Movements of a male greater spotted eagle (*Clanga clanga*) during its 2nd and 3rd calendar years

Pohyby samca orla hrubozobého (*Clanga clanga*) počas jeho druhého a tretieho kalendárneho roku

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Abstract: The greater spotted eagle (*Clanga clanga*) is poorly known compared to other European eagles. We tracked an immature greater spotted eagle during 2018–2020 within the eastern European part of the species' distribution, west of the Ural Mountains. Because so little is published about the annual movements of this species, especially from that region, tracking data from this single individual are valuable. 95% kernel density estimator (KDE) range sizes for the two complete winters in Yemen were 4,009 km² (2018), 1,889 km² (2019); 95% dynamic Brownian bridge movement models (dBBMM) encompassed 1,309 km² (2018) and 1,517 km² (2019). It returned to the same wintering area every year. During summer 2018, it settled into a small area (95% KDE = 126 km²; 95% dBBMM = 21 km²) near Birska, eastern European Russia; in 2019 it wandered over a huge area (95% dBBMM = 66,304 km²) of western Kazakhstan and southern Russia, south west of Yekaterinburg. Spring migration 2018 was west of the Caspian Sea; during 2019 it was east of it. Mean speed of spring migration was 160±120 km/day during 2018, and 132±109 km/day during 2019. Autumn migration passed east of the Caspian in both years, and the mean speed of migration was 62 ± 78 km/day in 2018, and 84 ± 95 km/day in 2019. During both spring and autumn migrations, the eagle made stopovers, mostly lasting 1–2 days. The eastern Alborz Mountains in northeastern Iran appeared to be an important stopover locale, where autumn stopovers lasted 19 days (2018) and 27 days (2019). These and other data suggest that most greater spotted eagles that spend summers west of about 42°E, winter in southern Europe, Asian Turkey, the Levant and Africa, and those that summer to the east of that meridian winter in southern Asia, including Arabia.

Abstrakt: Orol hrubozobý (*Clanga clanga*) je v porovnaní s ostatnými európskymi orlami málo známy. V rokoch 2018 – 2020 sme v rámci východoeurópskej časti areálu druhu, západne od pohoria Ural, sledovali nedospelého orla hrubozobého. Vzhľadom na malé množstvo publikovaných informácií o pohybe tohto druhu v priebehu roka, najmä z tohto regiónu, sú údaje o pohybe nami sledovaného jedinca cenné. 95%-ný odhad jadrovej hustoty (kernel density estimation, KDE) veľkosti areálu jedinca počas dvoch zim v Jemene boli 4009 km² (2018), 1889 km² (2019); 95%-né dynamické Brownove modely prepojeného pohybu (dynamic Brownian bridge movement models, dBBMM) zahŕňali 1309 km² (2018) a 1517 km² (2019). Jediniec sa vrátil zimovať na to isté územie každý rok. Počas leta 2018 sa usadil v malom území (95% KDE = 126 km²; 95% dBBMM = 21 km²) v blízkosti Birska, európska časť Ruska; v roku 2019 sa pohyboval ponad veľké územie (95% dBBMM = 66 304 km²) západného Kazachstanu a južného Ruska, juhozápadne od Jekaterinburgu. Na jar 2018 migroval západne od Kaspiku; v 2019 východne od neho. Priemerná rýchlosť jarnej migrácie bola v roku 2018 160 ± 120 km/deň a v roku 2019 132 ± 109 km/deň. V jeseni migroval východne od Kaspiku v oboch rokoch, priemerná rýchlosť migrácie bola 62 ± 78 km/deň v roku 2018 a 84 ± 95 km/deň v roku 2019. Počas jarnej aj jesennej migrácie robil orol zastávky trvajúce väčšinou 1 až 2 dni. Dôležitou migračnou zastávkou sa zdá byť východná časť pohoria Alborz v severovýchodnom Iráne, kde jesenné zastávky trvali 19 dní (2018) a 27 dní (2019). Tieto a ďalšie údaje naznačujú, že väčšina orlov hrubozobých, ktoré trávia letá západne približne od 42° východnej dĺžky, zimujú v južnej Európe, ázijskej časti Turecka, v Levante a v Afrike, a tie, ktoré trávia leto východne od tohto poludníka zimujú v južnej Ázii, vrátane Arabského polostrova.

Key words: satellite tracking, telemetry, migration, home range, stopovers

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Introduction

The greater spotted eagle (*Clanga clanga*) is a medium-sized, migrant eagle that breeds in forests located mostly in lowlands near wetlands or lakes. The breeding distribution lies between the boreal and steppe zones (i.e. mid-north latitudes) from easternmost Poland and the Baltic countries in the west to the Pacific Ocean in the east (i.e. NE China, Primorsky Krai, Russia), and spans more degrees of latitude in the west than in the east (Meyburg et al. 2016b, 2020b, BirdLife International 2021). The distribution of breeding greater spotted eagles in the Asian part of its distribution is patchy and little known (Väli et al. 2019). Breeding concentrations exist in the Volga-Ural region (e.g. Belaya River basin), the West Siberian lowlands (e.g. Tobol River basin), and in Altai-Sayan (e.g. Chulym River basin, Krasnoyarsk Krai) (Karyakin 2008, Karyakin et al. 2012).

