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Home Ranges and Migration Routes of Four Threatened Raptors in Central Asia: Preliminary Results

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Simple Summary: Raptors (birds of prey) range over vast areas and are often migratory, undertaking long annual migrations from their breeding grounds to wintering grounds and back. Hence, for their long-term conservation, it is important to understand their spatial ecology in their breeding and non-breeding habitats. This study reveals the preliminary information based on the first ever satellite telemetry study on four species of raptors viz. Greater Spotted Eagle (*Clanga clanga*), Indian Spotted Eagle (*Clanga hastata*), Tawny Eagle (*Aquila rapax*), and Pallid Harrier (*Circus macrourus*). This pioneering work gives unique insight and unveils important information about four threatened species and their migration routes in Central Asia.

Abstract: Understanding the migratory route of raptors in their breeding and wintering grounds is crucial for ensuring their effective conservation. This study presents the preliminary findings through satellite telemetry to describe the summer and winter home ranges, movement ecology, activity, and migration routes of single individuals of Greater Spotted Eagle (*Clanga clanga*), Indian Spotted Eagle (*Clanga hastata*), Tawny Eagle (*Aquila rapax*), and Pallid Harrier (*Circus macrourus*). We calculated the home ranges as the minimum convex polygons (MCPs) and kernel utilisation distributions (KUD). Pallid Harrier had the smallest home range size of 4.29 km^2 (95% MCP) and 3.98 km^2 (95% KUD) in its breeding ground located in Russia, while the Greater Spotted Eagle had the largest home range size of 9331.71 km^2 (95% MCP) and 5991.15 km^2 (95% KUD) in Kazakhstan. The monthly and daily distances covered by tagged birds were significantly higher during migration. Our study also reports the first record of the winter and summer home range of the Indian Spotted Eagle in Pakistan. The tagged raptor used low elevation flyways than the straighter northern flyways over the Himalayan Mountain range, as found in another earlier study. Our study is the foremost satellite telemetry attempt from the region, highlighting important aspects of the migration route of migratory raptors to India.

Keywords: home range; migration; movement ecology; raptors; Gujarat; satellite telemetry

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1. Introduction

There are approximately 557 raptor species worldwide, out of which 18% are threatened by extinction, and 52% of the total raptor species have globally declining population trends [1]. Most of the threatened raptor species exist in south and southeast Asia, and the knowledge of their spatial ecology within their wintering grounds is essential to plan conservation strategies [2,3]. Studying raptor spatial ecology can provide new insights into the factors determining their home range size [4,5]. Raptor home ranges are determined, in part, by prey availability [6]; and Marquiss and Newton [6] assumed that raptor home ranges are dependent on food availability, and four predictions are generally made about the raptor's

home range size [5]. First, bird-eating raptors are expected to have large home ranges than mammal-eating raptors for given body size. Second, the raptors specialised in feeding on a narrow prey base are expected to have larger home ranges in order to encounter sufficient prey, whereas a generalist raptor is expected to find sufficient food within a small area [7]. Third, raptors consuming larger prey are expected to have relatively smaller home ranges and fourth, as in mammals, raptor home ranges increase with latitude [8] due to a decrease in primary productivity with latitude [9]. Thus, breeding-season home ranges are expected to decrease with latitude due to a decrease in primary productivity in summer at north latitudes [5]. The estimation of the home range size and identifying areas of concentrated use within home ranges is an important part of understanding the ecological factors that determine habitat use.

Substantial population declines in the long-distance migrant raptors breeding in Eurasia and wintering in Sub-Saharan Africa are well reported [10]. More than 50% of the migratory raptors are reported to be in poor conservation status in Africa and Eurasia, with many species showing rapid or long-term declines. However, migratory pathways between breeding and wintering grounds are largely unknown for most raptor species [11]. In Asia, a few studies have used satellite telemetry to investigate the spatial ecology and migration flyways of long-distance migrant birds [12–15]. The telemetry study of Oriental-Honey Buzzards (*Pernis ptilorhynchus*) has revealed that they use the East China sea during autumn, whereas spring migration mostly occurs over land [16]. Likewise, similar telemetry studies using a least-cost pathway analysis indicate that birds use the prominent islands as leading lines of migration in oceanic migration [17]. Recent telemetry studies of Chinese Sparrowhawks (*Accipiter soloensis*), and Japanese Sparrowhawks (*Accipiter gularis*) indicated that Chinese Sparrowhawks wintered across a 3000 km-wide longitudinal span and spent 84–173 days on their wintering grounds while the Japanese Sparrowhawks spent 168–173 days on their wintering grounds before migrating back to China [18].

