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Source: Wildlife Biology, 2021(4)

Published By: Nordic Board for Wildlife Research

URL: https://doi.org/10.2981/wlb.00877

Wildlife Biology 2021: wlb.00877
doi: 10.2981/wlb.00877

Subject Editor: Shin-Jae Rhim. Editor-in-Chief: Ilse Storch. Accepted 30 August 2021

Applying the double observer methodology for assessing blue sheep population size in Nar Phu valley, Annapurna Conservation Area, Nepal

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This study was undertaken in spring, 2019 to assess the applicability of the double-observer survey method for estimating blue sheep *Pseudois nayaur* abundance in Nar-Phu valley of Manang District located in Annapurna Conservation Area of northern Nepal. Since counting large mammals in rugged mountain habitat poses a special challenge, we tested the efficacy of the double observer method for generating robust population estimates for this important protected area. The overall detection probability for observers (O1 and O2) was 0.94 and 0.91 for a total of 106 groups comprised of 2059 individual blue sheep. We estimated the area's blue sheep population at 2070 (SE ± 168.77; 95% CI 2059–2405) for the 246.2 km^2 of sampled habitat. We determined blue sheep to be widely distributed within the study area with a mean density of 8.4 individuals per km^2 based on a total study area of 246.2 km^2. We discuss demographic population structure and identify limitations when applying the double observer approach, along with recommending viewshed mapping for ensuring more robust density estimates of mountain-dwelling ungulates like blue sheep or ibex that inhabit extremely heterogeneous terrain which strongly influences sighting distances and overall animal detection rates.

Keywords: blue sheep, density estimation, double observer counts, Nepal, *Panthera uncia*, prey abundance, *Pseudois nayaur*, snow leopard, viewshed mapping

Blue sheep *Pseudois nayaur* represent the main wild prey for snow leopards *Panthera uncia* occupying the Himalaya Mountains as well as the Tibetan Plateau (Schaller et al. 1988). In Nepal, blue sheep constitute up to 40% of this carnivore's diet (Oli et al. 1993, Wegge et al. 2012, Devkota et al. 2013, Chetri et al. 2017). Thus, the health of these snow leopard populations is largely contingent upon the availability and abundance of blue sheep, which represents the predominant large ungulate across some 60% of snow leopard range. Most of Nepal's mountain protected areas (PAs), along with many unprotected landscapes harbor blue sheep, including the Annapurna Conservation Area (ACA), Shey Phoksundo National Park (SPNP) and the Kangchenjunga Conservation Area (KCA). The Nar-Phu Valley of Manang district, located within ACA, has snow leopard-blue sheep-vegetation, including livestock and small mammals such as pikas, voles and lagomorphs with snow leopards influencing blue sheep numbers that in turn modify vegetation cover (Wegge et al. 2012). Monitoring blue sheep populations (along with livestock) in this alpine ecosystem may highlight early signs of change in rangeland health over time, presuming repeated surveys include concurrent assessment of human–wildlife–livestock interactions.

Lack of baseline data on ungulate population size and related dynamics is often attributed to the difficulty of detecting and enumerating these key mountain inhabitants. Standardized methods for counting ungulate populations and characterizing their age structure were primarily designed for relatively smooth-sloping, accessible landscapes and include distance sampling (Buckland et al. 2001, Liu et al. 2008, Corlatti et al. 2015) and strip counts (Eberhardt 1978). Until development of the double observer method (Suryawanshi et al. 2012), most researchers working in mountainous landscapes employed the fixed-point count approach (Harris 1994, Jackson and Hunter 1996, Elphick 2008) which fails to adequately address observation-related errors: these include difficulties in detecting animals distributed over different spatial scales or terrain conditions; field observation factors preventing an unknown proportion of the population from being detected; and factors affecting researcher ability to quantify replicability when counting animals, given often difficult logistics and site accessibility (possibly precluding access to habitat known or suspected to be occupied by the targeted species); insufficiently trained observers, limited technical oversight, insufficient funding and several human observational errors. Thus, estimating ungulate abundance in Asia's mountainous areas represents major challenges, and readers are referred to Huapeng et al. (1997) and Singh and Milner-Gulland (2011) for more detailed discussion of the various approaches toward enumerating large mountain ungulates.

This study presents the first use of the double observer (hence-forth termed DO) survey method in Nepal. Suryawanshi et al. (2012) adapted this approach as originally proposed by Forsyth and Hickling (1997) to account for observation-related space and time factors. The two most important assumptions for DO surveys are 1) animal groups (i.e. blue sheep herds) must be reliably and individually identifiable (since the study population did not include artificially tagged animals, we relied upon cues from group size, age–sex classification, individuals with distinctive phenotypic features (e.g. mishappen horns) and sighting location; and 2) the population must remain closed during the survey period. The DO method allows for sampling error estimation, enabling more robust confidence levels to be assigned to resulting population estimates (Thinley et al. 2018, Suryawanshi et al. 2020). While comparable topographic conditions prevail in Bhutan (Thinley et al. 2018), Pakistan (Khattak et al. 2019) and Kyrgyzstan (Khanyari et al. 2021), the DO approach has yet to be widely applied for ungulates outside of Asia. Secondly, standardized procedures for estimating the proportion of land area visible to observers within survey blocks are important for search visibilities along transects vary substantially, even over short distances due to the rugged and variable mountain terrain.

Therefore, our study's objectives were to 1) assess the applicability of the DO method for estimating blue sheep abundance for a representative Nepal population, 2) explore the efficacy of applying GIS-generated viewshed mapping for quantifying extent of land visible to the surveyors exemplified using a representative transect; and 3) discuss findings, including survey limitations and offer further improvements to the DO method aimed at improving monitoring by protected areas staff for this important ungulate species.

Material and methods

Study area

The Nar-Phu Valley is located in northern Nepal (28°40′–28°50′N, 84°5′–84°13′E, Fig. 1) within the ACA, a community-designated protected area providing good-high quality habitat for blue sheep and snow leopard (although continuing to be negatively impacted through people–wildlife conflict and habitat degradation). Due to an abundance of pasturage, local people have traditionally maintained relatively large herds of yaks, horses, goats, sheep and cattle, making livestock holding an important economic activity at both household and community levels (Shrestha and Wegge 2008). The study area is remote, a two day walk from the nearest road-head (Koto), seasonal airstrip (Humde) and the district headquarters at Chame. The valley's human population totals 538 persons, making it among Nepal's least populated area. The community comprises traditional Tibetan ethnicity, with few external influences affecting their way of life until relatively recently, with tourism and collection of medicinal plants and yarsagumba *Cordiceps* (a caterpillar fungus) offering lucrative alternative business opportunities for local people. Trading plays an important supporting role in this subsistence economy, where local people practice Buddhism with the killing of any living creature deemed sinful.

