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### HOME RANGE AND EXCURSIVE POST-BREEDING MOVEMENTS OF EURASIAN EAGLE-OWLS REVEALED BY GPS SATELLITE TRANSMITTERS

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**ABSTRACT.**—Investigating space use of wild birds provides important knowledge of bird behavior and ecology, which is crucial in the management and conservation of threatened species. In the present study, we used GPS satellite telemetry to investigate space use and movements of seven adult Eurasian Eagle-Owls (*Bubo bubo*) in Norway during breeding and post-breeding seasons. Breeding adults had a mean home range size of 42.9 km<sup>2</sup> (SD ± 35.1 km<sup>2</sup>; 95% kernel density estimation  $H_{ad hoc}$ ), and five individuals performed long (>20 km) excursive movements away from their breeding territories during autumn. Such wide-ranging behavior has not previously been reported for adults of the nominate subspecies *B. b. bubo*. The study demonstrates the need to investigate seasonal movements of species, populations, and age groups even if they are considered residents, and provides valuable information for management and conservation of the Eurasian Eagle-Owl.

**KEY WORDS:** *Eurasian Eagle-Owl*; *Bubo bubo*; conservation; GPS telemetry; home range; seasonal movements.

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### ÁREA DE CAMPEO Y MOVIMIENTOS EXPLORATORIOS POSTERIORES A LA REPRODUCCIÓN DE *BUBO BUBO* REVELADOS MEDIANTE TRANSMISORES SATELITALES GPS

**RESUMEN.**—Investigar el uso del espacio por parte de las aves silvestres proporciona información importante sobre su comportamiento y ecología, la cual es crucial para la gestión y conservación de especies amenazadas. En este estudio usamos telemetría satelital GPS para investigar el uso del espacio y los movimientos de siete individuos adultos de *Bubo bubo* en Noruega, durante las estaciones reproductivas y no reproductivas. Los adultos reproductores mostraron un tamaño de área de campeo promedio de 42.9 km<sup>2</sup> (DE ± 35.1 km<sup>2</sup>; 95% KDE  $H_{ad hoc}$ ), y cinco individuos realizaron largos movimientos exploratorios (>20 km) durante el otoño lejos de sus territorios de cría. Este comportamiento de amplia exploración no ha sido informado previamente para adultos de la subespecie *B. b. bubo*. Nuestro estudio proporciona información valiosa para la gestión y conservación de *B. bubo*, como también demuestra la necesidad de investigar los movimientos estacionales de especies, poblaciones y grupos de edad considerados residentes.

[Traducción del equipo editorial]

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## INTRODUCTION

Home range, defined as “that area traversed by an individual in its normal activities of food gathering, mating, and caring for young” (Burt 1943), is a highly important feature of animal biology, and thus a widely investigated topic in field research (Burt 1943, Börger et al. 2008). Information about home range use provides insight into animal ecology and features such as habitat quality and preferences, food availability, and individual physiology (Rhodes et al. 2005, Campioni et al. 2013, Lourenço et al. 2015). Thus, home range analysis is an important tool to assess ecosystem quality and may provide crucial information for the conservation and management of species (Fryxell et al. 2014, Braham et al. 2015).

With the introduction of lightweight tracking technology in field research, our estimates and knowledge of animal space use and movements have greatly improved (López-López 2016). Hence, several previously unknown patterns of seasonal movements in migratory as well as resident species have been unveiled over the past few decades (McKinnon and Love 2018). The use of data loggers and radio transmitters frequently reveals surprising movement patterns not previously identified through mark-recapture or observation techniques (Therrien et al. 2011, Kempnaers and Valcu 2017). This new information adds complexity to the management of threatened species, but also offers opportunities to carry out more targeted protective measures.

Many species of birds breeding in the northern hemisphere are migratory (Somveille et al. 2013), and their protection often requires profound insight into space use on nesting grounds, migration routes, stopover sites, and wintering sites. Many species also have multiple migratory strategies, in which populations are composed of both resident and migratory individuals (Lack 1943, Chapman et al. 2011, Bloom et al. 2015). Additionally, some resident species may show marked differences in space use between breeding and nonbreeding seasons (Sagarío and Cueto 2014, Braham et al. 2015). Seasonal changes in space use may arise due to food availability, weather, territoriality of nearby individuals or social interactions (Chapman et al. 2011, Sagarío and Cueto 2014).

