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ESTIMATION OF POPULATION DENSITY OF BEARDED VULTURES USING LINE-TRANSECT DISTANCE SAMPLING AND IDENTIFICATION OF PERCEIVED THREATS IN THE ANNAPURNA HIMALAYA RANGE OF NEPAL

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Abstract.—Bearded Vulture (*Gypaetus barbatus*) populations are declining across most of the species' global range. We studied Bearded Vultures in the Annapurna Himalaya Range of Nepal using line-transect distance sampling, and quantified the perceptions of threats to the species by interviewing local people in two different elevational areas. We recorded 35 Bearded Vultures (26 adults, 5 non-adults, 4 birds of unknown age) along a 168-km transect, yielding an encounter rate of 0.21 individuals/km. Based on distance sampling, we estimated a vulture density of 0.184 individuals/km^2 in the study area. Local people in the two

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areas perceived population status and threats to the Bearded Vulture differently. At the lower elevational range (1398–2108 m), people perceived that the vulture population is declining and that the major threats are food shortage and secondary poisoning via the use of poisons by livestock herders to kill mammalian carnivores. At higher elevations (2538–3813 m), people perceived that the vulture population is stable with no lack of food; there also was a larger prevalence of the use of vulture body parts for traditional medicine in this area. Our study suggests that unintentional poisoning, food shortage, and use of vulture body parts are the primary threats to the Bearded Vulture in the Annapurna Himalaya Range of Nepal.

KEY WORDS: *Bearded Vulture*; Gypaetus barbatus; *Annapurna Himalaya Range*; *line-transect distance sampling*; *Nepal*; *poison*; *population abundance*.

EVALUACIÓN DE LA DENSIDAD POBLACIONAL DE *GYPAETUS BARBATUS* USANDO MUESTREO DE DISTANCIA EN TRANSECTOS LINEALES E IDENTIFICACIÓN DE AMENAZAS PERCIBIDAS EN LA CORDILLERA ANNAPURNA HIMALAYA DE NEPAL

RESUMEN.—Las poblaciones de *Gypaetus barbatus* están disminuyendo en la mayor parte del área de distribución mundial de la especie. Estudiamos a *G. barbatus* en la cordillera Annapurna Himalaya de Nepal utilizando muestreo de distancia en transectos lineales, y cuantificamos las percepciones de las amenazas a la especie entrevistando a la población local en dos áreas de diferente altitud. Registramos 35 individuos de *G. barbatus* (26 adultos, 5 no adultos, 4 aves de edad desconocida) a lo largo de un transecto de 168 km, obteniendo una tasa de encuentro de 0.21 individuos/km. Basados en muestreo de distancia, estimamos una densidad de 0.184 individuos/km^2 de *G. barbatus* en el área de estudio. La población local en las dos áreas percibió el estado de la población y las amenazas a *G. barbatus* de manera diferente. En el rango de altitud inferior (1398–2108 m), las personas percibieron que la población de buitres está disminuyendo y que las principales amenazas son la escasez de alimento y el envenenamiento secundario a través del uso de veneno por parte de los ganaderos para matar a los mamíferos carnívoros. En altitudes más altas (2538–3813 m), las personas percibieron que la población de buitres es estable y que no falta alimento; también hubo una mayor prevalencia en el uso de partes del cuerpo de los buitres para medicina tradicional en esta área. Nuestro estudio sugiere que las intoxicaciones no intencionadas, la escasez de alimentos y el uso de partes del cuerpo del buitre son las principales amenazas para *G. barbatus* en la cordillera Annapurna Himalaya de Nepal.

[Traducción del equipo editorial]

The Bearded Vulture (*Gypaetus barbatus*) is distributed across the main mountainous areas of Eurasia and Africa, although it is scarce to rare throughout its range and is declining globally (del Hoyo et al. 1994, Ferguson-Lees and Christie 2001, BirdLife International 2017). Based on its small global population size and declines of 25–29% over the last three generations (53.4 yr), this species was upgraded to globally near-threatened in 2014 (BirdLife International 2017). Although there have been widespread declines in southern Africa over the past five decades (Krüger et al. 2014, 2015) and more recently in Greece (Xirouchakis et al. 2001), the population in the Pyrenees has increased from 39 breeding pairs in 1994 (BirdLife International 2017) to 116 pairs in 2015 (Botha et al. 2017). Consequently, the range of the Bearded Vulture is shrinking worldwide except in Western Europe where reintroductions have taken place in recent years (Botha et al. 2017). However, details of the species' population distribution, size, and trends across large parts of its range in Asia are less well studied, which hampers effective conservation management (Cassey 1999).