In this study, we illustrate, for the first time in India, the winter and summer home ranges, seasonal movement and daytime activity rates, and migration routes of Greater Spotted Eagle *Clanga clanga*, Indian Spotted Eagle *Clanga hastata*, Tawny Eagle *Aquila rapax*, and Pallid Harrier *Circus macrourus* through satellite telemetry. Greater Spotted Eagle has a vast breeding range that extends from eastern Poland on the west to the Pacific Ocean on the east [19]. Its wintering grounds are known to be in southern Europe, the Middle East, and South Asia [19]. However, the information on its spatial ecology in the wintering grounds in the Indian subcontinent is very much lacking. Likewise, not much information is available on the spatial ecology of the Indian Spotted Eagle which breeds in the lowlands of India, Nepal, and Myanmar [20,21]. It occurs as a vagrant in Pakistan [22] and is extinct in Bangladesh [23]. Pallid Harrier breeds in the steppes of Asiatic Russia, Kazakhstan, and north-western China and winters in sub-Saharan Africa and the Indian subcontinent [24,25]. Though its movement and winter home ranges are well studied in Africa [25], the information in India is non-existent.

In this study, we provide new insights into breeding and non-breeding home ranges, activity rates, movement ecology, and the migration routes of single-tagged individuals, each of Greater Spotted Eagle, Indian Spotted Eagle, Tawny Eagle, and Pallid Harrier. The Greater Spotted Eagle, Indian Spotted Eagle, and Tawny Eagle are listed as vulnerable with a decreasing population trend, and Pallid Harrier as near-threatened on the IUCN list of threatened species. This study identifies the new flyways of the heavily understudied raptors in India. As opposed to the previously identified migration pathways of the different raptor species from India, we provide new insights into the spatial and movement ecology of the selected species. Our study is an attempt to fill the gap in our knowledge of these raptors. Moreover, such a pioneering study will also open a new avenue for future researchers to conduct similar work by tagging large numbers of individuals of different raptor species.

2. Materials and Methods

2.1. Study Area

The satellite tagging was carried in the Asiatic Lion Landscape (ALL), north-western India (Figure 1). Three species (Greater Spotted Eagle, Indian Spotted Eagle, and Pallid Harrier) were tagged in the Asiatic Lion Landscape located in the south-western part of the Saurashtra region of Gujarat, India, and Tawny Eagle was tagged in Abdasa taluka of Kutch district, Gujarat (Figure 1). The landscape consists of many small protected, reserved, and unclassed forest patches [26]. The landscape spans across an expanse of ~30,000 km^2 and represents a typical semi-arid biogeographical zone [27]. The area is characterised by three seasons; dry and hot summer (March–June), monsoon (July–October), and primarily dry winter (November–February). Livestock rearing, agriculture, and horticulture are the main economies of the region.