The Eurasian Eagle-Owl (*Bubo bubo*; hereafter: eagle-owl) is a widely distributed species in Europe and Asia (Penteriani and Delgado 2019). Telemetry studies have revealed that juvenile and immature eagle-owls may disperse widely before settling in a breeding territory (Delgado et al. 2009, Aebischer et al. 2010, Wassink 2014). However, breeders of the nominate subspecies *B. b. bubo* are generally thought to maintain their territories year-round (Solheim 1994, Campioni et al. 2010, Penteriani and Delgado 2019). The aim of the present study was to quantify home ranges and compare movements of adult eagle-owls in Southern Norway and Central Norway during breeding and post-breeding periods.

## METHODS

**Study Species and Study Area.** In Norway, the eagle-owl is primarily distributed in the counties of Rogaland, Hordaland, and Vest-Agder in the southwest, in Trøndelag County in Central Norway, and in the small area of the Solvær archipelago in Nordland County, northern Norway (Øien et al. 2014, Penteriani and Delgado 2019). Other than this, nesting pairs occur sparsely throughout Norway, and are rare or absent in the northernmost county of Troms and Finnmark (Øien et al. 2014, Penteriani and Delgado 2019). Due to a marked population decline since the 1990s, the species is listed as Endangered on the current Norwegian Red List (Kålås et al. 2015). We studied the movements of eagle-owls from two study areas, one in Southern Norway, where 21 territories have been annually monitored since 2012, and one in Central Norway (Fig. 1).

**Telemetry.** We equipped one adult with a GPS satellite transmitter (hereafter: transmitter) in Central Norway in 2011 and six adults in Southern Norway in 2014 (Fig. 1). Two of these seven birds were breeding in open mountain habitat at approximately 1000 masl, one was breeding on the coast, and the rest were breeding in forests dominated by *Pinus* spp. at approximately 200–400 masl. We intended to tag more eagle-owls in 2011–2013 but failed to capture more breeding owls. In many of the monitored territories eagle-owls do not nest every year, and the opportunities to catch breeding adults were therefore limited, which resulted in the 3-yr gap in the tagging period.

We surveyed for eagle-owls early in the breeding season (February–April) by listening for vocalizing individuals in known territories after sunset, following Ranke and Øien (2013). Nests (i.e., shallow unlined scrapes on the ground) were visited 2–3 wk into the nestling-rearing period (mid-June). At nests with nestlings, we caught one adult at night using a large bow net (100 × 130 cm) with an automatic mechanical release mechanism. The bow net was mounted on top of a small chicken-wire cage (65 × 40 × 30 cm, mesh size: 5 × 5 cm) covering the shallow nest cavity. We placed the 1–3 nestling(s), which were 1–2 mo old at the time of trapping (Table 1, 2), in the cage to attract the adults to the trap. The cage protected the nestlings from injury during trapping, and the nestlings were provided with food ad libitum in the cage during the 1.5–7.0 hr trapping process. The nesting site was monitored from a distance (0.2–1.0 km) and when an adult returned to the nest and triggered the release mechanism, a light on the trap was automatically turned on. We did not target any particular sex; however, females appeared to be more receptive to coming to the trap, likely because females of this species usually are responsible for guarding the nest and feeding the young (Mysterud and Dunker 1983, Penteriani and Delgado 2019).

We deployed one battery-powered transmitter and six transmitters powered by a solar-charged battery (Geo-Trak 65–70 g ARGOS/GPS; Table 1) using Teflon ribbon backpack harnesses (0.25 inch tubular Teflon tape, Bally

