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Post-fledging dependence period, dispersal movements, temporary settlement areas, and causes of mortality in saker falcons from Central Europe

Obdobie dospievania, disperzné pohyby, oblasti dočasných útočísk a príčiny úhynu u sokola rároha zo strednej Európy

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Abstract: We are currently aware of home-range sizes and mortality rates during the post-fledging dependency period (PFDP), as well as the migration routes and wintering sites of many raptors. In comparison, the period of natal dispersal is significantly understudied, including survival rates and information on the temporary settlement areas (TSA). Despite their importance, these data are unavailable for most raptor species, though they are crucial for more effective species protection and more efficient financing of nature conservation. Using satellite telemetry, we monitored twelve young saker falcons (*Falco cherrug*) from fledging through the start of dispersal, and continued monitoring until their deaths. None of them died during the PFDP, but only one survived the natal dispersal period, reached adulthood and joined the breeding population. Their PFDP lasted 47 days (median, hereinafter), and they occupied home ranges of 81 and 23 km², calculated using the 100% and 80% minimum convex polygon (MCP) methods, respectively. Monitored individuals exhibited two distinct dispersal movement/behaviour patterns: seven individuals dispersed over long (>500 km) distances, and five others over short (<100 km) distances from their natal areas. During these movements, ten individuals established 21 TSAs. These were occupied for 28 days and covered 981 and 278 km², according to the 100% and 80% MCP, respectively. The finding that only one individual survived to adulthood contrasts with the increasing population trend in Slovakia and may be a consequence of the survival impacts of tagging. However, at least half of all documented mortality was attributable to human-induced causes, including at least one-third of deaths being caused by overhead power lines. This highlights the need to eliminate or at least try to reduce all types of anthropogenic mortality, such as electrocution, hunting, and/or poisoning, as much as possible immediately, if we want to reverse negative population trends in many birds of prey and to preserve them in the long term.

Abstrakt: V súčasnosti poznáme veľkosti domovských okrskov a mieru úmrtnosti počas obdobia dospievania, ako aj migračné trasy a zimoviská mnohých dravých vtákov. Na porovnanie, obdobie rozptylu po osamostatnení je výrazne nedostatočne preskúmané, vrátane miery prežívania a informácií o územiach dočasných útočísk. Napriek ich dôležitosti nie sú tieto údaje pre väčšinu druhov dravých vtákov k dispozícii, hoci sú kľúčové pre účinnejšiu ochranu druhov a efektívnejšie financovanie ochrany prírody. Pomocou satelitnej telemetrie sme monitorovali dvanásť mladých sokolov rárohov (*Falco cherrug*) od vylietania až po začiatok ich rozptylu a pokračovali sme v monitorovaní až do ich úhynu. Žiaden z nich počas obdobia dospievania neuhynul, ale iba jeden prežil obdobie pohniezdeného rozptylu, dosiahol dospelosť a pripojil sa k hniezdiacej populácii. Obdobie dospievania trvalo 47 dní (medián, aj ďalej) a ich domovské okrsky počas tohto období zaberali 81, respektíve 23 km², vypočítané pomocou metódy 100% a 80% minimálneho konvexného polygónu. Monitorované jedince vykazovali dva odlišné vzorce rozptylu: sedem jedincov sa rozptýlilo na dlhé (> 500 km) vzdialenosti a päť ďalších na krátke (< 100 km) vzdialenosti od svojich oblastí vyliahnutia. Počas týchto presunov si desať jedincov založilo celkom 21 územiach dočasných útočísk. Tieto boli obývané 28 dní a pokrývali plochu 981, respektíve 278 km², podľa 100% a 80% minimálneho konvexného polygónu. Zistenie, že do dospelosti prežil len jeden jedinec, je v kontraste s trendom rastu populácie na Slovensku a môže byť dôsledkom vplyvu označovania jedincov vysielačkami. Avšak najmenej polovica všetkých zdokumentovaných úmrtí bola pripísaná príčinám spôsobeným človekom, vrátane najmenej jednej tretiny úmrtí spôsobených infraštruktúrou vysokonapäťového prenosu. To zdôrazňuje potrebu čo najviac eliminovať alebo sa aspoň pokúsiť znížiť všetky typy antropogénnej úmrtnosti, ako sú zásahy elektrickým prúdom, lov a/alebo otravy, ak chceme zvrátiť negatívne populačné trendy mnohých dravých vtákov a dlhodobo ich zachovať.

Key words: breeding period, causes of death, *Falco cherrug*, home range, minimum convex polygon, movement routes, overhead power lines, satellite telemetry

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Introduction

Migration, a relatively well-studied phenomenon that has been studied over a long time, is an ancient behavioural trait of many bird species that enables them to track changes in climate and habitat conditions across the globe (Somveille et al. 2020). As such, a migratory lifestyle is remarkably common among birds, producing many remarkable feats of migration (Thorup et al. 2021). Some migrating raptors follow distinct routes during their outbound and return journeys. Topography and water barriers, in combination with behavioural, ecological, and meteorological factors, define these routes (Kerlinger 1989; Bildstein 2006). From the current knowledge perspective, we are aware of the migration routes and wintering sites of many raptor species (Cepák et al. 2008).

However, much less is known about pre-migratory dispersal movements, specifically, movement routes, resting and temporary stops, also known as stopover sites or temporary settlement areas (hereinafter referred to as TSAs) during the natal dispersal period, including the speed of movement between them, etc., in newly independent juveniles (Belthoff & Ritchison 1989). Among the least researched topics is also the duration of the post-fledging dependence period (hereinafter referred to as PFDP), i.e., the period between fledging and reaching independence (e.g., Gamauf & Dosedel 2012; Kouba & Šťastný 2012; Kouba et al. 2013; Nemček et al. 2016; Literák et al. 2020). Previous studies primarily focused on the survival/mortality rates within a defined period (Penteriani & Delgado 2009), the PFDP in this case.

The development of remote tracking techniques has enabled researchers, not only to accurately determine different life phases in time and space, but also to determine risk factors (Nemček et al. 2014a) or show geographical limits for movements (McGrady et al. 2003; Limiñana et al. 2007, 2012; Cadahía et al. 2010). Another advantage of satellite telemetry is that it allows monitoring, for instance, even individuals that disperse over considerable distances after becoming independent, which could no longer be monitored by conventional radio telemetry. For their physical parameters, hawks and eagles (Meyburg et al. 2006), falcons (McIntyre et al. 2009), and owls (Penteriani et al. 2005) are suitable target groups for satellite telemetry. On the other hand, commonly used backpack harnesses may negatively influence behaviour and survival of both adults and juveniles (Steenhof et al. 2006; Booms et al. 2011; Dixon et al. 2016). Satellite transmitters with added mortality sensors could also help to record the mortality rate and its causes even in individuals which may be thousands of kilometres away from their natal areas, thus revealing the essential information needed to protect the biodiversity and save many different, not only critically endangered species (Cogan et al. 2012; Graham et al. 2012).

The saker falcon (*Falco cherrug*) is a widespread species throughout Eurasia, ranging from Central Europe to eastern China (Baumgart 1991; Ferguson-Lees & Christie 2001; Bauer 2020). The Carpathian Basin, south-western Slovakia, eastern Austria, and the south-eastern Czech Republic are the westernmost borders of its nesting distribution (Gamauf & Dosedel 2012; Kovács et al. 2014). Populations from Austria, Hungary and Slovakia are interconnected, as evidenced by movements, especially of young birds, and the nesting of birds from other countries in neighbouring ones (Slobodník 2008; Slobodník & Jenčo 2020). The population, for instance, in Ukraine and eastern Slovakia, after its recent increase, is currently showing a slight decline again (Chavko et al. 2019). On the contrary, the population in south-western Slovakia is slowly growing (Černecký et al. 2020; Chavko et al. 2025), primarily due to its positive population trend in the western part of the country (Chavko & Deutschová 2012; Chavko et al. 2014; 2019). The local breeding population, comprising approximately 40 breeding pairs, is a significant component of the European population (Chavko et al. 2025), which is currently estimated to range from 535 to 700 pairs across three distinct subpopulations (Prommer et al. 2025).

This study builds upon a previously published article by Kouba et al. (2021), which evaluated information on six young saker falcons monitored in 2021, and now processed data on a total of 12 individuals from both 2021 and 2023 to provide a more comprehensive picture and more robust data on the study species' monitored behaviours. We again aimed to determine the duration of the PFDP and to assess the home ranges occupied by the fledglings of the target species during this period in Central Europe, Slovakia. Additionally, we described the dispersal movements of the monitored individuals, identified possible TSAs established during dispersal and determined their duration and extent. Finally, we determined the mortality rates and causes in young saker falcons during the PFDP and dispersal movements.