Within Asia, the Himalayan region may be an important stronghold for the species, although the Bearded Vulture is listed as a vulnerable species in the national Red Data book of Nepal (Inskipp et al. 2016). Historically, the Bearded Vulture was widespread and fairly common throughout the Himalayas (Inskipp and Inskipp 1991), and the Annapurna Himalaya Range of Nepal was a major stronghold (Gil et al. 2009). However, substantial population declines have occurred over the past two decades in the region (Acharya et al. 2010), with a notable reduction in the observed distribution, especially at lower elevations in Nepal (Inskipp et al. 2016). Conflicting population trends have been reported from the Annapurna Range. One study in the Upper Mustang area concluded that the species had undergone massive (80%) population declines between 2002 and 2008 (Acharya et al. 2010).

Another study covering roughly the same area found the population stable within a similar time period (2002 to 2006; Giri 2013). This discrepancy is likely due to differences in survey methods, and the challenges of detecting individuals while working in a difficult environment.

The rugged terrain used by Bearded Vultures, their wide-ranging behavior, and the low detectability of nest and roost sites make counting birds at their roost sites and in their nesting territories logistically challenging. Methods such as capture-recapture, nest surveys, and calling counts are commonly used to estimate the density and abundance of birds (Bibby et al. 1992). These techniques generally are not feasible for large soaring raptors in extensive mountain ranges such as the Himalayas (Fuller and Mosher 1981). Alternatively, transects by foot and/or by vehicle have often been used to study the relative abundance (Ellis et al. 1990) and population trends of raptors (Brown 1992, Virani et al. 2011, Krüger 2014), as well as to generate population estimates using distance sampling (Andersen et al. 1985).

In addition to the lack of knowledge on population demographics, limited quantitative information exists on the most important threats to the Bearded Vulture in Asia. Human persecution, intentional and unintentional poisoning, and collisions with powerlines have been reported as the major threats to vulture populations in Europe and Africa (Margalida et al. 2008, Hernández and Margalida 2009b, Barov and Derhé 2011, Ogada et al. 2012, Ogada 2014, Ogada et al. 2016, Buechley and Şekercioğlu 2016). Poisoning has been identified as a major emerging threat to vultures and other scavenging birds throughout the world (Margalida 2012, Ogada 2014). Deliberate poisoning has been reported not only where vultures are used for trade or when body parts are included in traditional medicine (Beilis and Esterhuizen 2005, Buij et al. 2016), but also where poachers try to eliminate the presence of vultures as signals of illicit activities (Ogada et al. 2016). Secondary poisoning occurs when vultures feed on poisoned carcasses deposited by livestock herders targeting mammalian carnivores (Virani et al. 2011, Ogada et al. 2016, Santangeli et al. 2016), or when exposed to residues of toxic nonsteroidal anti-inflammatory drugs in livestock carcasses (Oaks et al. 2004).

The economy of the high mountain region of Nepal is largely agro-pastoral. Wildlife and livestock share common ranges leading to high levels of human–wildlife conflict (Aryal 2013). In the Upper Mustang Region of Annapurna, more than 3% of livestock lost annually is due to predation by snow leopard (*Panthera uncia*) and other carnivores such as the common leopard (*Panthera pardus*) and wolf (*Canis lupus*; Theile 2003, Aryal 2013). Although protected areas in Nepal play a significant role in community development and wildlife conservation, the vast majority (73%) of local people are willing to kill mammalian predators in the Annapurna Himalaya Range (Mehta and Heinen 2001). Illegal use of poisoned carcasses to target these predators is common throughout the high mountain region of the Himalayas (Theile 2003), leading to high mortality rates among vultures (Hernández and Margalida 2008, 2009a, Margalida 2012). In addition, the destruction of nest sites and harvesting of body parts are threatening vulture populations in the Annapurna Himalaya Range (Acharya et al. 2010, Paudel et al. 2016).