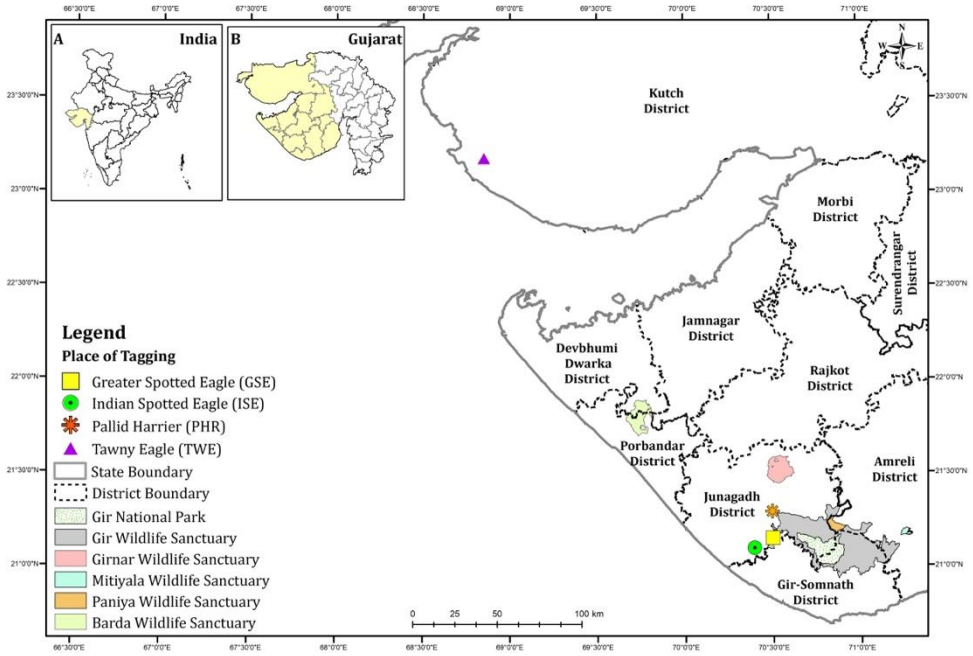

Figure 1. Location of Saurashtra and Kutch District. Greater Spotted Eagle (GSE), Indian Spotted Eagle (ISE), and Pallid Harrier (PHR) were tagged in Saurashtra Landscape (bottom-right corner), and Tawny Eagle (TWE) was tagged in Kutch District (upper-left corner). Map insets indicate the location of Gujarat in India (**A**) and the study area in Gujarat state (**B**).

2.2. Satellite Tagging

We deployed solar-powered satellite transmitters on a single individual of Tawny Eagle, Indian Spotted Eagle, Greater Spotted Eagle, and Pallid Harrier (Table 1). The transmitters were deployed as backpacks with 11 mm Teflon ribbon for eagles and 5 mm Teflon ribbon for Harrier (Supplementary Material S3). The GPS/GSM transmitters weighed less than 3% of the body mass of the raptors as recommended [28,29].

2.3. Statistical Analyses

A total of 36,162 location fixes were received with a mean number of 9040 ± 1765 fixes for each species for a year. A total number of 34,039 location fixes (94%) were retained after implementing the spatial refinements, such as removing fixes with negative elevation values, missing coordinates, and missing time stamps. For raptor home range estimation, a total of 16,093 location fixes were used with a 1788 ± 450 mean number of location fixes for each species (47%). Using these data, the winter and summer home ranges (Figures S1–S10 in Supplementary Material S1), monthly and daily movement patterns, seasonal activity rates, and migration routes to the breeding grounds were calculated. We estimated minimum convex polygons (MCPs) and kernel utilization distribution (KUD)

at 95% and 50% with adehabitatHR package [30] in R [31]. We calculated the winter and summer home ranges of each raptor species in their breeding and wintering grounds.

Table 1. Details of satellite tagging of selected migratory raptor species in Asiatic Lion Landscape, Gujarat, India.

Sr. No.	Species	Date of Tagging	Place of Tagging	Type of Tag (Model Details)	Tag Weight (g)	Bird Weight (g)
1	Greater Spotted Eagle (GSE) Adult	25 February 2021	GIZ Devaliya	Solar 3D—GPS PTT (Argos Satellite)	47	2400
2	Pallid Harrier (PHR) Adult Male	10 March 2021	Jhinjhuda *Vidi*	Ornitella GSM (OT-10-3G)	10	350
3	Indian Spotted Eagle (ISE) Adult	12 March 2021	Babara *Vidi*	Ornitella GSM (OT-20-3G)	20	1570
4	Tawny Eagle (TWE) Adult	26 March 2021	Abdasa, Kutch	Ornitella GSM (OT-E25-3G)	25	2130

We projected location fixes in UTM projection and calculated the daily and monthly distance travelled by each raptor species using the Tracking Analyst tool in ArcGIS version 10.8.1 [32]. The minimum travelled distance was determined by calculating the straight line distance between consecutive GPS fixes then segregated by months and days [32]. We tested a prior hypothesis that raptors were more active during migration than non-migration and covered significantly more distance across months and days while migrating. Statistical comparisons of the average distances covered across migration and non-migration months were made by performing the one-way analysis of variance test. Due to the small sample size, we fixed the significance level at $p = 0.10$.

The daily activity rates were quantified by comparing the proportion of daytime fixes as stationary or in flight. Only daytime fixes were included between sunrise and sunset to compare activity patterns. The R package 'RAtmosphere' [33] was used to characterise each GPS fix as day or night based on location-specific estimation of sunrise and sunset [34]. We characterised GPS fixes with an instantaneous speed of >1 km per hour as 'in flight' or otherwise 'stationary' [33]. The statistical significance between the proportion of daytime fixes in flight and rest state for each species was tested separately using the chi-square test of independence.