Materials and Methods

Twelve young saker falcons (6x two siblings) from six nesting boxes placed on high voltage transmission pylons in the south-west of Slovakia during two nesting seasons (2021, 2023) were ringed with aluminium and coloured rings (Table 1 and Supplementary Information File – Table S1) and equipped with backpack-type satellite transmitters (Anitra Systems s.r.o., Prague, Czech Republic) for their later satellite telemetry monitoring. All the young birds were weighed, and their sex was determined based on their weight and size (females are ca 15% larger and ca 40% heavier than males) (Clark 1999). The transmitters used weighed 19 g and did not exceed 3% of the marked individual's body mass (e.g., Withey et al. 2001). The solar-powered GPS-GSM transmitters were programmed to continuously collect positional data in a fixed five-minute interval. These intervals were dynamically supplemented by a series of positional data collected at one-second intervals, which began with flight detection once the transmitter batteries were sufficiently charged. Recording positions at one-second intervals enabled a detailed picture of the larger movements of the monitored individuals and their behaviour. Both types of data (five-minute and one-second) were merged prior to the entire analysis; none of the recorded positions was discarded, and they were used consistently together. The recorded GPS positions of individuals were first exported from the Anitra platform to GPX format and further analysed and processed using BaseCamp software (Garmin, Schaffhausen, Switzerland). The BaseCamp software automatically delivered results on time spent moving and resting (non-moving), as well as the overall average speed and the average speed of movement (Table 1 and S1). The GPS positions were then exported to the SHP (shapefile) format and further processed and evaluated in ArcGIS Pro 3.2.0 (Esri, Redlands, USA) and Biotas 2.0a (Ecological Software Solutions, Hungary). In the latter software program, the areas of all home ranges listed below were calculated using the minimum convex polygon method (hereinafter referred to as MCP) (Mohr 1947; Hayne 1949; Laver & Kelly 2008). The ranges were made for the 100%, 95%, and 80% MCP variants with the setting "Stationary Arithmetic Mean". The distances of all obtained locations of individual young birds from the nest box were evaluated, and the lengths of all their movement routes were measured in ArcGIS Pro. All map materials were also created in this software.

The duration of the PFDP was individually determined, following the methods by Kouba et al. (2021), based on an analysis of the movements of all individuals when nine of them performed a sudden dispersal movement (Fig. 1 and S1), when they irrevocably left their PFDP home ranges from one day to the next, which clearly defined their PFDP. In the case of the three others, the length of the PFDP was also determined based on analysis of their movements, particularly their excursions outside the so far occupied natal area. The TSAs of monitored individuals established during dispersal movements were defined as areas where individuals spent a longer time in a relatively small area within which they repeatedly occurred in the same places, which was in direct contrast to the movement patterns and distances that individuals were able to cover during a single day of their dispersal movements. Additionally, in the case of TSAs, when evaluating data on individual movements, these areas became very clear on their own as individuals stayed and repeatedly appeared in the same locations [in our case, for at least 7 days (see below)] (Kouba et al. 2021). In a few cases, TSAs followed on from the PFDP and were established not far from the individuals' natal areas. These TSAs might possibly also be described as an extended use of the natal area, but only a few of them partly overlapped the individual's PFDP home range; others were, for instance, tens of kilometres apart.

Tab. 1. Basic breeding data, data related to satellite telemetry, and data describing the post-fledging dependence period of a total of six saker falcon fledglings (G1, G2, J1, J2, S1, and S2) satellite-transmitter-tagged in 2023. Details on six individuals monitored in 2021 were published by Kouba et al. (2021) and are also provided in Table S1.
Tab. 1. Základné hniezdne údaje, údaje týkajúce sa satelitnej telemetrie a údaje opisujúce obdobie dospievanie celkovo šiestich mláďat sokola rároha (G1, G2, J1, J2, S1 a S2) označených satelitným vysielačom v roku 2023. Podrobnosti o šiestich jedincoch monitorovaných v roku 2021 publikovali Kouba et al. (2021) a sú uvedené aj v tabuľke S1.

Evaluated characteristics	Individual data						Mean ± SD[a]	Min - Max[a]	Median[a]
Year of fledging/tagging	2023		2023		2023			-	
Nestbox	Gabčíkovo (G)		Jurová (J)		Štvrtok na Ostrove (S)			-	
Date of nesting	14 March		12 March		12 March		17 March ± 5 days	12 March - 26 March	16 March
Date of hatching	13 April		11 April		11 April		16 April ± 5 days	11 March - 25 April	16 April
No. of eggs	3		2		4		4.0 ± 1.2	2 - 5	4.5
No. of hatchlings	3		2		4		4.0 ± 1.2	2 - 5	4.5
No. of fledglings	3		2		4		4.0 ± 1.2	2 - 5	4.5
ID of tracked individual	G1	G2[b]	J1	J2	S1	S2		-	
Ring number (metal ring/colour ring)	D8189 / DT	D8190 / ET	D8187 / BT	D8186 / AT	D8141 / JC	D8142 / KC		-	
Sex	female	female	female	female	female	male		-	
Date of fledging	29 May	29 May	27 May	27 May	27 May	27 May	31 May ± 5 days	27 May - 10 June	31 May
No. of tracking days	51	213	161	760	137	223	180 ± 183	51 - 760	133
No. of locations/fixes	32169	82528	135907	167985	98006	135204	82654 ± 52874	4139 - 167986	72044
Time spent moving (days)	6	43	32	83	30	39	28 ± 20	6 - 83	25
Time spent resting (days)	45	170	129	677	107	184	151 ± 164	45 - 677	110
Length of movement route (km)	2016	9176	5741	12438	6054	7245	5725 ± 3123	1693 - 12438	5162
Overall average speed[c] (km/h)	1.56	1.85	1.48	0.68	1.84	1.03	1.56 ± 0.45	0.68 - 2.25	1.56
Average speed of movement[d] (km/h)	13.9	8.5	7.5	6.2	8.5	7.8	9.4 ± 2.1	6.2 - 13.9	9
Date of last record/death	18 July 2023	December 2023	November 2023	24 June 2025	10 October 2023	4 January 2024		-	
Cause of death	power line collision	falconry	signal loss	signal loss	power line collision	unknown		-	
Duration of PFDP[e] (days)	41	43	48	50	48	45	47 ± 3	41 - 53	47
No. of locations/fixes during PFDP[e]	14266	13997	34150	26580	33094	40298	18382 ± 11665	1713 - 40298	14521
Distance from the nest during PFDP[e] (mean ± SD; km)	0.8 ± 0.6	2.7 ± 2.7	1.2 ± 1.0	0.9 ± 0.6	2.4 ± 2.8	2.4 ± 2.9	2.2 ± 1.7	0.8 - 3.4	2.4
Maximal distance from the nest during PFDP[e] (km)	3.8	14.7	7.4	4.1	22	14.1	10.4 ± 5.4	3.8. - 22	8.8
Home range size during PFDP[e] (100% MCP[f]; km^2)	10.2	168.6	30.7	17.3	227.4	239.2	91 ± 78	10.2 - 239	81
Home range size during PFDP[e] (95% MCP[f]; km^2)	6.7	47.6	18.1	9.4	90.1	140	47 ± 40	6.1 - 140	45
Home range size during PFDP[e] (80% MCP[f]; km^2)	3.6	26	5.1	3.6	24.5	35	23 ± 19	3.6 - 70	23
Date of independence	8 July	10 July	13 July	15 July	13 July	10 July	16 July ± 6 days	8 July - 26 July	15 July

[a]The descriptive statistics are based on 6 nests and 12 individuals satellite-transmitter-tagged in 2021 and 2023, thus including also data published by Kouba et al. (2021).
[b]Reported on 27 December from Libya (city of Mistrata), the individual was taken for falconry purposes.
[c]The overall average speed of movement, including both times spent moving and resting, was calculated automatically by BaseCamp software.
[d]The overall average speed of movement, excluding time spent resting, was calculated automatically by BaseCamp software.
[e]Post-fledging dependence period (PFDP).
[f]Minimum convex polygon (100%, 95%, 80% MCP).