Greater spotted eagle is considered to be globally Vulnerable (Meyburg et al. 1998, IUCN 2021). Habitat loss is considered the main cause of declines, though disturbance and persecution are also threats (Meyburg et al. 2001, 2020b, BirdLife International 2021, Väli et al. 2021). Across its vast distribution, but particularly east of the Ural Mountains, the annual movements of this rare species are rather poorly known. Information about migration and wintering is limited from across its distribution because ringing has revealed very little. Only a few tracking studies of small numbers of birds from the western borders of its global distribution have been published (Meyburg et al. 1995, 1998, 2005, Meyburg & Meyburg 2007, Dombrovski et al. 2018, Väli et al. 2018, 2021). Recently, a few birds have been tracked from as far east as areas near Vyazniki, Russia (~ 200 km east of Moscow, 56°E; A. Mischenko, V. Melnikov, <https://gps.aquila-it.pl/en/migration-maps/greater-spotted-eagle-moscow>). Greater spotted eagles tracked in

those studies migrated south in autumn, some southwest towards Iberia, others south and south east towards Greece, the Balkan countries, Turkey and the Levant. Some birds migrated only as far as the northern rim of the Mediterranean, but others wintered in Arabia and north east and East Africa, as far south as Zambia (Meyburg et al. 1998, Pérez-García et al. 2014, Väli et al. 2021). Tracking studies from farther east are few and of limited duration, but show birds from wintering grounds in Arabia migrating toward summering areas in northern Kazakhstan, and bordering areas of Russia in eastern Europe and western Siberia (Meyburg et al. 1995, Strick et al 2011).

We describe two years' of movements by a young greater spotted eagle that summered in Kazakhstan and eastern European Russia and wintered in southern Arabia. This bird was caught by chance during a study that targeted mostly Egyptian vultures (*Neophron percnopterus*, McGrady et al. 2019, B. Meyburg & M. McGrady unpublished data), and is the only greater spotted eagle that we tracked. However, given the general lack of detailed data on the movements of greater spotted eagles, data from even this single individual are potentially indicative of the movements of greater spotted eagles from summering grounds in eastern European Russia.

Methods

We captured, using a padded leg-hold trap (Bloom et al. 2007), a juvenile greater spotted eagle on 14 January 2018 at the Muscat municipal landfill at Al Multaqaa, Oman (28.34°N, 58.46°E). We ringed and measured it (wing: 490 mm, mass: 1,875 g), and took a blood sample. The bird had a large light brown nape patch, which is typical for *C. clanga* – *C. pomarina* hybrids, but very rare in pure *C. clanga* (Clark 1988, Meyburg et al. 2016b). We tested whether the bird was indeed a hybrid using a set of neutral microsatellite and single-nuc-

leotide polymorphism markers (Väli et al. 2010a, b); its sex was determined using the amplification of sex-chromosome specific loci of the chromo-helicase-DNA-binding protein gene (Fridolfsson & Ellegren 1999). Tests showed this bird to be pure *C. clanga*, and a male.

We fitted it with a 45g solar-powered GPS-PTT (Global Position System-Platform Transmitter Terminal; Microwave Telemetry, Inc., USA) as a backpack (Meyburg & Fuller 2007), and tracked it until 19 January 2020, when movement data ceased. [N.B. The eagle was observed and photographed without its transmitter, and identified from its colour ring in Kuwait on 17 October 2020 (R. AlHajii pers. comm.)]. Data from one partial and two complete autumn migrations and two complete spring migrations were collected. Data were also collected for two complete summers, two complete and one partial winter.

The PTT (ID = 47637) was programmed to acquire a GPS fix (including speed, bearing and altitude) every hour during 00:00–18:00 GMT, via the Argos system of satellites, which also provided Doppler locations of the bird (http://www.argos-system.org/manual/3-location/34_location_classes.htm).

GPS location data were visually screened for errors using QGIS 3.10, and R 4.02 (R Core Team 2020) using R-Studio (R-Studio Team 2020). R and R-Studio and the packages *move* (Kranstauber et al. 2012, 2020), *adehabitat*, *adehabitatHR* (Calenge 2006, 2015, 2020), and *ggplot2* (Wickham 2016) were used for analysing and visualizing data. All calculations were made using the North Pole Lambert Azimuthal Equal Area Projection (Gudmundsson & Alerstam 1988; WKID: 102017). In creating maps of the eagle's movement we used as background the digital elevation map from the U.S. Geological Survey (USGS) Earth Resources Observation & Science (EROS) Center, and satellite imagery available from Mapbox® & OpenStreetMap®. For all annual phases (i.e. summer, autumn and spring migration, winter) we used GPS data for our analyses. During summer 2019, major gaps (> 1 day) occurred in the GPS data. We filled those gaps, to the extent that was possible, by supplementing the GPS data with plausible Doppler locations (taking into account information on speed and the location of adjacent GPS data). The total distance travelled on migration (km) was the sum of the distance between migration locations. Mean daytime ground speed (km/hr) was the distance between daytime locations divided by the number of hours those locations spanned. Speed of migration (km/hr) was the Euclidean distance between successive night time roost

locations divided by the available daylight hours on that day. The mean speed of migration (km/day) was the sum of distances between night-time roosts divided by the number of days on migration.

When GPS data were sparse around the beginning and end of migration, we used Doppler data to determine more precisely when migration started and ended. The date of departure on migration was defined as the first day the eagle changed behaviour, and moved along a trajectory away from either the summering or wintering area at the end of the relevant season. The eagle arrived from migration when it reached the known summering or wintering distribution, and movements became short and non-directional. However, the within-season pattern of movement varied from year to year (e.g. movement during summer 2018 was different than in 2019) and across seasons, and this sometimes obscured when, precisely, migration began or ended. In summer 2019 the bird's behaviour made determining precisely the arrival and departure dates difficult; we used a balance of evidence (e.g. date, rate and direction of movement, flight behaviour, habitat) to determine those.