The goals of our study were twofold. First, we aimed to estimate the population density of Bearded Vultures using line-transect distance sampling (LTDS) in a section of the Annapurna Himalaya Range where population density has been estimated in the past (Gil et al. 2009, Acharya et al. 2010, Giri 2013, Paudel et al. 2016). For more robust estimation of density, here we used statistical approaches that were lacking in above studies. Second, we conducted a survey to characterize perceptions of local people regarding the population status of the Bearded Vulture and the prevalence of the threats to the species, including nest destruction, collection and use of body parts, poisoning, hunting, trade, and reduced availability of carcasses due to changing disposal practices. Results of previous studies in this region described differences in population trends for the upper- and lower-elevation areas of the Annapurna Himalaya Range (Acharya et al. 2010, Giri 2013). We therefore also evaluated whether status and threats differ by altitude.

Methods

Study Area. We conducted our study in the Mustang, Myagdi, and Kaski districts along the Annapurna Himalaya Range of western Nepal (Fig. 1) in habitat that varied from dry trans-Himalayan landscapes to moist areas with temperate to subtropical deciduous forests. Based on the known distribution of the Bearded Vulture in Nepal (Inskipp et al. 2016), we located sampling transects close to breeding territories along 168.4 km of accessible trails between Charang in Upper Mustang in the

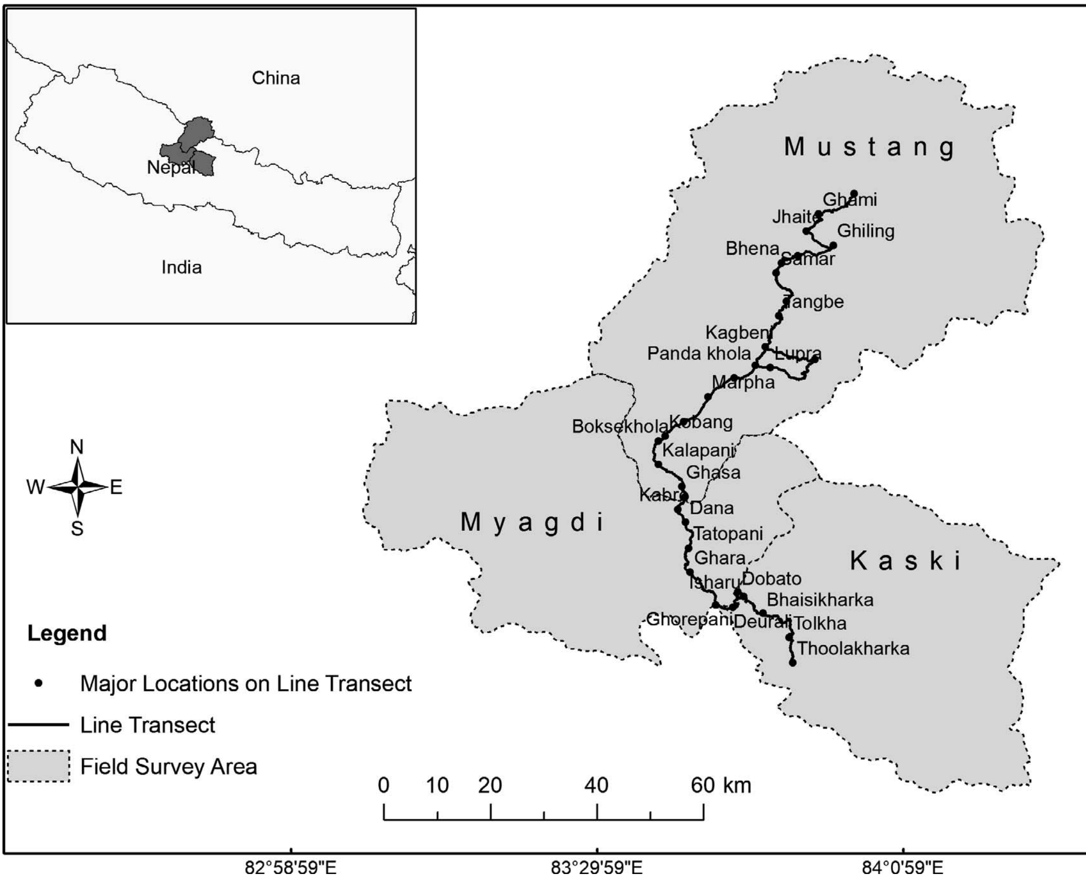

Figure 1. Location of the study area in the Annapurna Himalaya Range of Nepal, with the line transects and major landmarks within the three districts.