Methods

Delineation of study area and survey blocks

Blue sheep habitat ranges from about 3000 to 5400 m a.s.l. across much of Nepal (Jackson and Hunter 1996), and we selected this altitudinal range using Government of Nepal (Government of Nepal 2001) 1:50 000 topographic maps to delineate sampling blocks. Within the Nar-Phu Valley (total area 835.9 km^2) we estimated suitable habitat for blue sheep at 322.4 km^2 (Fig. 1), of which we surveyed 246.2 km^2 after excluding areas with excessively steep terrain (> 40 degrees) judged too inaccessible for surveying.

Prior to field visits, potential blue sheep habitat was outlined on topographic maps by team members familiar with the study area, including the first observer (O1) who had conducted several intensive blue sheep surveys earlier (Thapa 2005, Sharma et al. 2006). By plotting livestock pasture boundaries using ArcView ver. 10.7.1, and examining contour maps along with Google Earth images, we identified 11 watershed-based survey blocks for sampling (Fig. 2). Each survey block is separated by high mountain ridges or a large river, with the expectation that such geographic features limit blue sheep movement between different survey blocks during sampling intervals.

To ensure the entire study area was adequately covered, each survey unit (hereby termed, sampled block) ranging in size from 10.4 km^2 to 36.8 km^2, was divided into relatively small sections for survey purposes (Fig. 2, Table 1) as recommended by Suryawanshi et al. (2012) and the Government of Nepal (MoFSC 2017). Additional information included dominant habitat type, presence/absence of topographic barriers, dominant aspect and slope steepness and major landform type(s) along with a generalized map of habitat suitability for blue sheep covering the entire survey region. We also utilized a WWF-Nepal generated habitat suitability map for snow leopard (DNPWC 2017). We excluded non-habitat (rock, ice, snowfields), with prime and fair blue sheep suitability habitats comprising 49% and 51% respectively of the sampled area. We considered open forest, alpine grassland and barren habitats to offer suitable foraging habitat for blue sheep. The proportions of land use were barren land (56.3%), grassland (40.8%), forest cover (1.4%) and shrubland (0.89%). We excluded agricultural land, permanent water bodies and snow cover/glaciers from the areal calculations.

Census scheduling and protocols

Using the DO method, each sample block was sampled sequentially, following from one sample block to the adja-

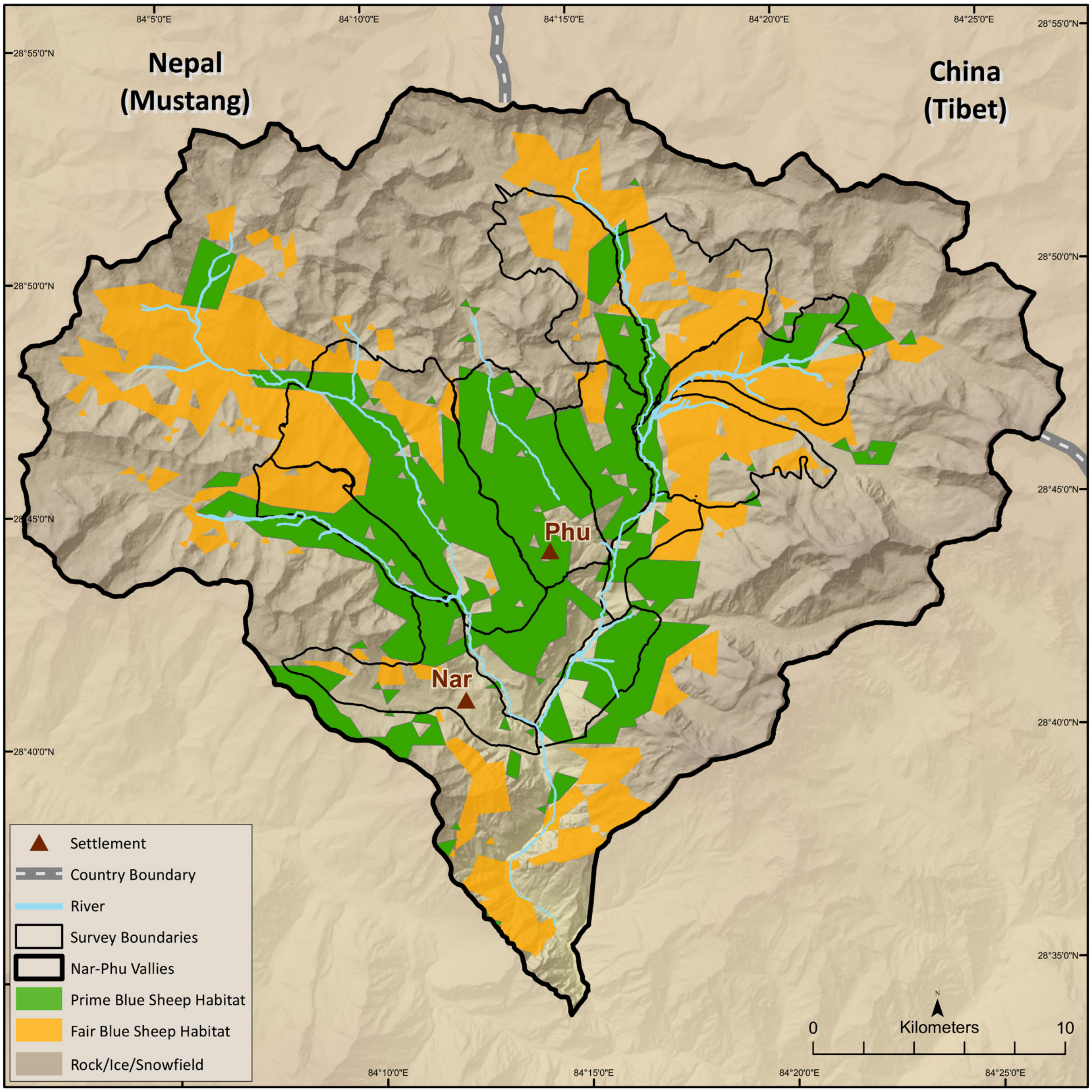

Figure 1. Potential habitat for blue sheep in Nar Phu valley, Manang district of Annapurna Conservation Area, Nepal (for names of survey pasture blocks, Fig. 2).

cent block for ensuring consistency and to minimize double counting between consecutive days by identifying individually distinctive animals in order to distinguish between different herds to the extent feasible. In each sampled block, we laid a transect using existing herder or livestock trails that offered the best viewing opportunities and provided practical altitudinal gradients, starting from the lowest elevation (typically a river or large stream), and terminating on or near cliffs, rocky outcrops or ridgelines at upper elevations. This chosen uphill pattern also generally coincided with the daily movement patterns of blue sheep (Thinley et al. 2018), which are known to descend to valleys in early morning for drinking water and then progressively ascend (while foraging along the way) and eventually reaching more secure areas (often ridge tops) by dusk where they bed down for the night (Schaller 1973). During spring, most blue sheep are concentrated in or near valleys, uninhibited herder camps or the vacated agricultural lands, the main places for foraging on grass at this time of year. We also scanned the opposite site of valleys from vantage points, using binoculars and spotting scope. We set a conservative upper limit of about one kilometer for the distance at which blue sheep can consistently be detected (Filla et al. 2020).