Night-time was defined as the period between sunset and sunrise on the relevant date at the relevant latitude/longitude. On nights when multiple roost locations were recorded, the nominal location of the roost was the mean of all locations.

We defined stopover sites as locations during migration periods where the distance between successive night-time roosts was ≤ 10 km. We chose the 10 km criterion because in none of the three winters did the median distance between winter-time roosts (i.e. when the bird was settled) exceed this value. In some cases the eagle moved farther than 10 km during the course of 24 hrs, but then returned to within 10 km of the earlier roost. In light of the migration patterns of the two complete autumn migrations (2018 & 2019), we judged that the eagle was on migration when caught in Oman, and that the capture location was therefore a stopover. We used the same method to identify temporary settlement locations during summer 2019, but used a 30 km distance criterion for successive night-time roosts and that the eagle stayed for at least three days at the same locale.

For analysing movements during winter and summer we calculated the eagle's Utilization Distribution (UD), and mapped the resulting isopleths using dynamic Brownian Bridge Movement Models (dBBMM, Kranstauber et al. 2012) and a kernel density estimator

Tab. 1. Annual phases of a young, male greater spotted eagle tracked via satellite during 2018–2020. *Doppler locations were used to supplement GPS data. See methods for details, also Fig. 3.

Tab. 1. Ročné fázy satelitne sledovaného mladého samca orla hrubozobého počas rokov 2018 – 2020. * Dopplerove pozície boli použité na doplnenie GPS údajov. Pre viac informácií pozri Metodiku a Obr. 3.

season / obdobie	dates / dátum	duration (days) / trvanie (dni)	GPS locations (Doppler) / GPS lokalizácie (Doppler)
autumn 2017 (partial) / jeseň 2017 (čiastočne)	14 Jan–15 Feb 2018	33	546
winter 2017–18 / zima 2017–18	16 Feb–23 Apr 2018	67	1146
spring migration 2018 / jarňá migrácia 2018	24 Apr–23 May 2018	30	461
summer 2018 / leto 2018	24 May–25 Sep 2018	126	788
autumn migration 2018 / jesenná migrácia 2018	28 Sep 2018–16 Jan 2019	111	1422
winter 2018–19 / zima 2018–19	17 Jan–25 Apr 2019	99	1678
spring migration 2019 / jarňá migrácia 2019	26 Apr–23 May 2019	28	425
summer 2019* / leto 2019*	24 May–1 Oct 2019	131	1069 (363)
autumn migration 2019 / jesenná migrácia 2019	2 Oct–28 Nov 2019	58	794
winter 2019–20 (partial) / zima 2019–20 (čiastočne)	29 Nov 2019–19 Jan 2020	52	681

(KDE; Worton 1989). Raster size was set for both calculations depending on the spatial extent of the eagle’s movement in each season: 500 m for all winters and summer 2018, and 2,500 m for summer 2019. In calculating the dBBMM we set margin size to 3, window size to 7 and time step to 4 min (see <https://bartk.gitlab.io/move/articles/move.html>). For the KDE analyses we used the reference bandwidth (href), but excluded locations separated by less than an hour to standardize the sampling interval and reduce temporal autocorrelation (Limiñana et al. 2007). Excluded data were only Doppler locations because the collection of GPS locations occurred hourly. We did not calculate the KDE for summer 2019 because the eagle wandered widely, which caused isopleths to balloon excessively. We summarised the UD for the dBBMMs at the 50%, 75%, 95% and 100% levels, and at the 50% and 95% levels for the KDEs.

We describe habitats at stopovers and non-migratory settlement areas as the predominant (>25%) IUCN Habitat Type (Level 1 for Natural & Level 2 for Artificial Terrestrial Habitats; See Jung et al. 2020) within a 10 km buffer around the stopover night-time roost location. We also visually examined zoomed-in satellite images of stopover and settlement areas, which provided further insight into the habitats used by the eagle at those places (see first summer).

Results

General description

The eagle was tracked for 735 days (14 Jan 2018–19 Jan 2020, Tab. 1). It wintered each year in southwestern Yemen (approx. 13.5°N, 43.8°E), spent summer 2018 in

a small area of southern Russia (approx. 55.5°N, 55.5°E), and during summer 2019 wandered over a very large area in western Kazakhstan. It made stopovers of variable duration along the migration routes in both spring and autumn (Fig. 1). In total the eagle flew a minimum of 44,443 km (Tab. 2) during tracking.

Winter movements

The eagle wintered in southwestern Yemen in every winter it was tracked; winter ranges overlapped considerably (Fig. 2). Dynamic Brownian Bridge range size estimates averaged 47.5 ± 5.3 km² for the 50% isopleth, and $1,658.4 \pm 357.1$ km² for the 95% isopleth (N = 3, Fig. 2, Tab. 3). Winter arrival dates in Yemen were highly variable; only two days separated the two winter departure dates we recorded (Tab. 1). The main habitats in the area used by the eagle during winter were shrub and savanna (Tab. 4), though visual inspection of zoomed-in satellite images of the area revealed these areas to also include small villages and farmland.