north to Thoolakharka in the Kaski district in the south; transects covered the entire habitat and elevation range (1176–4001 m) of the Bearded Vulture in the region. The area above 2500 m, mostly the region of Upper Mustang, has more open and arid subalpine to alpine habitat. Higher-altitude areas have lower human population densities with different cultures and traditions than lower-altitude areas. For example, Tibetan communities in Upper Mustang perform a unique funeral practice termed "sky burials," in which a human corpse is placed on the mountain for the vultures to consume.

Field Surveys. We collected data during the nestling-rearing period from 8–28 March 2016 using the LTDS method (Buckland et al. 1993). To minimize time effects, LTDS surveys (with no replication) were carried out between 0900-1600 H, the peak activity period of the species (Andersen 2007). We used a single-observer method for each survey, but two observers (TRS and SG) contributed to the dataset. We followed the protocol of Buckland et al. (1993) to meet the key assumptions of distance sampling; namely (1) sufficient length of the survey to detect an adequate number of Bearded Vultures, (2) accurate distance measurements from the transects, and (3) individuals close to transects are always detected. We also assumed that Bearded Vultures fly randomly over suitable habitat, which meets the criteria for distance sampling using foot transects. We counted all birds with no truncation distance. The Bearded Vulture is a large, unmistakable, soaring raptor, which ensured a high probability of detection while they were flying over or near the transect. We aged birds following Margalida et al. (2011). Most of the birds recorded in flight showed no response to the approach of observers.

For each encounter, we recorded direct radial distance (*r*) and sighting angle (*h*) from the transect line, and calculated perpendicular distance (*d*) as $d = r \cdot \sin h$. The distance of the bird to the line transect was determined from the initial detected location of each bird. For an accurate estimation of distance, we took reference points on the ground and later used distance categories of 25-m intervals (Buckland et al. 1993, Rivera-Milán et al. 2014).

While walking transects, we also counted the number of livestock observed and estimated other variables (see below). We categorized habitat type as closed or open, based on the presence or absence of vegetation (bushes and trees) and snow cover. The distance from the vulture to the nearest settlement and nearest road, and the slope of the mountain near the vulture were approximated.

Questionnaire Surveys. We developed a semi-structured questionnaire to gather information from local inhabitants on the perceived status and threats to the species. For our surveys, we selected livestock herders living in villages along the line transects, because they are most likely to have the deepest connection with nature and wildlife among local inhabitants in rural areas (Anadón et al. 2009, Cortés-Avizanda et al. 2018). We administered questionnaires orally in the Nepali language and included 19 questions related to perceptions of Bearded Vulture population trends and potential threats such as diminished carcass availability linked to changing livestock carcass disposal and sources of carcasses (domestic or wild), hunting/persecution, destruction of nests, poison use, and collection of vultures for trade in body parts or as medicine. Respondents were asked to answer either "yes," "no," or "don't know." If a respondent answered "yes," then we asked open-ended questions to deepen our understanding of their perceptions.

Statistical Methods. *Distance sampling.* We used DISTANCE 7.0 (Thomas et al. 2010) for the analysis of LTDS data. In addition to conventional distance sampling (CDS), multiple-covariate distance sampling (MCDS) engines with five variables (habitat type, distance to nearest settlement, distance to road, livestock number, and slope) were used for the LTDS data analyses (Buckland et al. 1993, 2001). The estimated perpendicular distance of all large soaring raptors detected from transects (vultures and eagles) was pooled for a more accurate estimation of the strip width during the survey. Because of the small sample size, we pooled all age classes of Bearded Vultures in the analyses to improve the inferences of the estimates and detection model (E. Rexstad pers. comm.). The fit of detection functions for each model was evaluated with quantile-quantile plots and goodness of fit tests (Burnham et al. 2004). The model with the lowest Akaike's Information Criterion corrected for small sample size (AIC_c) was selected as the most suitable model (Burnham and Anderson 2002).