On each survey day, the first observer (O1) walked slowly (about 2 km h^{-1}) uphill, commencing at 06:30 h (Nepal Standard Time; dawn 06:00 h) and finishing at around 11:30 h. The second observer (O2) followed the same trail after an interval of one hour, as suggested by Suryawanshi et al. (2012). Although O1 and O2 commenced their surveys an hour apart, they often completed the transect around the same time, then taking a 2-h lunch while the blue sheep also bedded down to rest (and are thus harder to detect than when moving and foraging). The second daily survey, following the same pattern, was initiated around 14:30 h and

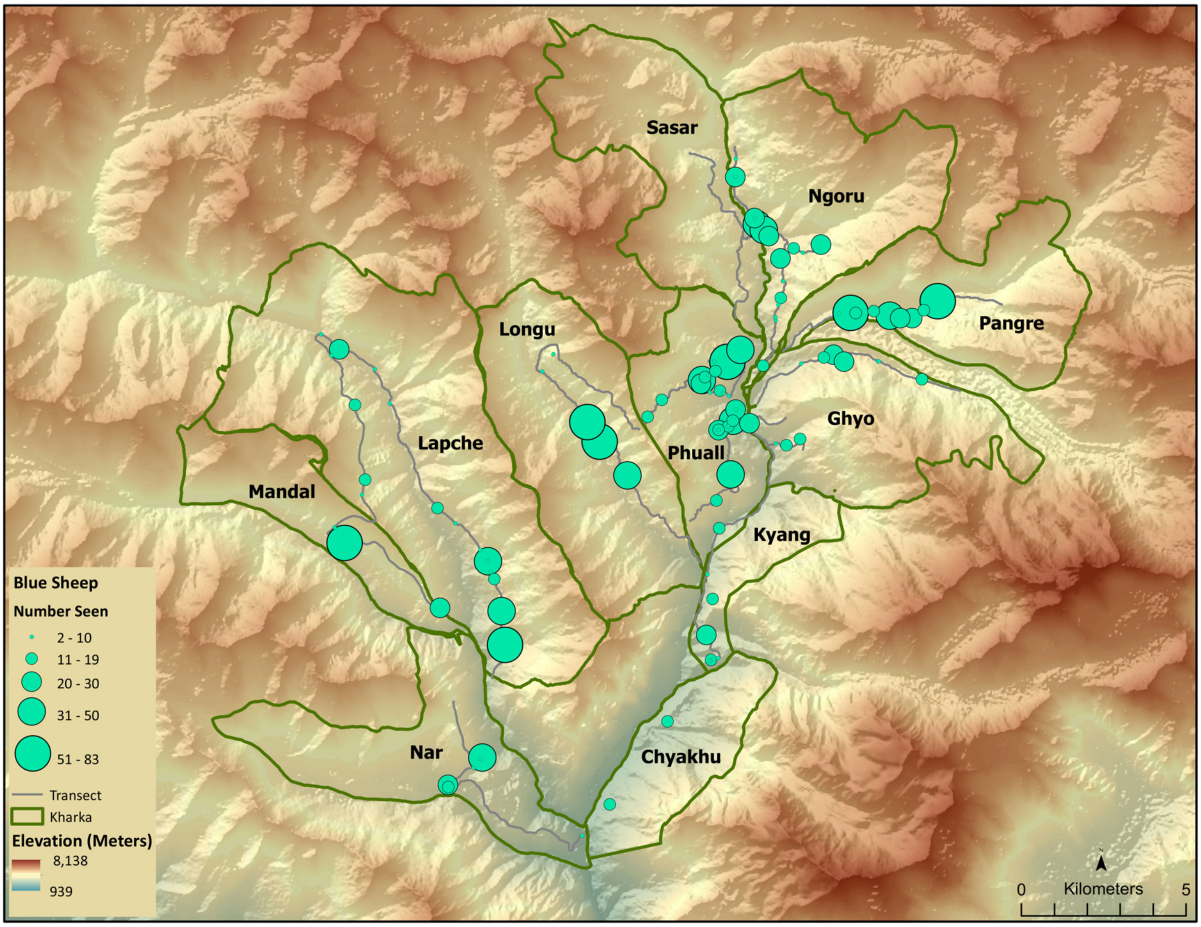

Figure 2. Sample blocks and blue sheep counts recorded during the survey of 11 survey blocks in Nar Phu valley, Manang district of Annapurna Conservation Area, Nepal.

continued until about 17:30 h. Whenever a blue sheep group was sighted, each observer stopped to record details, assisted by a village assistant serving as local guide, and who was provided with on-the-job training.

In order to meet assumptions of the DO method, including population closure, we completed all 11 study area block counts within 22 consecutive days including travel time. As noted above, each survey block was separated by high ridges, large glaciers or rivers, thus reducing likelihood of individual or group movement in or out of the sampling area, but not entirely eliminating that possibility. Separation of O1 and O2 observer surveys by 1-h is aimed at fulfilling the second assumption of independence, namely that the two observer surveys represent independent samples of the entire popula-

Table 1. Total individual and group counts observed by two observers during spring, 2019 in Nar Phu valley, Manang, ACA. Table describes sampled block name, area of survey in each sampled block, sex and ages of blue sheep, Group number denote total number of blue sheep group within the sampling block, FE denote adult female (more than two years), YO denote young (below one year age of both male and female), YE denote yearling (in between one and two year ages of both male and female), YM denoted young-aged male (male above two and below four years), MM denote middle-aged male (male above five and below seven years), AM denote adult-aged male (male above seven years) and UI denote unidentified (all ages both male and female) Thapa (2007) adapted from Wegge (1979).

