

## Short Communication

## Spatial and temporal movement of the Bearded Vulture using GPS telemetry in the Himalayas of Nepal

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This study addresses for the first time the movement patterns of the globally near-threatened Bearded Vulture *Gypaetus barbatus* in its most important stronghold, the high-altitude mountain ranges of Asia. Tracked individuals ( $n = 8$ ) in the Annapurna Himalayan range (Nepal) foraged over a vast range of 60 715.9 km<sup>2</sup> and our results indicated age-class differences in the use of space. Territorial adults showed very small annual home-ranges (K90 = 150.3 km<sup>2</sup>), whereas immatures wandered extensively and covered vast ranges of the mountains (K90 = 23 930.8 km<sup>2</sup>). For adults and immatures, these values are notably larger than the other two studied populations in the world (Pyrenees and South Africa). This suggests that the studied Annapurna population might exhibit lower breeding density than in the Pyrenees or South Africa, possibly due to lower food availability.

**Keywords:** Annapurna, distance travelled, *Gypaetus barbatus*, home-range, scavenger, sex segregation.

The Bearded Vulture *Gypaetus barbatus* inhabits mountainous areas in Eurasia and Africa, nesting on cliffs and foraging extensively over the surrounding mountains (Brown 1997). In the last two centuries, the species has been extirpated from several countries in the world (Tucker & Heath 1994, Margalida *et al.* 2013, Botha *et al.* 2017) and is currently in decline (Carrete *et al.* 2006, Margalida *et al.* 2008a, Krüger *et al.* 2014b, Ogada *et al.* 2016). The causes of its decline are mostly poisoning and human persecution, although habitat loss, reduction of food availability, and collision with powerlines and wind turbines also play a role (Margalida *et al.* 2008b, Virani *et al.* 2011, Ogada *et al.* 2012, Reid *et al.* 2015).

A detailed understanding of a species' movement ecology and behaviour in relation to biological and environmental factors is necessary to design and establish appropriate conservation management strategies (Morrison & Wood 2009). Although movement studies of the Bearded Vulture span more than three decades, they are limited to only a few mountain ranges in Europe and South Africa (Gavashelishvili & McGrady 2007, Urios *et al.* 2010, Margalida *et al.* 2013, 2016, Gil *et al.* 2014, Krüger *et al.* 2014a, Reid *et al.* 2015). Information on the movement ecology of vultures in the high-elevation ranges of Asia is largely lacking (Alarcón & Lambertucci 2018).

The present study provides information on the range behaviour for different age-classes of Bearded Vulture in the Himalayas. Our main objectives were: (1) to quantify home-range size and home-range use of the Bearded

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Vulture in the Himalayas, (2) to compare how the home-range and its use differs by age, sex and season, and (3) from a more applied perspective, to describe whether the studied Bearded Vultures spend significant time within the existing protected areas of Nepal.

## METHODS

### Study area

This study was conducted in the central Himalaya range along the Annapurna Himalaya Range of Nepal (Fig. 1a). The Annapurna range supports a population density of Bearded Vulture up to 0.18 birds/km<sup>2</sup> with high spatial variation (altitude range = 1445–4600 m asl) of the breeding area (Subedi *et al.* 2018, 2019).

### Capture and tracking

Between May 2016 and June 2017, 13 Bearded Vultures (four adult males, three adult females, five immatures, one juvenile; Table S1) were captured using string nooses and a Pandam noose trap baited with bone or meat of buffalo. Capture of the Bearded Vulture was opportunistic on sex and age categories because of the difficulty of capture and low abundance of birds. Birds were categorized into age-classes according to Margalida *et al.* (2016) (juveniles = within 1 year of life, immatures = 2–3 years, sub-adults = 4–5 years and adults = ≥ 6 years). Both members of two adult pairs were captured at once, which validated the sexing of all adults by body measurement.