3. Results

3.1. Home Range Patterns

Home ranges were calculated for the period where raptors had settled, and there was little evidence of evasive movements. MCP and KUD home range sizes varied for each raptor species in their respective summer and wintering grounds (Table 2). For Greater Spotted Eagle, two MCP home range polygons in Kazakhstan and the third home range polygon in Pakistan (Figures S1–S3 in Supplementary Material S1) were calculated. The home range of Greater Spotted Eagle in south Kazakhstan (April to May 2021) was larger during April–May than in June (Table 2). In winter (September–November 2021), the home range and core area size were smaller than in summer (Table 2). The kernel home range (95%) calculated in June 2021 was larger than its respective MCP home range for the same month, while the kernel core areas were smaller than their respective MCP core area for June 2021 (Table 2). Similarly, the kernel home range calculated in Pakistan during the winter season was larger than the MCP home range (Table 2).

Table 2. Home range size (in km^2) estimated as minimum convex polygons (MCPs) and kernel utilisation distribution (KUD) of four raptor species. Home ranges were calculated using R package adehabitatHR and were constructed across their breeding and non-breeding ranges.

Species	Place	Range	95% MCP	50% MCP	95% KUD	50% KUD
Greater Spotted Eagle	South Kazakhstan	April–May 2021	9331.71	427.56	5991.15	759.15
	North Kazakhstan	June 2021	3491.56	915.64	3915.25	735.75
	Pakistan	September–November 2021	5312.54	1898.54	6443.24	1013.54
Indian Spotted Eagle	Gujarat, India	March 2021	142.5	11.31	111.04	10.78
	Pakistan	May–June 2021	127.29	9.68	83.42	9.81
	Pakistan	October–November 2021	81.08	5.93	57.60	7.38
Tawny Eagle	Rajasthan, India	March 2021	5509.64	2109.66	4810.79	795.06
	Kazakhstan	July–September 2021	4820.62	399.51	3743.61	429.59
Pallid Harrier	Russia	May–July 2021	4.29	1.15	3.98	0.95
	India	March 2021	102.79	20.43	92.95	19.55

For Indian Spotted Eagle, the first home range was estimated in the month of March 2021 in Gujarat, India (Figures S6–S8 in Supplementary Material S1). Indian Spotted Eagle had a larger home range in the summer season than in winter; however, core areas were larger in summer than in winter (Table 2). Compared to MCP home ranges and core areas, the respective kernel home ranges and core areas calculated for the same months were smaller (Table 2).

Tawny Eagle had a larger home range size and core area in Rajasthan, India, than in Kazakhstan (Table 2). The respective kernel home range in Rajasthan, India, was smaller—as was the core area (Table 2). Similarly, the kernel home range and core area were smaller in Kazakhstan from July to September 2021 (Table 2). (Figures S4 and S5, Supplementary Material S1).

Pallid Harrier had the smallest home range of the four raptor species (Table 2). The kernel home range and core areas were also smaller for the same months in Russia than its respective MCP home range and core areas (Table 2). The kernel home range and core area were smaller than the MCP home range and core area in India (Table 2). (Figures S9 and S10 in Supplementary Material S1).

3.2. Movement and Activity Rates

There was a statistically significant difference in the distance travelled across months (migration and non-migration) ($F = 3.08$, $p = 0.04$) and across days ($F = 2.54$, $p = 0.07$). Overall, the monthly average distance moved was highest in Greater Spotted Eagle, followed by Pallid Harrier, Tawny Eagle, and Indian Spotted Eagle (Table 3).

Table 3. Monthly average distance travelled during migration and non-migration months by four raptor species. The monthly distance indices presented here were estimated using Tracking Analyst Tools in ArcGIS 10.8.1. Minimum and maximum distances correspond to the months during which raptors were non-migratory and the maximum distance corresponds to the months of active migration.

Species	Monthly Distance Moved (km) (Mean ± SE)	Maximum Distance (km)	Minimum Distance (km)
Greater Spotted Eagle	3957 ± 728	7280	1263
Indian Spotted Eagle	1541 ± 297	3481	653
Tawny Eagle	2027 ± 421	4118	501
Pallid Harrier	2641 ± 793	7649	517

Similarly, raptors covered more distance per day when migrating (Table 4). Among all species, Greater Spotted Eagle covered the highest daily (average) distance, followed by Pallid Harrier, Tawny Eagle, and Indian Spotted Eagle (Table 4).