SN	Sampled block	Area (km²)	Group number	FE	YO	YE	YM	MM	AM	UI	Total	Density per km²
1	Kyang	10.9	8	30	14	12	3	6	14	1	80	7.3
2	Ghyo	33.5	15	74	46	33	33	20	32	0	238	7.1
3	Pangre	21.2	9	100	50	38	23	18	21	23	273	12.9
4	Ngoru	25	13	88	52	27	17	20	43	0	247	9.9
5	Sasar	24	6	33	21	14	3	8	11	4	94	3.9
6	Phoo	16.3	22	143	88	54	43	29	58	9	424	26.2
7	Longu	30.1	5	44	34	19	17	10	19	24	167	5.5
8	Lapche	36.8	16	84	53	42	25	23	35	20	282	7.7
9	Mandal	13.8	4	40	30	20	15	7	16	1	129	9.3
10	Nar	22	5	28	23	10	11	6	10	3	91	4.1
11	Chyakhu	12.6	3	12	6	6	2	2	6	0	34	2.7
Overall		246.2	106	676	417	275	192	149	265	85	2059	8.4

tion. Based on computer modeling of field data Suryawanshi et al. (2012) deemed this temporal spacing adequate for minimizing detectability responses associated with O1's presence ahead of O2.

The DO survey method requires that each blue sheep group detected be uniquely identifiable based on herd composition and presence of individuals with distinctive body features (e.g. one animal with only one horn, another with a broken horn tip, furless patches on the body or other injuries and separable physical features). Each observer made note of such characteristics when classifying individuals to sex and age class, along with documenting key characteristics for each observation site (e.g. dominant geophysical feature, presence/absence of herder's camp, distance nearest cliff or other prominent landmark). These elements supported the post hoc evaluation of uniquely detected blue sheep groups by helping O1 and O2 match (or mismatch) each sighting and/or group through cross-referencing them with distinctive individuals and site-locations. Binoculars (10 × 50 power) and, whenever possible, a 15–30–45× spotting scope were used for validating total herd size and individual sex–age classes. We based the classes on size, body pattern and coloration, and size and shapes of horns following Wegge (1979, as simplified by Thapa 2007), recognizing the following classes: young (male and female) (< 1 year of age); yearling (male and female) (1–2 years age); adult female (> 2 years age); young-aged male (2–4 years); medium-aged male (4–6 years); and adult-aged male (> 7 years age) with fully grown horns.

The geographical center for each blue sheep group was estimated to the nearest 100 m using a GPS. We also recorded the habitat type(s), topographic feature, landform ruggedness class, aspect, slope and distance to the nearest escape cover along with the distance between observer and center of each group (Jackson and Hunter 1996; however, the compass direction from observer to each group was not taken).

At the conclusion of each day's field survey, the two observers met to reconcile and agree which groups should be designated as uniquely or commonly observed, aware that slight variations with respect to group number and/or sex–age composition may influence consensual decision-making. Therefore, for each herd tallied, the survey team evaluated total herd size, sex and age classes along with individuals with distinctive features (like misshapen horns found in female blue sheep), sighting location and the time of observation to help determine which blue sheep groups were likely sighted by both observers (common), or conversely which could be classified as unique and observed by only one observer (Harris 1994).

Viewshed mapping

Using the example of the Pangre survey block, we evaluated the utility of viewshed mapping for defining the extent of each survey block visible to observers as they walked along the transect scanning for blue sheep. A viewshed is defined as the geographical area that is visible from each location or a series of linked locations (i.e. along the entire transect length). Viewsheds include all surrounding areas that fall within line-of-sight from the transect centerline while observing from multiple locations, but excludes points fall-

Table 2. Showing abundance estimate of blue sheep populations obtained using double-observer survey in 11 sampled blocks of Nar Phu valley, ACA, Manang where C, number of groups seen in both surveys; S1, number of groups seen in first survey only; S2, number of groups seen in second survey only; Ĝ, estimated number of groups; N, estimated population; SE ±, standard error of estimated population; O1, O2, mean of the estimated detection probability for observer one and two, respectively and Overall estimates obtained from pooled data from all blocks.

	Phoo Valley							Nar Valley				
Variable	Kyang	Ghyo	Pangre	Ngoru	Sasar	Phoo	Longu	Chyakhu	Nar	Mandal	Lapche	Overall
C	8	11	9	11	6	19	5	2	4	3	13	91
S1	0	1	0	1	0	2	0	1	0	1	3	9
S2	0	3	0	1	0	1	0	0	1	0	0	6
Ĝ	8	15.3	9	13.1	6	22.1	5	3	5	4	16	106.6
N	80	242	273	249	94	426	167	34	91	129	282	2070
Var (N)	240	1610.6	4326.8	2046	1300	4796.4	3449	75	880	4944	4479	28 484
Mean group size	10	15.9	30.3	19	15.7	19.3	33.4	11.3	18.2	32.3	17.6	19.4
SE ±	15.5	41.2	65.9	45.2	36.1	59	58.7	8.7	29.7	70.32	66.9	168.7
± 95% CI	30.8	79.7	130.6	89.8	71.6	137.5	116.6	17.2	58.9	139.6	132.9	335.1
Total area (km²)	10.9	33.5	21.2	25	24	16.3	30.1	12.6	22	13.8	36.8	246.2
Density per km²	7.3	7.1	12.9	9.9	3.9	26	5.5	2.7	4.1	9.3	7.7	8.4
Distance walked per survey (km)	18.4	49.2	22	34.4	28	48	33.2	22	34	20	80	389.2
O1	1	0.8	1	0.92	1	0.95	1	1	0.8	1	1	0.94
O2	1	0.92	1	0.92	1	0.9	1	0.7	1	0.8	0.8	0.91

ing beyond the horizon or areas obstructed by terrain, rocky outcrops and other large obstacles.

Using the ArcMap GIS software tools Spatial Analyst Viewshed tool, with the 30m DEM from the Shuttle Radar Topography Mission (SRTM) (<https://earthexplorer.usgs.gov/>) as input, we generated viewsheds for eight randomly selected observation points along the 6.7-km Pangre Pasture transect (Fig. 3). The viewshed rasters of each observation point were merged into a single coverage representing the cumulative land area visible along the entire length of Pangre transect, but clipped to the Pangre survey block boundary. A 2-km buffer was placed around this transect, by adding one kilometer to either side, thereby indicating the areal extent most likely visible to each observer, along with areas hidden by ridgelines, hillsides or other large topographic features. We then computed the total visible land area and reported it as a percentage of the survey block deemed visible to both observers (Table 4).