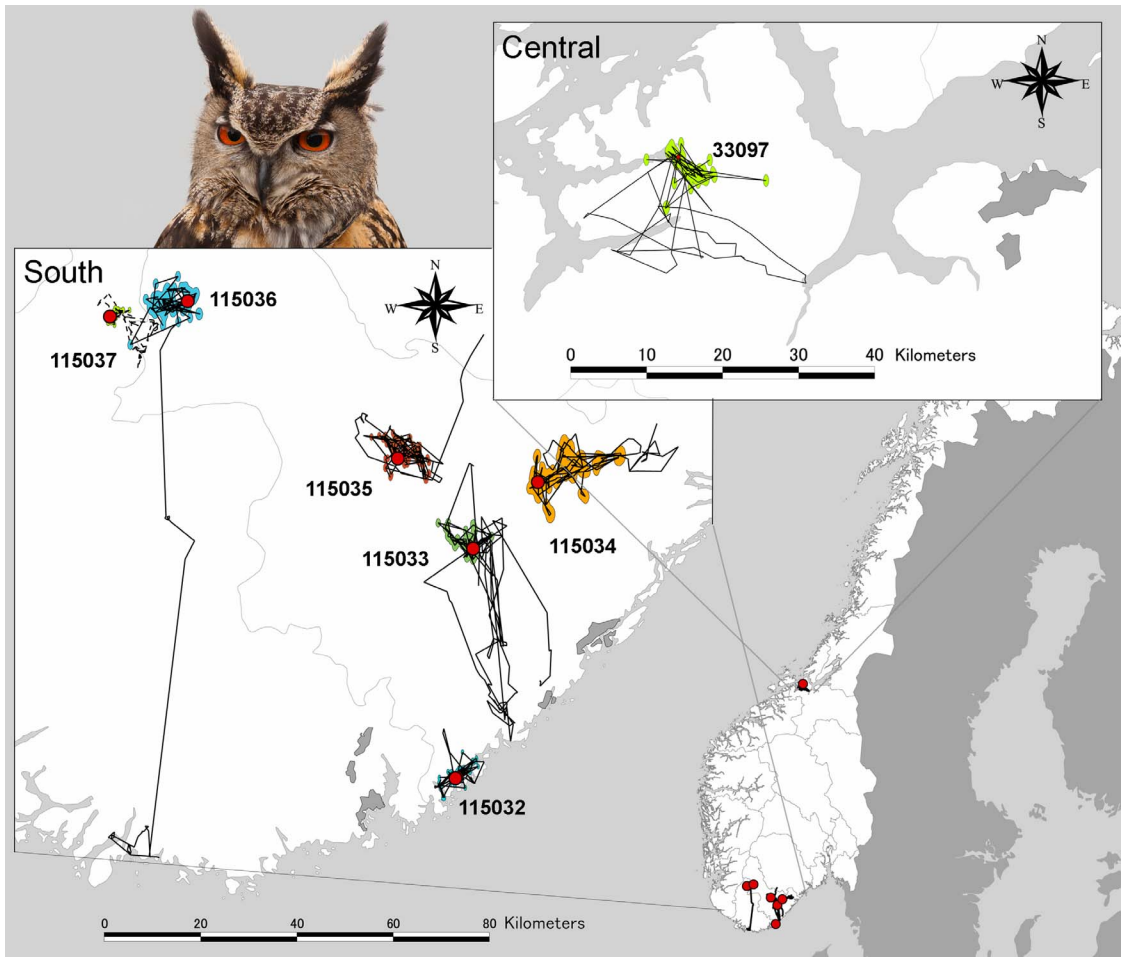


Figure 1. Individual movements of seven adult Eurasian Eagle-Owls equipped with GPS satellite transmitters during summer and autumn in Norway in 2011 (one bird in Central Norway) and 2014 (six birds in Southern Norway). Colored polygons indicate the 95% KDE  $H_{ad hoc}$  home ranges; red circles indicate the nesting sites, and lines show daily movements (Bird ID 115037 stippled for clarity). See online version for interpretation of color.

Table 1. Individual details of seven adult Eurasian Eagle-Owls equipped with GPS satellite transmitters in Norway during summer and autumn 2011 and 2014.

