Individual spatiotemporal histories of first year Golden Eagles in Denmark using GPS-tracking

Anders P. Tøttrup, Jonas Colling Larsen, Jan Tøttrup Nielsen, Hans Christophersen and Kasper Thorup

(Med et dansk resumé: Sporing af unger af danske Kongeørne)

Abstract The Golden Eagle *Aquila chrysaetos* established a breeding population in Denmark in 1998. Since then, at least 53 individuals have fledged yet the breeding population has remained small at 3-5 pairs. In this study, we used GPS/GSM-tracking technology to investigate dispersal and present individual spatiotemporal histories during the first year of life of Danish Golden Eagles, with notes on survival and causes of mortality. In total, nine individuals were tagged with GPS/GSM-transmitters during a seven-year period (2015-2021). Our results show that six individuals managed to disperse (> 5 km from nesting site), while three individuals died before dispersal. Status at the end of the study for the tagged individuals was: three were alive, the fate of two was unknown, and four were dead. We found a median fledging date of 3 July (ranging 15 June to 28 July) and a median dispersal date of 2 December (ranging 14 October to 21 April the following year). Mean dispersal distance for all dispersed individuals from nest site was 99 km (range 0.7-272 km) at the age of six months. By the age of one year, mean distance from nest site was 68 km (range 5-166 km). Our study confirms high mortality during the first year as shown in a number of other studies and provides further evidence that first year dispersal period is critical for juvenile Golden Eagles. This study contributes important knowledge for future conservation and management of Golden Eagles breeding in Denmark.

Introduction

The Golden Eagle *Aquila chrysaetos* established as a breeding bird in northern Jutland, Denmark in 1998 (Knudsen *et al.* 2000, Nielsen *et al.* 2023). Historic reports of Golden Eagles breeding in Denmark are uncertain (Schiøler 1931, Salomonsen 1963, Løppenthin 1967). Besides the breeding population, young individuals regularly visit Denmark during winter and on migration (Dybbro 1978, Nielsen *et al.* 2023) to give an estimated total winter population of 20-25 individuals including breeding birds (Christensen *et al*. 2022). Most reports of wintering individuals are from the eastern part of Denmark. Hence, they are suspected to originate from Sweden and Norway (Dybbro 1978, Ehmsen *et al*. 2011, Viktrøm & Moshøj 2020).

Since 1998, the Golden Eagle population in Denmark has grown slowly, and since 2005 it has been stable at 3-5 breeding pairs (Ehmsen *et al*. 2011, Skelmose & Larsen 2022). Seven different territories have been utilized since 1998 within a total area of approximately 1300 km^2 in northern Jutland, though only three of these territories have been used by breeding pairs during the entire period (Ehmsen *et al*. 2011, Skelmose & Larsen 2022). Based on visual observations and ringing activity, 53 nestlings are assumed to have fledged between 1998 and 2021, but the population remains low and fluctuated between one and five breeding pairs over the period, and our knowledge of the fate of the offspring remains very limited.

In 2015, we initiated The Danish Golden Eagle Project (Project Golden Eagle 2022) to increase our knowledge of the Golden Eagle breeding population in Denmark. Using GPS/GSM-tracking technology, we aimed to gain detailed data from individual birds with a specific focus on movements of and threats to nestlings hatched in Denmark so as to improve management and conservation efforts for the species. In this study, we present overall dispersal distance and direction as well as individual spatiotemporal histories during the first year for Danish Golden Eagles with notes on survival and causes of mortality.

