

Influence of prey availability on the movement pattern of breeding saker falcons (*Falco cherrug*) in Mongolia

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Abstract

As an apex predator in arid steppe, saker falcon plays a crucial role in maintaining ecosystem balance. Understanding their movement patterns concerning conspecific competition and prey availability is important for their conservation. We aim to understand how movement pattern of breeding saker falcons relates to prey availability. Twelve adult sakers were tracked during the breeding seasons, using satellite transmitters. Throughout the breeding season, sakers exhibited territorial behavior, with minimal overlap in range use among neighboring conspecifics. Males occupied larger areas (mean = 2,397 ha, median = 1,221 ha), compared to females (mean = 1,241 ha, median = 554 ha), and it remained consistent throughout breeding season. Female home range size increased notably during a late nestling stage and post-fledging dependence periods, indicating release from brooding constraints. Notably, we found a negative relationship between male home range size and prey availability. In high rodent density areas, males occupied smaller areas (mean = 1,135 ha, median = 1,034 ha), contrasting with low rodent density areas (mean = 6,815 ha, median = 6,516 ha). However, no significant relationship was observed between female home range size and prey availability. We also noted instances of nest abandonment and early dispersal behavior in some females, potentially influenced by a handicapping effect of tagging. Our findings offer valuable insight into how prey availability shapes saker falcon space use and defines their spatial requirements for successful breeding. This knowledge is crucial for the conservation and management of globally endangered saker falcons, informing targeted habitat protection and resource management strategies.

Key words: birds of prey, distance from the nest, home range, prey availability, territory, tagging effect.

Studying the movement patterns of animals is essential for understanding animal ecology and supporting conservation initiatives (Moorcroft and Barnett 2008; Therrien et al. 2014). Analyzing movement patterns helps to assess variations in individual space use (Börger et al. 2006; Baert et al. 2021) and responses to factors like competition and prey availability (Marzluff et al. 2004; Sirén et al. 2021; Zhang et al. 2024). Birds of prey exhibit distinct movement patterns influenced significantly by prey availability (Kouba et al. 2013; Therrien et al. 2014; McCabe et al. 2018). During the breeding season, increased food demand for growing nestlings requires parents to increase their foraging efforts (Village 1982). Consequently, the foraging distance of parents may change (Sokolov et al. 2014; Ramellini et al. 2022). Assessing the travel distance of breeding birds from the nest is vital for determining space required for successful breeding, especially in territorial species. It also sheds light on factors influencing nesting dispersal among conspecifics and other species (Jenkins and Benn 1998; Rozsypalová et al. 2022).

The saker falcon (*Falco cherrug*) is classified as endangered due to a rapid global population decline over 3 generations at the turn of the 21st century (BirdLife International 2021). They do not build their nests and typically use large, stick nests built by other species (Orta et al. 2020), making nesting site availability a key limiting factor for breeding population density (Rahman et al. 2016). The placement of artificial nests in areas with limited natural nests is an important conservation technique for endangered raptorial species, and it may also play a role in biological rodent control (Meyrom et al. 2009; Paz et al. 2013). This study, conducted as part of an artificial nest project for saker falcon conservation in Mongolia (Dixon et al. 2011; Rahman et al. 2014), used satellite telemetry to monitor the movement of some breeding individuals. We measured the linear distances between saker GPS locations and their nests, along with examining the home range size during the breeding season. We aim to understand how these distances and home range size relate to prey availability. In addition, we seek to characterize the movement pattern

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of saker falcons concerning neighboring breeding birds. The anticipated outcome will provide valuable insights into how prey availability shapes the saker's movement patterns and the spatial requirements for successful breeding, making a significant contribution to the conservation and management of the globally endangered sakers.

Materials and Methods

Study area

The study was conducted in Bayan and Bayantsagaan Districts, Tuv Province of central Mongolia, where 150 artificial nests were constructed in 2006. These nests were placed at 1 km intervals within six spatially separated 4 × 4 km grids, covering approximately 830 km² of flat and undulating steppe terrain, with limited natural nesting sites suitable for saker falcons (Figure 1). In the 2009 study period, 16 nests were occupied by saker falcons, 25 nests were occupied by upland buzzards (*Buteo hemilasius*), 82 nests were occupied by common kestrels (*Falco tinnunculus*), and 9 nests were occupied by common ravens (*Corvus corax*). In 2010, 16 nests were occupied by saker falcons, 27 nests were occupied by upland buzzards, 64 nests were occupied by common kestrels, and 10 nests were occupied by common ravens.

Tag deployment

In 2009 and 2010, we captured a total of 12 adult sakers (5 males and 7 females, including 2 breeding pairs) from 10 different nests during the early nestling (EN) stage of the breeding season using a hand-held net (Table 1). Sex determination was based on biometric measurements, specifically the length of the wing chord. We classified birds with a wing chord of 385 mm or more as females and those with a wing chord of less than 385 mm as males (Dixon et al. 2020). Each captured bird was equipped with a solar-powered Argos/GPS PTT (platform transmitter terminal) transmitter, weighing 22 g, produced by Microwave Telemetry Inc. (MD, USA). The backpack transmitters were securely fastened using an 8 mm wide Teflon-coated tubular ribbon harness (Bally Ribbon Mills, PA, USA). The combined weight of the transmitter and harness accounted for approximately 1.7–2.8% of adult body weight [males: 885–1,015 g; females: 1,185–1,470 g; see Dixon et al. (2016)]. The PTTs were programmed to receive up to 10 GPS fixes per day at 2-h intervals, starting from 04:00 to 22:00 local time, throughout the study period. However, it is worth noting that all four PTTs fitted to birds in 2010 failed shortly after deployment, likely due to prolonged storage in darkness before deployment as communicated by P. Howey from the manufacturer. The GPS fixes obtained were recorded with