ID	SEX	NO. OF NESTLINGS	BREEDING HABITAT	TRANSMITTER TYPE	START OF TRACKING PERIOD	END OF TRACKING PERIOD	OPERATIONAL TIME (d)	NO. OF FIXES
33097	F	1	pine forest	battery	29 June 2011	21 Oct 2011	122	99
115032	F	1	coastal	battery/solar	04 June 2014	28 Nov 2014	177	159
115033	F	3	pine forest	battery/solar	05 June 2014	28 Dec 2014	206	177
115034	F	1	pine forest	battery/solar	25 June 2014	19 Dec 2014	177	162
115035	M	2	pine forest	battery/solar	21 June 2014	15 Dec 2014	177	154
115036	F	3	mountain	battery/solar	19 July 2014	16 Jan 2015	181	129
115037	F	1	mountain	battery/solar	17 July 2014	27 Oct 2014	102	77

Table 2. Home range size of seven adult Eurasian Eagle-Owls equipped with GPS satellite transmitters in Norway during summer and autumn 2011 and 2014. Home range sizes were based on adult space use during the nestling period (i.e., from “start date” to “early end date”, or from “start date” to “estimated nestling dispersal date (150 d)” using kernel density estimation (KDE) and minimum convex polygon (MCP). For KDE, three different smoothing parameters were used; ad hoc ( $H_{ad\ hoc}$ ), reference ( $H_{ref}$ ) and least squares cross validation ( $H_{lscv}$ ).

BIRD ID	START DATE	ESTIMATED HATCH DATE	ESTIMATED NESTLING		NO. OF DAYS	NO. OF FIXES	KDE <sub>ad hoc</sub> 95% (km <sup>2</sup> )	KDE <sub>ref</sub> 95% (km <sup>2</sup> )	KDE <sub>lscv</sub> 95% (km <sup>2</sup> )	MCP (km <sup>2</sup> )
			DISPERSAL DATE (150 d)	EARLY END DATE						
33097 <sup>a</sup>	29 June 2011	17 May 2011	14 Oct 2011	27 Aug 2011 <sup>b</sup>	60	48	23.2	118.1	17.0	70.8
115032	04 June 2014	04 May 2014	01 Oct 2014		120	106	15.7	41.2	2.5	41.8
115033 <sup>a</sup>	05 June 2014	04 May 2014	01 Oct 2014	18 July 2014 <sup>b</sup>	44	45	34.4	96.9	6.2	43.2
115034 <sup>a</sup>	25 June 2014	30 Apr 2014	27 Sep 2014		95	92	110.1	415.7	17.3	163.5
115035 <sup>a</sup>	21 June 2014	30 Apr 2014	27 Sep 2014		99	82	43.3	134.6	35.5	75.6
115036 <sup>a</sup>	19 July 2014	19 May 2014	16 Oct 2014	13 Oct 2014 <sup>b</sup>	87	76	64.9	145.1	32.2	102.3
115037	17 July 2014	11 June 2014	08 Nov 2014	16 Aug 2014 <sup>c</sup>	30	26	8.7	27.5	2.7	8.9

<sup>a</sup> Bird performed long (>20 km) excursive post-breeding movements.

<sup>b</sup> Date that the adult departed on a long excursive movement. Home range was calculated using location data collected from the start date to this date only.

<sup>c</sup> Date of nestling mortality. Home range was calculated using location data collected from the start date to this date only.

Ribbon Mills Inc., Bally, PA, USA); transmitter and harness together constituted 2.7–3.8% of individual body mass. This harness was X-shaped and designed to remain on the owl permanently. The midpoint was placed at the sternum where the strands joined through a specially designed tubular silver “Y” (produced by silversmith Kirsti Gulsrud, Norway) that was clamped after the harness was adjusted. Each eagle-owl was banded, measured and tagged in the field and released within 0.5–1 hr after trapping. We did not monitor the adults’ return to their nests after tagging. We programmed transmitters to fix one GPS position daily at 2300 H UTC, a time chosen to target when adults were actively hunting (Eriksen and Wabakken 2018).

We determined the sex of captured owls by morphological measurements following Delgado and Penteriani (2004; Table 1). To estimate the hatch date of the nestlings, we back-calculated from the estimated nestling age (following Penteriani et al. 2005) when the adult was captured (Table 2). Published age of dispersal of young is 150–160 d post hatching (Penteriani et al. 2005, Aebischer et al. 2010). Because space use of adults may change when the young disperse, we defined the end date for the calculation of the breeding home range as 150 d after the hatching of the oldest nestling, unless GPS data on adults showed they left their breeding home range earlier ( $n=3$ ), or the entire brood of young died before dispersal ( $n=1$ ). We defined excursive movements as those movements in which adults traveled far (>20 km) from their breeding home range. We received GPS positions from tagged eagle-owls for up to 206 d (Table 1). However, limited data prevented further analyses of home range after dispersal of the young.

