsely distributed prey (e.g. avian vs mammalian prey) increase their home ranges in order to meet their energy requirements (Marzluff et al. 1997a; Peery 2000); a pattern also observed with Tengmalm's Owls (*Aegolius funereus*). Home range sizes of Tengmalm's Owls increased with decreased prey abundance (Kouba et al. 2017). Therefore, raptor home ranges may expand or shrink depending on habitat quality and local food availability, age and competence of the bird and its immediate food needs (Newton 1979; Santangeli et al. 2012; Campioni et al. 2013).

Patches of intensive use within home ranges (core areas) are believed to be bearing important resources to an animal (Powell 2000) and in birds this area is usually around its nest (Newton 1979). During the breeding season nesting pairs spend a greater proportion of their time at or near their nests (Haworth et al. 2006), but they may also range outside of this territory, for example to seek better feeding opportunities (Pérez-García et al. 2013). Males of Lesser Kestrels (*Falco naumanni*) have been reported to take many short foraging trips around their nests as opposed to few long foraging trips taken by females suggesting different foraging strategies between the sexes (Hernández-Pliego et al. 2017).

Long-crested Eagles (*Lophaetus occipitalis*) occur in a variety of tropical and subtropical habitats across Africa including in agricultural landscapes, open woodlands and marshy areas (Steyn 1983), and may even occur in highly disturbed areas (Seavy and Apodaca 2002). These eagles maintain their nesting territories throughout the year in some areas (Brown et al. 1982), although it has been suggested that females, but not males, vacate their territories during the non-breeding season (Hall 1992). Because of their diet, they are expected to benefit from heterogeneous habitats that result from anthropogenic land use changes in human-modified landscapes (Ferguson-Lees and Christian 2001) and have indeed moved into formerly treeless grasslands of South Africa (Johnson 2005). As expected of raptors feeding on small mammals, Long-crested Eagles appear to breed throughout the year (Johnson 2005), depending on food availability. This further highlights plasticity in their behaviour. The main objective of the present study was to describe the home range of Long-crested Eagles in a human-modified mainly agricultural landscape, using geographic positioning system (GPS) transmitters. We expected the home ranges of male and female eagles to be similar in extent except during the breeding season when female home ranges were expected to be significantly smaller because of their brooding responsibilities (Jarvis and Crichton 1978; Johnson 2005).

Materials and methods

Trapping and monitoring

From August 2016 to May 2017, we trapped twelve adult Long-crested Eagles using a bal-chaltri trap baited with laboratory mice in the Midlands of KwaZulu-Natal Province, South Africa (Fig. 1). Two of the eagles were located within peri-urban/suburban landscapes and the rest were located in agricultural landscapes. We placed the trap alongside roads within territories of resident birds. Standard morphometric measurements (mass, wing length, etc.) were taken from captured birds. A drop of blood was obtained from each bird using a 5ml syringe and venipuncture to verify sex, and was later analysed by Molecular Diagnostic Services (Durban, South Africa). All birds caught were ringed and fitted with geographic positioning system (GPS) transmitters. No bird was injured during capture and all birds were safely released at the same area they were trapped.

Ten of the eagles were fitted with non-solar Ultra-High Frequency Geographic Positioning System (UHF-GPS) avian transmitters (www.wirelesswildlife.co.za) weighing ~40 g. GPS units were programmed to take four GPS fixes per day (06h00, 10h00, 14h00 and 18h00) and to switch off at night to prolong battery life. Data were downloaded to a base station mounted on a vehicle which in turn transmitted data to a remote server via global system for mobile communication (GSM) network. We also used solar charged GPS-GSM-LoRa devices (http://iot-gps.co.za), weighing 30 g, programmed to take a GPS fix every 2 h between 06:00 and 18:00, on two of the eagles. The transmitters were attached to the birds as back packs made of 6 mm teflon ribbon (Bally Ribbon Mills, Bally, USA) and never exceeded 5% of the body mass of the bird as recommended by Kenward (2000). The data from each transmitter included latitude, longitude, date and time. We defined breeding season as the period from the beginning of incubation to the day the nestling fledged, and all other times outside the breeding season were considered as non-breeding season.