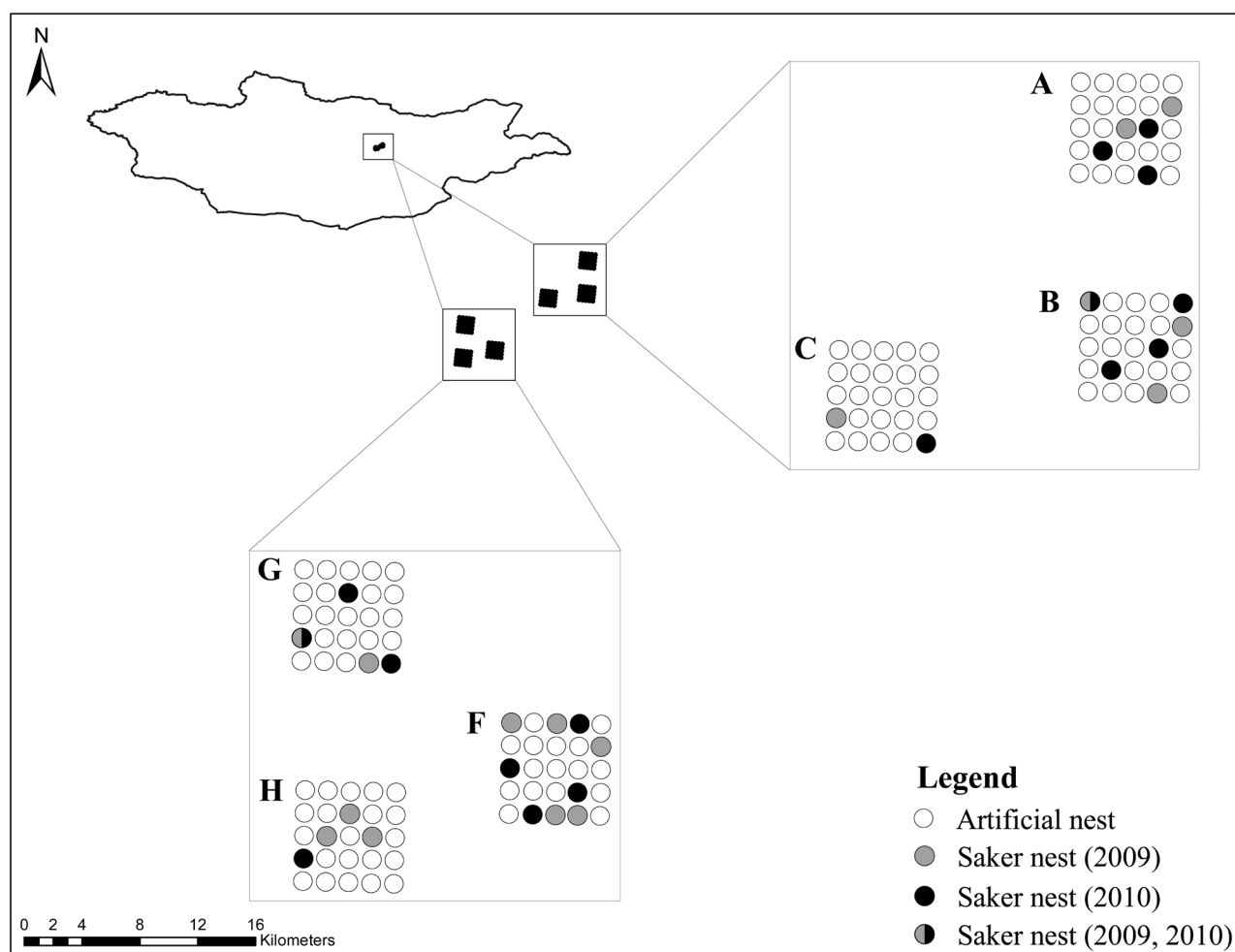


Figure 1. Spatial distribution of saker nests during the study period in 2009 and 2010. A, B, C, F, G, and H are the artificial nest grid ID. Grids D and E are not shown where nest boxes are not installed.

Table 1. GPS transmitter data obtained from saker falcons tracked in different artificial nest grids in Mongolia.

Bird ID	Sex	Grid and nest ID	Date deployed	Date transmission stopped	No. of days tracked	No. of locations	Status
885	♂	F20	03 May 2009	30 August 2009	118	655	Unknown
886	♂	G4	07 May 2009	22 November 2010	563	2,057	Alive (PTT failure)
889	♀	B22	03 May 2009	15 July 2009	73	184	Unknown
890	♀	A13/A09	12 May 2009	23 July 2010	436	1,618	Unknown
891	♂	F15	29 April 2009	18 January 2010	263	1,408	Unknown
892	♀	F20	29 April 2009	09 January 2010	254	834	Alive (Trapped)
893	♀	C04	05 May 2009	28 February 2010	298	1,301	Alive (PTT failure)
894	♀	G4	13 May 2009	10 November 2009	180	677	Alive (Trapped)
121	♀	B18	27 May 2010	12 July 2010	46	56	Alive (PTT failure)
122	♀	B01	25 May 2010	04 July 2010	40	13	Alive (PTT failure)
123	♂	C25	30 May 2010	26 June 2010	27	54	Alive (PTT failure)
124	♂	B09	25 May 2010	19 June 2010	25	148	Alive (PTT failure)

Note: Birds 885 & 892, and 886 & 894 are breeding pairs. Bird 890 nested at A13 in 2009 and A09 in 2010, respectively.

Coordinated Universal Time (UTC) stamps, and we categorized each fix as either night or day based on the local UTC sunrise and sunset times (UTC + 8 h). The fixes recorded during the daytime were used to calculate the distance from the nest and home range size.