The study was approved by the Norwegian Animal Research Authority (FOTS ID: 3345 and 5170) and the Norwegian Environment Agency (2009/3512 ART-VI-ID/ and 2014/4978).

**Data Analyses.** We used GPS tracking data from all seven eagle-owls to investigate individual movements (Table 1). We analyzed GPS tracking data using the R package “adehabitatHR” (Calenge 2006) to estimate home range sizes using a 95% fixed kernel (kernel density estimation [KDE]; Worton 1989, Kernohan et al. 2001). We used three different smoothing (H) approaches: reference ( $H_{ref}$ ), least squares cross validation ( $H_{lscv}$ ), and ad hoc ( $H_{ad\ hoc}$ , a step-wise procedure starting at  $H_{ref}$  and subtracting 10% from H until the home range becomes discontinuous (Kie 2013, Schuler et al. 2014)). When we report home ranges, we primarily use  $H_{ad\ hoc}$ , as this approach has been shown to represent the closest approximation to the actual area used by an individual (Kie 2013). We furthermore included 100% minimum convex polygons (MCP; Mohr 1947) to facilitate comparison with previous studies reporting this commonly used estimator (Seaman et al. 1999). MCP values were obtained from the R package “adehabitatHR” using the “mcp” function (Calenge 2006). To examine seasonal differences in daily movements we developed a linear mixed-effects model, using daily movements as the response variable and month as fixed effect, and accounting for non-independence of data points by adding bird identity as a random factor. Distance moved per day was log-transformed to comply with model assumptions, and then back-transformed to obtain parameter estimates. We note that, because an individual may move in opposing directions multiple times during a day, the distances between daily positions are likely underestimates of the

total distances moved. We performed all statistical tests using R ver. 3.4.3 (R Core Team 2017). All tests were two-tailed and results were considered significant at  $P \leq 0.05$ . Results are presented as mean  $\pm$  SD.

## RESULTS

Eurasian Eagle-Owls' mean home range (95% KDE  $H_{\text{ad hoc}}$ ) was  $42.9 \pm 35.1 \text{ km}^2$  (range: 8.7–110.1  $\text{km}^2$ ). Other smoothing approaches produced considerably larger (95% KDE  $H_{\text{ref}}$ ;  $\bar{x} = 139.9 \pm 129.6 \text{ km}^2$ ) and smaller (95% KDE  $H_{\text{scv}}$ ;  $\bar{x} = 16.2 \pm 13.5 \text{ km}^2$ ) home ranges. Moreover, mean 100% MCP home range ( $\bar{x} = 72.3 \pm 50.1 \text{ km}^2$ ) was larger than KDE  $H_{\text{ad hoc}}$  (Table 2).

The only coastal breeding eagle-owl in our study (ID 115032) had the second smallest home range, but its home range was larger than that of another individual (ID 115037) breeding in the mountains; however, this latter bird's nestling died just 30 d after transmitter deployment. Two individuals (one in inland pine forest and one in mountain habitat) had the largest home ranges (ID 115034 and 115036; Table 2).

Five of the seven eagle-owls in our study performed excursive movements out of their established breeding home range during late summer and autumn. Those individuals also had larger home ranges ( $\bar{x} = 55.2 \pm 34.3 \text{ km}^2$ ; Table 2) than those that had no excursive movements recorded (15.7  $\text{km}^2$  and 8.7  $\text{km}^2$ , respectively). One individual (ID 115034) moved farther from its nesting site as the autumn progressed. Two others (ID 115033 and 115036) moved from their inland territories to the coast, approximately 40 and 112 km away from their nesting sites, respectively. Although one of the owls that bred in the mountains (ID 115036) traveled the longest distance away from its nesting site, another eagle-owl breeding in the same mountain range (ID 115037) remained in the same region until the transmitter entered dormancy on 27 October (Fig. 1).

Eagle-owls performed their first excursive movements outside established home ranges between 18 July and 24 November (mean: 1 October  $\pm$  49 d,  $n = 5$  owl and  $n = 11$  excursive movements). Two individuals (ID 115035 and 115036) left their breeding home ranges in autumn and did not return before the transmitters went dormant (on 15 December 2014 and 16 January 2015, respectively).