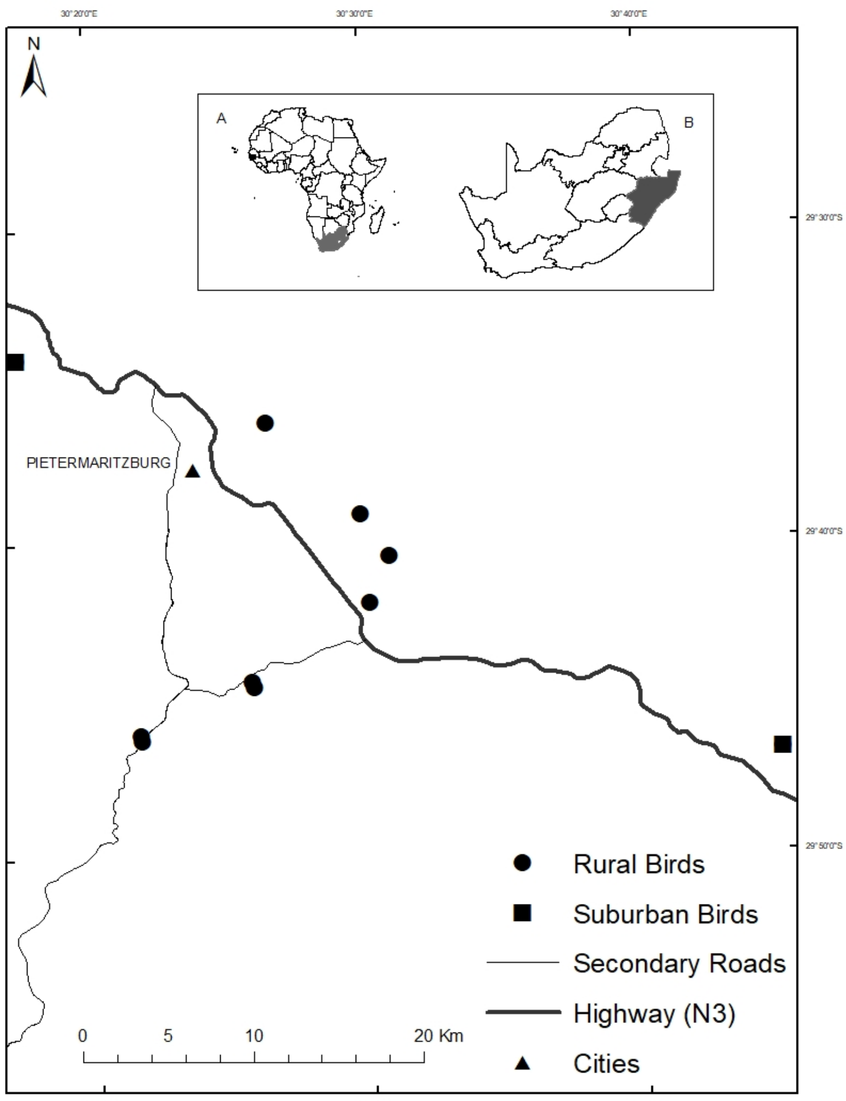

Figure 1: Location of the study area in KwaZulu-Natal Province, South Africa, showing trapping sites of twelve Long-crested Eagles tagged with GPS transmitters. Insert: **a** location of South Africa in Africa and **b** location of the KwaZulu-Natal Province in South Africa

Data analyses

Datasets from each tracked eagle were screened to remove null locations and duplicates. They were then transformed to Universal Transverse Mercator (UTM) projection, WGS 1984, UTM zone 36 S in R (R Core Development Team 2014). We used the rhr package to test for site fidelity for each bird as recommended by Laver and Kelly (2008). Home range analyses, movement and site fidelity tests were performed in R version 3.1.3 (R Core Development Team 2014) using adehabitat, rhr and ctmm packages (Calenge 2006; Signer and Balkenhol 2015; Calabrese et al. 2016). Plots of semi-variance as a function of time lag between observations (variogram) were used to determine if the tracked eagles were range residents (Calabrese et al. 2016, Noonan et al. 2019). The kernel density estimator (KDE) method with reference band width was used to estimate core areas and home range sizes. In this method contours (isopleths) are created around a predetermined percentage of the GPS fixes which are reflective of the amount of time the animal spends within a particular contour (Hemson et al. 2005). The 50 % contour predicted areas of intensive use (referred to as core areas here after) based on 50 % of the fixes and nests of breeding raptors are usually found within this area (Walker et al. 2005; Moss et al. 2014; Watson et al. 2014). To minimise exploratory movements, we used 95 % of the fixes to estimate home range sizes for each eagle following Moss et al. (2014). We also fitted a continuous-time model to the data to assess the effects of autocorrelation on the home range estimates using the ctmm package, incorporating the autocorrelated kernel density estimator (AKDE) (Fleming et al. 2015, Calabrese et al. 2016, Fleming and Calabrese 2017). When the data are independent and identically distributed, home range estimates calculated using the AKDE method revert to the conventional KDE estimates (Calabrese et al. 2016).