Methods

Nine Golden Eagle nestlings from three different territories in Northern Jutland were tagged with GPS/GSM-transmitters (CTT-1080-BT3 Series 3rd Gen from Cellular Tracking Technologies) from 2015 to 2021 (Tab. 1). The size of the transmitters was L: 100 mm, W: 44 mm, H: 22 mm, and the total weight of transmitter and harness was 80 g (less than 3% of the body weight of an adult eagle) (e.g. Sergio *et al*. 2015). The transmitters were solar powered by a Lithium Ion Polymer battery. The attachment type was a backpack style, body harness (y-harness) made from a 10 mm Teflon harness loosely fitted to allow room for the juvenile eagle to gain muscle mass (Buehler *et al*. 1991, Buehler & Fraser 1995, McIntyre *et al*. 2006). We tied and sewed the harness using Spiderwire Teflon thread, and the ends of the harness were superglued to avoid threading. The ventral side of the GPS-transmitter was fitted with a protective foam mat to minimize the risk of skin irritation and abrasion. We timed the attachment of the transmitters carefully when nestlings were c. 60 days old. At this stage, the nestlings' body feathers are developed but flight feathers and flight muscles are not fully developed. We tagged, ringed and sexed (by tarsus length) the birds on the ground at the nest site. The nestlings were fitted with a falconry hood during handling. Our visits at each nest sites lasted no more than one hour.

We used GPS-data and visual field observations to determine fledging dates. We defined the date of dispersal as the first day on which the individuals were at least 5 km from the nest without returning during the following 4 months (see discussion and other definitions in Weston *et al*. 2013).

Results

All nine individuals fledged, with a median fledging date of 3 July ranging from 15 June to 28 July (Tab. 1). Six individuals successfully dispersed, with a median dispersal date of 2 December ranging from 14 October to 21 April the following year.

Three individuals dispersed in autumn between 14-19 October, while three individuals stayed in their natal territories until the following year when one individual dispersed during January 2016 (precise date unknown because of GPS-transmitter malfunction), another on 16 March 2021, and the third on 21 April 2022. Three individuals fledged but never dispersed. They were found dead within their natal territories eleven months (18 May 2021), two months (25 August 2016) and one month (23 July 2019) after fledging, respectively (Tab. 1).

Overall, we found that juvenile Golden Eagles move short distances within their first year but there is large individual variation (Tab. 1). By 1 January (age since fledging c. 6 months), the mean dispersal distance from the nest across all dispersed individuals was 99 km and ranged from 0.7-272 km (n = 7). By 1 June (age since fledging c. 12 months), mean distance from the nest was 68 km and ranged from 5-166 km (n = 7; Tab. 1). Dispersal direction also showed large individual variation (Tab. 1). After dispersal at age 12 months since fledging, four individuals had moved northward and three moved southward from their natal territories (Tab. 1).

Individual spatiotemporal history

Hals2015 fledged on 23 June 2015 but, unfortunately, the GPS-transmitter proved unstable and stopped transmitting data on 28 November 2015. At that point, *Hals2015* was still within the natal territory. The GPS-transmitter regained connection in March 2016 and transmitted data for the next three months revealing that *Hals2015* had dispersed during the period of transmitter malfunction. The dispersal date for *Hals2015* is therefore unknown. However, based on visual observa-

Tab. 1. The nine individual Golden Eagles tagged with GPS-transmitters during 2015-2021 with tagging date, location, sex, ID-name, current status (as of 1 June 2022), fledging date, dispersal date, distance to nest at age six months with direction in relation to nest, distance to nest at age 12 months with direction in relation to nest. Fledging date was determined as the first day the GPS-data showed movement away from the nest. Dispersal date was determined as the first day the GPS-data showed the individual eagle moving > 5 km way from the nest. Distance and direction from nest measured on 1 January (at age c. 6 months) and 1 July (at age c. 12 months). Distances marked with an asterisk indicate distance measured at nearest date possible after loss of signal or death: *3 June 2016, **4 June 2021, ***18 May 2021, ****30 May 20 # exact dispersal date unknown due to transmitter failure.
Oversigt over de ni Kongeørne som blev forsynet med GPS-sendere i perioden 2015-21.