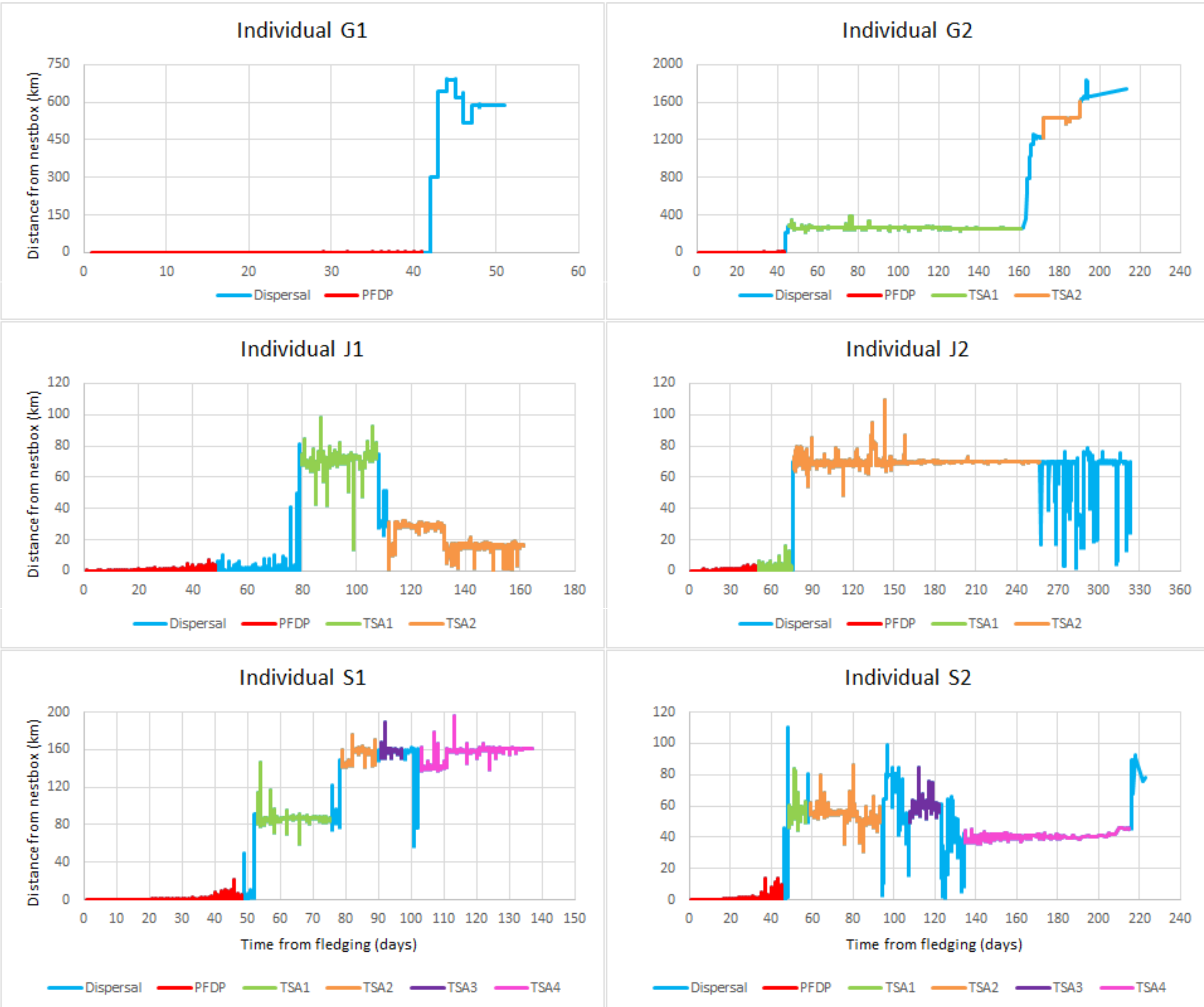

Fig. 1. Visualisation of the distance from the natal nest box and gradual moving away from it during the entire monitoring period of the six young saker falcons (G1, G2, J1, J2, S1, and S2) satellite-transmitter-tagged in 2023. The post-fledging dependence period (PFDP; red line) followed by the natal dispersal phase, and particular phases of temporary settlement areas (TSA; 1 – green, 2 – orange, 3 – purple, and 4 – pink line) occupied by each individual during their dispersion (blue line) are depicted.
Obr. 1. Vizualizácia vzdialenosti od hniezdnej búdky a postupného vzďaľovania sa od nej počas celého monitorovacieho obdobia šiestich mladých sokolov rárohov (G1, G2, J1, J2, S1 a S2) označených satelitným vysielačom v roku 2023. Zobrazené je obdobie dospievania (červená čiara), po ktorom nasleduje fáza pohniezdeného rozptylu, a jednotlivé obdobia dočasne obývaných útočísk (1 – zelená, 2 – oranžová, 3 – fialová a 4 – ružová čiara), ktoré jednotlivé jedince využívali počas svojho rozptylu (modrá čiara).

We assume each of them fully meets the TSA definition, with the only difference being that some were established far from the natal area, while others were quite close to it. The causes of death were initially assessed in the field when a carcass was found. In the case of electrocution or wire collision, the deaths were proved by autopsies. Unknown reasons are stated when individuals were not found, but there were clear signs indicating their death, for instance, the finding of the metal or colour ring, and the transmitter signal was never detected again. Important information was also provided by local ornithologists, who helped confirm the poaching and weather-related causes of death.

To test whether there were differences between long- and short-dispersers (see below) in various individual characteristics regarding their PFDP and established TSAs, we used the Mann-Whitney U-test (Statistica Inc., USA).

This study was carried out in accordance with the relevant permits (based on the decisions of the Ministry of the Environment, No. 664/297/05-5.1 and No. 3320/20196.3), which allow an exception from prohibited activities under several sections of Act No. 543/2002 Coll. on Nature and Landscape Protection.

Results

A total of ten out of twelve young saker falcons (five males and seven females) were observed from leaving the nest until signal loss (very probably in connection with their deaths), which occurred during dispersal within six months after reaching independence. One individual reached adulthood, and another was captured in the wild for falconry in Libya. The monitoring took place from June 1 to November 15, 2021, and from May 27, 2023, to June 24, 2025 (Table 1 and S1). The individuals were monitored for 133 days (median value is stated hereinafter), and 72,044 locations were recorded per bird. The total length of their movement routes was 5,162 km (Fig. 2 and S2). The young saker falcons spent 110 days in a state of rest (non-movement) and 25 days in a state of movement, with an average speed of 9 km/h, as indicated by automatic satellite data analysis in BaseCamp software (Table 1 and S1).

The PFDP of all twelve young birds lasted 47 days, during which 14,521 locations were recorded (Table 1 and S1). The distance of individuals from the nesting boxes during the entire PFDP was 2.4 km, with a maximum recorded distance of 8.8 km. The PFDP home range area, calculated using the 100% MCP method, was 81 km² (Fig. 3 and S3), 45 km² (95% MCP), and 23 km² (80% MCP). All the young birds became independent between July 15 and 26, 2021, and between July 8 and 15, 2023 (Table 1 and S1).

Subsequent dispersal movements occurred in nine fledglings in a very similar manner: individuals suddenly left their PFDP home ranges and began to move significantly away from them, usually every day (Fig. 1 and S1). For example, the female G1 reached 301 km from the nest during the first day of dispersal, 642 km on the second day, and then started to turn back on the third (Fig. 4).

A total of 10 of the 12 monitored individuals set up at least one TSA during their dispersal (Figs. 5 – 10 and S4). Young saker falcons inhabited TSAs (n = 21 areas, Table 2 and S2) for 28 days. Their locations within the TSAs were 93 km from the nest boxes (minimum and maximum distances were 1.7 and 1,428 km). The movement routes of individuals within the TSAs totalled 1097 km. The TSAs of the ten individuals covered 981 km², 629 km², and 278 km² (100%, 95%, and 80% MCP), respectively.

We recorded three basic patterns of dispersal movements/behaviours by the 12 monitored individuals after they reached independence. Six individuals (G1 and G2 – Fig. 1, and B1, B2, L1, and T1 – Fig. S1) started their natal dispersal immediately or within a few days after reaching independence over a long distance (usually more than 500 km from their nests). One individual (L2 – Fig. S1) continued to establish a TSA within its natal area after the end of the PFDP. After that, it dispersed over a long distance. The last five individuals (J1, J2, S1, and S2 – Fig. 1, and T2 – Fig. S1) also started their natal dispersal immediately or within a few days after reaching independence, but only over a short distance (less than 100 km from their nests). These individuals also began to establish TSAs, between which they moved some distance, but they never dispersed over a long distance and remained in relative proximity (up to 200 km) to their natal areas for their entire lives.

The long-dispersers (7 individuals) and short-dispersers (5 individuals) did not differ in their PFDP home range size according to 80% or 100% MCP or mean and maximal distance from the nest during the PFDP (Mann-Whitney U-test, $Z = -0.32 – 1.30$, $p = 0.19 – 0.75$); however, the long-dispersers tended to have shorter PFDP (Mann-Whitney U-test, $Z = -1.64$, $p = 0.10$). There was no difference in duration and range size according to 80% or 100% MCP of the TSAs established by the long-dispersers (4 areas; mean values were taken for individuals with multiple TSAs) and short-dispersers (6 areas) (Mann-Whitney U-test, $Z = 0.11 – 1.39$, $p = 0.17 – 0.92$).

The only individual (J2) who survived to adulthood lived for approximately 2 years and 1.5 months. This female established two TSAs (Fig. 8), never dispersed over a long distance, and after 60 days of dispersal movements (ca. between day 260 and 320 of her life), she established a pre-breeding range, followed by a breeding range from August 13, 2024, to June 24, 2025 (Fig. 11). Her pre-breeding range occupied an area of 1261 km², and the breeding range 626 km² (100% MCP; Fig. 12, Table 3). She did not survive until the end of her first breeding attempt, as she was found dead 12 km from her nest due to an unknown reason.