Minimum convex polygons (MCP) were also estimated to facilitate comparison with older studies. The distance between any two consecutive fixes was calculated using the adehabitat package (Calenge 2006). Distance covered per day was calculated by adding the distance between the four consecutive fixes within a day. Movements of females were expected to have considerable variations because of incubating females and therefore minimal movement. Hence, we only described movements of males to avoid reporting means that have too much variation. Means are presented with their standard deviations (± SD).

Results

Three of the 12 transmitters (one UHF-GPS and two GPS-GSM-LoRa devices) failed because of mechanical faults and their data could not be used for analyses. Only three tagged females were able to breed during the tracking period. Of these we obtained complete movement data (that included both breeding and non-breeding seasons) from one female because the other two started breeding towards the end of the tracking period. All tracked males did not breed during the study and their movements were considered to be outside of the breeding season.

Long-crested Eagles were tracked for an average of 212 ± 78 days (range: 101 - 294 days, Table 1). Variograms of the nine eagles used in the analysis showed asymptotic use of space over time, suggesting range residency (Appendix 1). The telemetry data showed that the eagles travelled a mean distance of 2131 ± 917 m per day, i.e. added distance between consecutive fixes within a day. Maximum distance recorded between consecutive fixes was less than 13 km for all the birds except for two birds with exploratory movements outside of their home range (Table 1, Appendix 2). These were recorded 27 and 49 km away from the centre of their home range and were one adult male and one adult female, respectively.

Table 1: Home range sizes (ha) of nine Long-crested Eagles in a human-modified landscape in KwaZulu-Natal Province, South Africa. Maximum refers to maximum distance in meters recorded between two consecutive fixes. (Abbreviations: KDE = kernel density estimator, AKDE = autocorrelated kernel density estimator, CI = confidence interval, MCP = minimum convex polygon)

	Fixes	Days	AKDE 95%	AKDE CI		KDE 95 %	KDE CI		MCP 95%	Maximum
Males										
A3	448	112	150	135	165	191	174	209	135	1468
A8	805	227	304	284	326	415	387	444	271	2923
H6	484	122	438	398	479	541	493	590	368	3603
A7	963	245	596	557	635	638	652	745	658	3628
A4	913	264	1550	1371	1741	4392	4112	4682	525	26713
Mean	723	194	608	549	669	1235	1164	1334	391	7667
SD	241	72	552	485	624	1773	1657	1882	206	10683
Females										
K1	1167	294	92	84	100	99	94	105	148	1928
K2	1030	275	257	230	287	1244	1169	1321	60	12927
H5	999	272	388	352	427	438	411	465	452	4274
A1	377	101	1917	1720	2125	4696	4233	5182	334	48854
Mean	893	236	664	597	735	1619	1477	1768	248	16996
SD	352	90	844	757	936	2107	1892	2332	178	21759

The conventional KDE and AKDE methods produced similar home range estimates in all tracked birds with the exception of the two wide ranging individuals. Mean home ranges of males estimated using the MCP, conventional KDE and AKDE methods were 391 ± 206, 1235 ± 1773 and 608 ± 552 ha, respectively. Mean home ranges of female Long-crested Eagles were 248 ± 178, 1619 ± 2107 and 664 ± 844 ha using the MCP, conventional KDE and AKDE methods, respectively (Table 1). AKDE home range estimates of males and females were not significantly different (Mann-Whitney U = 27, $p = 0.7133$, $n_1 = 5$, $n_2 = 4$, Fig. 2) and the other estimates calculated using MCP and KDE were also not significantly different. Using the conventional KDE method, core areas of males and females were estimated to be 80 ± 37 and 39 ± 20 ha, respectively.