Data analysis

We used the computer simulation Excel spreadsheet provided by Suryawanshi et al. (2012) for estimating blue sheep population size. Observer group detection rates and the ratio of the sum of the number of groups were derived from the number of groups seen by both observers, and the number of groups seen by only one of the two observers. Densities were computed assuming a 246.2 km^2 survey area.

Results

Population size and structure of blue sheep

The blue sheep population survey was conducted from 24 April to 15 May 2019, a period representing the spring season, with each observer sampling 389.2 km of transect. We surveyed an estimated total area of 246.2 km^2 representing blue sheep habitat within 11 sampling blocks (size range: 10.9–36.8 km^2) (Table 1). Out of a total of 2059 individual blue sheep observed among 106 groups (Table 1, Fig. 2), O1 sighted 100 groups for a total of 2004 individual blue sheep, while O2 observed 97 groups containing 1981 individuals in all. The mean group size of blue sheep, as estimated during the survey, was 19.4 (SE $\pm$ 1.6) with a range of 2–83 individuals ($n = 11$ survey blocks; $n = 106$ groups detected).

Thus, the detection probability was 0.94 and 0.91 for observers' O1 and O2 respectively (Table 2). Using this method, we estimated the total population of blue sheep in the Nar-Phu Valley at 2070 individuals (SE $\pm$ 168.77; 95% CI 2059–2405) within the designated survey blocks (Table 2). The overall sex ratio was 90 males per 100 females, varying from 62 to 115 males per 100 females for the blocks sampled (Table 3). The young to female ratio was estimated at 63 young per 100 females over the survey period with the proportion of young amounting to 20.3% of the total population. The ratio of yearlings (male and female) to adult female was 42 per 100 females, but this ratio also differed between sampled blocks ($n = 11$) as indicated in Table 3.

Viewshed analysis

Figure 3 illustrates the geographic area or viewshed which is visible at various points to observers walking along Pangre, a typical transect, while Fig. 4 depicts one-kilometer-wide buffer either side of the transect line, showing the cumulative visible and obscured sections. We estimated the visible total proportion of this survey block at 48.6% or 10.3 km^2, based on a total block area of 21.2 km^2 (Table 4). Similar metrics could be generated for the other 10 transects completed during our survey and applied to adjust density estimates if so desired.

Discussion

Comparison with blue sheep density and population structure with other studies

We estimated the mean density of blue sheep in Nar-Phu at 8.4 km^{-2}, a relatively high number which is generally similar to surveys employing other techniques conducted in neighboring parts of Nepal's Manang District over the past 25 years (e.g. 6.6–10.2 km^{-2} Oli 1994, 8.4 km^{-2} Wegge et al. 2012, 5.9 km^{-2} Chetri et al. 2017). Other observers have reported notably lower blue sheep numbers: for example, Aryal et al. (2014) observed 0.86 individuals km^{-2} in upper Mustang, while Devkota et al. (2013) and Thapa (2013) recorded similar densities 2.3 individuals km^{-2} in upper Mustang of ACA

Table 3. Showing ratio of female to male, young, yearling respectively and yearling to young (during spring season 2019 in Nar Phu valley, Manang, ACA).

SN	Block	Ratio in 100 individuals			
		Male:Female	Young:Female	Yearling:Female	Young:Yearling
1	Kyang	77	47	40	86
2	Ghyo	115	62	45	72
3	Pangre	62	50	38	76
4	Ngoru	91	60	31	52
5	Sasar	67	63	42	67
6	Phoo	91	62	38	61
7	Longu	104	77	43	56
8	Lapche	99	63	50	79
9	Mandal	95	75	50	67
10	Nar	96	82	36	43
11	Chyakhu	83	50	50	100
Overall		90	63	42	66

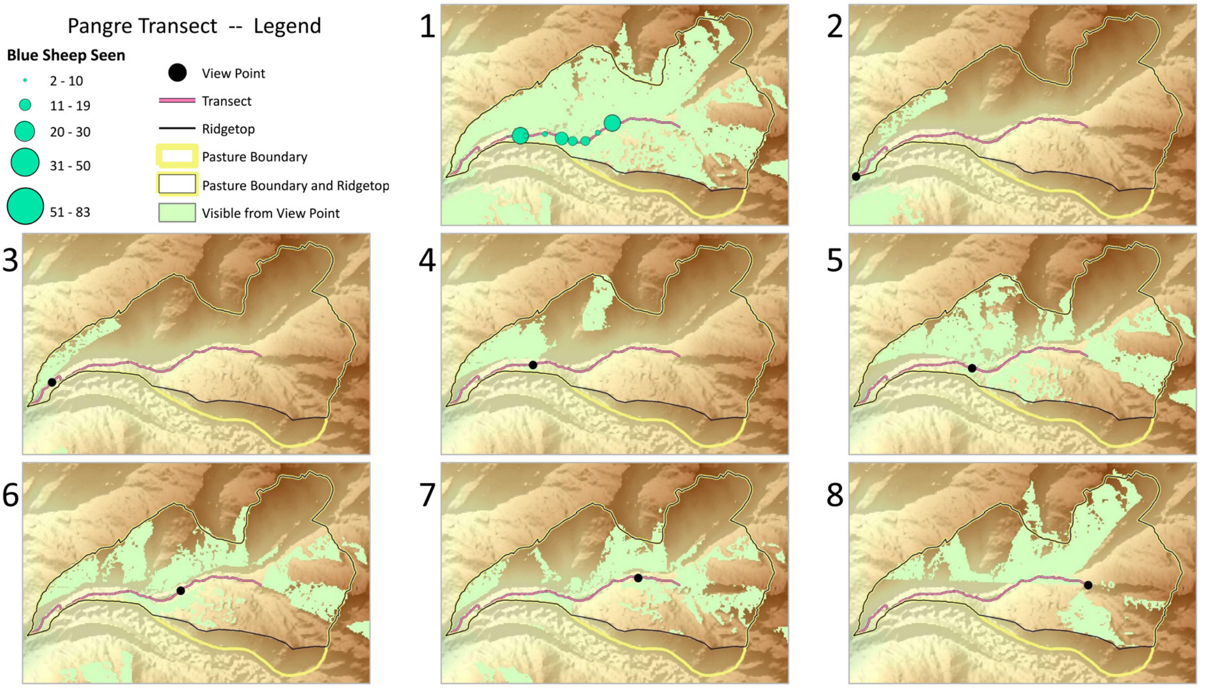

Figure 3. Viewshed visibilities for Pangre Survey Block, from selected locations along the entire transect route.

and SPNP respectively. Similarly, Wilson (1981) recorded 0.7–0.8 km^{-2} in the Dhorpatan Hunting Reserve (DHR), Schaller (1977) recorded 1.4 km^{-2} in Lapche and 0.9–1.3 km^{-2} in SPNP. Recently, Khanal et al. (2020) estimated 1.8 and 1.6 blue sheep km^{-2} in Upper and lower Dolpa of SPNP. Reasons for these differences are unclear, but probably reflect different survey methods (e.g. point area counts versus transect counts) as well as different times of year (Wegge et al. 2012, Aryal et al. 2014, Chetri et al. 2017). Blue sheep group composition and dynamics vary seasonally and are particularly affected by the annual rut that occurs in the fall – winter months of November through mid-January. In any case, our study suggests that Nar-Phu Valley supports a good blue sheep population notably worthy of full protection.