Distance from the nest and home range size

We monitored artificial nests throughout the breeding season from early April to mid-July 2009–2010. Each occupied nest was checked at approximately 10-day intervals to record nest contents and track the growth development of chicks. Using a photographic chart illustrating 14 growth development stages for captive-bred saker falcon chicks at 3-day intervals from 1 to 42 days old, we established a chronological record for each nest. In instances where direct observation of laying dates and hatching dates were not possible, it was estimated by back-dating from the chick age (Rahman et al. 2014). This method relied on growth development of chicks, assuming eggs were laid on alternate days and the incubation period lasted for 35 days from the penultimate egg. Based on the chronological record, we divided the breeding season into 4 stages, namely incubation (IN), EN, late nestling (LN), and post-fledging dependence period (PFDP). The incubation stage spans from the first egg-laying date until the entire clutch hatched, lasting ca. 39 days for a modal clutch size of 4 eggs. The EN stage covers the first 20 days after hatching, while the subsequent 24 days constitute the LN stage. The PFDP refers to the 40 days following fledging, as described by Rahman et al. (2014).

Firstly, all the location points were transformed into UTM coordinates, using the “PBSmapping” package in R 4.3.1 (Schnute et al. 2015; R Core Team. 2021). Subsequently, we measured the linear distance of locations from the nest during different breeding stages using the “fossil” package in R (4.3.1) (Vavrek 2011). We also estimated the 95% Minimum Convex Polygon to describe the overall home range size in different breeding stages using the “adehabitatHR” and “SP” packages in R (4.3.1) (Pebesma and Bivand 2005; Calenge 2006; Bivand et al. 2013). Then, we compared the distance from the nest and home range size across different stages of the breeding season. To effectively depict the changes in distance from the nest and home range size throughout different stages of the breeding season, we utilized the relative value for each bird. This relative value was

calculated by dividing the distance from the nest (or home range size) during each breeding stage by the overall distance from the nest (or home range size) used by the same bird throughout the entire breeding period.

In circumstances where the nearest conspecific neighbor was also tracked via telemetry, we explored the extent of overlap in home ranges between breeding birds. To assess the extent of potential territorial interaction, we examined the sequential location points of each individual, especially when their locations overlapped with those of other birds. Whenever such overlaps occurred, we carefully examined associated timestamps. The “rgeos” package in R (4.3.1) (Bivand and Rundel 2023) was employed to estimate range overlap, defined as the proportion of territory shared by sakers in different stages of the breeding season.

Rodent density in the artificial nest grids

To estimate the rodent density within the artificial nest grids, we divided each 4 × 4 km grid into 4,600 cells measuring 50 × 50 m. We randomly selected cells for rodent trapping and transect surveys. From April to July 2009, we placed 36 baited small mammal traps at 10 m intervals across 152 randomly selected cells in the 6 grids, rechecking the traps over 24 h. These trapping data were later used to validate more extensive grid transect data (See Figure 5). During the breeding season in 2009 and 2010, we counted active rodent holes along six transect strips measuring 50 × 5 m in 606 randomly selected cells. The active holes were identified by the presence of footprints, wear, tracks, and droppings near their entrance. To analyze saker falcon movements in relation to rodent availability in the nesting grids, we classified 2 blocks of grids (i.e., A, B, C and F, G, H) as having either a high or low rodent density relative to one another in each year.

Statistical analysis

The Wilcoxon rank test (Zar 1999) was used to examine the difference in both the distance from the nest and the home range size between male and female saker falcons. Similarly, this test was applied to compare rodent hole count data between different years and grids, respectively. To examine potential differences in both distance from the nest and home range size across different breeding stages and in areas with

different rodent densities, we employed separate generalized linear mixed models (Bolker et al. 2009) for male and female sakers. The models were fitted using the glmer function from the lme4 package in R (4.3.1) (Bates et al. 2015). Distance from the nest and home range size served as the response variables, utilizing the Gamma distribution and log link functions except for female distance from the nest. Gaussian distribution was used for female distance from the nest as data were normally distributed. Breeding stages and grid rodent density category were treated as fixed variables. Additionally, bird ID and artificial nest grids were included as random variables to account for potential variation among individual birds and different grids. The model encountered convergence and singularity issues for the female distance from the nest and home range size, likely due to the small sample size, leading to overfitting. Since simplifying the model structure did not alter the results, adjustments were not made to the model structure.

Three birds (PTT121, PTT122, and PTT890) were excluded from the analysis because they deserted their nests during the breeding season.

For visualization, figures were generated using the ggplot2 package in R (4.3.1) (Wickham 2016). In addition, mapping procedures were carried out using ArcMap 10.0. The threshold for statistical significance was set at $P < 0.05$.

Results

Territoriality

In the artificial nest grids, breeding saker falcons exhibited strong territorial behavior. Even when neighboring birds

nested just 1 km apart, each pair occupied an exclusive area, resulting in minimal overlap throughout the nestling stages and PFDP. Only a few GPS locations of the two neighboring birds were recorded very close to each other. However, we did not find any temporal overlap on those location points (Figure 2). The overlapping home range area of two neighboring males amounted to 14.4 ha during the LN stage, increasing to 78.7 ha during the PFDP, representing a maximum of 5.8% and 7.1% of their respective home ranges. However, this intra-specific separation was not reflected in inter-specific segregation, as the home range of saker falcons overlapped with the nesting sites of other species nesting in the same grid, that is, common kestrel, upland buzzard, and common raven (Figure 2).

We tracked two breeding pairs in our artificial nest grids. Throughout the nestling stages and PFDP, both members of each pair shared the same spatial area, as shown in Figure 3. The female's smaller range entirely overlapped with the male's range (99.8%), while 44.7% of the male range overlapped with the female's.