Tagging date *Mærk-ningsdato*	**Location** *Sted*	**Sex** *Køn*	**ID-name** *Navn*	**Status**	**Fledging date** *Udflyv-ningsdato*	**Dispersal date** *Spredning-sdato*	**Distance and direction, 6 months** *Afstand og retning fra rede, 6 mdr.*	**Distance and direction, 12 months** *Afstand og retning fra rede, 12 mdr.*
03.06.2015	Hals Nørreskov	♀	Hals2015	Unknown	23.06.2015	01.2016#	0	67 km NW*
24.06.2015	Høstemark Skov	♂	Hoste-mark2015	Alive	07.07.2015	14.10.2015	263 km SW	166 km SW
08.07.2015	Tofte Skov, SW	♀	Tofte2015	Alive	28.07.2015	14.10.2015	272 km SW	92 km NE
13.06.2016	Høstemark Skov	♂	Hoste-mark2016	Dead	27.06.2016	-	-	-
10.06.2019	Tofte Skov, NE	♀	Toftehun19	Dead	21.06.2019	-	-	-
10.06.2019	Tofte Skov, NE	♂	Toftehan19	Unknown	18.06.2019	19.10.2019	51 km N	59 km N
03.07.2020	Tofte Skov, SW	♂	Tofte-han20_1	Dead	13.07.2020	16.03.2021	< 3 km SE	18 km SE**
03.07.2020	Tofte Skov, SW	♂	Tofte-han20_2	Dead	17.07.2020	-	< 5 km W	< 5 NW***
18.06.2021	Tofte Skov, NE	♀	Toftehun21	Alive	30.06.2021	21.04.2022	< 1 km NW	< 3 km SW****

tions we know that the bird stayed within the natal territory until January after which it dispersed northwards. The dispersal distance at age one year was 67 km northwest of the nesting site (Fig. 1, Tab. 1).

Hostemark2015 and *Tofte2015* fledged on 7 July 2015 and 28 July 2015, respectively. The two birds dispersed simultaneously on 14 October 2015, following the same route south for the first c. 10 km and then continuing south along separate routes. They spent the winter in northern Germany at separate sites c. 50 km from each other. At the age of ~½ year, they were respectively 263 km southwest (*Hostemark2015*) and 272 km southwest (*Tofte2015*) of their nesting sites. Both eagles returned to Denmark during spring 2016, *Hostemark2015* in April and *Tofte2015* in May. From here onwards, they explored different areas of Denmark (Fig. 2 and 3). By age ~1 year, *Hostemark2015* was 166 km southwest of its nest site (Fig. 2) and *Tofte2015* was 92 km northeast of its nest site (Fig. 3).

Hostemark2016 fledged on 27 June 2016. However, *Hostemark2016* never dispersed and was found dead in the natal territory in Høstemark Skov on 25 August the same year.

Toftehun19 fledged 21 June 2019, but never dispersed and was found dead underneath the nest on 23 July 2019. We estimate that it died on 10 July 2019 (two weeks after fledging and one month after GPS-tagging).

Toftehan19 fledged on 18 June 2019 and dispersed on 19 Oct 2019 towards the north. By age ~½ year, *Toftehan19* was 51 km north of the nest site. During the spring of 2020, *Toftehan19* flew further north and spent spring and summer in northern Jutland. By age ~ 1 year, *Toftehan19* was 59 km north of the nest site (Fig. 4). The GPS-transmitter stopped sending data in August 2020, but the eagle has since been spotted in the field (latest observation is October 2021).

Toftehan20_1 and *Toftehan20_2* fledged on 13 July 2020 and 17 July 2020, respectively. Both eagles stayed in the natal territory during summer and gradually started exploring their surroundings. In mid-October, *Toftehan20_1* flew 37 km southwest. A few days later, it returned to the natal territory where it stayed alongside

Fig. 1. GPS-positions of Golden Eagle *Hals2015* (Tab. 1) for the period 3 June 2015 – 6 June 2016. Current status: unknown due to GPS-tag malfunction. Red circle indicates tagging location.
Positioner fra Kongeørnen Hals2015 *(se Tab. 1) i perioden 3. juni 2015 til 6. juni 2016. Dens senere skæbne er ikke kendt på grund af fejl på GPS-senderen. Den røde cirkel viser mærkningsstedet.*