Questionnaire surveys. In order to quantify the perceptions of local peoples on the population trend of the Bearded Vulture and to assess the prevalence of specific threats, questionnaire respondents were categorized into two groups based on elevation, either above or below 2500 m, because an earlier study showed different population trends at different elevations (Acharya et al. 2010, Giri 2013). Data from the questionnaires were analyzed in Statistical Package for the Social Sciences (SPSS), version 22. We evaluated the differences in response variables (poison use, use of body parts, food availability, nest destruction, hunting, and trade) for the two elevation ranges using a Mann-Whitney *U*-test. We used Spearman's rank order correlation to evaluate the relationships among reported population declines, food availability, and elevation.

RESULTS

Population Size and Abundance. We recorded 35 Bearded Vultures along 168.24 km of line transects: 26 (74.3%) adults, 4 (11.4%) sub-adults, 1 (2.9%) juvenile, and 4 (11.4%) individuals of unknown age. When pooled across age classes, this sample size exceeded the minimum ($n = 30$) suggested for distance-sampling analyses (Buckland et al. 1993, Boano and Toffoli 2002). We observed the Bearded Vultures at a distance range of 0–1691 m from the line transect.

In our study, quantile-quantile (*q-q*) plots and goodness-of-fit tests showed no major deviations in the Bearded Vulture data. Using a CDS engine, the fitted cumulative distribution function (*cdf*) and the empirical distribution function (*edf*) did not differ significantly (Kolmogorov-Smirnov test: $D_n = 0.068$, $P = 0.99$). Both functions were tied throughout the entire range of the data (Cramer-von Mises family tests: $W^2 = 0.0189$, $P > 0.90$, $C^2 = 0.011$, $P > 0.90$), which indicated a good model fit (Buckland et al. 2001). Based on the smallest value of AIC_c, the hazard-rate key function model with or without adjustment was the best-fitting model ($\chi^2 = 3.49$, df = 5, $P = 0.62$, Table 1) in the CDS engine. Of the five covariates used in MCDS modeling, the variables

Table 1. Model-fitting results for the analyses of line-transect distance sampling to estimate Bearded Vulture abundance (with lower to upper critical limit in parentheses) and density (per km^2 with lower to upper critical limit in parentheses) in the Annapurna Himalaya Range of Nepal. Models were developed using the conventional distance sampling (CDS) and multiple covariate distance sampling (MCDS) engines in Distance. Models were selected using Akaike's Information Criterion corrected for small sample (AIC$_c$). Key functions are half-normal (HN) and hazard-rate (HR). "None" under adjustment indicates no usefulness of the adjustment term. Bold font indicates the selected model.

COVARIATES	KEY FUNCTIONS/ ADJUSTMENT	ABUNDANCE	DENSITY	% CV	df	ΔAIC	AIC$_c$
Livestock number and distance to road	**HN/none**	**122 (60–246)**	**0.184 (0.09–0.37)**	**36.2**	**65.27**	**0.00**	**494.8**
Habitat type	HR/none	99 (58–171)	0.15 (0.09–0.26)	27.8	69.99	11.78	506.57
Distance to settlement	HR/none	115 (67–199)	0.17 (0.1–0.3)	27.8	69.99	11.76	506.55
Distance to road	HN/none	101 (57–179)	0.15 (0.087–0.27)	29.02	73.14	2.51	496.91
Livestock number	HN or HR/cosine	111 (65–189)	0.17 (0.1–0.28)	27.1	67.88	11.58	506.38
Slope	HR/none	107 (62–184)	0.16 (0.09–0.28)	27.9	70.29	12.84	507.64
None	HR/none	122 (57–264)	0.184 (0.08–0.39)	39.9	60.65	10.40	504.8