Movement patterns at different stages of the breeding season

Throughout the entire breeding season, male sakers maintained a longer median distance from the nest compared to females (median: 1.3 km vs 0.6 km, Wilcoxon Rank Test: $W = 25$, $P = 0.002$; Table 2). However, the distance from the nest exhibited variations across different breeding stages for both sexes. Notably, the female distance increased significantly during the PFDP (GLMM: estimate = 0.7, SE (Standard

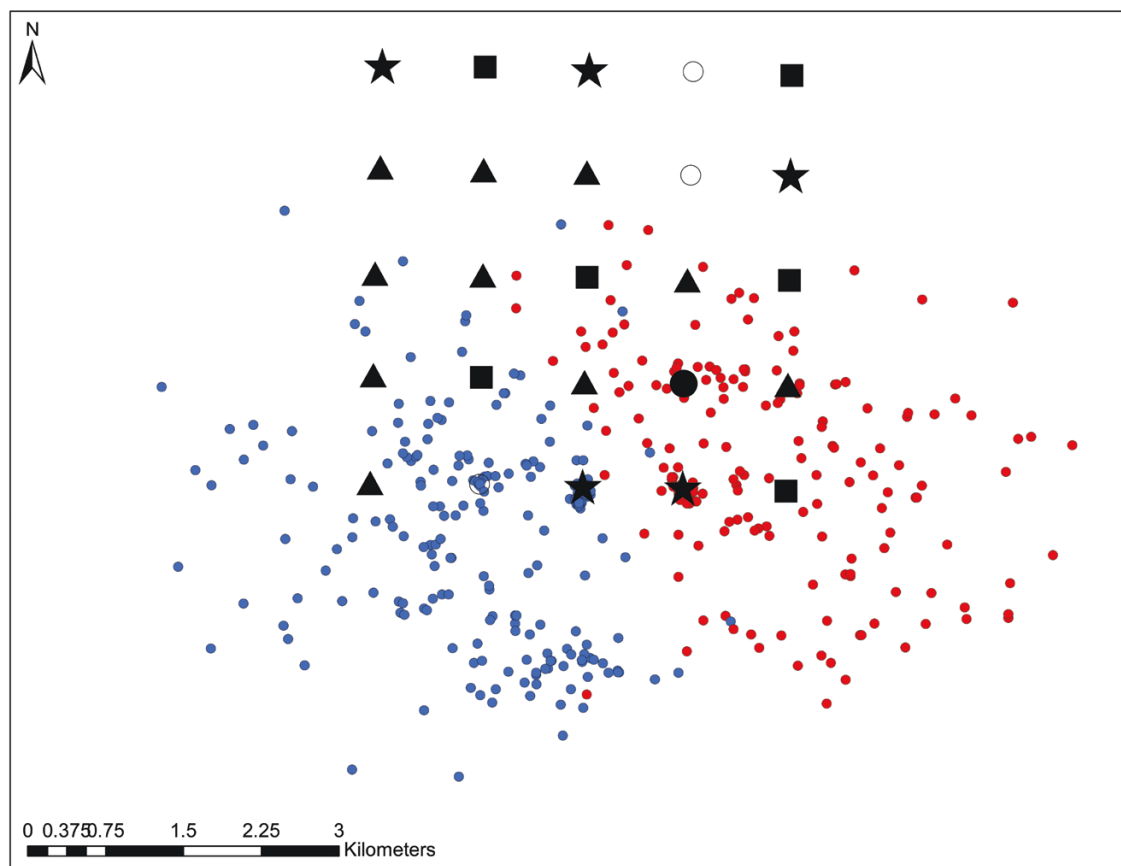


Figure 2. Locations of neighboring saker falcons in grid F in 2009. Black circle—common raven nest, star—saker falcon nest, square—upland buzzard nest, triangle—common kestrel nest, open circle—unoccupied artificial nest. Red—PTT885 (male) in F20 nest, blue—PTT891 (male) in F15 nest.

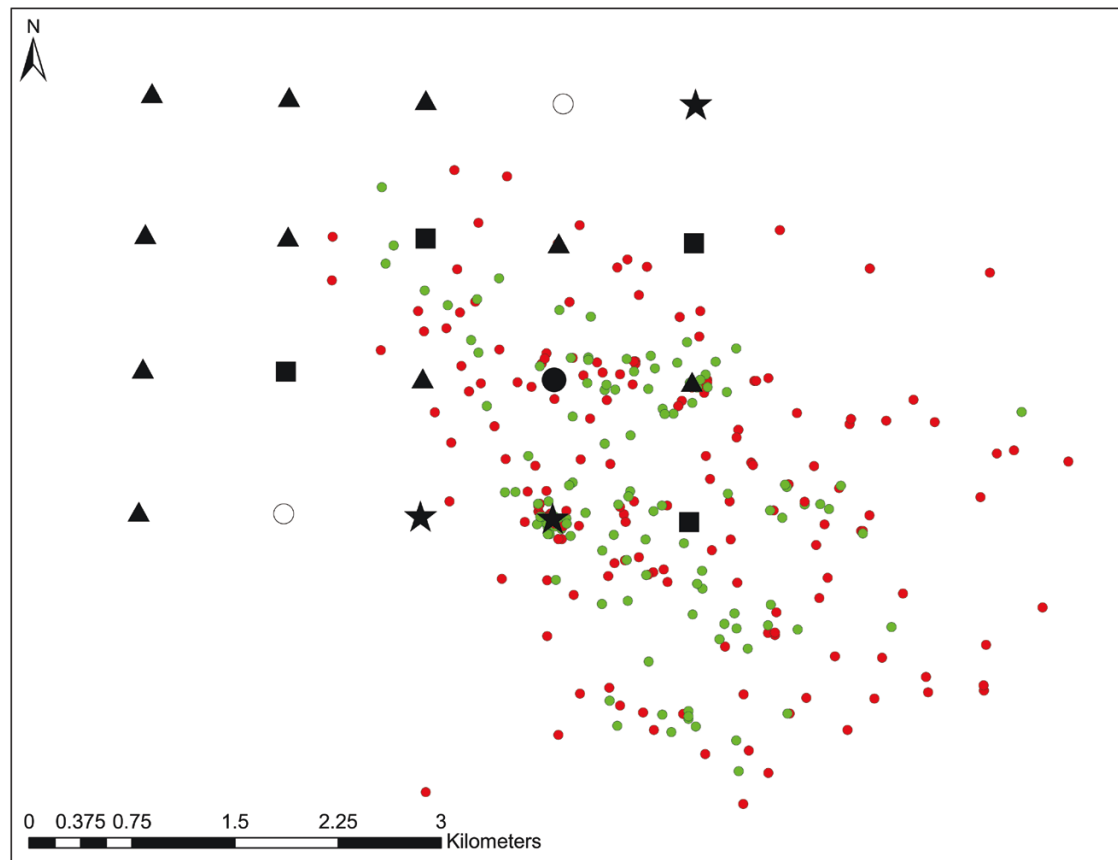


Figure 3. Locations of breeding pairs in grid F in 2009. Black circle—common raven nest, star—saker falcon nest, square—upland buzzard nest, triangle—common kestrel nest, open circle—unoccupied artificial nest. Red—PTT885 (male), green—PTT892 (female).