Two different solar-powered GPS-GSM transmitters were used: (1) 72-g Wild-Trackers (WT-200, WT-300) manufactured by the Korea Institute of Environment Ecology (Yuseong-Gu, Daejeon, South Korea) and (2) 58-g ST2010 developed by Savannah Tracking Limited (Nairobi, Kenya). Transmitters were attached as a backpack using a Teflon ribbon harness. The total weight of transmitters and harness was ~1.5% of the bird's body mass. Seven transmitters were programmed to obtain GPS fixes every 2 h on a 24-h cycle (three of WT-200 and four of WT-300). Three WT-200 transmitters were programmed to obtain a location every hour on a 24-h duty cycle. All ST2010 units were programmed for a 10-h cycle (07:45–17:45 h local time) and a 14-h off-duty cycle to obtain a location every hour. Transmitters recorded GPS position along with the date, time, elevation and flight speed.

### Movement data

Of 13 individuals tracked, five were excluded from the analyses due to lack of sufficient data (four individuals provided data for < 20 days and another died after a

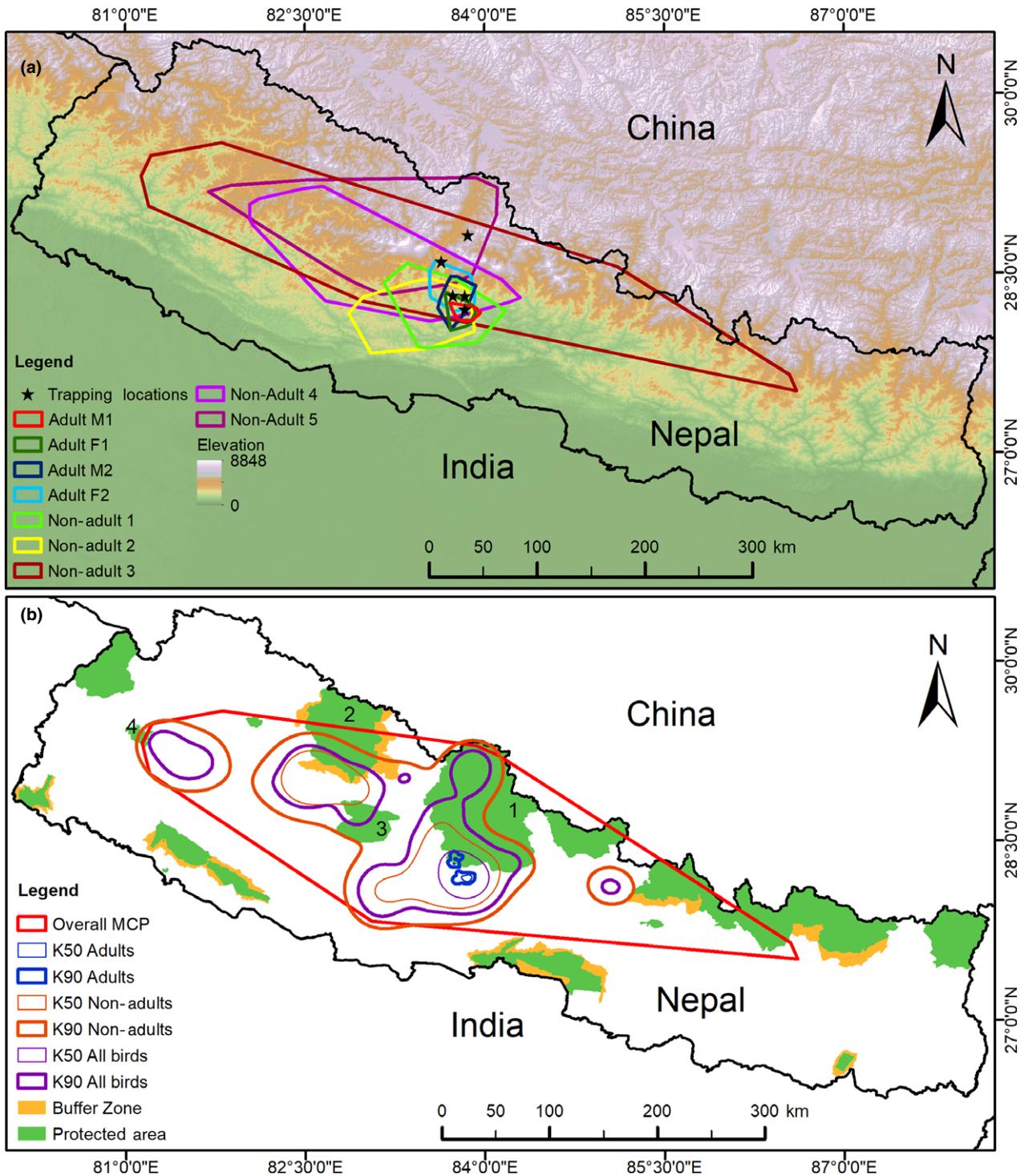
few days). Our sample included one newly fledged juvenile; after 1 year of age that bird was transferred into the next age-class (immature). Although that individual was included twice, the significant difference between the behaviour of juveniles (parental dependence period) and immatures (dispersal period) justified its inclusion (Margalida *et al.* 2016). So we considered a total of nine samples (bird/age-class) in the analysis. GPS fixes were filtered to remove the overnight roosting and only fixes recorded between 05:45 and 17:45 h local time zone were used for the analysis (García-Jiménez *et al.* 2018).