Migration

Autumn migration was east of the Caspian Sea in both 2018 and 2019; spring migration was west of the sea in 2018, and east of it in 2019. (Fig. 3). Autumn migration was slower than spring migration (Tables 1 and 2). The mean migration speed in autumn was 96.4, 61.8 and 84.4 km/day for 2017 (Oman to Yemen), 2018 and 2019, respectively. For spring migration the values were 159.8 and 132.3 km/day for 2018 and 2019, respectively.

During the two complete migration cycles the eagle was tracked, six spring stopovers and 16 autumn stopovers were identified (Tab. 5 and Fig. 1). Counting the

Fig. 1. Movements of a young, male greater spotted eagle tracked during 14 January 2018–19 January 2020. a) 14 January–31 December 2018, b) 1 January 2019–19 January 2020. Stopover locations are identified by the number of stopover days spent at each (i.e. 1 stopover day = 2 overnight roosts). Black and purple line = autumn migration 2017 (partial), light blue = spring migration, red = summer, purple = autumn migration.

Obr. 1. Pohyby mladého samca orla hrubozobého sledovaného od 14. januára 2018 do 19. januára 2020: a) 14. január – 31. december 2018, b) 1. január 2019 – 19. január 2020. Lokality zastávok sú označené počtom dní na nich strávených (t.j. 1 deň zastávky = 2 nocovania). Čierno-fialová čiara = jesenná migrácia 2017 (čiastočne), svetlomodrá = jarná migrácia, červená = leto, fialová = jeseň.

capture location as a stopover location, there were two stopovers during the partial autumn migration from Oman to Yemen. Most stopovers were used only once, and were at various locations. However, the eagle stopped in the Alborz Mountains, Golestan Province, Iran (approx. 37.5°N, 55.5°E), during both autumn migrations (See later), albeit in different locations.

Spring migration

Tables 2 and 3 detail spring migration distances and speeds; table 5 contains information about the stopovers made during spring migration in 2018 (N = 3), and 2019 (N = 3; Fig. 1).

On 24 April 2018 the eagle left its wintering area, and started its northward migration, crossing Saudi Arabia, Iraq and Iran, then flying west of the Caspian Sea

through Azerbaijan. It crossed the Greater Caucasus in Georgia at or near the Arkhotisghele Pass (2,968 m, approx. 42.62°N, 44.89°E), then flew down the Asa River valley, and onto the east European Plain. It arrived at its summering location in southern Russia (approx. 55.43°N, 55.48°E) on 24 May (30 days after commencing migration, See Summer movements). The migration between wintering in Yemen and summering in Russia in 2018 spanned about 41.5 degrees of latitude. The mean daytime ground speed during spring migration 2018 was 13.6 ± 17.4 km/hr, N = 380 (Tab. 2). Three stopovers were recorded during this migration (Tab. 5, Fig. 1).

The path of spring migration 2019 was different than spring 2018, and took the eagle east of the Caspian Sea (Fig. 1), commencing on 26 April and ending on 23 May (Tab. 1) in western Turkmenistan, northwest of the town

of Serdar (38.98°N, 56.28°E). The 2019 spring migration spanned about 35 degrees of latitude. The mean daytime ground speed during spring migration 2019 was 11.7 ± 16.4, N = 322 (Tab. 2). Three stopovers were recorded during this migration (Tab. 5, Fig. 1).

Summer movements

During summer 2018 the eagle settled initially (23 May) in a mostly forested area along the Belaya River, about 10 km south of the town of Birsk, Russia (approx. 55.49°N, 55.51°E), west of the Ural Mountains. On 6 June it moved to a forested location along that river, about 8 km northwest of the town. During summer 2018, the 95% KDE encompassed 125.7 km², the 95% dBBMM encompassed 20.7 km² (Fig. 4a, Tab. 3). It spent at least 99 days at this summer location. Habitat in the area used by the eagle was predominantly arable (Tab. 4), but close visual inspection of satellite images showed that almost 100% of the locations were in a strip of forest adjacent to the river. After 12 September and before migration, only a few locations were recorded, including a short (~ 20 km) movement west (downstream) before the eagle embarked on autumn migration (28 September); summering lasted 130 days (Tab. 1).

During summer 2019 (Tab. 1) the eagle wandered over a huge area of mostly western Kazakhstan (Fig. 2b), in contrast to its settled behaviour the previous summer. Over the course of summer 2019 it travelled at least 8,950.1 km; the 95% dBBMM encompassed 66,304 km² (Tab. 3). There was no overlap between the summer 2018 and summer 2019 ranges. The eagle settled for at least four days at a minimum of six locations during summer 2019 (Fig. 4b, Tab. 4). The main habitats at those settlement areas were rocky areas, savanna, shrub, and wetland.

Autumn migration

On 20 January 2018, six days after release at the capture site, the eagle moved to southwestern Saudi Arabia, then more slowly south to inland southwestern Yemen (Fig. 1), west of the city of Ibb (approx. 13.77°N, 43.92°E), arriving on 16 February and settling there for the rest of the winter. The movement from Oman to Yemen covered 4,241 km, and was achieved in 33 days. The mean daytime ground speed during autumn migration between Muscat and Yemen was 10.4 ± 13.3 km/hr, N = 354 (Tab. 3).