Table 4. Daily average distance travelled during migration and non-migration months by four raptor species. The daily distance indices presented here were estimated using Tracking Analyst Tools in ArcGIS 10.8.1. Minimum and maximum distances correspond to the days during which raptors were non-migratory and the maximum distance corresponds to the days of active migration.

Species	Daily Distance Moved (km) (Mean ± SE)	Maximum Distance (km)	Minimum Distance (km)
Greater Spotted Eagle	129 ± 24	242	42
Indian Spotted Eagle	50 ± 9	116	221
Tawny Eagle	66 ± 13	132	16
Pallid Harrier	86 ± 26	254	17

Each of the raptors travelled more monthly and daily distances while migrating. Pallid Harrier travelled significantly more distance while migrating ($F = 4.17$, $p = 0.08$). The highest distance was travelled in April 2021 while migrating from India to Russia. As we expected, the daily distance travelled was significantly higher in April 2021, ($F = 4.11$, $p = 0.08$). Likewise, Tawny Eagle travelled significantly more distance monthly ($F = 6.11$, $p = 0.04$) and daily ($F = 6.54$, $p = 0.04$) while migrating towards Kazakhstan in the months of June and July 2021. Conversely, Tawny Eagle covered a shorter distance in August after it settled, with a daily distance also declining during the same month.

A similar trend of the highest monthly and daily distance being covered in migration was also observed in the Indian Spotted Eagle, We observed a significant difference in distance travelled during migration across all months ($F = 5.32$, $p = 0.06$) and days ($F = 41.72$, $p = 0.001$). Greater Spotted Eagle covered a significantly greater distance in April and May while migrating towards Kazakhstan and in September while migrating back ($F = 24.07$, $p = 0.001$). It also moved significantly more distance per day during migration ($F = 24.63$, $p = 0.001$).

Overall, the proportion of 'in rest' fixes was higher than the proportion of 'in flight' fixes in Indian Spotted Eagle, Tawny Eagle, Pallid Harrier, and Greater Spotted Eagle (Supplementary Information S2) (Table 5). Only daytime fixes between sunrise and sunset were considered for determining the daily activity rates of raptors. Indian Spotted Eagle spent significantly more time resting than in flight ($\chi^2 = 28.79$, df = 3, $p = 0.001$). Similarly, Pallid Harrier ($\chi^2 = 28.77$, df = 5, $p = 0.001$), Tawny Eagle ($\chi^2 = 44.80$, df = 7, $p = 0.001$), and Greater Spotted Eagle ($\chi^2 = 40.48$, df = 8, $p = 0.001$) spent significantly more time in rest state than in flight state (Table 5).

Table 5. Month-wise and the overall proportion of time spent in flight and in rest state. GPS fixes with an instantaneous speed of more than 1 km per hour were characterised as 'in flight' state and otherwise as 'in rest' state.

Species	Months	In Rest (%)	In Flight (%)
Indian Spotted Eagle	April	40.89	59.11
	May	60.06	39.94
	June	63.97	36.03
	July	70.69	29.31
	August	69.72	30.28
	September	52.62	47.38
	October	52.49	47.51
	November	54.73	45.27
	Overall	57.14	42.86

Table 5. *Cont.*

Species	Months	In Rest (%)	In Flight (%)
Pallid Harrier	April	43.10	56.90
	May	55.25	44.75
	June	75.15	24.85
	July	68.07	31.93
	August	69.24	30.76
	September	65.27	34.73
	Overall	60.17	39.83
Tawny Eagle	April	46.12	53.88
	May	49.57	50.43
	June	60.37	39.63
	July	53.61	46.39
	August	76.02	23.98
	September	76.44	23.56
	October	59.20	40.80
	November	74.76	25.24
	Overall	58.78	41.22
Greater Spotted Eagle	March	63.45	36.55
	April	58.68	41.32
	May	60.68	39.32
	June	72.73	27.27
	July	83.06	16.94
	August	76.22	23.78
	September	79.56	20.44
	October	83.47	16.53
	November	81.98	18.02
	Overall	73.30	26.70