We did not record any case of death during the PFDP; however, ten individuals died before reaching adulthood, and all perished during the dispersal period. Four individuals died due to medium- and high-voltage power line infrastructure (two were electrocuted, and two collided with power lines; Figs. 13 and 14). Two saker falcons were caught/killed by humans (the L1 individual

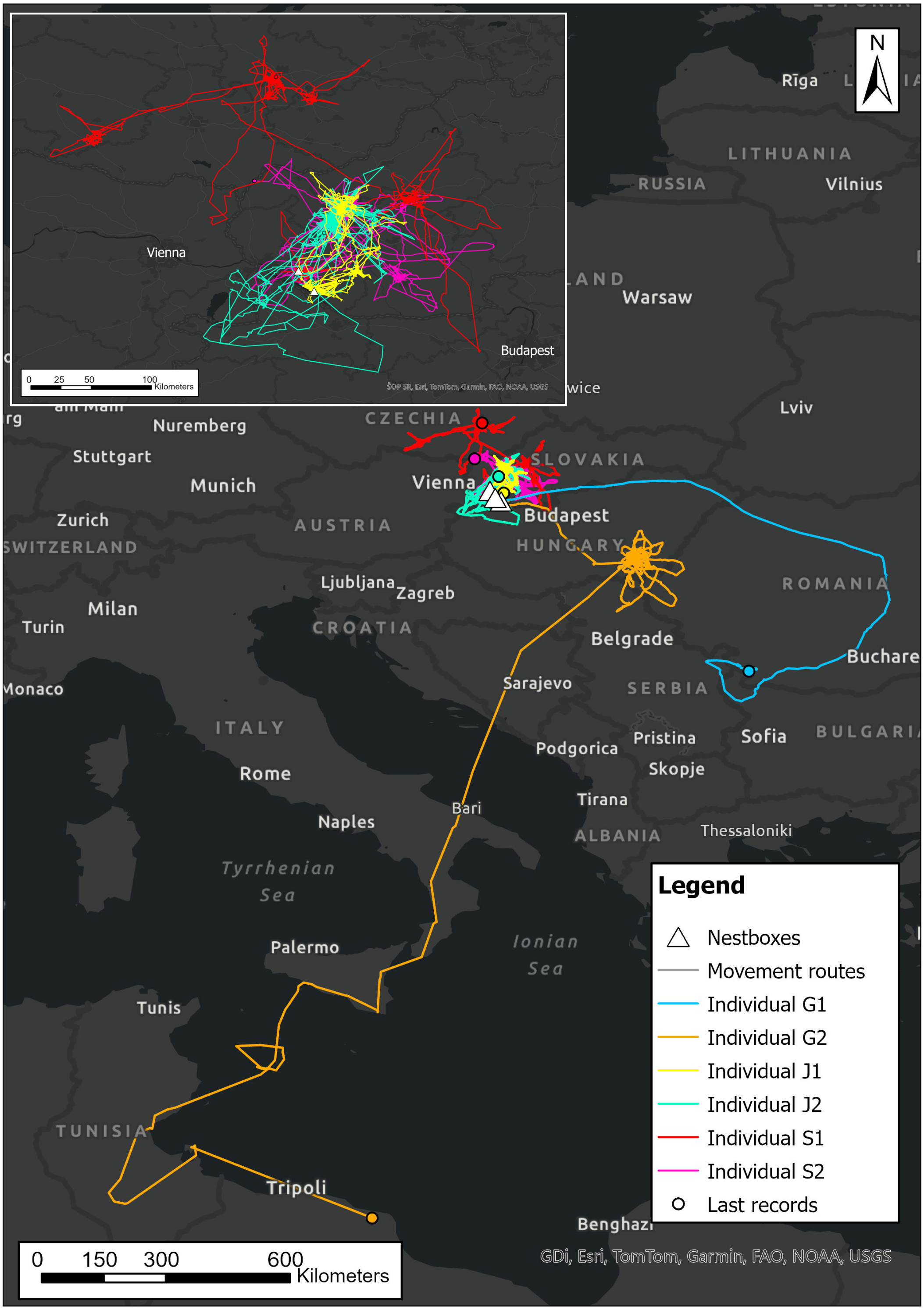

Fig. 2. Nesting boxes, overall movement routes, and the last-recorded locations of the six young saker falcons satellite-transmitter-tagged in 2023 and monitored by satellite telemetry.

Obr. 2. Hniezdne búdky, celkové trasy pohybu a miesta posledných záznamov šiestich mladých sokolov rárohov označených satelitnými vysielačmi v roku 2023 a monitorovaných satelitnou telemetriou.

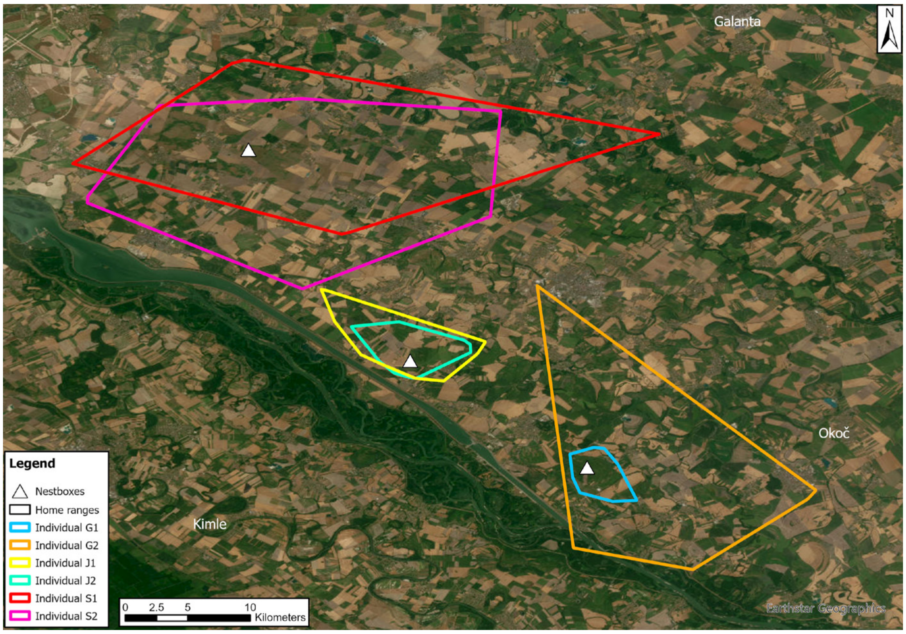

Fig. 3. Home ranges of the post-fledging dependence period recorded in the area of interest in Slovakia for six saker falcon fledglings from a total of three nests, calculated by the 100% MCP.
Obr. 3. Domovské okrsky počas obdobia dospievania zaznamenané v záujmovej oblasti na Slovensku pre šesť mláďat sokola rároha z celkovo troch hniezd, vypočítané metódou 100% MCP.

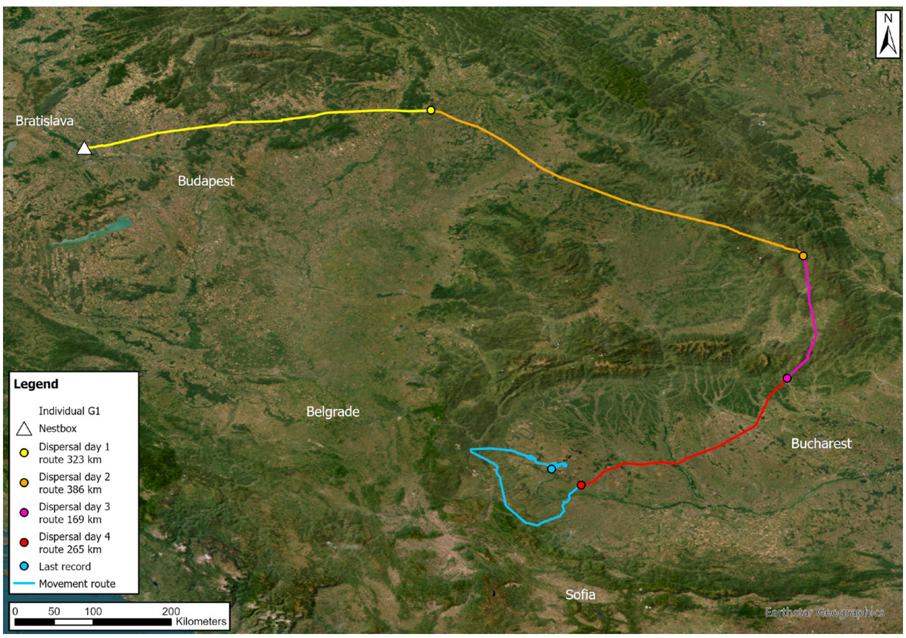

Fig. 4. The overall route of movement of the individual G1, including her position at the end of days one, two, three, and four from the start of the dispersal (points), including her last recorded position where she collided with power lines on day 51 after hatching, and day 10 of her natal dispersal phase.
Obr. 4. Celková trasa pohybu jedinca G1, vrátane jeho polohy na konci prvého, druhého, tretieho a štvrtého dňa od začiatku rozptylu (body), vrátane jeho poslednej polohy, kde narazil do elektrického vedenia na 51. deň po vyliahnutí, a 10. dňa jeho natálneho rozptylu.