On 28 September 2018 the eagle commenced autumn migration. It followed a path east of the Caspian Sea, across Turkmenistan, Iran, southern Iraq and Saudi

Tab. 2. Summary of migratory movements by a young, male greater spotted eagle during different annual phases, 14 Jan 2018–19 Jan 2020. Tab. 2. Súhrn migračných pohybov mladého samca orla hrubozobého počas rôznych ročných fáz, 14. január 2018 – 19. január 2020.

	great circle distance (km) / ortodróma	total distance (km) / celková vzdial.	mean speed of migration ± SD (km/d) / priem. rýchľ. migrácie	max. distance covered in a single day (km) / max. denná vzdialenosť	mean daytime ground speed ± SD (km/hr) / priem. rýchlosť počas dňa ± SD	mean hourly speed of migration ± SD (km/daylight hr) / priem. rýchľ. migrácie (km/hod. denn. svitu)	number of night roosts identified / počet zaznamenaných nocovísk
Oman–Yemen (autumn 2017) / Oman–Jemen (jeseň 2017)	1822.9	4106.9	96.4 ± 80.1	256.1	10.4 ± 13.2	8.7 ± 7.3	34
Yemen–Russia (spring 2018) / Jemen–Rusko (jar 2018)	4696.6	5562.6	159.8 ± 120.5	370.1	13.5 ± 17.4	11.6 ± 8.8	29
Russia–Yemen (autumn 2018) / Rusko–Jemen (jeseň 2018)	4589.5	7448.3	61.8 ± 78.2	516.2	6.3 ± 9.6	5.8 ± 7.2	95
Yemen–Kazakhstan (spring 2019) / Jemen–Kazachstan (jar 2019)	3249.4	4300.9	132.3 ± 108.8	399.0	11.7 ± 16.4	9.9 ± 8.3	28
Kazakhstan–Yemen (autumn 2019) / Kazachstan–Jemen (jeseň 2019)	3640.0	5103.7	84.4 ± 95.2	323.9	8.4 ± 12.8	7.7 ± 8.7	57

Fig. 2. Kernel Density Estimator (KDE) and dynamic Brownian Bridge Movement Model (dBBMM) representations of movements of a young, male greater spotted eagle in Yemen during the winters of: a) 2017–18, b) 2018–19 (complete), and c) 2019–20 (partial). NB: Scale is the same for all maps. UD: utilization distribution; KDE: 50% and 95% isopleth.

Obr. 2. Jadrový odhad hustoty (KDE) a dynamický Brownov model prepojeného pohybu (dBBMM) reprezentujúce pohyb mladého samca orla hrubozobého v Jemene počas zimy a) 2017 – 2018, b) 2018 – 2019 (celé) a c) 2019 – 2020 (čiastočne). NB: Mierka je rovnaká pre všetky mapy. UD: rozloženie využitia; KDE: 50 a 95% izolína.

Arabia, then into Yemen (Fig. 1). It arrived at its wintering site after 81 days, on 16 January 2019. The 2018 autumn migration covered 7,448 km (Tab. 3), and spanned about 41.5 degrees of latitude. The mean daytime ground speed during autumn migration 2018 was 6.3 ± 9.6 km/hr, $N = 871$ (Tab. 3). Thirteen stopovers were recorded during this migration (Tab. 5, Figures 2 and 3); the eagle stopped for relatively longer periods (19 days in 2018, 27 days in 2019) in the Alborz Mountains, Iran, during both autumn migrations. The habitats at those locations were Arable and Grassland (Tab. 5), a characterization that agreed, in general, with visual examination of satellite images.

Autumn migration 2019 commenced on 2 October. The eagle migrated along a path that took it east of the Caspian Sea, and then along a similar route to that used in autumn 2018. The mean daytime ground speed during autumn migration 2019 was 8.4 ± 12.8 km/hr, $N = 479$ (Tab. 3). Three stopovers were recorded during this migration (Tab. 5, Figures 2 and 3). During the 2019 autumn migration the eagle flew 5,103.7 km, and its migration spanned about 30 degrees of latitude.

Discussion

Migration and the use of stopovers

Keeping in mind the wide longitudinal distribution of greater spotted eagle and that individuals can be short-, medium- or long-distance migrants, the behaviour of the bird that we tracked comported well with other tracking studies of greater spotted eagles (See: Meyburg et al. 2016b, 2020b, Väli et al. 2018, 2021), especially those that wintered in Arabia (Meyburg et al. 1995, Strick et al. 2011, Environment Agency Abu Dhabi (EAD) 2020, Kuwait Environmental Lens (KEL) unpublished data) – all migrated between Arabia to locations in Kazakhstan and southern Russia, west of the Urals, except the adult tracked by Meyburg et al. (1995), which migrated to the western Siberian lowlands east of the Urals. Also, migration arrival and departure dates were similar to other studies, as was ranging on summering and wintering areas, taking into account the age and breeding status of the tracked birds (Meyburg et al. 1995, Strick et al. 2011).

Tab. 3. Sizes (km²) of ranges of a young, male greater spotted eagle during winters (2017–18, 2018–19 (complete), 2019–20 (partial)), and summers (2018, 2019).

Tab. 3. Veľkosti (km²) okrskov mladého samca orla hrubozobého počas zím (2017 – 18, 2018 – 19 (celé), 2019 – 20 (čiastočne) a liet (2018, 2019).

	dBBMM UD 50 %	dBBMM UD 75 %	dBBMM UD 95 %	dBBMM UD 100 %	KDE 50 %	KDE 95 %
winter / zima 2017–18	46.7	284.7	2149.0	14711.4	556.5	4009.8
winter / zima 2018–19	41.5	243.0	1309.2	16087.4	177.9	1889.1
winter / zima 2019–20	54.4	330.2	1517.0	8690.6	472.2	2349.0
summer / leto 2018	1.1	4.5	20.7	1990.3	17.6	125.7
summer / leto 2019	464.0	6213.1	66304.0	768396.2	Not calculated	Not calculated

Tab. 4. Locations where a young, male greater spotted eagle settled for ≥4 days during summers and winters 2018–2020.