Error) = 0.1, $t = 7.2$, $P < 0.001$; Table 3, Figure 4A). In comparison to females, the male distance showed less variation throughout the breeding season. Nonetheless, males tended to move relatively further from their nests during the incubation stage (estimate = 0.7, $SE = 0.2$, $t = 3.3$, $P = 0.001$) and PFDP (estimate = 0.7, $SE = 0.1$, $t = 4.4$, $P = 0.001$; Table 3, Figure 4A).

In addition to the distance from the nest, we also examined the home range size. During the whole breeding season, males occupied larger areas compared to females (median: 1221 ha vs 554 ha, Wilcoxon Rank Test: $W = 45$, $P = 0.03$; Table 2). As the breeding season progressed, the female home range size notably expanded. Particularly, during the LN stage (GLMM: estimate = 3.9 ± 0.9 , $t = 4.2$, $P < 0.001$) and the PFDP (estimate = 3.5 ± 0.8 , $t = 4.3$, $P < 0.001$; Table 3, Figure 4B) the female home range sizes were significantly larger than that during the EN stage. In contrast, the male home range size increased gradually as the breeding season progressed, ultimately reaching its peak during the PFDP, where it was notably larger than that during the EN stage (estimate = 0.4 ± 0.2 , $t = 2.6$, $P = 0.008$; Table 3, Figure 4B).

Movement patterns and prey availability

We identified a significant positive correlation between the average number of rodent holes and the average number of trapped rodents ($r_{(4)} = 0.97$, $P = 0.001$; Figure 5). There were spatial variations in rodent density among the grids, with the block of grids A, B, and C exhibiting low median densities of 1.4 holes/cell (range: 0.4–7.9 holes/cell, $n = 18$), while the

block of grids F, G, and H showed high median densities of 10.6 holes/cell (range: 2.8–19.9 holes/cell, $n = 18$; Wilcoxon Rank Test: $W = 301$, $P < 0.001$; Figure 6) relative to one another in each year. We thus categorized A, B, and C grids as low rodent density and F, G, and H grids as high rodent density for analyses of saker falcon movement and home range. Furthermore, there were temporal variations in rodent density, with a lower density observed across all grids in 2010 (median: 2.7 holes/cell, range: 0.4–12.4 holes/cell, $n = 18$) compared to 2009 (median: 8.6 holes/cell, range: 1.4–19.9 holes/cell, $n = 18$; Wilcoxon Rank Test: $W = 261$, $P = 0.002$; Figure 6).

There was a negative relationship between the male distance from the nest and rodent density (GLMM: estimate = 1.4, $SE = 0.4$, $t = 3.6$, $P < 0.001$; Table 3, Figure 7A). In grids where the rodent density was low, male sakers traveled further from their nests, with a median of 4.3 km (range: 2.4–6.1 km, $n = 2$), in contrast to a median of 1.1 km (range: 0.8–3.1 km, $n = 3$) from nests in grids with high rodent density. However, there was no significant relationship between female movement distance from the nest and rodent density (estimate = -0.4 , $SE = 0.5$, $t = -0.7$, $P = 0.4$; Table 3, Figure 7A).

As for home range size, we found a negative relationship between male home range size and rodent density (GLMM: estimate = 1.9 ± 0.3 , $t = 5.3$, $P < 0.001$; Table 3, Figure 7B). In grids where rodent densities were low, male saker falcons had notably larger home ranges, covering a median of 6,516 ha (range: 4,538–9,692 ha, $n = 2$). Whereas, in grids with high

Table 2. Distance from the nest (km) and home range size (ha) at grids with different prey availability by breeding stages.

Sex	Breeding stages	Low food availability					High food availability				
		Median	Min	Max	No. of birds	No. of points	Median	Min	Max	No. of birds	No. of points
Distance from the nest											
Male	IN	–	–	–	–	–	2.06	1.02	3.1	1	112
Female	IN	–	–	–	–	–	–	–	–	–	–
Male	EN	4.26	2.43	6.1	2	31	0.9	0.78	1.04	3	150
Female	EN	0.2	0.2	0.2	1	23	0.62	0.62	0.62	1	18
Male	LN	4.31	3.07	5.5	2	135	1.06	0.83	1.23	3	282
Female	LN	0.45	0.22	0.69	2	175	0.55	0.42	0.68	2	129
Male	PFDP	–	–	–	–	–	1.8	1.4	2.5	3	559
Female	PFDP	0.93	0.54	1.33	2	186	1.29	1.2	1.39	2	202
Male	Overall	4.31	2.4	6.1	2	166	1.13	0.78	3.1	3	1,103
Female	Overall	0.54	0.2	1.33	2	384	0.68	0.42	1.39	2	349
Home range size											
Male	IN	–	–	–	–	–	991	584	1397	1	112
Female	IN	–	–	–	–	–	–	–	–	–	–
Male	EN	6,209	4,538	7,880	2	31	940	629	1,042	3	150
Female	EN	5.3	5.3	5.3	1	23	46	46	46	1	18
Male	LN	7,422	5,152	9,692	2	135	943	619	2,210	3	282
Female	LN	3,580	963	6,197	2	175	460	384	5,36	2	129
Male	PFDP	–	–	–	–	–	1,379	1,100	1,782	3	559
Female	PFDP	1,224	236	2,213	2	186	914	573	1,256	2	202
Male	Overall	6,516	4,538	9,692	2	166	1,034	584	2,210	3	1,103
Female	Overall	963	5.3	6,197	2	384	536	46	1,256	2	349

Note: IN, incubation stage; EN, early nestling stage; LN, late nestling stage; PFDP, post-fledging dependence period.

rodent densities, males utilized a median area of 1,034 ha (range: 584–2,210 ha, $n = 3$). In contrast, we did not find a significant relationship between female home range size and rodent densities (estimate 0.6 ± 0.7 , $t = 0.9$, $P = 0.3$; Table 3, Figure 7B).