Females slightly outnumbered males (90 males:100 females) during our survey. Chetri and Pokharel (2005) and Aryal et al. (2014) reported 56 and 79 males per 100 females in Upper Mustang, respectively. Elsewhere, in Tibet for instance, blue sheep populations had extremely low male to female ratios (25:100; Schaller 1977), likely due to sexual segregation of those populations at time of survey, increased pressure on males from hunting or other undetermined sources of mortality. However, no sexual segregation was observed during this study, a finding consistent with same-time surveys conducted by Wegge (1979) and Wilson (1981) in DHR in west Nepal. Several decades ago, Manang's blue sheep populations showed slightly higher male-to-female ratio (93:100; Oli et al. 1993). Evidently, adult females outnumbered males in contrast to most other ungulate species that demonstrate close to a 1:1 ratio, which Schaller (1977) considered typical for wild sheep and goats under low predation pressure and with limited or no hunting. Other explanations may include snow leopards killing disproportionally more males, perhaps because they are less vigilant or provide greater nutrient return over the smaller-bodied females or juveniles (Schaller 1977). However, no evidence of intensive poaching was observed nor reported for this blue sheep population at the time of survey.

The strong young to female ratio is encouraging, but seasonally replicated surveys are needed in order to infer if the population is stable and growing. These need to include assessments of age class survival rates (Gaillard et al. 2000). A decade ago, Thapa (2005) concluded the number of young to females was 47:100. Weather, range condition and nutritional levels are all factors expected to affect reproductive success as several ungulate studies have shown (Schaller 1973, Wegge 1979). Evidently, blue sheep reproductive success varies greatly from area to area: in Nepal for example, this ratio ranged from 40:100 in the SPNP (Schaller 1977) to 83:100 at DHR (Wilson 1981), but no recent information

Table 4. Proportion of the Pangre Survey Block visible to observers conducting this transect route based on GIS and viewshed analysis.

Details of survey area and transect	Area in square kilometers	Percent visible
Total area of Pangre Survey Pasture	21.2	
Total area visible from transect	13.7	64.6%
Total area visible within 1 km distance	10.3	48.6%
Total number of blue sheep counted	273	
Maximum blue sheep density (within the one-kilometer buffer)	26.51 km^{-2}	
Blue sheep density based on total area of Pangre Survey Block	12.88 km^{-2}	

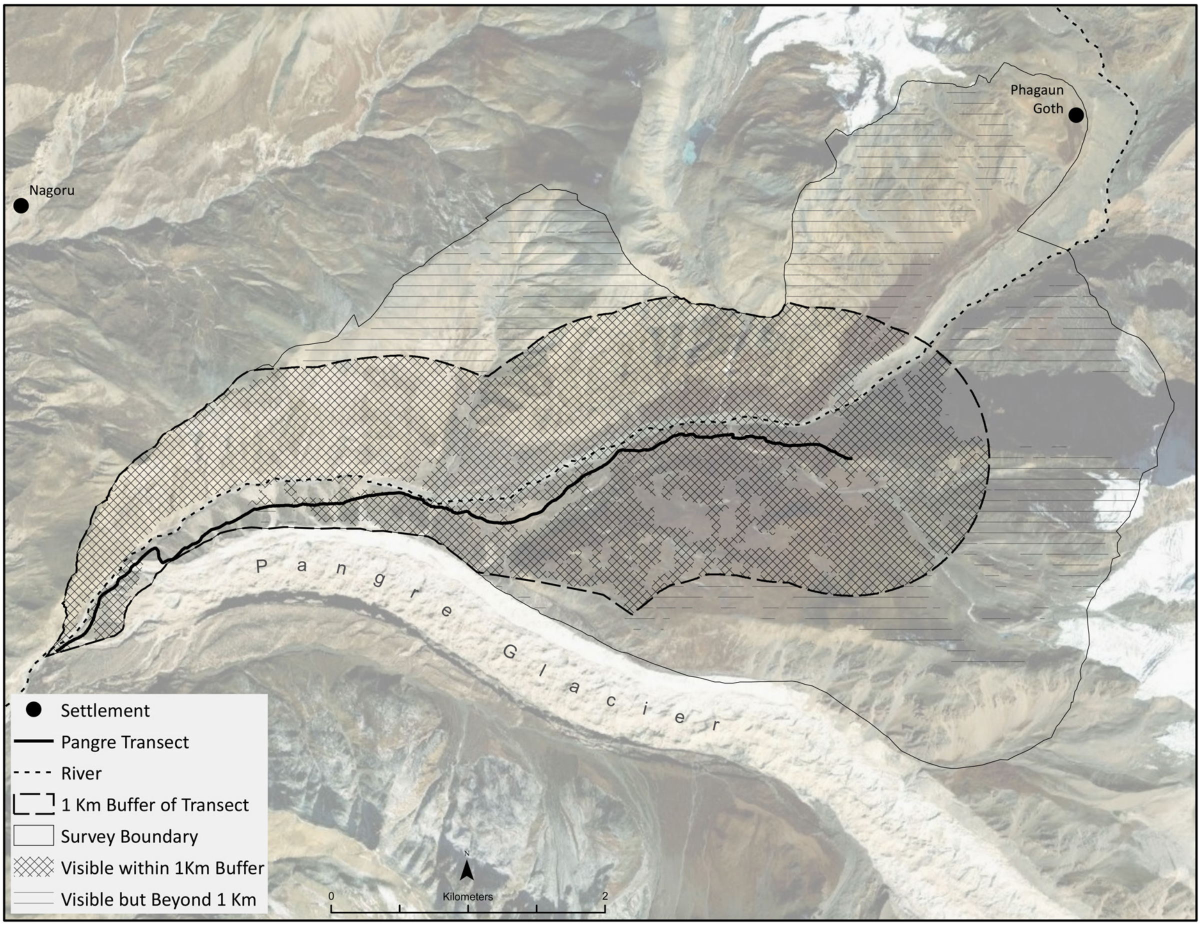

Figure 4. Cumulative viewshed extent visible within a one-kilometer-wide distance along the Pangre Transect, as well as within the entire Pangre Survey Block.

is available to indicate if these ratios may have changed over the past 40 years given the increased emphasis on conservation. Chetri and Pokharel (2005) and Aryal et al. (2014) reported 45 and 30 young per 100 females respectively for Upper Mustang in the autumn following lambing. Young blue sheep need to invest significant energy in body growth and establishing fat reserves for surviving their first winter, while also being more susceptible to malnutrition, disease and predation (Schaller 1977).