Tab. 4. Lokalita, kde mladý samec orla hrubozobého ostal na ≥4 dni počas liet a zím 2018 – 2020.

phase / obdobie	arrival–departure dates / datum priletu – odletu	duration (days) / trvanie (dni)	mean latitude, longitude (decimal degrees) / priemerná zemepisná šírka, dĺžka (desatinné stupne)	habitat* / habitat*
winter 2017–18 / zima	19 Feb–3 Mar	13	13.423, 43.820	shrub ¹
	6–16 Mar	11	13.478, 43.777	shrub
	19–24 Mar	6	13.530, 43.778	shrub
	27–30 Mar	4	13.480, 43.788	shrub
	12–23 Apr	12	13.960, 43.986	savanna ²
summer 2018 / leto	24 May–24 Sep	124	55.449, 55.496	arable ³
winter 2018–19 / zima	22 Jan–3 Feb	13	13.504, 43.847	savanna, shrub
	5 Feb–6 Mar	30	13.880, 43.967	savanna
	8 –19 Mar	12	13.937, 43.968	savanna
	21 –25 Mar	36	13.978, 44.018	savanna
summer 2019 / leto	30 Mar–7 Jun	9	40.851, 55.528	desert ⁴
	9 –12 Jun	4	41.025, 55.405	desert, grassland ⁵
	17 Jul–27 Aug	42	49.472, 55.730	grassland
	5–8 Sep	4	46.465, 49.709	wetland ⁶
	11 –14 Sep	4	46.455, 49.673	wetland
	17 –29 Sep	13	46.431, 49.768	wetland
winter 2019–20 / zima	29 Nov–7 Dec	9	13.945, 43.912	savanna, shrub
	10–21 Dec	12	13.909, 43.974	savanna
	23–27 Dec	5	13.525, 43.850	shrub, savanna
	29 Dec–3 Jan	5	13.665, 43.918	shrub
	07–18 Jan	12	13.762, 43.915	savanna, shrub

* IUCN Habitat Type. See text for details from visual examination of zoomed-in satellite images. /

Typ habitatu podľa IUCN. Pozri text pre viac informácií o vizuálnom posúdení zväčšených satelitných fotografií. ¹Kroviny, ²savana, ³orná pôda, ⁴púšť, ⁵trávnaté habitaty, ⁶mokrad.

Generalizations about migration being affected by the ecology of the species, distance between summering and wintering areas, the existence of stopover sites, and age/experience/breeding status of the individual (Newton 2008) appeared to hold true for the tracked bird. Although detailed published data for greater spotted eagle are limited, the general pattern of migration of this species also finds similarities with other long-distance migrant raptors in Europe and Africa, particularly the closely-related lesser spotted eagle (*Clanga pomarina*; Meyburg 2021, Väli et al. 2021).

Our data and those from other greater spotted eagles that wintered in Arabia (two adult, one juvenile) show spring migration starting between 2 February (adult, Meyburg et al. 1995) and 26 April (this study), and ending between 21 April (Meyburg et al. 1995) and 5 June (Strick et al. 2011, See also RRRCN 2014, 2017a, b). Timing of spring migration for birds from farther west seems to be similarly variable, and linked to age (See: Väli et al. 2021). The bird we tracked arrived in the summering area almost a month later than the adult male tracked by Meyburg et al. (1995), and an adult of

Fig. 3. Distance between successive night time roost locations of a young, male greater spotted eagle during January 2018–January 2020. Vertical lines indicate change of annual phase.

Obr. 3. Vzdialenosť medzi po sebe idúcimi miestami nočného odpočinku mladého samca orla hrubozobého v období od januára 2018 do januára 2020. Zvislé čiary označujú zmenu ročnej fázy.

unknown gender that wintered in Kuwait (KEL unpublished data). While on spring migration, it travelled at a rate similar to the adult eagle tracked by Meyburg et al. (1995), and others from the west (Väli et al. 2021). Although the bird we tracked was too young to breed, spring migration was faster than autumn migration (as it was for European birds migrating from Africa: Väli et al. 2021). Stopovers occurred during both spring migrations we studied (see later), but were not consistently located in or near large areas of wetter habitats. However, this result may have been affected by the scale of the habitat data we used as visual examination of satellite images showed that stopovers were sometimes near small areas of wetter habitat, near lakes, streams or in valleys.

Greater spotted eagles are generally present in Arabia from late September to late April–early May (Meyburg et al. 2016b, Väli et al. 2021). Autumn migration of tracked greater spotted eagles of different ages from the flyway used by our eagle commenced during 28 September (this study)–5 October (KEL unpublished data), and ended during 16 October (KEL unpublished data)–16 February (this study), and were not different

than those recorded for eagles from more western parts (Väli et al. 2021). In the two years of our study, the bird we tracked commenced its autumn migration in the last week of September; its end was variable (15 Feb (2017–18), 16 January (2018–19), 28 November (2019–2020)). This variability in arrival dates on the wintering grounds was probably driven, at least in part, by food availability; as the bird travelled south it found places to forage with sufficient food to slow migration, and perhaps cause it to stopover. However, age/experience may have also played a part. The juvenile tracked by Strick et al. (2011) wandered in Arabia during its first winter, settled on the Indus delta, Pakistan during its second winter, and returned to the delta in the two subsequent years (NARC unpublished data). Autumn migration was consistently slower than spring migration for the bird we tracked: mean autumn 2018 = 61.8 km/day, mean autumn 2019 = 84.4 km/day. As in spring migration, the speed of our tracked bird fell within the range of highly variable speeds reported for western eagles (e.g. 57 km/day, Meyburg et al. 2005; 217 km/day, Dombrovski et al. 2018).