Potential effects of tagging

A total of 12 birds were equipped with PTTs and tracked for a median duration of 149 days (range: 25–563 days). The number of recorded locations varied from 13 to 2,057 (Table 1). Only two birds with PTTs returned to breed in the next year, accounting for a 16.7% return rate. Six PTTs ceased transmission due to PTT failure, with 4 likely experiencing issues due to prolonged storage before deployment. Two birds were caught by falcon trappers, resulting in the removal of their PTTs. Additionally, two PTTs stopped transmitting for unknown reasons (Table 1).

Three female sakers abandoned their nests during the LN stage. A female (PTT121) deserted her nest with four chicks and did not return to its nest after 02 June 2010. However, she remained near the artificial nest grid (up to 6 km from its nest) until its PTT stopped transmitting on 12 July 2010. A second female (PTT122) also deserted her nest with four chicks at the beginning of the LN stage and moved southwest on 13 June 2010 and did not return to its nest. Three weeks later the PTT stopped working 69 km from the nest. A third female (PTT890), deployed with a satellite transmitter in the previous year, abandoned its nest with four chicks on 15 June 2010 and never returned. She moved from the nest site to a temporary settlement area in China and remained there

until 15 July 2010, after which the PPT stopped transmitting. During the breeding season, females that deserted their nests moved significantly greater distances from their nests compared to those that did not desert their nests (Wilcoxon Rank Test: $W = 10$, $P = 0.005$). The median distance from the nest for females that deserted their nest was 3.3 km, (range: 0.3–15.4, $n = 2$), whereas it was 0.6 km, (range: 0.2–1.4, $n = 4$) for females that did not abandon their nest.

In 2009, two female sakers exhibited early post-breeding dispersal behavior. Notably, one of these was a female that deserted its nest in 2010 (PTT890). This bird made a long excursion, moving from the nesting area during the PFDP on 23 July 2009 (30 days after five chicks had fledged from its nest), traveling up 270 km from its nest site, before subsequently returned to the nesting area on 05 August 2009. A second female (PTT894) left its nest area on 19 July (26 days after five chicks had fledged from its nest) and traveled approximately 300 km southwestward during the PFDP and stayed at a temporary settlement area for a month before returning to the nesting area, where she remained until 10 November 2009 when she was subsequently captured by falcon trappers. In both cases, we do not know how long the fledglings survived or, if they survived, when they dispersed from the natal area.

Discussion

Saker territoriality

Saker falcons breeding in our artificial nest grids exhibited exclusive territorial behavior among pairs with minimal

Table 3. Summary of generalized linear mixed effect models for the influence of fixed variables on distance from the nest and home range size.

Dependent variable	Variable	Estimate	SE	<i>t</i> -value	<i>P</i> -value	Variance
Female location distance from the nest	LN	−0.1	0.1	−0.9	0.3	
	PFDP	0.7	0.1	6.9	<0.001	
	Rodent (Low)	−0.7	0.5	−1.2	0.2	
	Grid					0.02
	Bird ID					0.06
	Residual					0.01
Male location distance from the nest	IN	0.7	0.2	3.3	0.001	
	LN	0.09	0.1	0.7	0.5	
	PFDP	0.7	0.1	4.4	<0.001	
	Rodent (Low)	1.4	0.4	3.6	<0.001	
	Grid					0.03
	Bird ID					0.001
Female home range size	LN	3.9	0.9	4.2	<0.001	
	PFDP	3.5	0.8	4.3	<0.001	
	Rodent (Low)	0.6	0.7	0.9	0.3	
	Grid					0
	Bird ID					0
	Residual					0.7
Male home range size	IN	−0.09	0.2	−0.4	0.7	
	LN	0.2	0.1	1.5	0.1	
	PFDP	0.4	0.2	2.6	0.008	
	Rodent (Low)	1.9	0.3	5.3	<0.001	
	Grid					0.03
	Bird ID					0.002
	Residual					0.08

Note: IN, incubation stage; LN, late nestling stage; PFDP, post-fledging dependence period. Significant values are highlighted in bold.

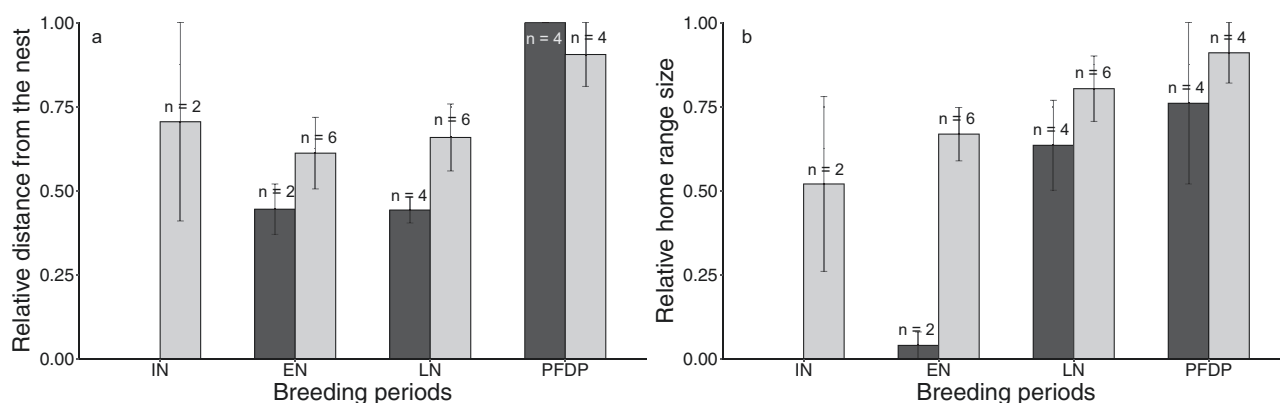


Figure 4. Relative distance from the nest (A) and relative home range size (B) in different breeding stages, based on data collected in both 2009 and 2010. Black—female, gray—male. IN, incubation; EN, early nestling stage; LN, late nestling stage; PFDP, post-fledging dependence period. Sample size (*n*) indicates the number of measurements taken across various breeding stages.