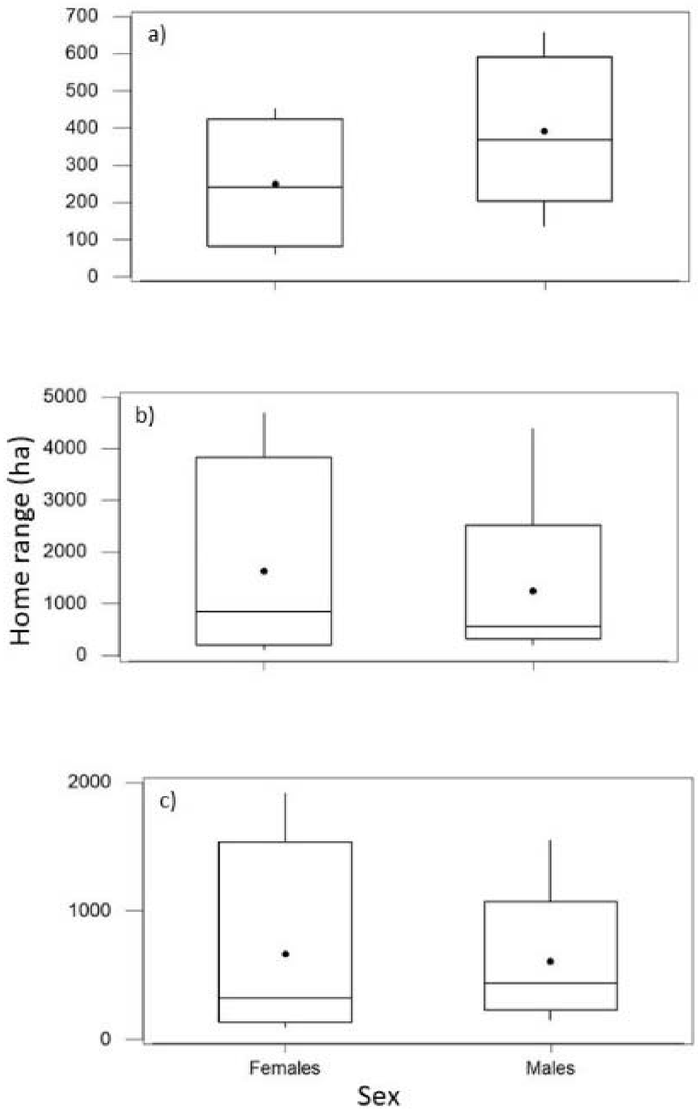

Figure 2: Boxplots of home range sizes of female and male Long-crested Eagles in a human-modified landscape in KwaZulu-Natal Province, South Africa. (a**)** minimum convex polygon, (b) conventional kernel density Estimate which ignores autocorrelation, **(**c) autocorrelated kernel density estimate which accounts for autocorrelation. (Black dots indicate means on each graph).

The tracking period of one of the females which began in August 2016 and ended in May 2017 included two incubation periods. The home range size of this female was smallest during the incubation periods, i.e. September/October 2016 and April/May 2017 (Fig. 3). In December 2016 when the chick left the nest, the home range size of the adult female rapidly increased and began to contract again in March when it prepared for the next breeding season. After the chick had fledged the home range of the adult reached a maximum size of 216 ha which was smaller than the mean home range for all the tracked females.