We found the longest distances between daily GPS positions in July–September (July mean = 2.5 km [95% CI 1.2–5.5 km], August mean = 2.5 km [95% CI 1.2–5.1 km] and September mean = 2.3 km [95% CI 1.1–5.0 km]). Owls made significantly shorter daily movements in October (October vs. July–September:  $t \geq 3.05$ ,  $P \leq 0.002$ ) and November (November vs. July–September:  $t \geq 2.50$ ,  $P \leq 0.013$ ; October mean = 0.8 km [95% CI 0.4–1.7 km], November mean = 0.9 km [95% CI 0.4–2.0 km], Fig. 2).

## DISCUSSION

Our study reports home range sizes and movements of six female and one male adult Eurasian Eagle-Owls breeding in Southern and Central Norway. Perhaps the most important result of our study was the clear pattern of excursive post-breeding movements of five out of seven individuals. These excursions were performed throughout late summer and autumn. In this period, some of the eagle-owls entered a period of more directed ranging behavior away from their home range, although distances moved per day were shorter later in autumn.

Home range sizes estimated using the ad hoc procedure (Kie 2013, Schuler et al. 2014) were closest to estimated MCP home range size, whereas  $H_{\text{ref}}$  generally seemed to overestimate and  $H_{\text{scv}}$  seemed to underestimate home range sizes (Kie 2013). Although home range size estimates varied widely depending on the choice of smoothing parameter, the estimates in the present study are large compared to most of those previously reported for eagle-owls (Penteriani and Delgado 2019). Oddane et al. (2012) found the median home range (95% kernel) of transmitter-equipped territorial eagle-owls in southwestern Norway were 31  $\text{km}^2$  in the breeding season and 66  $\text{km}^2$  outside the breeding season. Other studies report much smaller home ranges (e.g., 2.2–3.2  $\text{km}^2$  using 90% kernel; Bevanger et al. 2011, Campioni et al. 2013, Lourenço et al. 2015).

Large differences in home range sizes may be attributed to variability in factors such as prey species and density, diet diversity, landscape structure, and density of breeding pairs (Lourenço et al. 2015, Penteriani and Delgado 2019). In southwestern Norway, eagle-owls have a widely varied diet, which may reflect low prey density and may result in relatively large home ranges (Oddane et al. 2012). In contrast, in southwestern Spain and northern Norway (Solværøyen) eagle-owls benefit from a very high abundance of European rabbits (*Oryctolagus cuniculus*) and European water voles (*Arvicola amphibius*), and home ranges are small (Bevanger et al. 2011, Campioni et al. 2013, Lourenço et al. 2015). Information about prey choice was not recorded in the present study; however, based on breeding habitat and prey remains found during nest visits, there may be considerable variability in prey choice among the individuals we studied.

Interestingly, the five individuals with the largest home ranges performed excursive post-breeding movements away from their breeding home ranges. We hypothesize that such movements are facultative and predominately performed during poor environmental conditions, given that the large home range sizes may reflect low prey availability. Similar movements have been documented for high-latitude adult Golden Eagles (*Aquila chrysaetos*), which may remain in their breeding territories one winter and migrate south the following winter (Ollila 2013); this phenomenon lends support to the proposition that this behavior represents an adaptation to the prevailing conditions. The same may also be true for the eagle-owl.