overlap between neighbors, even those nesting just 1 km apart did not share significant areas of their home ranges. Similar findings were reported in studies on the home range exclusivity of peregrine falcons, and Bonelli's eagles, where the ranging areas of neighboring birds showed only a small overlap, and the duration of these overlaps were relatively short (Jenkins and Benn 1998; Bosch et al. 2010). However,

the ranging area of sakers overlapped with the nesting sites of other species in the same grid, suggesting either limited interspecific territoriality among species or the dominance of sakers over neighboring species that were not excluded from their home ranges.

Throughout the nestling stages and PFDP, partners of the breeding pairs we tracked shared the same spatial area. This

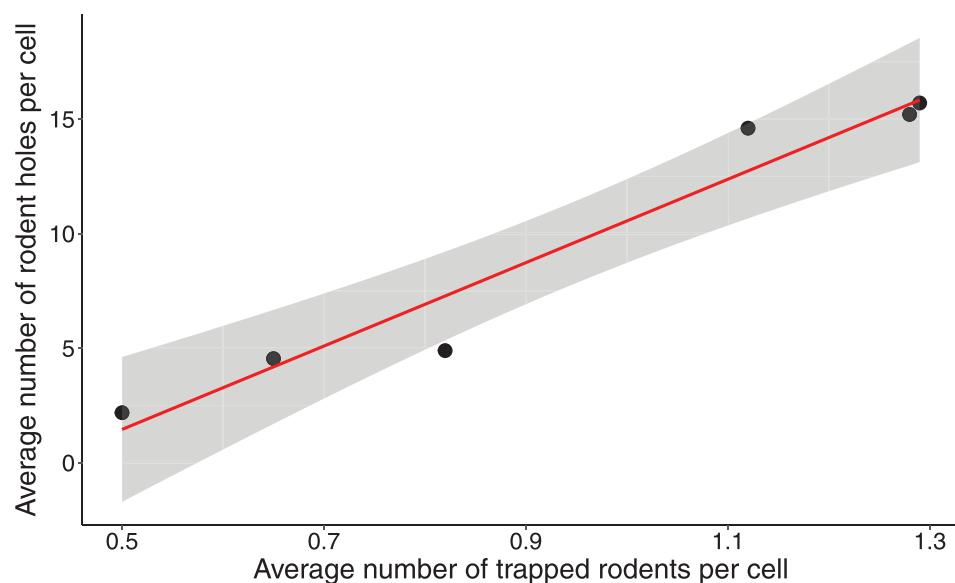


Figure 5. The relationship between the average number of rodent holes and the average number of trapped rodents in six artificial nest grids in 2009. The shaded area represents standard error.

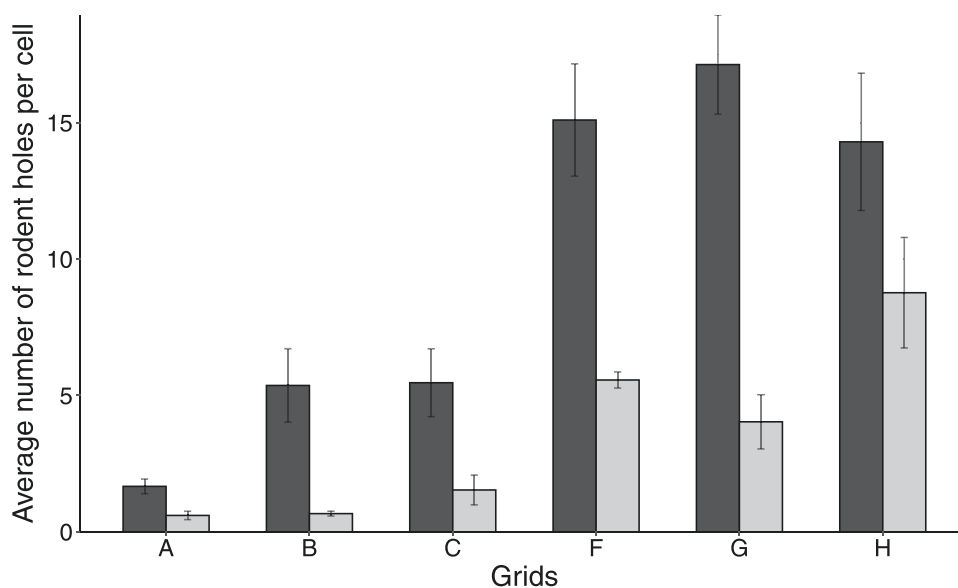


Figure 6. An average number of rodent holes in different grids in both 2009 and 2010. Black—2009, gray—2010.