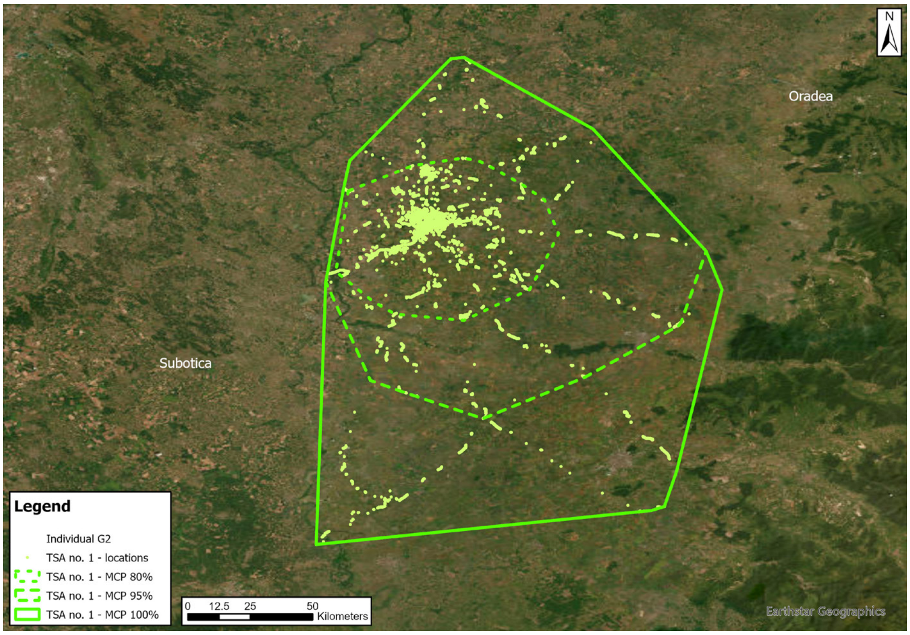

Fig. 5. Details of the first temporary settlement area (TSA; calculated by the 80%, 95%, and 100% MCP) during dispersal movements by the individual G2 across Hungary, Romania and Serbia, including individual locations of her stay within this area.
Obr. 5. Podrobnosti o prvom dočasne obývanom útočisku (vypočítanom metódou 80%, 95% a 100% MCP) vytvorenom počas rozptylu jedinca G2 naprieč Maďarskom, Rumunskom a Srbskom, vrátane jednotlivých miest jeho pobytu v tejto oblasti.

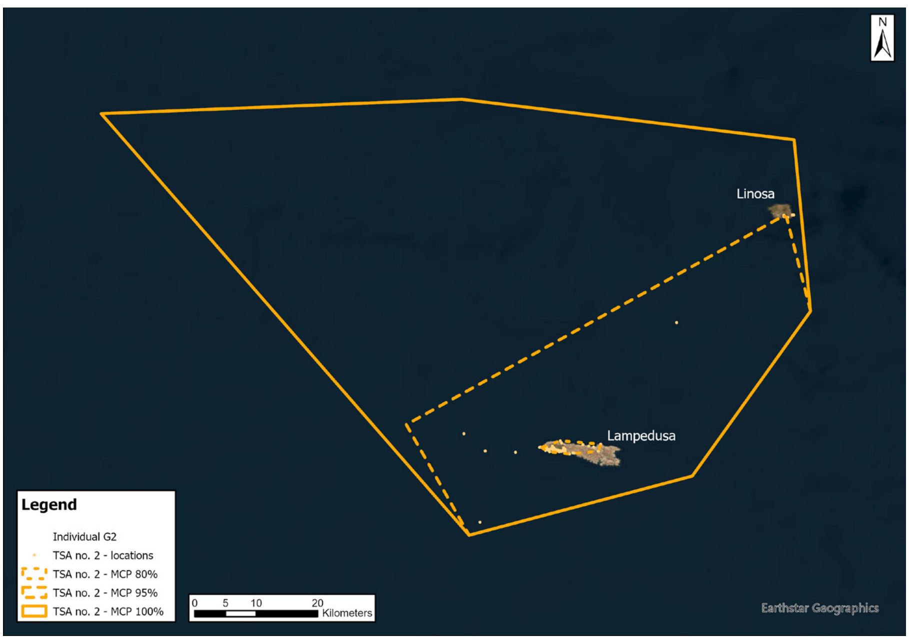

Fig. 6. Details of the second temporary settlement area (TSA; calculated by the 80%, 95%, and 100% MCP) established during dispersal movements by the individual G2 in Italy, on and around the islands of Lampedusa and Linosa, including individual locations of her stay within this area.
Obr. 6. Podrobnosti o druhom dočasne obývanom útočisku (vypočítanom metódou 80%, 95% a 100% MCP) vytvorenom počas rozptylu jedinca G2 v Taliansku, na ostrovoch Lampedusa a Linosa a v ich okolí, vrátane jednotlivých miest jeho pobytu v tejto oblasti.

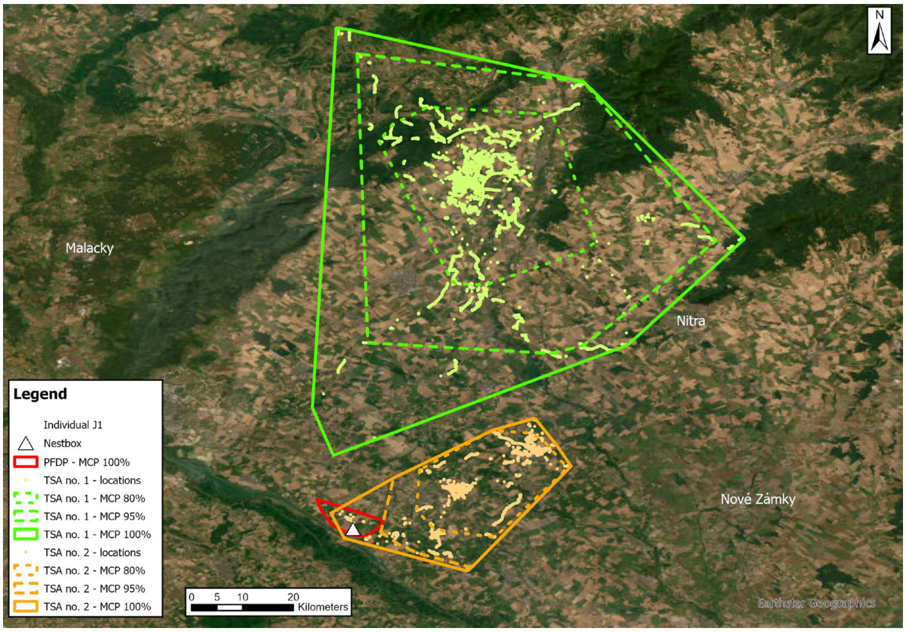

Fig. 7. Details of the two temporary settlement areas (TSA; calculated by the 80%, 95%, and 100% MCP) established during dispersal movements by the individual J1 in the relative vicinity of her natal area in Slovakia, and her post-fledging dependence period (PFDP) home range.

Obr. 7. Podrobnosti o dvoch dočasne obývaných útočiskách (vypočítaných metódou 80%, 95% a 100% MCP) vytvorených počas rozptylu jedinca J1 v relatívnej blízkosti miesta jeho vyliahnutia na Slovensku, a jeho domovského okrsku počas obdobia dospievania.

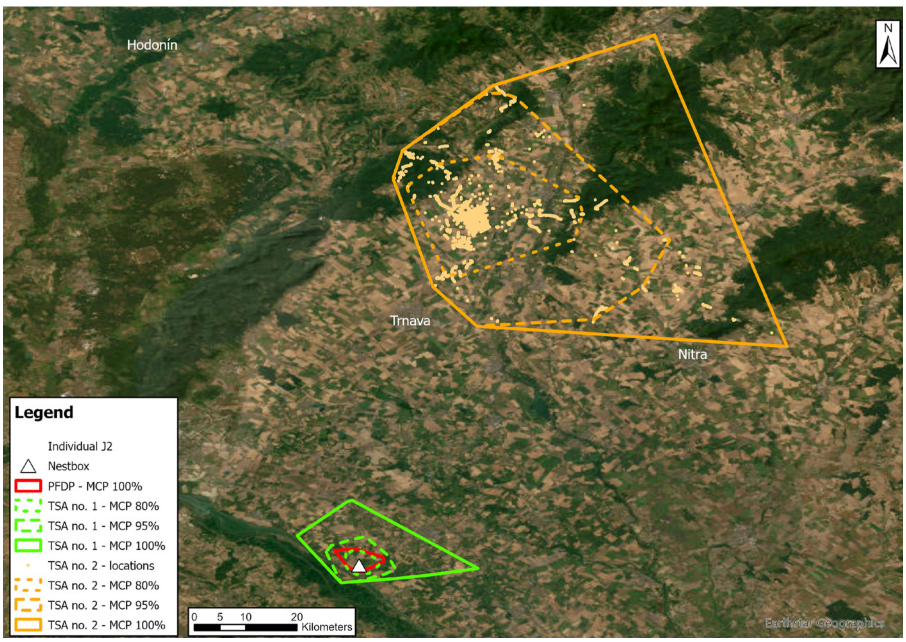

Fig. 8. Details of the two temporary settlement areas (TSA; calculated by the 80%, 95%, and 100% MCP) established during dispersal movements by the individual J2 in the relative vicinity of her natal area in Slovakia, and her post-fledging dependence (PFDP) period home range.