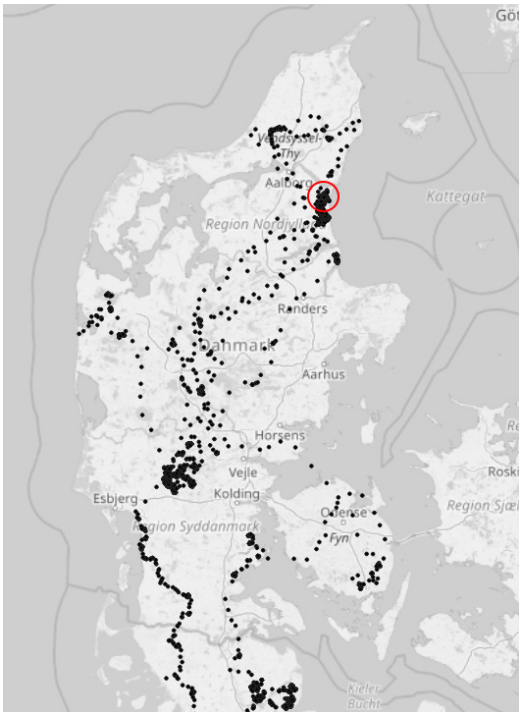

Fig. 2. GPS-positions of Golden Eagle *Hostemark2015* (Tab. 1) for the period 8 July 2015 – 1 July 2016. Current status: breeding. Red circle indicates tagging location.
Positioner fra Kongeørnen Hostemark2015 *(se Tab. 1) i perioden 8. juli 2015 til 6. juni 2016. Dens nuværende status er som ynglefugl. Den røde cirkel viser mærkningsstedet.*

its sibling, *Toftehan20_2*, for the rest of the year. By age ~½ year, *Toftehan20_1* was 2.5 km southeast of the nest site and *Toftehan20_2* was 4.5 km west. *Toftehan20_1* dispersed on 16 March 2021. In the beginning of June 2021, *Toftehan20_1* was found dead 18 km southeast of the nest site (Fig. 5). *Toftehan20_2* never dispersed and was found dead 5 km west of the nest site mid-May 2021 (Fig. 6).

Toftehun21 fledged on 30 June 2021 and dispersed on 21 April 2022. By age ~½ year *Toftehun21* was less than 1 km NW of the nesting site and at age ~1 year. It was still less than 5 km from the nesting site, but it had been 9.5 km West of the nesting site during its first year (Fig. 7).

Survival and causes of death

Of the nine individuals in the study, five survived the first year from day of tagging (~56% survival rate), resulting in a mortality rate, one year from tagging at ~44%. Formal necropsies were performed on the four dead individuals. These revealed the causes of death to be airway infection (one individual) and starvation/malnutrition (two individuals), while cause of death of the fourth remains unknown due to poor condition of the corpse (Center for Diagnostik, DTU).

Discussion

We found large individual variation in timing of dispersal as well as dispersal distance and direction of natal dispersal in young Danish Golden Eagles. This is similar to findings in the Scottish and Swedish populations (Nygård *et al*. 2016, Whitfield & Fielding 2017, Whitfield *et al*. 2022). From populations in Sweden, young individuals have been reported to perform long southward autumn flights (Sandgren *et al*. 2014). This is similar to what we found in two individuals that flew c. 300 km south, stayed for the winter, and migrated north in spring. However, four individuals performed only shorter flights of c. 50 km during spring without longer movements northwards, and two