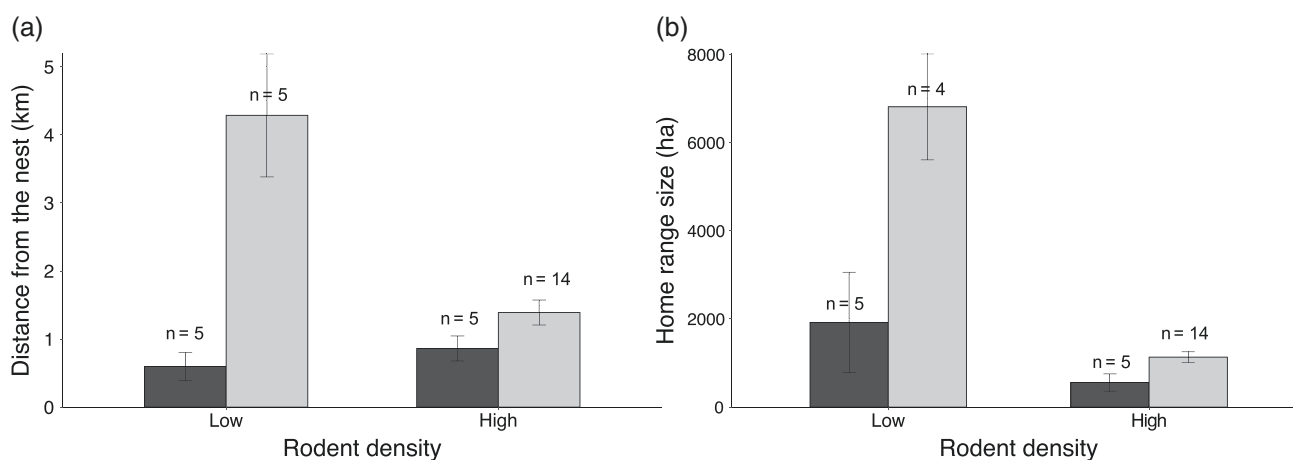


Figure 7. Average distance from the nest (A) and average home range size (B) in high and low rodent density areas in both 2009 and 2010. Black—female, gray—male. Sample size (n) indicates the number of measurements taken across different rodent density areas.

territorial overlap potentially facilitates close association and cooperative behavior between the female and male partners during the breeding season. A shared territory and close association may enhance communication and ensure efficient parental care, both critical factors influencing breeding success and offspring survival (Swenson 1993; Boal et al. 2003). However, it is essential to acknowledge that our study had a limited sample size, especially regarding tracked breeding pairs. Future research with a larger sample size and higher resolution for temporal associations would help validate our results.

Sex differences in saker movement patterns

In the artificial nest grids, male sakers tended to travel farther from their nests and have larger home ranges than females and this pattern remained relatively consistent throughout the breeding season. This difference in ranging behavior aligns with the distinct roles of female and male sakers in raising their nestlings. During the breeding season, males primarily focus on hunting and providing food for the young and the mate (Palmer et al. 2001; Dawson and Bortolotti 2002; Gustin et al. 2014), while females dedicate more time to brood the nestlings, especially in the EN stage (Cavé 1968; Collopy 1984; Wiehn et al. 2000). Bagyura et al. (2004) reported that during the breeding season, approximately 90% of the hunting was carried out by male sakers, while females were responsible for feeding the chicks in most cases except when they were not in the nest. We observed a notable increase in the distance from the nest and home range size of female sakers during the later stages of the breeding season compared to the EN stage. As the nestlings grow, they become more proficient at regulating their body temperature and feeding themselves with prey brought by their parents. The independence of nestling releases the females from the constraints of nestling care (Wiehn and Korpimäki 1997; Palmer et al. 2001; Brodin et al. 2003). Consequently, they can move farther from the nest to fulfill the increasing energy demands of their offspring, which increase with age (Olsen and Tucker 2003; Low et al. 2012).

Influence of prey availability on saker movement patterns

According to optimal foraging theory, animals try to spend less time and consume less energy to obtain the necessary energy for their everyday life (Pyke 1984). Our findings reveal a negative relationship between male distance from the nest, and home range size, in relation to rodent density. When the local rodent density is high around the nesting area, males tend to forage closer to their nests rather than seek prey farther away. This allows sakers to minimize energy expenditure while ensuring successful chick provisioning—a behavior documented in other species such as Tengmalm's owls (*Aegolius funereus*) (Kouba et al. 2013) and snowy owl (*Bubo scandiacus*) (Therrien et al. 2014). Thus, our finding indicates that breeding male sakers adapt their hunting strategy based on variations in prey availability within their nesting area. However, we did not find a significant relationship between the female distance from the nest, nor home range size, and rodent density in the nesting area. This discrepancy could result from the different roles of the sexes during the breeding season, as discussed earlier males predominantly engage in hunting while females are more involved in brooding (Sodhi 1993; Brodin et al. 2003).

Therefore, assessing rodent density in an area is important for the optimal placement of artificial nests, which can

potentially increase the breeding population size of birds of prey (Gottschalk et al. 2011; Rahman et al. 2014). However, in environments where rodent populations exhibit wide variations both temporally and spatially, occupancy rates of artificial nests may experience fluctuation (Valkama et al. 1995; McCabe et al. 2018).

Effects of tagging on saker behavior

The average transmission period of 149 days was consistent with the findings from Burnham and Newton (2011) where adult gyrfalcons with PTTs transmitted an average of 147 days. However, the annual breeding return rate for sakers equipped with PTTs was notably low at 17%. This low return rate may be attributed to the potential negative impacts of harness-mounted PTT deployment which can impact behavior and even the survival of birds (Steenhof et al. 2006; Dixon et al. 2016). Interestingly, we observed three instances of nest desertion and two cases of early dispersal behavior among the tagged sakers, and notably, these behaviors were exclusively exhibited by females. In instances of nest desertion, males reared the chicks to fledge on their own. The underlying reasons for nest desertion during the LN stage and early dispersal during the PFDP remain unclear. We speculate that these unusual behaviors we observed may be the consequence of the handicapping effect of tagging (Steenhof et al. 2006; Dixon et al. 2016) or they could be attributed to other unknown factors. Ellis et al. (2011) reported an apparent high incidence of unoccupied nests and inferred nest abandonment and nomadism may be a characteristic of Mongolian sakers. It is important to acknowledge that detecting nest desertion and early dispersal by only one sex is challenging without tagging (Eldegard and Sonerud 2009).

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Authors' Contributions

X.Z. and A.D. designed the study. A.D. and G.P. tagged the birds. A.S. collected the prey availability data. B.B. analyzed the data. L.R. helped to do analyses. B.B., A.D., and X.Z. wrote the manuscript.

Conflict of Interest statement

None declared.

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