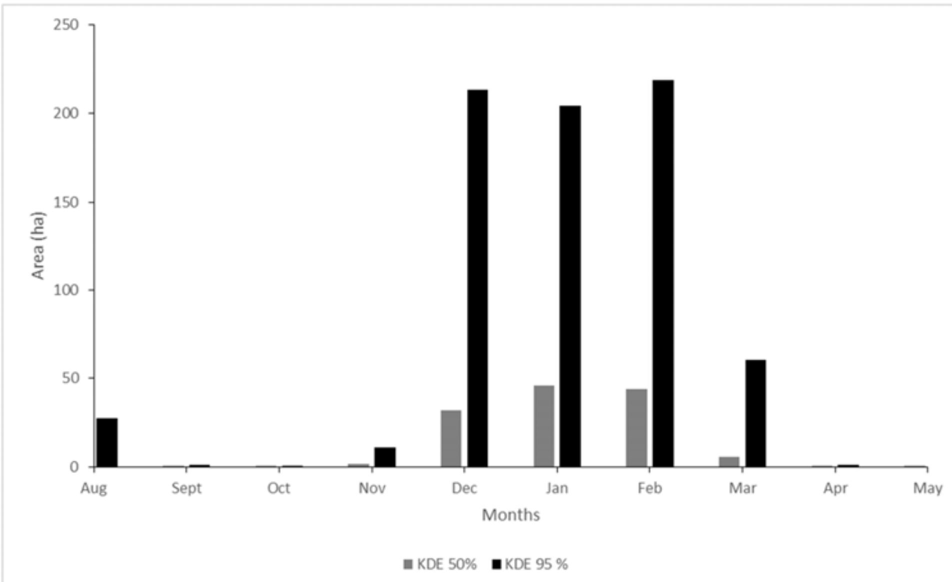

Figure 3: Changes in the home range size of a female breeding Long-crested Eagle in a human-modified landscape in KwaZulu-Natal Province, South Africa. Incubation began in September and the nestling fledged in December 2016. The female then laid again in March/April 2017. KDE 50 % indicates areas of intensive use or core areas and KDE 95 % represents home range estimate using the kernel density estimator method

Discussion

To the best of our knowledge, our study presents the first telemetry based home range estimates of Long-crested Eagles in an agricultural landscape. According to the autocorrelated kernel density estimator method, mean home ranges for Long-crested Eagles in the present study were 608 ± 552 ha (n = 5) and 664 ± 844 ha (n = 4) for males and females, respectively. Although the tracked eagles were generally sedentary with relatively small home ranges, there was notable individual variation in their ranging behavior, with some individuals recorded over 20 km away from the centre of their home range. However, home ranges of males and females were not significantly different suggesting similar ranging behaviour between sexes.

The sizes of home ranges of male and female Long-crested Eagles in the present study were smaller than those reported for Mpumalanga Province of South Africa, which were 2500 – 3500 ha (Steyn 1983; Johnson 2005). Small home ranges are generally indicative of high prey densities as eagles do not have to travel long distances to obtain food (Fernández et al. 2009). Therefore this difference may be a result of differences in the two provinces such as difference in habitat structure which influences prey availability. Steyn (1983) reported comparable home range sizes for Long-crested Eagles in Zimbabwe which were 400 – 650 ha. Autocorrelation appears to have had minimal effects on the home range estimates in the present study as the conventional KDE home range estimates were almost similar to the AKDE estimates, which is a method that accounts for autocorrelation. The 4 h intervals between observations used in the present study possibly improved independence of each GPS fix because autocorrelation decreases with increasing sampling intervals in general (Swihart and Slade 1985; Perotto-Baldivieso et al. 2012). However, we realise the trade-off between collecting fewer independent data and the loss of more detailed information between observations.

The sedentary behaviour of this raptor species was also highlighted by the relatively small mean distance travelled per day, which was at least 2 km. Raptors that rely on the sit and wait hunting strategy, like Long-crested Eagles, tend to spend most of their time perching and less time flying (Mendelsohn and Jaksic 1989; Plumpton and Andersen 1997; Baladrón et al. 2006). Long-crested Eagles often have a few favourite perches within their home range from which they hunt (Johnson 2005). They are also known to be opportunistic foragers, visiting new places where there is sudden abundance of prey (Steyn 1983), as is expected for a rodent eating raptor (Korpimäki and Marti 1995). The movements of the two wide ranging eagles may have been motivated by their search for new and better feeding opportunities elsewhere as suggested for Bonelli's Eagles (*Aquila fasciata*) (Pérez-García et al. 2013). This behaviour needs further investigation as there could be other reasons for such movements, such as searching for new territories. Hall (1992) also suggested that during the non-breeding season females vacate their territories and may be seen outside of their home range.