For the temporal analysis of all birds, a comparison of movement between two seasons was made (Krüger *et al.* 2014a). For both the immatures and juvenile bird, seasons were summer (1 April–30 September) and winter (1 October–31 March), which is based on daylight hours. For adults, categorization of the season was based on breeding activity (Naoraji 2006): breeding period (1 October–31 May) and non-breeding period (1 June–30 September). Additionally, annual utilization distribution of each bird was computed using GPS fixes that were obtained within each year.

Home-range was estimated by means of the minimum convex polygon (MCP) and kernel utilization density (KUD) estimators (Worton 1989). Annual and seasonal KUD was estimated using the adehabitatHR package (Calenge 2006) in R (R Core Team 2017). KUD was estimated using a bivariate normal kernel function and the smoothing parameter was computed with the *ad hoc* method (*href*) for comparison with previous studies (Krüger *et al.* 2014a, Margalida *et al.* 2016). Isopleths of 95% (K95), 90% (K90) and 50% (K50) were calculated. K90 represents the home-range size and K50 represents the core area of a bird's activity (Krüger *et al.* 2014a, Margalida *et al.* 2016).

Movement was described using four metrics, average and maximum hourly distance travelled, and total and maximum daily distance travelled, following Margalida *et al.* (2016). The average hourly distance travelled was calculated as a straight-line distance (in km) between consecutive locations and was standardized in relation to an hour spent between locations. The daily distance travelled was calculated by summing the distances between the first and the last location of the same day. The maximum distance travelled per day was calculated as a maximum distance from the initial location to the final location of the same day. Monthly mean elevation range used by each individual was obtained by calculating the elevation data from each GPS fix and a digital elevation model (90 m) downloaded from Shuttle Radar Topographic Mission (Jarvis *et al.* 2008).

Captured individuals incidentally included both members of two breeding pairs (male and female). This gave us the rare opportunity to study seasonal and annual segregation of the use of space by sex within the same breeding territory, an issue rarely explored in large raptors and



**Figure 1.** (a) Minimum convex polygon showing geographical range used by eight GPS-tracked Bearded Vultures in the Himalayas of Nepal from 2016 to 2018. (b) Home-range overlap of the Bearded Vulture with the protected areas (1 = Annapurna Conservation Area, 2 = Shey Phoksundo National Park, 3 = Dhorpatan Hunting Reserve and 4 = Khaptad National Park) of Nepal. A significant proportion of the Bearded Vulture home-range area remains outside protected area systems in Nepal. [Colour figure can be viewed at [wileyonlinelibrary.com](http://wileyonlinelibrary.com)]

vultures (but see Bosch *et al.* 2010, Pérez-García *et al.* 2013). In particular, we quantified the degree of overlap of the home-ranges of both members of the breeding pair.