Fig. 4. Kernel Density Estimator (KDE) and dynamic Brownian Bridge movement model (dBBMM) representations of summertime movements of a young, male greater spotted eagle in: a) 2018, b) 2019. NB: Scale is different in a) and b). UD: utilization distribution; KDE: 50% and 95% isopleth.

Obr. 4. Jadrový odhad hustoty (KDE) a dynamický Brownov model prepojeného pohybu (dBBMM) reprezentujúce pohyb mladého samca orla hrubozobého počas leta v a) 2018, b) 2019. NB: Mierka máp je odlišná. UD: rozloženie využitia; KDE: 50 a 95% izolína.

Stopovers were also made during autumn migration, especially in 2018, when they accounted for about 45% of the time spent on migration (Tables 1 and 5). The bird was captured at an autumn stopover (as revealed by its subsequent movement), where food (carrion) was super-abundant (Al Fazari & McGrady 2016). Thus, factors other than simply food availability appear to affect the settlement of greater spotted eagles in winter. Stopovers were more common, and comprised a greater proportion of the migration period in autumn than in spring. As with spring stopovers, there was no apparent link between the autumn migration stopovers and wet habitats when using only the IUCN habitat data, but satellite images revealed that stopovers were sometimes near small areas of wetter habitat.

Additionally, some individual greater spotted eagles wander after arriving on summering and wintering grounds (Strick et al. 2010, RRRCN 2014, 2017a, b, Meyburg et al. 2020b, unpublished data, Väli et al. 2021, KEL, Maciorowski unpublished data, this study), making it difficult to identify when exactly migration stops and wintering/summering begins. Wandering is likely more common in young individuals because they are anchored neither to breeding sites nor wintering areas. All young greater spotted eagles (N = 4) tracked in eastern parts of the European distribution have

wandered on either or both summering and wintering grounds to some extent (Strick et al. 2010, RRRCN 2014, 2017a, b, this study).

Although data are still few, and there are sure to be exceptions, telemetry and the few ring recoveries that exist tentatively suggest that most greater spotted eagles that spend summers west of about 42–44°E, winter in Europe and Africa, and those that summer to the east of those longitudes winter in Arabia, southern and South-east Asia (Meyburg et al. 1995, 2016b, 2020b, Strick et al. 2011, RRRCN 2014, 2017a, b, Väli et al. 2021, but see also: “Rudy” <http://en.orlikgrubodzioby.org.pl/artikul/satellite-tracking>).

The bird we tracked showed fidelity to its wintering area, a characteristic of most adult greater spotted eagles that have been tracked (Meyburg & Meyburg 2005, Pérez-García et al. 2014, Meyburg et al. 1998, 2016b, Maciorowski & Meyburg unpublished data, KEL unpublished data), but not of all young eagles (Strick et al. 2010, Meyburg et al. 2016b, Väli et al. 2021). This is consistent with the view that age and experience appear to influence, but not necessarily determine, fidelity to wintering sites (Newton 2008).

Stopover locations are where eagles might refuel, and modulate speed of migration in response to local environmental conditions (e.g. weather), and might be

Tab. 5. Migratory stopovers made by a young, male greater spotted eagle during 2018–2019. A = autumn, S = spring.
Tab. 5. Migračné zastávky mladého samca orla hrubozobého počas rokov 2018 – 2019. A = jeseň, S = jar.

	arrival date / prilet	departure date / odlet	location / lokalita	latitude, longitude / zemepisná šírka, dĺžka	habitat / habitat*
A 2017	Unknown	20/01/2018	Muscat, Oman	23.33, 58.45	Desert ¹ /rocky areas ²
	08/02/2018	11/02/2018	W Yemen / Z Jemen	16.84, 43.18	Arable ³ , grassland ⁴
S 2018	09/05/2018	11/05/2018	NE Georgia / SV Gruzínsko	41.91, 45.95	Forest ⁵ , arable
	11/05/2018	14/05/2018	NE Georgia	42.30, 45.00	forest, grassland
	19/05/2018	21/05/2018	Chuvash, Russia / Čuvaško, Rusko	55.48, 47.80	Shrubland ⁶
	03/10/2018	05/10/2018	Orenburg, Russia / Orenburg, Rusko	53.43, 53.54	arable
	18/10/2018	01/11/2018	Alborz Mountains, NE Iran / Alborzské vrchy, SV Irán	37.32, 55.34	arable
	02/11/2018	04/11/2018	Alborz Mountains, NE Iran	37.32, 55.34	arable
	11/11/2018	13/11/2018	near Tehran, Iran / pri Teheréne, Irán	35.47, 51.78	desert
	19/11/2018	21/11/2018	S Central Iran, near Ahvaz / juh stredného Iránu, blízko Ahvazu	31.10, 51.16	shrubland, grassland
A 2018	21/11/2018	08/12/2018	S Central Iran / juh stredného Iránu	30.83, 51.35	shrubland, grassland
	13/12/2018	15/12/2018	S Iraq / J Irak	30.62, 48.59	arable
	17/12/2018	21/12/2018	SW Iraq / JZ Irak	30.91, 45.94	desert
	24/12/2018	26/12/2018	Central Saudi Arabia / stredná Saudská Arábia	25.99, 45.15	desert
	26/12/2018	28/12/2018	Central Saudi Arabia	25.79, 45.19	desert
	01/01/2019	03/01/2019	Central Saudi Arabia	25.13, 43.44	desert
	04/01/2019	06/01/2019	Central Saudi Arabia	23.82, 43.00	desert
	11/01/2019	13/01/2019	SW Saudi Arabia / JZ Saudská Arábia	17.97, 42.46	rocky areas, shrub
S 2019	10/05/2019	11/05/2019	NW of Tehran, Iran / SZ od Teheránu, Irán	36.69, 51.16	forest, wetland ⁷
	11/05/2019	14/05/2019	E of Tehran, Iran / V od Teheránu, Irán	36.70, 53.20	arable
	21/05/2019	24/05/2019	Mangystau, Kazakhstan / Kazachstan	41.58, 55.21	desert
	10/10/2019	12/10/2019	Kopet Dag Mountains, Turkmenistan / pohorie Kopet Dag Turkménsko	38.94, 56.45	arable/grassland
A 2019	12/10/2019	14/10/2019	Alborz Mountains, NE Iran	37.77, 55.96	grassland/arable
	14/10/2019	08/11/2019	Alborz Mountains, NE Iran	37.32, 55.35	arable