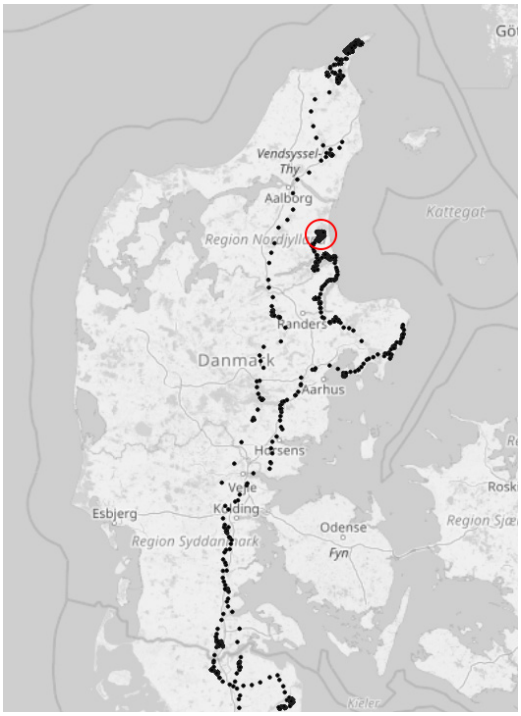

Fig. 3. GPS-positions of Golden Eagle *Tofte2015* (Tab. 1) for the period 24 June 2015 – 1 July 2016. Current status: breeding. Red circle indicates tagging location.
Positioner fra Kongeørnen Tofte15 *(se Tab. 1) i perioden 24. juni 2015 til 1. juli 2016. Dens nuværende status er som ynglefugl. Den røde cirkel viser mærkningsstedet.*

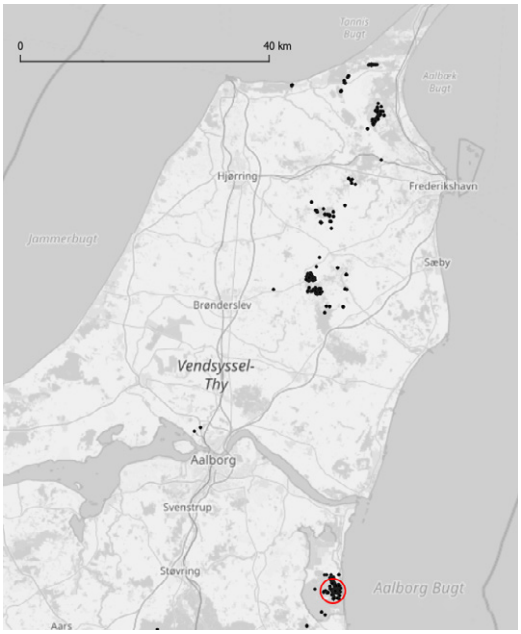

Fig. 4. GPS-positions of Golden Eagle *Toftehan19* (Tab. 1) for the period 10 June 2019 – 3 August 2020. Current status: unknown due to GPS-tag malfunction. Red circle indicates tagging location.
Positioner fra Kongeørnen Toftehan19 *(se Tab. 1) i perioden 10. juni 2019 til 3. juni 2020. Dens nuværende status er ukendt på grund af fejl på GPS-senderen. Den røde cirkel viser mærkningsstedet.*

birds stayed very close to the natal territory. These results indicate that breeding Golden Eagles in Denmark accept their offspring remaining close to their territories, as has been shown for other populations (Nygård *et al*. 2016, Murphy 2017, Whitfield & Fielding 2017).

In a GPS-tracking project of Golden Eagles in Norway, mortality rate within the first year from day of tagging was 42% for 25 GPS-tagged individuals (Nygård *et al*. 2016). We obtained a similar result, with four out of nine (44%) individuals found dead within one year from the tagging day. Another study from the USA of GPS-tagged Golden Eagles over an 11-month period starting with first autumn migration of the individual young birds found mortality rates of between 0.19 ± 0.07 and 0.34 ± 0.10 for two cohorts (McIntyre *et al*. 2006). A direct comparison with our study, where one of four individuals died after dispersal (= 25%), places our results between the findings of the two aforementioned studies. A large study on Golden Eagles in Scotland found a surprisingly high survival rate during the first year of life of tagged individuals, and the authors point to an absence of illegal persecution of GPS-tagged eagles as a possible explanation (Whitfield & Fielding 2017). In fact, Whitfield & Fielding showed that tagged individuals are able to survive and establish in areas with known human persecution, which they argue could be a result of the GPS-transmitters serving as a "life insurance". Potential effects of GPS-tagging have been investigated in a number of studies of Golden Eagles and similar species but have shown no direct effects (Bowman *et al*. 1995, McIntyre *et al*. 2006, Urios *et al*. 2007, Sergio *et al*. 2015, Whitfield & Fielding 2017).

We found infection and starvation to be causes of mortality as has also been reported in other Golden Eagle populations (McIntyre *et al*. 2006, Nygård *et al*. 2016, Murphy 2017). Causes of mortality is in need of further study especially among pre-breeding individuals.