Finally, to evaluate the home-range of Bearded Vulture with the protected areas in the Himalayas of Nepal, we used the cartography of the protected areas system of Nepal and overlapped with the overall home-ranges (K90 and K50) of all birds, adults and non-adults.

### Statistical analysis

We used a Wilcoxon test to analyse all movement matrices (Wilcoxon 1945). We independently tested for age- and sex-related differences (the latter only for adults) on annual home-ranges and seasonal home-ranges. In addition, we also tested for seasonal differences in monthly mean hourly distances, mean hourly and daily distances, maximum hourly and maximum daily distance, and seasonal differences in altitudinal range used by age-classes.

### RESULTS

A total of 3257 bird days were monitored (from the eight birds used in the final analyses) and the mean number of monitoring days per bird was  $407.1 \pm 176.0$  (range 205–621; Table S1). A total of 22 538 GPS fixes were obtained and the mean number of fixes per bird was  $2817.3 \pm 1108.9$  (range 1427–4106).

### Home-range

All adults were territorial ( $n = 4$ ), so that the foraging area of these adult birds remained within that of the non-adults' range ( $n = 5$ ; with one bird included as both a juvenile and an immature; Fig. 1b). Adults showed home-ranges (MCP, K50, K90 and K95) that were more than 100× smaller than those of immatures; the single juvenile had a home-range smaller than immatures but larger than that of adults (Table 1). Home-range (K90), core area (K50) and foraging area (MCP) showed significant differences between ages (adults vs. non-adults, Wilcoxon test,  $P < 0.01$ ).

For territorial males ( $n = 2$ ), home-range overlap between two seasons (breeding and non-breeding) was  $61.0 \pm 5.3\%$  with K90 and  $46.6 \pm 8.2\%$  with K50; this pattern was similar among females (Table S2). Annual home-range overlap between the male and female of each territorial pair was  $75.9 \pm 10.4\%$  on K90 and  $61.6 \pm 12.9\%$  on K50, with a slightly greater overlap during the breeding than the non-breeding season (Table S2).

### Hourly and daily movements

Mean hourly distances ranged from  $2.3 \pm 2.8$  km for adults to  $3.1 \pm 4.5$  km for immatures, whereas mean

**Table 1.** Total and seasonal home-range size (km<sup>2</sup>) by different age-class and sex (only for adults) of Bearded Vulture tracked in the Himalayas of Nepal.

Age/sex	n	Seasonal home-range														
		Annual home-range					Breeding/winter <sup>a</sup>					Non-breeding/summer <sup>a</sup>				
		MCP	K50	K90	K95		MCP	K50	K90	K95		MCP	K50	K90	K95	
Adult F	2	714.4 ± 470.2	25.4 ± 17.9	131.4 ± 111.2	220.0 ± 178.1	416.6 ± 294.5	22.8 ± 15.1	113.7 ± 91.7	221.1 ± 166.2	286 ± 115.9	41 ± 47.1	169.1 ± 178.6	308.0 ± 306.9			
Adult M	2	429.1 ± 396.2	40.7 ± 47.1	169.2 ± 180.6	294.3 ± 297.1	234.3 ± 156.1	35.7 ± 29.6	154.1 ± 103.2	226.2 ± 156.5	322.5 ± 342.8	55.0 ± 75.2	205.2 ± 260.0	361.3 ± 395.0			
Adult (All)	4	571.7 ± 419.1	33.0 ± 32.9	150.3 ± 135.8	257.2 ± 195.9	315.3 ± 232.3	30 ± 23.9	136 ± 94.5	218.6 ± 132.1	304.2 ± 229.7	48 ± 56.7	187.1 ± 200.4	334.6 ± 290.5			
Immature	4	544.9 ± 11 800.9	7194.1 ± 10 262.4	23 930.8 ± 32 366.2	23 340.4 ± 23 248.0	12 486.2 ± 10 779.3	4997.6 ± 7112.9	19 157.0 ± 26 133.2	20 342.3 ± 16 494.6	9326.5 ± 7462.7	3810.7 ± 5423.9	14 964.7 ± 22 461.9	15 029.3 ± 13 736.6			
Juvenile	1	4795.8	254.5	1815.5	2452.3	4745.7	713.3	2511.6	3237.5	1992.8	2.2	12.1	22.1			