¹Púšť, ²skaly, ³omá pôda, ⁴trávnaté habitáty, ⁵jesy, ⁶kroviny, ⁷mokrade.

particularly important for young birds during their initial migrations (Newton 1979, Klaassen et al. 2014, Meyburg et al. 2017). Not all stopover sites comprised predominantly wetter habitats that are typically associated with greater spotted eagles. Indeed, this bird was caught at a stopover at a landfill surrounded by arid natural habitats. Most stopovers by our bird were used only once. However, the eagle stopped in the Alborz Mountains, Golestan Province, Iran, during both autumn migrations. A migration bottleneck has been identified between the northern slopes of those mountains and the Caspian Sea (Panuccio et al. 2018), and a tracked adult greater spotted eagle migrated in autumn along the southern slopes (Meyburg et al. 1995). Migration stopovers should be investigated more fully when data from other individuals are available.

For the bird we tracked, spring migrations took less time, its mean speed of flight was higher, and fewer stopovers were made than in autumn. Keeping in mind the benefits to adults of arriving early on the breeding grounds, these consistent differences between autumn and spring support the impression that individual greater spotted eagles are rather adaptable in terms of their migration behaviour, and can opportunistically modulate their migration (via stopovers or slower pace of migration) to feed. Indeed, the effect of stopping over may be the main reason the pace of autumn migration was slower for our tracked bird than reported for eagles from farther west (Väli et al. 2021). As with our bird, two juvenile eagles from nests in Altai, Russia made stopovers as they approached their wintering and summering grounds (RRRCN 2014, 2017a, b).

W i n t e r a n d s u m m e r m o v e m e n t s

The ecological and behavioural flexibility displayed by our bird and other tracked greater spotted eagles during migration (e.g. RRRCN 2014, 2017a, b, Väli et al. 2021, this study) extended to periods when not migrating, and was similar to that of young *C. pomarina* (e.g. Meyburg et al. 2007). When captured, the eagle we tracked was juvenile (about 7 months old). During 2018 it settled into a small summer home range (Figures 1 and 4), where the density of greater spotted eagle territories in the surrounding area was high (the nearest known nesting site was about 7 km away, Karyakin 2008). In 2019, the eagle did not show fidelity to the summering area of 2018, and behaved very differently (Figures 1 and 4). IUCN habitat types at places where it settled for short periods during the summer of 2019

were not what are normally thought of as being good for greater spotted eagles (i.e. wet). Much of the area over which the bird ranged in summer 2019 was steppe habitat comprised mostly of grasslands that might have held concentrations of small mammals (e.g. susliks).

Väli et al. (2018) states that winter home ranges are small (especially when compared to lesser spotted eagle, Meyburg & Meyburg 2009, Meyburg 2020b), and are typically at wetland sites (Maciorowski et al. 2019), but also at anthropogenic dump sites and sometimes drier locations (see also Meadows 2011). The winter home range of an adult greater spotted eagle that wintered in Yemen was about 50 km² (Meyburg et al. 1995), which is similar to the 50% dBBMM estimates for the three winters our bird was tracked.

The data we present are important in that they provide some of the first detailed information on the movements of an immature greater spotted eagle along this flyway over a longer period. Other information exists (e.g. Meyburg et al. 1995, Strick et al. 2010, RRRCN 2014, 2017a, b), but is not so detailed, and some data are, as yet, unpublished (e.g. EAD 2019, 2020, KEL, Meyburg et al., Maciorowski et al. unpublished data). Although data are from only a single individual, they appear to agree with the results of those other studies, and studies from farther west (See Meyburg 2020b, Väli et al. 2021 for summaries). However, when considering our results and comparing them with other studies it is important to keep in mind that gaps existed in our GPS data, and tracking technology has improved collection rates and accuracy (See: Poessel et al. 2017). As a consequence, data from more individuals using improved technology are needed to understand more fully the year-round ecology of greater spotted eagle, and promote their conservation.

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