The results presented in this paper are overall in line with findings reported from other European popula-

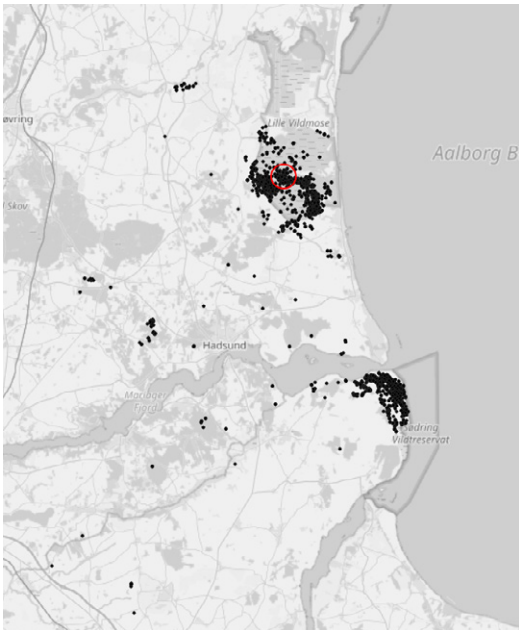

Fig. 5. GPS-positions of Golden Eagle *Toftehan20_1* (Tab. 1) for the period 3 June 2020 – 6 June 2021. Current status: dead on 6 June 2021. Red circle indicates tagging location.
Positioner fra Kongeørnen Toftehan20_1 *(se Tab. 1) i perioden 3. juni 2020 til 6. juni 2021. Fuglen blev fundet død den 6. juni 2021. Den røde cirkel viser mærkningsstedet.*

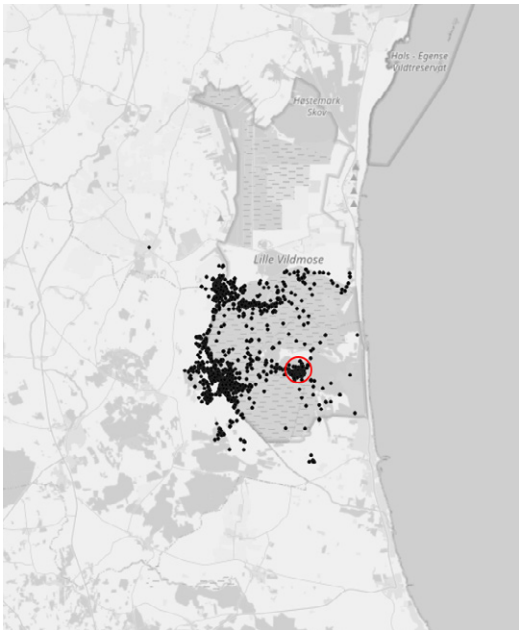

Fig. 6. GPS-positions of Golden Eagle *Toftehan20_2* (Tab. 1) for the period 3 June 2020 – 21 May 2021. Current status: dead on 21 May 2021. Red circle indicates tagging location.
Positioner fra Kongeørnen Toftehan20_2 *(se Tab. 1) i perioden 3. juni 2020 til 21. maj 2021. Fuglen blev fundet død den 21. maj 2021. Den røde cirkel viser mærkningsstedet.*

tions of Golden Eagles. However, our results based on GPS-tagging present new insights that have not previously been clear from more than 20 years of intensive field observations of Danish breeding Golden Eagles. We therefore recommend and encourage further research to compliment these first results from GPS-tagging to ensure a more detailed insight into the new and still very small population of Golden Eagles in Denmark. Furthermore, future analyses of new GPS-data will provide us with better knowledge on habitat selection, movement patterns and survival rates, contributing to improved conservation and management of Golden Eagles breeding in Denmark.

Acknowledgements

We thank Aage V. Jensen Naturfond for funding and supporting the project, for generously sharing their facilities and assistance during fieldwork. We would also like to thank all collaborators especially Thorkild Lund, Tscherning Clausen, Anton Thøger Larsen, Christian Hjorth, Flemming Ahlmann and all members of Fuglegruppen Lille Vildmose. The Copenhagen Bird Ringing Centre at the Natural History Museum of Denmark provided permits and securing ringing and tagging data. Finally, we thank the two reviewers for improving the manuscript and Nick Quist Nathaniels for correcting our English.