livestock number and *distance to road* together, with half-normal key function, provided the best model fit (AIC$_c$ = 494.8, ΔAIC = 0, Table 1) to the LTDS data (Fig. 2a, 2b, 2c). The *q-q* plot of the best MCDS model showed that fitted *cdf* and *edf* did not differ significantly ($D_n = 0.15$, $P = 0.41$), and tied over the entire range of the data ($W^2 = 0.16$, $P > 0.3$, $C^2 = 0.098$, $P > 0.3$), indicating a good model fit of the LTDS data. Based on the MCDS detection model with the covariates *livestock number* (Fig. 2b) and *distance to road* (Fig. 2c), the estimated density along the transect area was 0.184 individuals/km^2 (95% CI: 0.09–0.37, SE = 0.066, CV = 36.2%, df = 65.27; Table 1). The effective strip width was 565.5 m (SE = 159.7, CV = 28.25%, df = 32, 95% CI: 322–994), the detection probability was 0.33 (95% CI: 0.19–0.58, SE = 0.094, CV = 28.25, df = 32), and the percentage of variance (D) for detection probability was 60.9%. Overall, the encounter rate of Bearded Vulture on the line transects was 0.21 individuals/km (CV = 22.63%, df = 41, 95% CI: 0.13–0.33), and the percentage of variance (D) for the encounter rate was 39.1%. Based on the fitted MCDS model, the estimated total population of Bearded Vulture in the surveyed area of the Annapurna Himalaya Range was 122 individuals (95% CI: 60–246 individuals, SE = 44.15, CV = 36.19%, df = 65.27). No other models were informative (ΔAIC >2; Burnham and Anderson 2002).

Local Knowledge on Population Trends and Threats. We interviewed 34 respondents, 30 males aged from 33–85 yr and four females aged 40–61 yr (21 people in the higher- and 13 people in the lower-elevation area). There were significant differences in the perceived vulture population trend ($U = 70.5$, $P < 0.01$) between the two elevational ranges: 11 (84.6%) of 13 people at lower altitudes agreed that the Bearded Vulture population was declining, while at high elevations 15 (71.4%) of 21 people agreed that the population was stable although two (9.5%) of 21 people from the higher-elevation group agreed that the population was declining and four (19.0%) did not know.

Poisoning, use of body parts in trade or medicine, and food (carcass) shortage were identified as major threats to the Bearded Vulture (Table 2). There was a significant difference in the level of agreement with the statement that use of poison was a threat to Bearded Vultures between respondents at the two elevation ranges studied ($U = 82.5$, $P = 0.04$), with 54% ($n = 7$) of respondents at the lower elevation reporting that people use poison, compared with 38% ($n = 8$) at the higher elevation (Table 2). Perception that the use of vulture body parts was a threat also differed significantly ($U = 79.5$, $P = 0.02$) between higher-elevation survey participants (81%, $n = 17$) vs. those at lower elevations (23%, $n = 3$). At higher elevation, 9.5% ($n = 2$) of respondents perceived the lack of food (availability of carcasses) as a threat to the Bearded Vulture compared to 84.6% (n = 11) of people at lower elevations ($U = 34.5$, $P < 0.001$). Corresponding well with these local perceptions, carcass availability was highly correlated with altitude ($r_s = 0.717$, $P < 0.001$). Other factors presented to the respondents as potential threats to vultures (collection of nestling/eggs, destruction of nests, hunting and trade) were not perceived to be threats except by one of the respondents (Table 2).