3.3. Migration Routes

3.3.1. Greater Spotted Eagle

Raptors differed in the total distance covered, flight elevation, and the number of stopovers used during migration (Table 6). All four raptors differed only slightly in their use of migratory flyways (Figure 2). Greater Spotted Eagle took a northward route across central Pakistan and diverted to the north-west in the Khyber-Pakhtunkhwa province along Khyber-pass, avoiding the high elevation Hindukush mountainous range. From Tajikistan onwards, it diverted northwards and crossed over the Zarafshan mountain range in north Tajikistan to reach Kyrgyzstan (Figure 2). It crossed over urban areas in Kyrgyzstan and reached its summer grounds in Kazakhstan on 21 April 2021. During its winter migration, it crossed over the Kyzlkum desert in Kazakhstan and Uzbekistan in a single day. It took a slightly westward route from its previous summer route and crossed over the Amu Darya River to reach Afghanistan. It reached Pakistan (Balochistan province) by taking a route approximately 200 km to the east of Kandahar (Afghanistan). In Pakistan, Greater Spotted Eagle settled in Punjab province and established a winter home range there.

3.3.2. Tawny Eagle

Tawny Eagle took a slightly different route than Greater Spotted Eagle, as it crossed into the Sindh province of Pakistan from north-west Rajasthan and reached central Pakistan and central Afghanistan. From Afghanistan, Tawny Eagle took a north-east route, crossing over the Amu Darya River in north-east Turkmenistan. It maintained its north-east route while crossing Uzbekistan to the west of the Zarafshan mountain range (Figure 2). It crossed the Zarafshan mountain range and diverted northwards to continue its journey towards Kazakhstan (Figure 2).

Its return journey started during late September 2021. Tawny Eagle used an almost similar route up to Uzbekistan; after that, it diverted eastwards from its previous route, crossing over northern Afghanistan. It continued the same route while avoiding the

Hindukush Mountain range and reached Pakistan by crossing over Khyber-Pakhtunkhwa province using Khyber Pass while avoiding high-elevation mountain ranges (Figure 2).

Table 6. Details of the distance travelled, number of days stayed, and average elevation used during migration from wintering grounds (India) to breeding grounds (outside India) by Greater Spotted Eagle, Tawny Eagle, Indian Spotted Eagle, and Pallid Harrier fitted with satellite transmitters.

Species	Average Fight Elevation (m) While Migrating from India	Average Fight Elevation (m) While Migrating to India	Total Distance Travelled (km) While Migrating from India	Total Distance Travelled (km) While Migrating to India	Number of Days Taken to Reach Breeding Ground (Outside India)	Number of Days Taken to Reach Wintering Ground (India)
Greater Spotted Eagle *	760 ± 45	618 ± 96	5696	2450	13	3
Tawny Eagle	1075 ± 33	657 ± 26	3740	2740	11	22
Indian Spotted Eagle	643 ± 42	259 ± 22	939	1365	2	1
Pallid Harrier **	336 ± 6.5	167 ± 3.15	11,998	9021	34	52

* Final destination was not India but Pakistan, ** Final destination unknown; tag malfunction occurred in Pakistan.