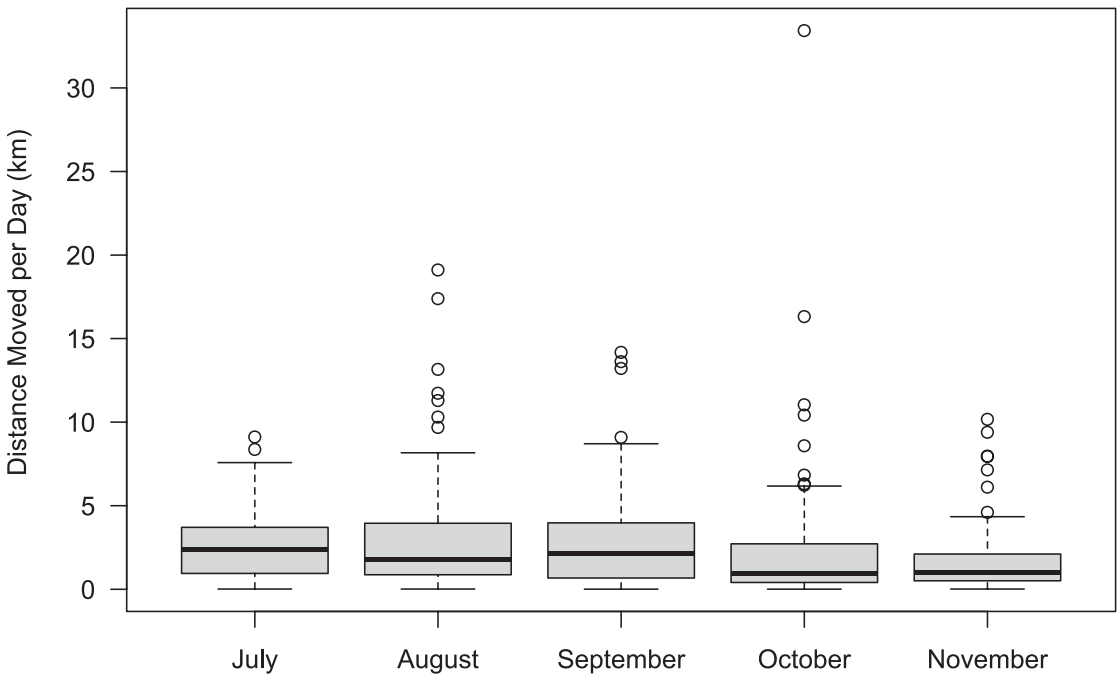


Figure 2. Distance moved per day for adult Eurasian Eagle-Owls equipped with GPS satellite transmitters in Norway during summer and autumn 2011 and 2014. Data from June, December, and January were excluded due to small sample sizes. Box plots include the median (horizontal line inside boxes), interquartile range (boxes), range (bars) and outliers (circles).

Whether the behavior is confined only to populations breeding at higher latitudes (and altitudes), as in several other species (Newton and Dale 1996), needs further investigation.

Wide-ranging behavior in Eurasian Eagle-Owls of the nominate subspecies has previously been documented only for young individuals prior to settlement in breeding territories (Aebischer et al. 2010). Adult breeders increase their home range size during the nonbreeding season but are generally thought to maintain their territories year-round (Penteriani and Delgado 2019). Although several central Asian subspecies perform seasonal migration (Mitropolskiy and Rustamov 2007), the present study is the first to report large-scale movements of adults of the nominate subspecies away from their breeding home range.

The finding that adult eagle-owls in Norway may leave their breeding home range completely for periods lasting from days to months during the nonbreeding season has important implications for their conservation. It demonstrates the need and value of suitable hunting areas for the species even outside established breeding home ranges, and the importance of mitigating threats, such as electrocution and the risk of collision with electricity structures, also in such areas, as previously identified by others (Sergio

et al. 2004, Penteriani et al. 2011). Moreover, three of the individuals performing excursive movements in the present study visited several formerly used eagle-owl nesting sites outside their own breeding home range. Thus, observations of adult eagle-owls during the nonbreeding season may lead to wrong conclusions regarding territory occupancy and should therefore be interpreted with caution.

We found the longest distances between daily GPS positions in July–September, and those daily movements became significantly shorter in October and November. This was surprising because we had expected eagle-owls on excursions to move farther as the season progressed, and because three individuals did not start performing post-breeding excursions until late September and October (Table 2). However, the longer distance between daily GPS positions in July–September compared to October–November may reflect longer displacements in search for food due to the high energy demand of the young during the post-fledging dependence period (60–150 d post-hatching; i.e., July–mid-October in the present study; Wassink 2003, Penteriani et al. 2012).

The factors that caused the wide-ranging behavior in adult eagle-owls in the present study are currently unknown, but as previously suggested this may be related to limited food resources or harsh weather conditions

during autumn and winter (Penteriani and Delgado 2019). Individual characteristics, such as physiology, may also be important determinants of post-breeding excursive movements (Goossens et al. 2020). Whether some individuals or populations perform such movements every year, or whether they are more irruptive in nature, is presently unknown. More long-term telemetry studies combined with investigations of prey availability and climatic variables such as temperature and precipitation could provide additional insight.

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