Resumé

Sporing af unger af danske Kongeørne
Kongeørnen *Aquila chrysaetos* begyndte at yngle i Danmark i 1998 efter mange års fravær. Siden er mindst 53 unger registreret frem til 2021. Ynglebestanden har de sidste år ligget fast på 3-5 par. I dette studie undersøger vi de unge Kongeørnes spredning fra redeområdet i løbet af deres første leveår ved hjælp af data fra GPS/GSM-sendere monteret på fuglene. Desuden rapporterer vi dødsårsager og overlevelsesrater. I alt har ni redeunger fået en GPS/GSM-sender monteret mellem 2015-21. Vores resultater viser, at seks individer formåede at sprede sig fra redeområdet (>5 km), mens tre døde i deres redeområder inden for deres første leveår. Ud af de ni individer var tre fortsat i live, fire er døde, og for to individer er status ukendt ved færdiggørelsen af dette manuskript. Fuglene fløj fra reden med en mediandato 3. juli (fordelt mellem 15. juni og 28. juli) og en median spredningsdato 2. december (fordelt fra 14. oktober til 21. april det følgende år). I en alder af seks måneder opholdt individerne sig i gennemsnit 99 km fra deres redeområder, men med stor individuel spredning fra 0,7 til 272 km. I en alder af et år opholdt individerne sig i gennemsnit 68 km fra deres redeområder ligeledes med en stor spredning fra 5 til 166 km. Vores resultater bekræfter en høj dødelighed i løbet

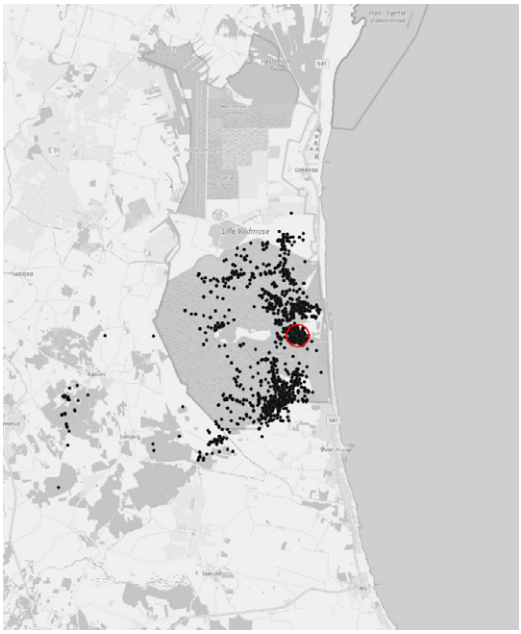

Fig. 7. GPS-positions of Golden Eagle *Toftehun21* (Tab. 1) for the period 18 June 2021 – 31 May 2022. Current status: alive. Red circle indicates tagging location.
Positioner fra Kongeørnen Toftehun21 *(se Tab. 1) i perioden 18. juni 2021 til 31. maj 2022. Fuglen er stadig i live. Den røde cirkel viser mærkningsstedet.*

af første leveår, som det tidligere er blevet vist i udenlandske studier. Resultaterne viser således, at det første leveår er kritisk for Kongeørnene, og viden om den store individuelle variation kan bidrage til bedre beskyttelse og forvaltning af Kongeørnen som ynglefugl i Danmark.

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Authours' addresses
Anders P. Tøttrup (aptottrup@snm.ku.dk) and Jonas Colling Larsen, Natural History Museum of Denmark, University of Copenhagen, Øster Voldgade 5-7, DK-1350 Copenhagen K, Denmark
Jan Tøttrup Nielsen, Espedal 4, DK-9870 Sindal, Denmark
Hans Christophersen, Rosenvænget 10, DK-9520 Skørping, Denmark
Kasper Thorup, Center for Macroecology, Evolution and Climate, University of Copenhagen Universitetsparken 15, DK-2100 Copenhagen Ø, Denmark.