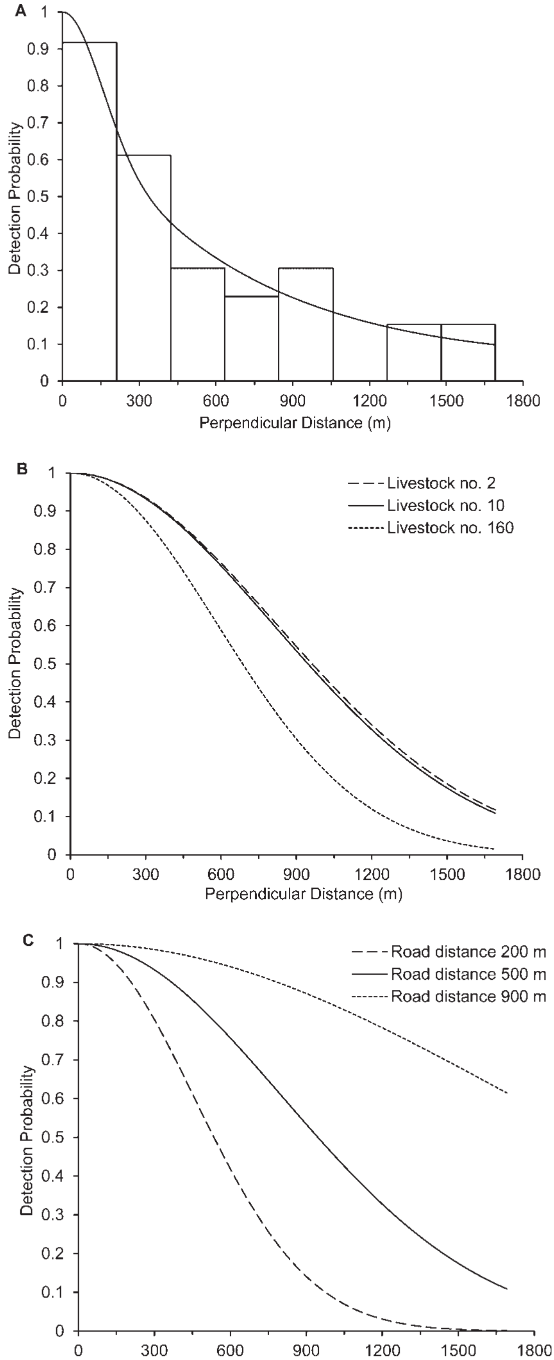

Figure 2. Histograms of detection of Bearded Vultures along line transects: (a) a half-normal detection function of Bearded Vultures from the line transects using the multiple covariate distance sampling (MCDS) engine with covariates livestock number and distance to road and fitted detection curve ($\chi^2 = 3.42$, df = 4, $P = 0.48$). (b) Detection probability of Bearded Vultures as a function of distance with the covariate livestock number. Detection probability presented under conditions of 2, 10, or 160 livestock detected within the surveyed area. (c) Detection probability of Bearded Vulture with the covariate distance to the road depicted at three distances.

DISCUSSION

Bearded Vulture Population. Our study was the first to use a distance-sampling approach for estimating Bearded Vulture populations and indicates that the Annapurna Himalaya Range supports a relatively high density of individuals compared to other parts of the global distribution. Our calculated density of 0.184 birds/km^2 (approximately equal to 0.137 adults/km^2 based on the proportion of adults in our sample) exceeds estimates for southern Africa (0.019 birds/km^2, 0.007 adults/km^2; Krüger et al. 2014), the Pyrenees (0.003 adults/km^2; synthesized from Margalida et al. 2016, Botha et al. 2017), the central Alps (0.007 adults/km^2) and western Alps (0.003 adults/km^2; Jenny et al. 2018), Greece during the mid-1980s (0.006 birds/km^2) and Crete during the late 1990s (0.013 birds/km^2; Xirouchakis et al. 2001). Because of the small sample size, we pooled all individuals (adults and non-adults) in our analyses and it was not possible to estimate the breeding density of vultures in our study area. We strongly recommend that future studies develop a larger sample of breeding individuals to provide a more robust estimate of the breeding population. Computing density estimates for our data following the methods used by Acharya et al. (2010) produced a similar density estimate (0.08 birds/km^2) to the estimates of these authors (0.07 birds/km^2) for the Jomsom to Charang area in Upper Mustang. Similarly, our density estimates were 0.05 birds/km^2 for the Kagbeni-Muktinath-Lupra-Pandakhola transect using this simplified approach and 0.04 birds/km^2 for the lower-elevation area (Jomsom to Thoolakharka). The latter findings also match the perceptions of the local inhabitants that the population in the higher-elevation range has been stable over the last decade (see below).

Local Knowledge on Population Trends and Threats. Local people in the Annapurna Range perceive that the Bearded Vulture is declining at the lower altitudes (<2500 m) but not in the higher areas; people identified poisoning, food shortage, and the use of body parts in traditional medicine as

Table 2. Threat information obtained from surveys of local community members. Results are number of positive responses of the total response in higher-elevation areas ($n=21$) and lower-elevation areas ($n=13$), and results of Mann-Whitney U-test.