Nests of the three breeding females in the present study were located within their core areas and they remained near their breeding areas throughout the duration of the study. Although the sample size of breeding females in the present study was small, we suspect that Long-crested Eagles remain near their nesting sites throughout the year as suggested for other raptors. Bosch et al. (2010) suggested that Bonelli's Eagles remain near their breeding sites to prevent nest usurpation by competitors. This likely applies to Long-crested Eagles, whose nest site potential competitors are Black Sparrowhawks (*Accipiter melanoleucus*) and Egyptian Geese (*Alopochen aegyptiaca*) (M. Maphalala pers. obs.). During the study at least one Long-crested Eagle nest was taken over by a Black Sparrowhawk and the following year the Long-crested Eagle built a new nest, about 400 m from its previous nest. Egyptian Geese appear to compete with Black Sparrowhawks for nests (Curtis et al. 2007; Wreford et al. 2017) and it would be reasonable to expect that they would also compete with Long-crested Eagles as well because these two raptors have similar nesting habitat preferences. Resident Egyptian Geese were observed in the nesting territories of two of the three breeding females studied here but no aggressive interaction was witnessed. Other raptorial species that are potential competitors for nesting trees with Long-crested Eagles include Black Kite (*Milvus migrans*), Wahlberg's Eagle (*Aquila wahlbergi*), Jackal Buzzard (*Buteo rufofuscus*) and the African Harrier-hawk (*Polyboroides typus*) (Malan and Robinson 2001).

The data from the Long-crested Eagle that was tracked for both the breeding and non-breeding seasons suggests that Long-crested Eagles used smaller home ranges during the breeding season and then expanded their home ranges during the non-breeding season. This can be explained by the fact that breeding raptors (females in particular) forage around their nests during the nestling period but progressively travel further as the chick grows older (Newton 1979). Home ranges of Golden Eagles (*Aquila chrysaetos*) in southwestern Idaho were found not to vary between years or sex but varied according to seasons, being larger in the non-breeding than the breeding season (Marzluff et al. 1997b). However, breeding birds have also been reported to have larger home ranges in places of low prey density resulting in the birds travelling to distant undefended territories where food is more abundant (Fernández et al. 2009; López-López et al. 2014).

Due to the relatively short duration of the study and small sample size, home range estimates presented in the present study should be used with caution. There appears to be notable variation in ranging behavior of Long-crested Eagles as shown by the present study. Since most of the birds tracked in the study were non-breeding adults, the results will most likely be different for breeding birds. Future studies should therefore aim for longer tracking periods to be able to compare ranging behavior during the breeding and non-breeding seasons. It would be interesting to compare inter-annual variation in home range of breeding birds, for example see Pérez-García et al. (2013). Management plans for this species should prioritise maintenance of nesting habitats and preservation of foraging habitats around nests.

Data availability

The data that support the findings of the present study are available on request from the corresponding author. The data are not publicly available because of privacy or ethical restrictions.