Obr. 8. Podrobnosti o dvoch dočasne obývaných útočiskách (vypočítaných metódou 80%, 95% a 100% MCP), ktoré vytvoril jedinec J2 počas rozptylu v relatívnej blízkosti miesta jeho vyliahnutia na Slovensku, a jeho domovského okrsku počas obdobia dospievania.

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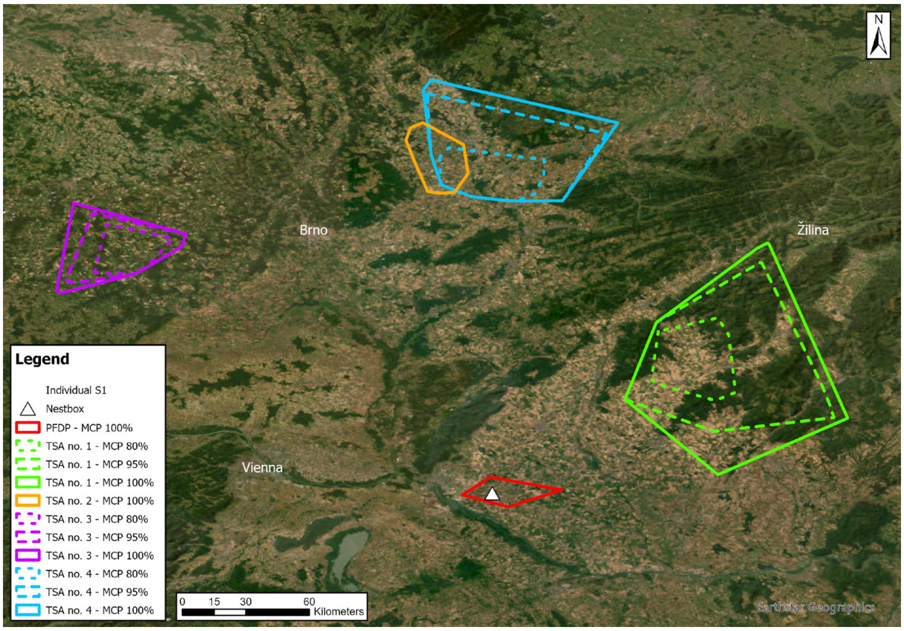

Fig. 9. Details of the four temporary settlement areas (TSA; calculated by the 80%, 95%, and 100% MCP) established during dispersal movements by the individual S1 in the wider area of her natal site in Slovakia, including her post-fledging dependence period (PFDP) home range.
Obr. 9. Podrobnosti o štyroch dočasne obývaných útočiskách (vypočítané metódou 80%, 95% a 100% MCP), ktoré vytvoril jedinec S1 počas rozptylu v širšej oblasti miesta jeho vyliahnutia na Slovensku, vrátane jeho domovského okrsku počas obdobia dospievania.

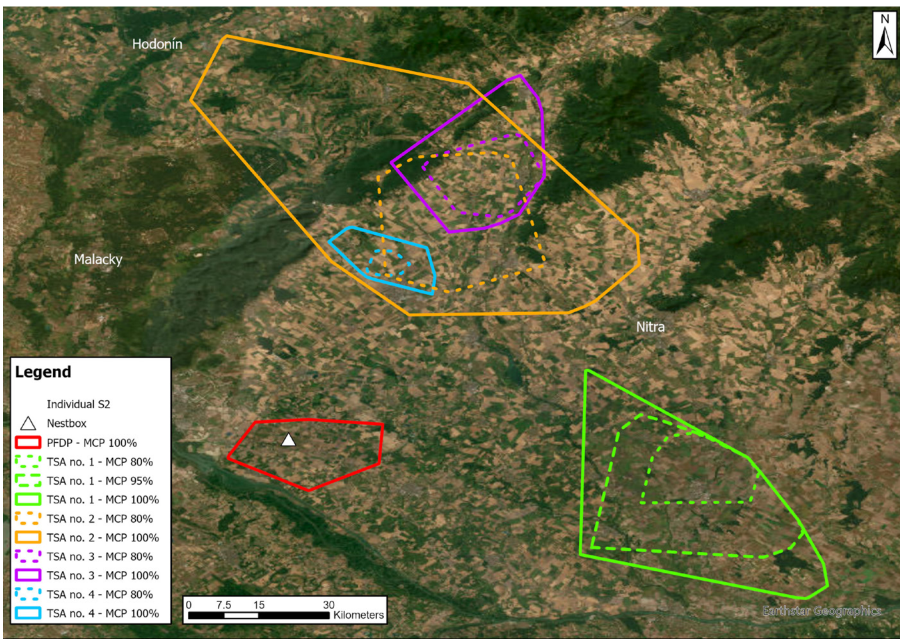

Fig. 10. Details of the four temporary settlement areas (TSA; calculated by the 80%, 95%, and 100% MCP) established during dispersal movements by the individual S2 in the wider area of his natal site in Slovakia, including his post-fledging dependence period (PFDP) home range.
Obr. 10. Podrobnosti o štyroch dočasne obývaných útočiskách (vypočítané metódou 80%, 95% a 100% MCP), ktoré vytvoril jedinec S2 počas rozptylu v širšej oblasti miesta jeho vyliahnutia na Slovensku, vrátane jeho domovského okrsku počas obdobia dospievania.

Tab. 2. Data on a total of fourteen temporary settlement areas established during dispersal movements by five young saker falcons (G2, J1, J2, S1, and S2) satellite-transmitter-tagged in 2023. Details on seven more temporary settlement areas established by five other saker falcons satellite-transmitter-tagged in 2021 were published by Kouba et al. (2021) and are also provided in Table S2.

Tab. 2. Údaje o celkovo štrnástich dočasne obývaných útočiskách vytvorených počas rozptylových pohybov piatimi mladými sokolmi rárohmi (G2, J1, J2, S1 a S2) označenými satelitným vysielačom v roku 2023. Podrobnosti o siedmich ďalších dočasne obývaných útočiskách vytvorených piatimi ďalšími sokolmi rárohmi označenými satelitným vysielačom v roku 2021 publikovali Kouba et al. (2021) a sú uvedené aj v tabuľke S2.

Evaluated characteristics	**Individual data**														**Mean ± SD**[a]	**Min - Max**[a]	**Median**[a]
ID of tracked individual[b]	G2		J1		J2		S1				S2						
Temporary settlement area – "TSA"	1	2	1	2	1	2	1	2	3	4	1	2	3	4		-	
Date of TSA establishment	13 July 2023	16 Nov. 2023	14 Aug. 2023	15 Sep. 2023	16 July 2023	11 Aug. 2023	18 July 2023	13 Aug. 2023	25 Aug. 2023	6 Sep. 2023	14 July 2023	24 July 2023	11 Sep. 2023	8 Oct. 2023		-	
Duration of TSA (days)	116	19	28	50	25	181	23	11	7	35	9	35	15	81	42 ± 40	7 - 181	28
No. of locations/fixes during TSA	64772	194	40540	11661	16116	23179	20597	8037	4799	10928	17565	28261	6324	601	18452 ± 5144	194 - 64772	16116
Length of TSA movement route (km)	5036	446	1815	1152	722	2431	1223	547	431	1097	686	1457	704	536	1278 ± 1015	431 - 5036	1097
Distance of TSA from the nest[c] (mean ± SD; km)	270 ± 22.2	1428 ± 15.7	68 ± 11.5	20 ± 8.1	1.7 ± 1.5	70 ± 6.1	93 ± 14.7	158 ± 8.3	160 ± 7.5	151 ± 14.4	59 ± 7.0	53 ± 6.8	63 ± 7.5	40 ± 1.6	368 ± 8.2	1.7 - 1428	93
Minimal distance of TSA from the nest[d] (km)	230	1378	15	1	0	49	61	142	151	138	45	32	50	36	349 ± 482	0 - 1378	61
Maximal distance of TSA from the nest[e] (km)	384	1451	98	32	16	110	146	176	189	196	84	86	84	46	395 ± 482	16 - 1451	146
Home range size of TSA (100% MCP[f]; km^2)	16404	4220	2993	498	199	2007	4360	427	981	2320	1010	2255	449	123	2047 ± 3448	120 - 16404	981
Home range size of TSA (95% MCP[f]; km^2)	10016	1329	2039	424	53	1053	3177	411	729	1912	629	1115	435	81	1307 ± 2096	53 - 10016	629
Home range size of TSA (80% MCP[f]; km^2)	2988	12	689	278	15	357	771	339	372	623	193	556	200	24	486 ± 638	12.88	278
Date of TSA termination	5 Nov. 2023	4 Dec. 2023	10 Sep. 2023	3 Nov. 2023	9 Aug. 2023	7 Feb. 2024	9 Aug. 2023	23 Aug. 2023	31 Aug. 2023	10 Oct. 2023	22 July 2023	27 Aug. 2023	25 Sep. 2023	27 Dec. 2023		-	
Cause of TSA termination[g]	aband.	aband.	aband.	signal loss	aband.	aband.	aband.	aband.	aband.	death	aband.	aband.	aband.	aband.		-	

[a]The descriptive statistics are based on 21 TSAs established by 10 individuals satellite-transmitter-tagged in 2021 and 2023, thus including also data published by Kouba et al. (2021).
[b]Two monitored individuals, specifically L1 and G1, did not establish any TSA, including data published by Kouba et al. (2021).
[c]Mean distance of locations/fixes from the nest recorded for a given individual during the time of TSA duration.
[d]Minimal distance from the nest recorded for a given individual during the time of TSA duration.
[e]Maximal distance from the nest recorded for a given individual during the time of TSA duration.
[f]Minimum convex polygon (100%, 95%, 80% MCP).
[g]Abandoned.