Home-ranges (mean ± sd) are presented as MCP, K50, K90 and K95; all adults are territorial. <sup>a</sup>Breeding/non-breeding for adults and winter/summer for non-adults.

daily distances ranged from  $17.6 \pm 14.0$  km in adults to  $28.2 \pm 23.7$  km in immatures. No differences were detected on either movement metric between these age-classes ( $P > 0.05$ ). Marginally significant differences were found between the maximum hourly and daily distance travelled for adults and immatures ( $P = 0.06$ ). The juvenile vulture studied showed shorter distances than adults or immatures for all four movement metrics (Table 2). Within age-classes (adults vs. non-adults), we obtained marginal differences in monthly mean hourly distances travelled ( $W = 38, P = 0.05$ ).

Monthly mean hourly distance travelled between seasons was significantly different for adults ( $P < 0.01$ ) and non-adults ( $P < 0.05$ ). Among adults, distance travelled peaked during incubation (November–December) and during the early stage of chick-rearing (until February) and was lower during the post-fledging period (June–July, Fig. 2). Among non-adults, the monthly distance travelled peaked in November and was the lowest during the summer months. No differences were observed between male and female adults for any movement metric (all Wilcoxon tests  $P > 0.05$ ).

**Monthly elevation range use**

Non-adults utilized relatively higher elevation ranges during the summer season (mean  $3075 \pm 1070$  m a.s.l., range = 691–6400 m a.s.l.) compared to the winter season ( $2449 \pm 959.3$  m a.s.l., range = 562–5979 m a.s.l.;  $W = 36, P < 0.01$ ). For adults, there were no statistical differences between the mean elevation ranges used during the breeding and non-breeding seasons (Wilcoxon test  $P > 0.05$ ; Fig. S1).

**Home-range overlap with the protected areas**

Kernel utilization density ranges overlapped with four protected areas (Fig. 1b, Table S3). The maximum overlap of all home-ranges was primarily concentrated in the Annapurna Conservation Area. For adults, 30.1% ( $86.7 \text{ km}^2$ ) of the home-range (K90) overlapped with the Annapurna Conservation Area; in contrast, the entire core area remained outside the protected areas. Among non-adults, 30.3% ( $9241 \text{ km}^2$ ) of the home-range (K90) and 23.5% ( $1786.2 \text{ km}^2$ ) of the core area (K50) overlapped with the protected areas and buffer zone areas (Fig. 1b, Table S3).