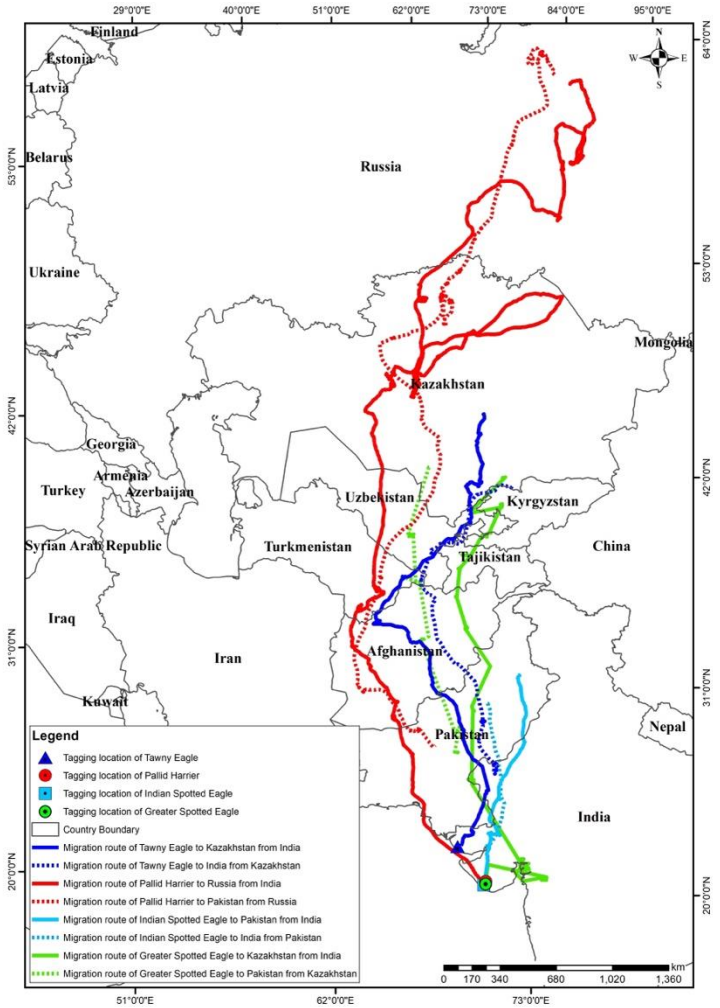

Figure 2. Migration route of tagged raptors between their wintering ground and breeding ground.

3.3.3. Indian Spotted Eagle

Indian Spotted Eagle migrated to Pakistan (Punjab province) and did not go further. It started migrating towards north Gujarat on 9 April 2021 and reached Pakistan (Punjab province) on 11 April 2021 (31 days after tagging) (Figure 2).

It stayed in Pakistan until 27 November 2021, and on 28 November 2021, it reached back to India (Bikaner district).

3.3.4. Pallid Harrier

Pallid Harrier started migrating from India 14 days after tagging, crossed over the Arabian sea along the north-west coastline, and reached Pakistan on the same day, ~30 km west of Karachi (Figure 2). It crossed the Registan Desert in south-east Afghanistan, the Karakum Desert in Turkmenistan, and Kyzylkum Desert in Uzbekistan, and reached Kazakhstan on 9 April 2021. During its journey to Russia, Pallid Harrier used five stopovers in Pakistan, Afghanistan, Turkmenistan, Uzbekistan, and Kazakhstan (Table 6).

Pallid Harrier used the same five stopovers during its return journey from Russia by travelling along the same path, differing by only a few km (Figure 2). The tag stopped transmitting the signals from 10 October 2021 from the Gandawah area of Balochistan province in Pakistan due to unknown reasons.

4. Discussion

Our study determined the new flyways of heavily understudied raptor species. As opposed to the earlier identified migration route of different raptor species across Himalaya [15], we report here new migration routes for the studied raptors from India. The migratory behaviour in raptors remains understudied in the Indian subcontinent and using satellite telemetry, we were able to fill this gap in our knowledge of these raptors.

4.1. Raptor Home Ranges

Greater Spotted Eagle established two home ranges, one in south and north Kazakhstan along water bodies. Our results are in agreement with the previous studies, which have found that water bodies and open natural lands positively influence the home ranges and habitat use in Greater Spotted Eagle [35–38]. In winter, it stopped in Pakistan and established a winter home range adjacent to Nareri Lake in south-east Pakistan. The core areas were adjacent to the canals, river basins, and lakes in Pakistan and Kazakhstan. The precise knowledge of the home range size of any species is critical for their effective conservation and management [39]. Our results indicate that riverine habitats, marshlands, river basins, and open natural habitats are important conservation sites for Greater Spotted Eagle across its summer and winter range.

Since the information on the spatial ecology of the Indian Spotted Eagle is lacking, we made comparisons with Lesser Spotted Eagle, a closely related species to Indian Spotted Eagle. Home range sizes in Lesser Spotted Eagle have been found to vary across its range. The home ranges in Germany are two times larger than those recorded in Latvia [40]. In agreement with these finds, we also observed variations in the home range size of the Indian Spotted Eagle in India and Pakistan. The results indicate that open landscapes and cultivated lands with water may be the preferable habitats for Indian Spotted Eagle in India and Pakistan [41]. The agricultural landscape may provide foraging opportunities where the Indian Spotted Eagle predates on commonly occurring small mammalian prey species such as rodents [41,42].

This study presents the first detailed aspects of its spatial ecology in its wintering ground in India. It is the first documented record of Tawny Eagle spending summer in Kazakhstan. The home range size was relatively larger in India than in Kazakhstan. The smaller home range in Kazakhstan may have been due to the possible breeding of Tawny Eagle, due to which movement may have been concentrated towards the breeding site. Its habitat preferences are dry open habitats, wooded, and non-wooded savannahs, and in India, it is found near cultivated lands in proximity to human habitations [43–45].