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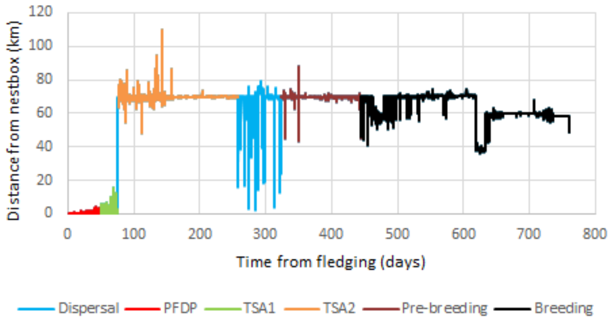

Fig. 11. Visualisation of the gradual distance from the natal nest of the individual J2 during the entire monitoring period. The post-fledging dependence period (PFDP; red line), two phases of temporary settlement area (TSA; 1 – green, 2 – orange line) occupied during her dispersion (blue line), and her pre-breeding (brown line) and breeding (black line) home range periods are depicted.

Obr. 11. Vizualizácia postupujúcej vzdialenosti od hniezda jedinca J2 počas celého sledovaného obdobia. Zobrazené je obdobie dospievania (PFDP; červená čiara), dve fázy dočasne osídlených útočísk (TSA; 1 – zelená, 2 – oranžová čiara) obsadených počas jeho disperzie (modrá čiara) a obdobia jeho domovského okrsku pred hniezdením (hnedá čiara) a počas hniezdenia (čierna čiara).

was killed by poachers, and the G2 individual was taken for falconry, Table 1 and S1). Next individual most likely died in connection with bad weather (see details in Kouba et al. 2021), and another individual disappeared (signal loss). The cause of death for the last four individuals could not be determined because they were found in an advanced stage of decay (classified as unknown; Table 1 and S1).

Discussion

The current study doubled the information on the post-fledging dependency period, dispersal movements, temporary settlement areas, and mortality rates, as well as their causes, in young saker falcons from Slovakia, compared to the previous study by Kouba et al. (2021). The merged data on the six past individuals (Kouba et al. 2021), together with those on the current six more saker falcons, emphasised a fundamental issue: the high level of mortality during the dispersal period. Only one individual joined the breeding population, and most juveniles died due to human-caused mortality.

Interestingly, no deaths were recorded during the PFDP, although mortality rates are usually very high across different bird species during this phase (e.g., Adams et al. 2001; Keedwell 2003; Sunde 2005; Boileau & Bretagnolle 2014; Kouba et al. 2024). Our findings thus align well with those from Ukraine, Bulgaria, and Mongolia, where nearly all young saker falcons also survived throughout the PFDP (Prommer et al. 2014; Rahman et al. 2015; Dixon et al. 2019). These results might be well explained by the fact that the saker falcon is a quite large species, whose fledglings fall prey to other predators only rarely compared to other smaller bird of prey species (Obuch & Bangjord 2016).

In contrast, ten young saker falcons died during their dispersal movements, which, however, is in line with findings from many other studies, indicating that the mortality of young, independent birds is also very common (Small et al. 1993; Prommer et al. 2012; Faccio et al. 2013).

Tab. 3. Data on pre-breeding and breeding home range of adult female saker falcon (J2).
Tab. 3. Údaje o predhniezdnom a hniezdnom domovskom okrsku dospelej samice sokola rároha (J2).

ID of tracked individual	J2			
Home range – HR	pre-breeding		breeding	
Nest-box/nest event[a]	hatching	breeding	hatching	breeding
Date of HR establishment	14 April 2024		13 August 2024	
Duration of HR (days)	121		316	
No. of locations/fixes during HR	33988		39765	
Length of HR movement route (km)	1646		3693	
Distance of HR from the nest[b] (mean ± SD; km)	69 ± 5.7	13 ± 4.2	60 ± 4.6	4.02 ± 3.96
Minimal distance of HR from the nest[c] (km)	44	2	37	0
Maximal distance of HR from the nest[d] (km)	88	35	75	27
Home range size (100% MCP[e]; km²)	1261		626	
Home range size (95% MCP[e]; km²)	882		259	
Home range size (80% MCP[e]; km²)	40		112	
Date of HR termination	12 August 2024		24 June 2025	
Cause of HR termination	abandoned		death	

[a]Information linked to the original nest (hatching) from which the individual fledged, and the nesting box (breeding) where the individual started to breed in 2025.
[b]Mean distance of locations/fixes from the nest recorded for a given individual during the time of HR duration.
[c]Minimal distance from the nest recorded for a given individual during the time of HR duration.
[d]Maximal distance from the nest recorded for a given individual during the time of HR duration.
[e]Minimum convex polygon (100%, 95%, 80% MCP).

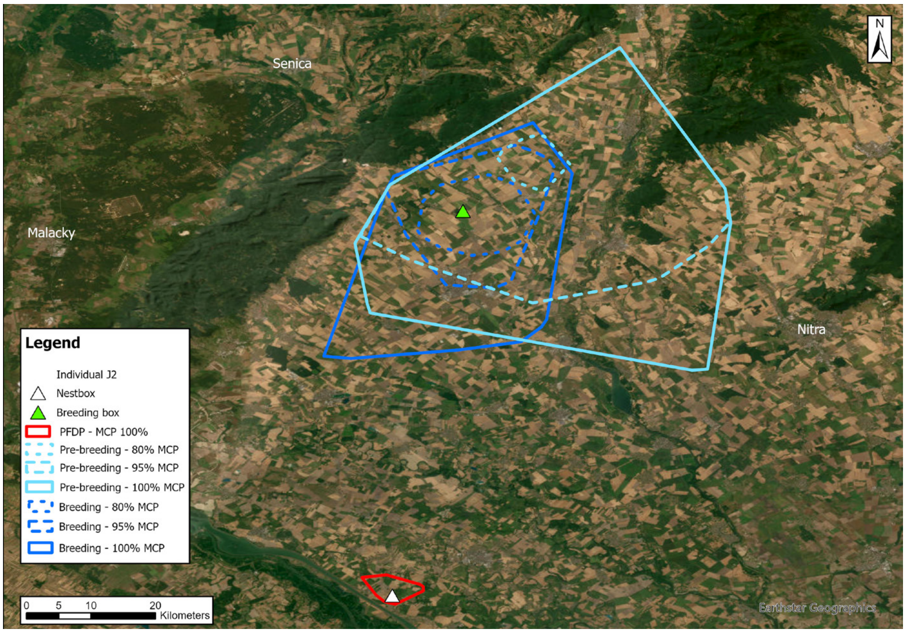

Fig. 12. Details of the pre-breeding and breeding home ranges (calculated by the 80%, 95%, and 100% MCP) established after the natal dispersal by the individual J2 in the relative vicinity of her natal area in Slovakia, including her post-fledging dependence period (PFDP) home range.

Obr. 12. Podrobnosti o domovských okrskoch pred hniezdením a počas hniezdenia (vypočítané metódou 80%, 95% a 100% MCP), ktoré jedinec J2 osídlil po ukončení natálneho rozptylu v relatívnej blízkosti miesta jeho vyliahnutia na Slovensku, vrátane jeho domovského okrsku počas obdobia dospievania.

Similarly, our results regarding survival rate during natal dispersal align well with those of previous studies on the target species. Up to 100% mortality has been reported by other researchers in young saker falcons from Austria, Bulgaria, Slovakia, and Ukraine (Gamauf & Dosedel 2012; Nemček et al. 2014a; Prommer et al. 2014; Dixon et al. 2019). As we have suggested previously (Kouba et al. 2021), the main reason is that young saker falcons usually disperse over vast distances, during which they may encounter a wide range of potential dangers. Very worrying is that electric lines and pylons are a major cause of death among young saker falcons during this period (e.g., Nemček et al. 2014a; Dixon et al. 2019). This also confirmed our study, in which at least one-third of individuals died due to wire collision or electrocution, aligning with previous studies that have shown overhead power line infrastructure significantly affects the target species population dynamics (e.g., Kovács et al. 2014; Demeter et al. 2018; Gális et al. 2019; Dixon et al. 2020; Chavko et al. 2025).