**DISCUSSION**

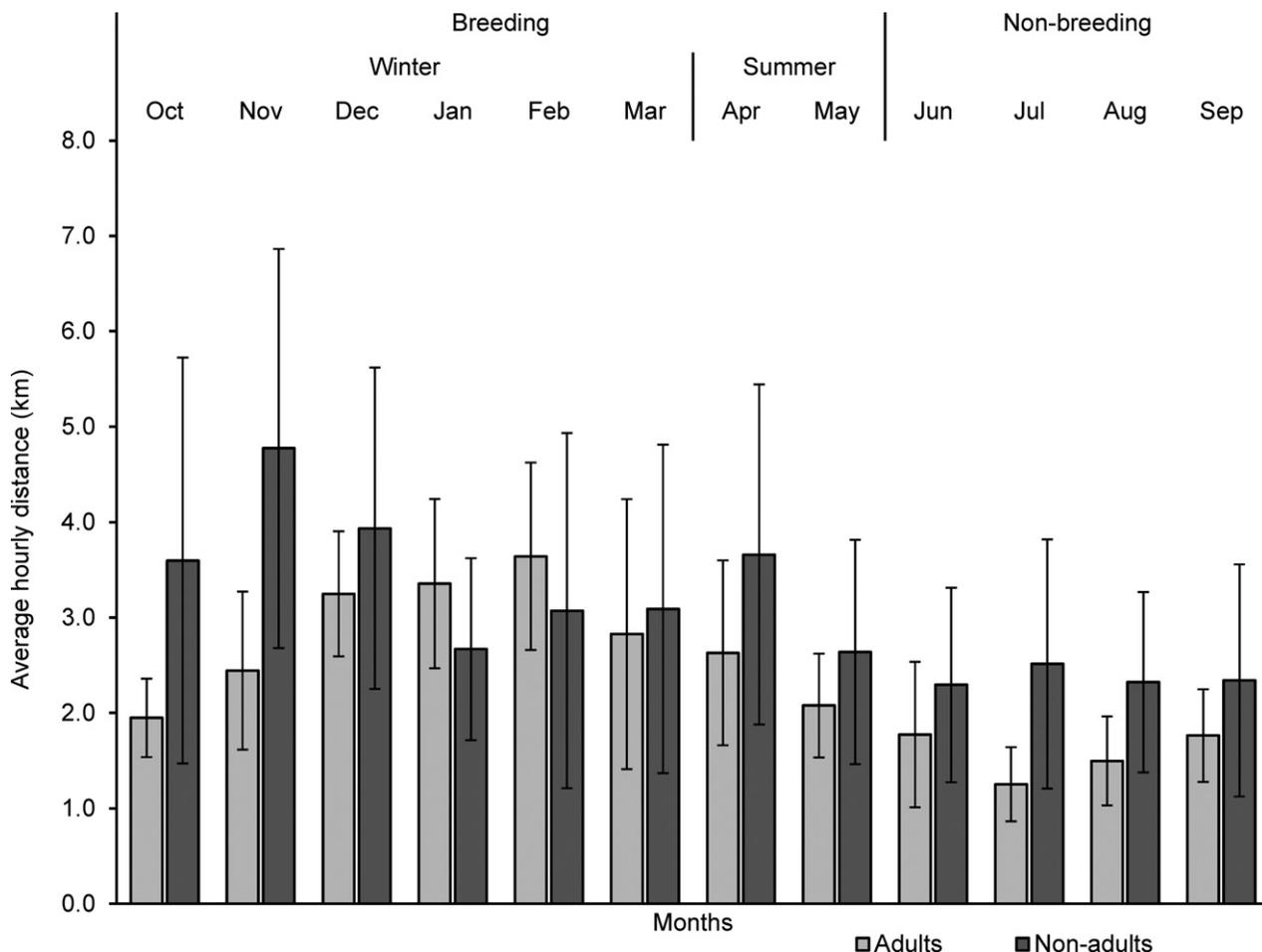
**Home-range size**

Our study addresses for the first time the movement patterns of the globally near-threatened Bearded Vulture

**Table 2.** Average daily and hourly distance travelled for the total tracking period and each season by different age-class and sex (only for adults) of Bearded Vultures tracked by GPS-GSM transmitter in the Himalayas of Nepal.