The ratio of yearlings (male and female) to adult females was 42 per 100 females but varied between sampled blocks (n = 11; Table 3). Corresponding figures for several populations on the Tibetan plateau ranged from 26:100 to 40:100 (Schaller 2000), again confirming the favorable status of our study population. However, the ratio of yearling to young was found to be 66, which indicates a 34% mortality rate from birth to two years of age. At DHR about 50% of the blue sheep died during this time interval, with most succumbing during winter (Wegge 1979).

Implication, limitations and improvements of double observer methodology

This study indicated high detection probabilities at 0.94 and 0.91 for O1 and O2 respectively, comparable to those of Thinely et al. (2018). By contrast, Khattak et al. (2019) reported lower detection rates in Pakistan's isolated blue sheep population (0.78 and 0.47); Khanal et al. (2020) estimated detection rates of 0.67 and 0.70 in Lower Dolpa and 0.78 and 0.75 in the Upper Dolpa sector of Nepal's SPNP. Khanyari et al. (2021) reported similar ranges (0.36–0.74) in the central Tien Shan landscape of Kyrgyzstan.

Our data suggests Nar-Phu blue sheep are relatively accustomed to humans. High detection rates reflect 'easy-to-detect' groups being sighted by both observers, while wary herds tend to be detected by one observer only. Detection rates may also be influenced by non-independence of observations as well as a population's herd dynamics and imbedded heterogeneity. Suryawanshi et al. (2012) suggested that if the detection probability for certain groups was < 0.50, then simultaneous surveys could underestimate the number of groups by approximately 15% and overestimate the observer-specific detection probability by approximately 10%. However, if the detection probability for all groups was likely to be higher (ca > 0.50), then the estimates from simultaneous surveys were almost equal to spaced surveys and true values. Suryawanshi et al. (2012) consider detection probabilities of 0.7–0.8 are sufficient for detecting changes of 20% or greater in populations compromising 420 or more individuals and detection probabilities greater than 0.85 for smaller populations (approx. 100 individuals) at 30% change level. Our study revealed higher detection rates of both observers, and thus should be capable of detecting a smaller change. In order to maximize sighting probabilities (especially for the second observer), the first observer should minimally disturb any blue sheep encountered (Suryawanshi et al. 2012). We followed this precautionary rule by moving cautiously and quietly, carefully scanning the area, and by maximizing observer–animal distance using powerful binoculars (10–50×). The mean estimated distance to blue sheep groups for both observers was around 90 m; however, this is only feasible if blue sheep are well protected and sufficiently accustomed to human presence. In more remote areas with limited human visitation or where poaching may occur, we observed blue sheep to be wary, usually taking flight and significantly increasing their distance from humans.

In order to address population closure assumptions, we concluded all counts within a relatively short time frame (i.e. 22-days). In addition, many survey blocks were separated by ridges, large glaciers or large rivers, reducing the likelihood of frequent blue sheep movement in and out of adjacent sampling blocks. Population closure may not have been met in areas lacking such barriers, in longer duration surveys (Thinley et al. 2018) or involving teams less experienced with designating survey blocks. The senior investigator benefitted from prior experience through his studies undertaken 15 years earlier (Thapa 2005, Sharma et al. 2006). Our survey also profited from having local assistants familiar with the terrain and least intrusive access point for each survey block.

DO counts require each observer to reliably classify each ungulate group and individual members encountered using standardized criteria for recording unique or sufficiently distinctive body features (defined in the methods section) as well select landmark features (e.g. distance to nearest escape cover). Both observers utilized powerful binoculars (10–50×) for scanning the terrain, and once blue sheep were spotted, resorted to use of a spotting scope (15–30–45×) for sex and age-class classification, – enabling 96% of all groups to be classified. Each observer had 10–20 years of experience counting and classifying blue sheep, making for similar skill levels, thus minimizing this potential source of bias. Where possible, we used digital cameras to capture images for later comparison and discussion.

During our study, only three blue sheep groups were found to be exceptionally wary, with all moving quickly far away from observers in the Ghyo survey block, Nar village and the Mandal area. Local informants reported occasional poaching from these localities; otherwise, we observed blue sheep to be not particularly evasive of human presence, enabling us to approach as close as 10–30 m before the group moved away or took flight. The presence of snow leopards may also increase wariness among blue sheep as noted by Thinley et al. (2018).

Suryawanshi et al. (2012) do not address all potential sources of bias related to ungulate DO surveys. Corlatti et al. (2015) noted possible bias resulting with chasing (intended or inadvertent) of individual blue sheep or groups. Their results, based on clearly marked individuals (males) suggested that such bias is unlikely to have occurred over all survey (i.e. replicated) occasions when using the mark–resight procedure and distance sampling. Since our study was a one-time undertaking, we are unable to evaluate this aspect. Further, we highlight the desirability of keeping field methodologies relatively simple in order encourage more regular, seasonally repeated counts conducted by local staff (i.e. forest or park rangers) rather than costly, highly trained but scarce professional biologist staff.

The DO method has been adopted by the Global Snow Leopard and Ecosystem Protection Program (GSLEP) in support of standardizing survey methodologies across the 12 snow leopard range countries under its PAWS initiative (GSLEP 2017). Suryawanshi and associates concluded this survey approach generated precise and statistically robust data for estimating population size in mountain ungulate species, although it has seen limited adoption outside of Asia.