There were, moreover, five cases of "unknown" and "signal loss" death causes recorded. Though speculative, some of them could also relate to the power line infrastructure. Alternatively, at least some of these individuals could have been poisoned, as it is still widely reported in birds of prey worldwide, including our study area in Slovakia (e.g., Brochet et al. 2016; 2019; Veselovský et al. 2024). If we add one young saker falcon shot by hunters and another one removed from the wild by trappers due to falconry purposes, what is relatively common and considered a limiting factor for the target species' survival in the Middle East (Houdková 2004; Cepák et al. 2008), there is only one individual left, which died for natural reasons, specifically harsh weather (tornado/waterspout). Of course, we admit that in the mortality of the five individuals with uncertain cause of death, natural causes, such as starvation and/or disease, could also be involved. Alternatively, tagging could have adverse effects, leading to decreased survival and, in turn, a very low recruitment rate. Tagged saker falcons may be more susceptible to predation [e.g., by northern goshawks (*Astur gentilis*)] or harassment by other birds, such as corvids or conspecifics (Zink et al. 2025). In this regard, we may speculate that the low juvenile survival recorded in our study may also partly be a consequence of backpack tagging (Geen et al. 2019) because the

Fig. 13. A saker falcon (*Falco cherrug*) female (individual S1) found dead (due to a power line collision) in 2023 in the middle of an agricultural field close to conductors of a high-voltage power line in the Czech Republic (author: Ondřej Boháč).
Obr. 13. Samica sokola rároha (*Falco cherrug*, jedinec S1) nájdená uhynutá (v dôsledku kolízie s elektrickým vedením) v roku 2023 uprostred poľnohospodárskeho poľa v blízkosti vedenia vysokého napätia v Českej republike (autor: Ondřej Boháč).

Fig. 14. Detailed picture of the saker falcon (*Falco cherrug*) female (individual S1) found dead in 2023 under conductors of high-voltage power line in an agricultural field in the Czech Republic after picking her up and inspecting her (author: Ondřej Boháč).
Obr. 14. Detailný obrázok samice sokola rároha (*Falco cherrug*, jedinec S1) nájdená uhynutá v roku 2023 pod vedením vysokého napätia v poľnohospodárskej krajine v Českej republike po jej objavení a prezretí (autor: Ondřej Boháč).

finding that only one monitored saker falcon survived to adulthood contrasts with the increasing population trend in south-western Slovakia (Chavko et al. 2025). However, it is concerning that most death causes are undoubtedly linked to people and human activities, regardless of whether intentional or accidental.

Though we doubled our sample size compared to the study by Kouba et al. (2021), the mean PFDP duration remained the same, specifically just under seven weeks, which is comparable to findings from Ukraine and Mongolia, where the saker falcon post-fledging phase took approximately six weeks (Prommer et al. 2014; Rahman et al. 2015). It appears that the life history of the saker falcon, particularly in terms of PFDP duration, prevails over specific environmental conditions within ecologically distinct study areas. Although it remains unclear whether and how prey abundance affects the PFDP duration in saker falcons, as it has been described as crucial in other birds of prey (Alonso et al. 1987; Bustamante 1994; Kouba et al. 2013). We encourage researchers to focus on this aspect in their further studies on the target species.

The mean PFDP home range size, based on data from six individuals, was 67 km² (Kouba et al. 2021). If analysed together with six more, the mean PFDP home range increased to 91 km². This is roughly double the size of 55 km² recorded in Mongolia (Rahman et al. 2015). However, the authors of this study evaluated home ranges only for the first 28 days of the PFDP. We believe this is most probably causing the recorded difference between the two studies, along with differences in prey abundance and the much higher breeding density of saker falcons in Mongolia. Although not specifically evaluated, the saker falcons in our study increased their distance from the nest and occupied larger home ranges with increasing age, as documented also in other birds of prey (Belthoff et al. 1993; Penteriani et al. 2005; Stehlíková Sovadinová et al. 2024). As with the PFDP duration, the specific environmentally distinct study areas do not significantly influence the PFDP home range size of the target species.

Within the two study years, we have recorded two very distinct dispersal patterns. The first group of seven individuals (G1, G2, B1, B2, L1, L2, and T1) made dispersal movements over distances of at least several hundred kilometres. The second group of five young saker falcons (J1, J2, S1, S2, and T2) dispersed, as a rule, over distances of tens of kilometres only. In 2021, five of the six individuals underwent long-distance dispersal, and in 2023, four of the six fledglings undertook short-distance dispersal; however, this pattern was not linked to sex (females to males, 4:3, 3:2, respectively) or date of hatching, which was very similar within both years. It appears that the only important factor was the nest of origin, as, with one exception, the siblings exhibited the same dispersal pattern (i.e., five out of six monitored twins). However, it is worth noting that in five study nests there were more than two siblings, and we have no information on the dispersal patterns of the non-monitored ones, a situation similar to that described by Nemček et al. (2014b) in their study on imperial eagles (*Aquila heliaca*). Distinguishing the heritable versus environmental basis of dispersal behaviour is another interesting topic that warrants further research and careful examination.

Closely linked to the two above-described dispersal patterns are the temporary settlement areas that we have recorded during our study. In a previous study (Kouba et al. 2021), we excluded individual T2 completely and L2 from the evaluation of the TSAs' descriptive statistics. The first one because it remained relatively close to its natal area until death as the only monitored individual in 2021; the second one because it did not disperse at the end of the PFDP, and its subsequent TSA partly overlapped its PFDP home range. However, after evaluating data from birds tagged in 2023, we realised that this behaviour is quite common, and one TSA was retrospectively detected also in the T2 individual (Fig. S4). Overall, our results regarding TSAs are consistent with those of previous studies in various species of birds of prey. TSAs are established during dispersal movements, occupied for a period, covering a relatively small area (in which the individual occurs repeatedly in the same places), and are suddenly left, after which the birds continue their dispersal movements (e.g., Meyburg et al. 1995; Sielicki et al. 2009; Literák et al. 2020).

The characteristics of TSAs did not differ between long- and short-dispersers, suggesting that specific environmental/ecological conditions within the distinct regions where monitored individuals established their TSAs were not decisive in determining their duration of use or size. It seems, from our observations, that TSAs might be established almost anywhere, regardless of the distance from the natal area (1.7 to 1,428 km). We recorded TSAs following PFDP home ranges, and three of them even partially overlapped with this range. The more distant ones were found in various environments, ranging from near large cities to sparsely populated areas, including islands in the Mediterranean Sea. Their duration, 41 days on average, was comparable to 27 days found in the study by Dixon et al. (2019). Our data revealed the shortest use of TSAs of 7 and 9 days. Even in these shortest cases of the TSAs, it was already easily possible to distinguish settlement behaviour from mere dispersal movements. More importantly, the question of why TSAs are established remains unanswered. Most likely, young saker falcons establish and occupy TSAs due to high prey abundance in the areas, which they use for some time, or until the prey is depleted (Dixon et al. 2017, 2020). It can also be connected to the transition from exploratory strategies, when animals have incomplete environmental information, to a more familiar way of exploiting the occupied areas as they become more familiar with the environment (Delgado et al. 2009). As with the aforementioned topics, this one also deserves more scientific attention, particularly because we found that TSA sizes may differ significantly.

Only one monitored saker falcon female reached adulthood and joined the breeding population in south-western Slovakia. Specifically, she raised offspring to late nestling age in a box 60 km distant from her natal nest; however, she did not finish the breeding season and was found dead 12 km from her nesting box. Her partner, after that, successfully fledged two chicks. The cause of her death remained unknown because her carcass was found in an advanced state of decay. However, she was found close to a high-voltage power line, so we can speculate that she collided with this man-made obstacle. Interesting in her case was the establishment of the pre-breeding home range, which bordered the subsequent breeding site (considering 80% MCP ranges; Fig. 12), already almost one year before nesting. This likely marks the end of her natal dispersal phase and her settling down in the area/population for future reproduction. Her subsequent establishment of the breeding home range at the end of summer 2024 matches exactly the time when saker falcons are described to form pairs for the future breeding season in the coming spring (Glutz von Blotzheim et al. 1971; Šťastný & Hudec 2005).

Finally, we would like to reiterate our appeal (Kouba et al. 2021) to the relevant authorities and all those responsible for installing and managing power line infrastructure to make every effort to secure their electricity grids worldwide, ensuring that no organisms are harmed as a result. As our study and many others suggest, mortality (and injuries) as a result of electricity structures, posing a risk of collision or electrocution is enormous, affecting millions of birds worldwide each year (Jenkins et al. 2010), which is utterly unsustainable in the long term and, it is necessary to introduce measures that will reverse this very pessimistic trend as soon as possible (e.g., Šmídt et al. 2019). Moreover, our data suggest that other sources of mortality are also human-induced, which is extremely alarming and threatens the biodiversity and population viability of free-ranging organisms across different taxa worldwide.

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