Age/sex	n	Seasonal distance travelled (km)					
		Average distance travelled (km)		Breeding/winter <sup>a</sup>		Non-breeding/summer <sup>a</sup>	
		Hourly distance	Daily distance	Hourly distance	Daily distance	Hourly distance	Daily distance
Adult F	2	$2.6 \pm 3.3$ (0.0–24.7)	$18.9 \pm 16.1$ (0.0–120.2)	$3.1 \pm 3.6$ (0.0–22.2)	$21.7 \pm 17.4$ (0.0–86.1)	$1.4 \pm 1.9$ (0.0–24.7)	$13.1 \pm 10.7$ (0.0–120.2)
Adult M	2	$2.0 \pm 2.1$ (0.0–17.6)	$16.4 \pm 11.6$ (0.0–73.6)	$2.1 \pm 2.1$ (0.0–12.7)	$17.5 \pm 11.9$ (0.0–73.6)	$1.8 \pm 2.1$ (0.0–17.6)	$14.9 \pm 11.0$ (0.1–70.2)
Adult (All)	4	$2.3 \pm 2.8$ (0.0–24.7)	$17.6 \pm 14.0$ (0.0–120.2)	$2.7 \pm 3.1$ (0.0–22.2)	$19.7 \pm 15.2$ (0.0–86.1)	$1.6 \pm 2.0$ (0.0–24.7)	$14.1 \pm 10.9$ (0.0–120.2)
Immature	4	$3.1 \pm 4.5$ (0.0–75.6)	$28.2 \pm 23.7$ (0.0–165.1)	$3.6 \pm 5.3$ (0.0–75.6)	$32.2 \pm 26.7$ (0.0–165.1)	$2.7 \pm 3.8$ (0.0–43.1)	$25.1 \pm 20.5$ (0.1–125.7)
Juvenile	1	$2.1 \pm 2.6$ (0.0–20.3)	$25.7 \pm 15.6$ (1.6–82.5)	$2.2 \pm 2.6$ (0.0–20.3)	$27.2 \pm 15.0$ (1.6–82.5)	$1.9 \pm 2.5$ (0.0–12.4)	$22.2 \pm 16.6$ (3.2–62.6)

All data show mean  $\pm$  standard deviation and range (minimum–maximum); all adults are territorial. <sup>a</sup>Breeding/non-breeding for adults and winter/summer for non-adults.



**Figure 2.** The mean hourly distance (km) travelled per month by adult and non-adult Bearded Vultures in the Himalayas of Nepal (mean  $\pm$  sd).

in its most important stronghold, the high-altitude mountain ranges of Asia. As expected, our study showed a marked difference in home-range size between breeding adult and non-adult Bearded Vultures. Non-territorial individuals showed home-ranges an order of magnitude larger than those of territorial adults. This result is similar to that found in other populations of the species in South Africa and Europe (Gil *et al.* 2014, Krüger *et al.* 2014a, Margalida *et al.* 2016).

Territorial adults in the Himalaya mountain range used annual total home-ranges (K90) of around 150 km<sup>2</sup>, which is almost three times larger than those reported for territorial adults in the Pyrenees (Margalida *et al.* 2016). Comparison with the South African population of Bearded Vulture (Krüger *et al.* 2014a) is less straightforward, as these authors report a total home-range size (K90) over several years (1–4 years, depending on the individuals). Regardless, the total home-range size (K90) in our study ( $192.1 \pm 153.9$  km<sup>2</sup>), considering the

entire study period, was larger than that reported for the South African population ( $95 \pm 19$  km<sup>2</sup>). For immatures, however, the home-range size comparison with other populations does not yield a clear pattern. The studied immature individuals in the Himalayas showed slightly smaller home-ranges than in South Africa but larger than in the Pyrenees (Krüger *et al.* 2014a, Margalida *et al.* 2016).

Territory size in raptors, including vultures, is largely driven by habitat quality (i.e. abundance of food resources) and population density (Marquiss & Newton 1982, Peery 2000), with smaller territories found in food-rich and high-population-density areas. Our results indicate that according to the size of the home-ranges, the Annapurna population might have lower breeding density than in the Pyrenees or South Africa, due to lower food availability. In addition, different availability of supplementary feeding sites between populations may play a role in these differences (Margalida *et al.* 2013,

2016, 2017), particularly for non-territorial birds (Margalida *et al.* 2017).