	Positive Responses % (n)		Difference Between Elevations	
Threat Information	Higher Elevation	Lower Elevation	U-value	P-value
Use of poison	38 (8)	54 (7)	82.5	0.04
Use of body parts	81 (17)	23 (3)	79.5	0.02
Food shortage	10 (2)	85 (11)	34.5	< 0.001
Hunting	0	0	130	0.43
Nest-site destruction	0	0	130	0.43
Collection of egg/nestling	0	8 (1)	123.5	0.25
Local trade	5 (1)	0	123.5	0.25

the most prevalent threats. Other potential threats, such as direct persecution (hunting, nest destruction), collection of eggs, and local trade were infrequently identified. Territory abandonment by the Bearded Vulture has been reported at lower elevations in southern Africa (Simmons and Jenkins 2007) and the species is now rare at lower elevations in Nepal (Inskipp et al. 2016). In our study area, food shortage (noted by 85% of respondents) and poisoning (noted by 54% of respondents) were identified as threats at lower elevations where the species was also believed to be declining. By contrast, only the use of body parts (81% respondents) was perceived as a major threat at high elevations. As in our study, anthropogenic threats were identified as having a strong influence on territory abandonment by Bearded Vultures in southern Africa (Krüger et al. 2015) and the population decline in the Pyrenees (Margalida et al. 2008, Margalida 2012) and Balkans (Parvanov et al. 2018).

Medium-sized domestic and wild ungulates are the most preferred prey items of Bearded Vultures (Brown and Plug 1990, Margalida et al. 2009). The perception that food is scarce at lower altitudes, due to decreasing livestock populations and a lower density of wild ungulates when compared to high elevations, may reflect real differences in food availability that affect the abundance of the Bearded Vulture. Decreased livestock could be the result of a decrease in the number of livestock herders due to the migration of laborers to more urban areas (Government of Nepal 2016). However, this effect may be localized, as livestock populations in Nepal actually increased by 19.6% between 1997 and 2014 (Government of Nepal 2017). There may also be differences in livestock carcass availability for scavengers due to varied or changing disposal methods. At higher elevations, dead livestock are left in meadows away from villages, whereas carcasses are more likely to be buried as quickly as possible in lower-elevation communities for sanitary reasons, thus reducing the amount of available food.

Though vultures generally are perceived as a beneficial ecosystem service providers, livestock herders believe that the majority of facultative scavengers are harmful (Morales-Reyes et al. 2018). This could lead to illegal activities to control facultative scavengers or predators, a factor reflected in the high proportion of respondents to our survey who believed that if mammalian carnivores kill livestock then the owner of the livestock will poison the carcass as a retaliatory measure. Although the intensity of poisoning may vary, this behavior is similar to cases in Africa in which livestock keepers frequently poison carcasses to exterminate predators, which has subsequently caused vulture populations to crash in the Afro-tropical region (Ogada et al. 2016). According to information from our local respondents, they use indigenous herbs (e.g., *Aconitum* spp.), which are highly toxic to both mammals and birds (Chan 2009, T. Subedi unpubl. data).

The Buddhist people of the Annapurna Himalaya Range in Upper Mustang believe that vultures are a symbol of a god and that they help to carry the soul of the deceased to heaven when vultures feed on the carcass at a "sky burial" site. Accordingly, the killing and hunting of the Bearded Vulture to use body parts as traditional medicine and the destruction of the nest to collect eggs/nestlings were reportedly infrequent in this region. However, our work also suggested that demand for vulture body parts exists and may be high in the local community; 60% of respondents believed that vulture body parts cured several diseases and they reported others collecting the parts when dead Bearded Vultures were found.

We used distance-sampling techniques in this study to provide more robust estimates of current vulture abundance. A long-term monitoring program of the Bearded Vulture population using similar methods should be considered to estimate population trends in Nepal. Distance sampling works best with observations of animals that are not moving and when the species is relatively common (Boano and Toffoli 2002). Despite these considerations, the detection model of our study fit the Bearded Vulture LTDS data adequately. Our study also documented the threats to Bearded Vultures in the Annapurna Himalaya Range perceived by local people. Future conservation programs should take into consideration these perceptions when developing strategies to improve Bearded Vulture survival in the Himalaya Range of Nepal.

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