Pallid Harrier had the smallest home range among all raptor species surveyed in this study. The home range was established in wet, marsh grassland with a large number of small inland water bodies fed by many tributaries originating from the nearby Pur and Taz rivers. Pallid Harrier is reported to favour wet grasslands and marshlands, often in proximity to water bodies in Europe as well [46,47]. The findings of this study also indicate the preference of Pallid Harrier for such habitats in its breeding range. Its habitat preferences in wintering grounds (non-breeding range) have been reported to be similar to those of a closely related Montagu's Harrier (*Circus pygargus*), which mainly exists in croplands during winter [48].

4.2. Movement, Activity, and Migration

All raptors were significantly more active and covered more distance when migrating than when not migrating. In Europe, high activity rates and travel for longer distances have been noticed in Greater Spotted Eagle during migration [49,50]. The Montagu's Harrier has been reported to travel a mean distance of 187 km per day during their autumn migration and 114 km per day during their spring migration [48]. Our results are consistent with such studies that raptors are more active when in migration and cover large distances. As expected, the average daily distance travelled and the daytime activity rates considerably decreased once it settled in its breeding range. A similar decline in activity was reported in Pallid Harrier in their African wintering grounds after settling and establishing home ranges [25]. Likewise, for Tawny Eagle, the monthly distance moved was the highest during migration. As expected, both daily distances moved and the proportion of time spent in flight was higher during the same months (June–July 2021).

It is essential to identify migratory routes and stopover sites in migratory species for their management and conservation. In recent satellite telemetry conducted in India, Kumar et al. [15] reported that Black Kites (*Milvus migrans*) undertook a northward route along a narrow corridor, crossing the Himalayan Mountains range at high elevation. Contrary to Kumar et al. [15], we found that tagged raptors used the north–west route for their migration to breeding grounds. The results of this study indicated that the Greater Spotted Eagle used Khyber-pass in Khyber-Pakhtunkhwa province in north-west Pakistan as a flyway corridor. Greater Spotted Eagle diverted to the north-west, avoiding the high elevation Hindukush mountainous range. Tawny Eagle used a slightly different migratory flyway by following the north–west route (north–east in Greater Spotted Eagle) while crossing Pakistan and Afghanistan. After crossing Afghanistan, Tawny Eagle took a north–east route, crossing over the Amu Darya River in north-east Turkmenistan. It maintained its north–east route while crossing into Uzbekistan to the west of the Zarafshan mountain range. The movement and migration patterns in Pallid Harrier are well studied [51, 52]. Pallid Harrier is defined as a broad-front migrant, which means it does not pass-through narrow mountain passes or short-sea crossings as many raptors do [47]. This strategy is reported to protect Pallid Harrier from shooting by hunters at the narrow migration passes [47]. The site fidelity to wintering grounds in Pallid Harrier varies as the same birds may return to the areas approximately 1000 km apart during their second migration [25]. In our study, we could not ascertain the site fidelity of Pallid Harrier to wintering grounds in India due to the loss of signal from the transmitter. However, the study by Limiñana et al. [24] suggested that Pallid Harrier may settle in new areas in their wintering grounds depending on the food availability.

Due to the small sample size, the results obtained may not be generalised for whole-species spatial ecology; this study is, however, a starting point for investigating the migration routes of migrating raptors using satellite telemetry in India.

5. Conclusions

In conclusion, our study shows that migratory raptors exhibit considerable variability in movement and activity patterns and space use across annual cycles and seasons. The space use, daily and monthly movements, and seasonal activity rates in raptors are highly

influenced by the seasons. In our first attempt, we provide important information on the spatial ecology of four threatened species of raptors at fine spatial and temporal scales in Central Asia.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/birds3030020/s1, Supplementary S1: Summer and winter home range polygons of studied raptor species calculated as 95% MCP and 50% MCP; Supplementary S2: Activity rates of Indian Spotted Eagle (ISE), Tawny Eagle (TWE), Pallid Harrier (PHR), and Greater Spotted Eagle (GSE) calculated as the proportion of daytime location fixes in rest and in-flight state for each month; Supplementary S3: Photos of Tagging Work.

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