We noted several apparent shortcomings to the DO approach. First, we documented potential flight bias with greater flushing and escape flight distances in blue sheep groups subject to poaching or exposure to humans. In these situations, we would expect detection probabilities for O2 to be negatively affected by passage of the first observer flushing groups further and possibly out-of-sight for the second observer. Even if both observers detect a group in the same general vicinity, this method relies upon their ability to recognize individuals and thus designate groups as 'common' or 'different', using consistently applied, robust post survey observer dialog and debate. Harris 1994 suggested applying 'uniqueness' values (crudely equivalent to probabilities) when comparing spatial, temporal or observer differentiated herd groups he termed 'bands.' The fluidity of individuals leaving or joining nearby groups can greatly confound herd group identification in blue sheep and other ungulate species, especially during rutting periods (Yi et al. 2013) when movements, the mixing of sexes and related breeding activities are most pronounced. Therefore, surveys outside these times of year may provide more consistent estimates.

Given these and other confounding factors, we offer the following management recommendations, along with encouraging multispecies ungulate surveys in sites exhibiting varied terrain, heterogeneous viewshed visibilities, time of day and season, and effects of disturbances like poaching or livestock herding:

1) To enhance survey precision and information gathering reliability, each observer (O1 and O2) should have comparable levels of observational skills, knowledge and experience at sighting the targeted species, accurately locating their position with respect to the transect, classifying habitat and topographic conditions, as well as with aging and recording animal behavior. The use of similar equipment in terms of binoculars, spotting scope, GPS units, high zoom digital cameras and compass is also desirable. This could best be accomplished by deploying properly trained park rangers, rather than one-off specialized and more experienced researchers to undertake annual counts. The involved cost savings should allow for more replicate counts along fixed transect routes covering multiple seasons, rather than a one-off survey like this study.
2) In order to generate more comparable, consistent and useful data for monitoring purposes, it is essential to conduct multiple monitoring surveys at the same time each year. Spring/early summer and late winter counts could generate data for assessing sex–age class survival and thus population trends.

3) We therefore recommend that survey block counts be repeated at fixed times of year counts using the same observers. This will help highlight any seasonal changes in detectability and/or population size, thus leading to more robust counts (Dail and Madsen 2011).
4) It is important to note that 'straight line' transects are rarely feasible in mountainous areas where rugged terrain dominates and visibilities change rapidly over short distances. This is one of the main reasons that distance sampling is rarely attempted. At a minimum, researchers should estimate the proportion of each defined block that is visible along the full-length of the walked travel route in order to generate accurate estimates of the total land area visible to observers. This could allow for a similar approach and calculations to the distance set of protocols (Kiana et al. 2002). However, obtaining such information will be time-consuming and challenging given the often highly sinuous travel routes and need to accurately estimate observer–animal distance and compass angle for each observation. We offer an alternative approach to addressing this issue by including spatial estimates for the visible viewshed within each survey block (recommendation number 5). Also, by making binocular or spotting scope searches from strategically located high vantage transect points, one reduces the chances of target species detecting the observer first and moving (unseen) beyond line-of-sight to one or both observer. Following completion of each transect, the two observers could also consider conducting a long-distance supplementary count from the opposite side of the valley, focusing on group numbers and size rather than attempting sex or age classifications. This would help maximize the proportion of each defined sampled block actually searched; however, such data would not be included in the formal analysis, but rather used for contextualizing survey results and conclusions.
5) Wherever possible, we recommend that future surveys include viewshed mapping, in support of robustly measuring the amount of land area deemed visible to each observer as they walk the transect. Figure 3 and 4 illustrate graphically different portions of a representative survey block (Pangre) likely to be visible to observers of this study. Geographic boundaries should be designated based on local topographic and vegetative cover conditions: for example, we set a one kilometer distance or the nearest ridgeline (whichever is closer) as our boundary for observations. A word of caution, however: researchers should be cognizant of the scaling limitations to DEM modeling when used to generate viewsheds, along with ensuring the 'observer's eye level' is set at around 2 m. The finest resolution DEM in Asia currently is the 30 m dataset, although data may be also affected by error sources like terrain roughness, grid size and interpolation algorithms employed. DEMs in mountainous areas are significantly more prone to error than those developed for gently rolling or level areas used by other ungulates (e.g. argali, *Ovis* spp.).
6) Finally, we note that the DO counts are generally more costly than simple point or transect counts involving a single observer, along with being equally difficult to execute especially in remote, rugged terrain. Neither approach will always perform well for these reasons. The most notable benefit of the DO survey method is that it accounts for imperfect detection (Sutherland 2006).

Another avenue worth exploring, at least in some areas, involves use of thermally equipped UAS craft (drones) flying fixed autonomous, and preferably repeatable transect routes. Video imagery could be reviewed during flight or later to detect thermally diagnostic patterns of large ungulates, with validation including visual confirmation and independent counting (Beaver et al. 2020). Of course, the use of UAS tools also bring new issues to bear, including high equipment start-up cost and need to ensure safe and compliant aerial flights (in turn, constrained by steep terrain, limited line-of-sight for maintaining communications between craft and operator, and potentially also low air-density limitations imposed by high base elevations, generally more than 3000–5000 m). In summary, we encourage researchers and conservationists to resolve the many challenges surrounding population abundance or density estimates of blue sheep, ibex or other species (including domestic livestock) that constitute the primary prey source for the threatened snow leopard – with the ultimate goal of detecting changes in their populations so managers can take timely and appropriate remedial action at stabilizing both predator and prey numbers.

Acknowledgements – The Conservation Area Management Committees and Snow Leopard Conservation Committees, including the local people of Nar-Phu valley, assisted in counting blue sheep. We express appreciation to Dr. Shailendra Thakali and Brian Peniston for their support during various phases of this research program (design, field work and review of manuscript). Sincere thanks also go to Mr. Karma Hisi Lama and Mr. Karma Tenjing Lama from Phu, and Mr. Ritar Phunjo Lama and Mr. Sonam Phunjo Lama of Nar for assistance in the field. We thank DNPWC staff members Mr. Bhupendra Yadav and Mr. Hem Raj Acharya, and ACAP staff Mr. Rishi Baral and Om Prasad Gurung (Maila Dai) for their valuable assistance, especially during the important preliminary phase of this survey. Finally, the authors thank Ms. Charleen Gavette of the Snow Leopard Conservancy for generating the digital maps and associated GIS analysis.
Funding – We express our gratitude to the United Kingdom Darwin Initiative Program for funding this project under grant no. 25-027, Round 25, along with the Snow Leopard Conservancy and The Mountain Spirit who provided logistic support, while the Department of National Parks and Wildlife Conservation (Ref.: 1213/076/77), Annapurna Conservation Area Project (Ref.: 426/076/77) and Narpa Bhumi Rural Municipality provided the research permit for which we offer our thanks.
Conflict of interest – Authors declare that there is no conflict of interest.

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