### Home-range use

In our studied population, adult Bearded Vultures used the home-range area intensively but relatively close to the nest locations, as indicated by the smaller home-ranges but longer mean hourly distances moved. This pattern is similar to that found in other populations such as those in Spain and South Africa (Krüger *et al.* 2014a, Margalida *et al.* 2016). Non-adult birds travelled longer distances during winter. The longer distance during winter could be related to food constraints related to snow cover (Subedi *et al.* 2019). Intra-breeding pair overlap was larger during the breeding season than the non-breeding season, when both sexes are involved in territory defence and potential movements are restricted.

The Bearded Vulture has been regarded as a wide-spread altitudinal migrant in the Himalaya Range (Bird-Life International 2015). However, our results did not show any sign of strong altitudinal migration, particularly in territorial adults. However, the non-adults in our study moved to relatively lower ranges (*ca.* 2500 m a.s.l.) in summer, which is probably related to avoiding adverse climatic conditions during the winter season, and follow the movements of trophic resources such as livestock (Xirouchakis & Nikolakakis 2002).

### Conservation considerations

Our work indicated that tracked Bearded Vultures were primarily located in areas that are currently not protected. Nests of the territorial pairs ( $n = 2$ ) were spaced 2 km (Deupur) and 11 km (Aarukharka) from the boundary of the closest protected area; however, only 30% of their home-range (K90) overlapped with a protected area (Table S3). In the case of territorial individuals, the overlap of their home-range within the protected areas depends directly on the location of the trapping sites, due to the reduced size of the territorial home-ranges. Therefore, the results of this analysis are not representative of the rest of the territorial pairs. By contrast, the overlap analysis with non-adults, because they are *a priori* less conditioned by the location of the trapping site, is likely to be more typical of other non-territorial birds. In our study, a large percentage (70%) of non-adult home-ranges were outside protected areas. This result matches the results obtained for the population in the Pyrenees (Margalida *et al.* 2016, Morales-Reyes *et al.* 2017). As in other species, in the Bearded Vulture the use of non-protected areas increases non-natural mortality due to the effects of several anthropogenic threats (Margalida *et al.* 2008b, Krüger *et al.* 2015, Ogada *et al.* 2016, Krüger & Amar 2017,

Parvanov *et al.* 2018). Therefore, it is important also to develop conservation strategies outside protected areas and in human-dominated landscapes (Pérez-García *et al.* 2011). In particular, mitigating human–carnivore conflict is likely to be a key aspect in the conservation of the species, in order to reduce non-intentional poisoning of the scavenging communities. Although understudied in Nepal, some reports indicate that the number of conflict cases might be relatively higher than in neighbouring countries (Mehta & Heinen 2001, Theile 2003).

Increasing infrastructure development is expected in the future for the mountainous ranges of Nepal, including wind turbine placement (Ghimire *et al.* 2011), power lines, and both unpaved and paved roads. Home-range and movement information about Bearded Vulture from this study can be taken as a reference for the execution of conservation programmes or planning of such development programmes within the Bearded Vulture habitat or foraging ranges.

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### DATA AVAILABILITY STATEMENT

After the manuscript is published, the GPS data will be uploaded in the Movebank repositories and made available for non-commercial use.

### ETHICS STATEMENT

The research was conducted following relevant national and international guidelines. Capture and tagging of the Bearded Vulture was conducted in compliance with the protocol and permit from the Department of National Parks and Wildlife Conservation, Nepal (permit #072/73 Eco-14 invoice #416 and extension #073/74 invoice #2271) and Annapurna Conservation Area Project (references #295/072/073, #504/073/074).

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Figure S1.** Mean ( $\pm$ s.d.) monthly elevation of adult and non-adult (immature and juvenile) Bearded Vultures in the Himalaya of Nepal.

**Table S1.** Details of features of the 11 Bearded Vultures out of 13 tracked by GPS-GSM transmitter between May 2016 and March 2018 in the Himalaya of Nepal.

**Table S2.** Home-range overlap within breeding male and female between seasons, male vs. female (within a breeding pair) among seasons and overall range of breeding Bearded Vultures in the Himalaya of Nepal.

**Table S3.** Home-range overlap of the Bearded Vulture with the protected areas in Nepal.