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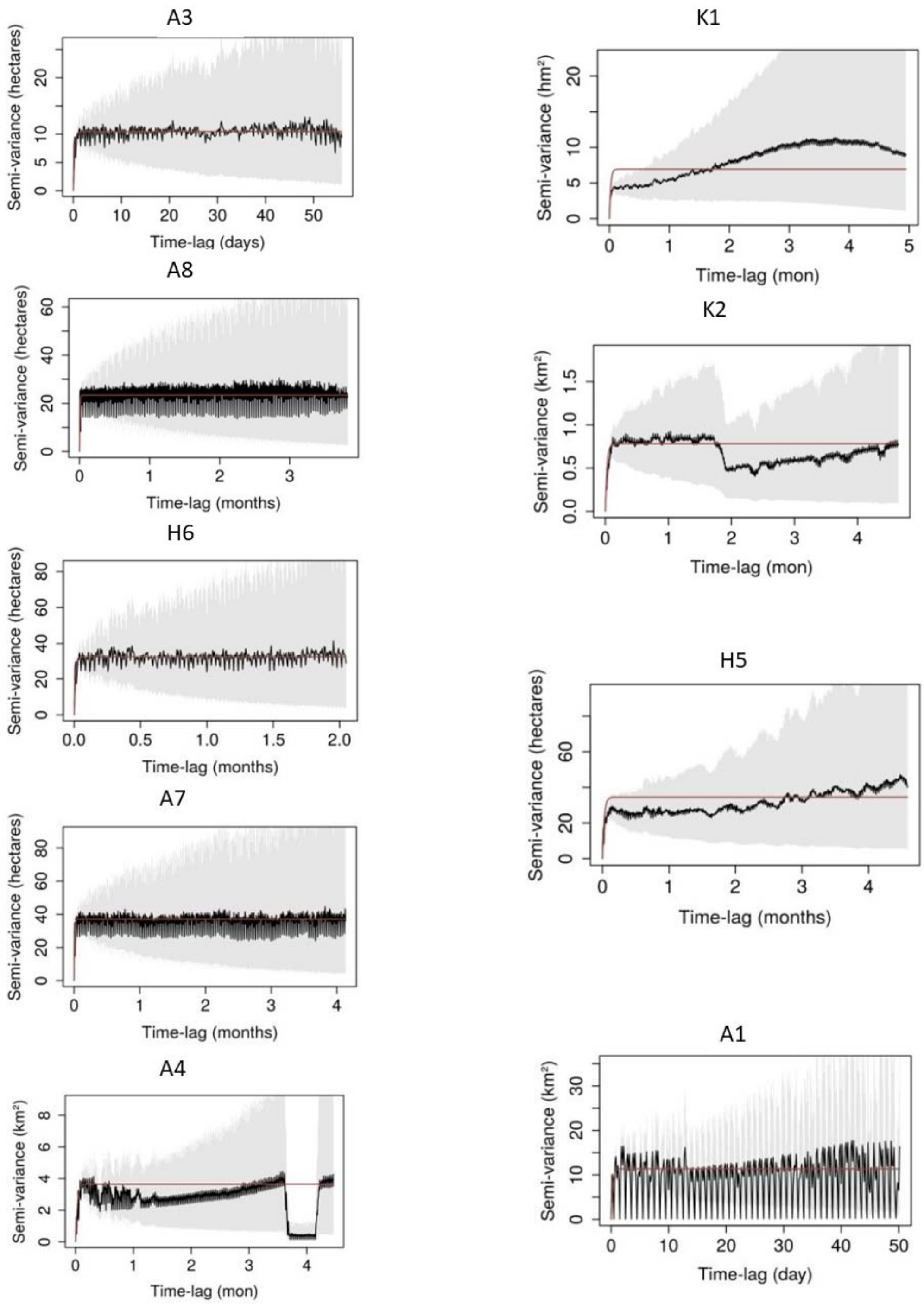
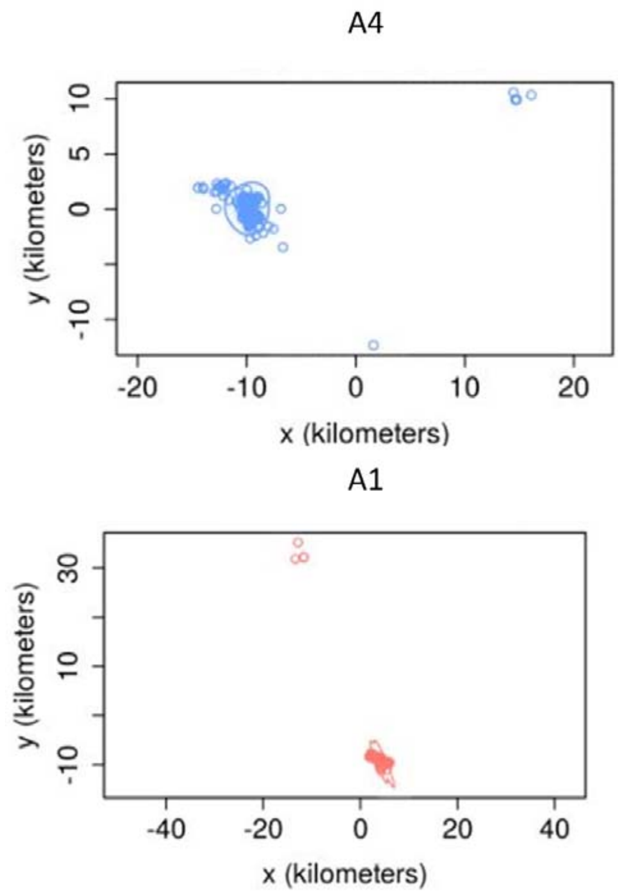


Appendix 1: A visual assessment of semi-variance over time for each tracked Long-crested Eagle. Asymptotes are indicative of a range resident eagle or restricted space use. Males are shown on the left and females on the right column.



Appendix 2: A scatterplot of GPS fixes and home range estimates of one adult male (A4) and one adult female (A1) Long-crested Eagle. The male was recorded 27 km away from the centre of its home range and the female was 49 km away. N.B. This is not a pair and each bird moved independently from the other.