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Spatial density pattern of Himalayan Ibex *(Capra sibirica)* in Pakistan

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A R T I C L E I N F O

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A B S T R A C T

Mountain ungulates perform a key role in maintaining the balance of ecosystems as they are the primary consumers of vegetation and prey for large predators. The mountain ranges of northern Pakistan are home to six species of mountain ungulates, and the Himalayan ibex *(Capra sibirica)*, hereafter ibex, is the most abundant among them. This study was conducted in three administrative regions of northern Pakistan, viz. Gilgit-Baltistan (GB), Azad Jammu and Kashmir (AJK), and Khyber Pakhtunkhwa (KP), to generate a range-wide density pattern map of ibex. A double-observer survey was conducted in 25 study sites during 2018–2021 across the ibex distribution range, covering an area of about 35,307 km^2, by walking transects totaling 1647 km. Within the ibex range where the survey was not conducted due to financial and logistical constraints, we obtained species population information from local wildlife departments' most recent annual survey data. The aim was to generate a density map for the entire ibex range. Using the BBRecapture package in program R, we estimated an ibex population of 7639 (95 % CI) with a mean density of 0.21/km^2 in the surveyed area. Combining with the secondary data from un-surveyed areas, the total population estimate for the country came to 10,242 ibex. The largest population densities were observed in four valleys (Shimshal, Gulkin-Hussaini, Khyber, and Khunjerab) of the Karakoram-Pamir range, followed by the Hindu Kush range (Chitral Wildlife Division [WD]). The central and eastern parts of the Karakoram range had moderate to low densities, while the Himalayan range (e.g., Astore Valley) supported a small population. The mean herd size was 15 individuals (range: 5–41), and the average detection probability of observers A and B was 0.69 and 0.48, respectively. The average male and young ratios per 100 females were estimated to be 75 and 81, respectively. The range-wide density map developed during the study provided an evidence for the impact of trophy hunting programs and an objective tool for range-wide conservation planning of the species.

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1. Introduction

Wild ungulates play a vital and vigorous role in maintaining a balance in ecosystems through nutrient recycling, by influencing vegetation structures and species composition and serving as prey for large carnivores (Karanth et al., 2004; Suryawanshi et al., 2017, 2012). The conservation of ungulates has a direct relationship with the conservation of their predators (Khara et al., 2021) because the former constitute a major portion of large carnivores' diets (Bagchi et al., 2003; Jathanna et al., 2003). The available density of ungulate prey is an important determinant of the density of large predators (Karanth et al., 2004; Tumursukh et al., 2016). For example, declines in the populations of tigers *(Panthera tigris)* were attributed to low prey populations (Dinerstein et al., 2007). A clear connection between the number of tigers and their prey densities has been established in previous studies (Karanth and Stith, 1999; Karanth, 1995; Schaller, 2013).

The mountains ecosystem of Central and South Asia has a rich diversity of mountain ungulate species (Schaller, 1998). However, these ungulate species are insufficiently studied, and information about their distribution and population is patchy, thus undermining the need for conservation efforts in this region (Singh and Milner-Gulland, 2011). In Pakistan, 11 ungulate species were found occupying diverse habitats in high-altitude areas in the north to the hills in desert areas in the south (Hess et al., 1997). The Himalayan, Hindu Kush, and Karakoram mountain ranges in Pakistan have significant diversity of globally recognized wild ungulates that are deemed important from a conservation standpoint (Khan et al., 2014). Six of the 11 ungulate species share habitats with snow leopards, including blue sheep *(Pseudois nayaur),* Marco Polo sheep *(Ovis ammon polii),* Ladakh urial *(Ovis vignei vignei),* Himalayan ibex *(Capra sibirica),* markhor *(Capra falconeri),* and Kashmir musk deer *(Moschus cupreus)*.

The global distribution range of Himalayan ibex (hereafter ibex) is spread across India, China, Afghanistan, Pakistan, Mongolia, Russia, Kazakhstan, Tajikistan, Uzbekistan, and Kyrgyzstan (Reading et al., 2020). In northern Pakistan, ibex are the most abundant wild ungulate species present in the snow leopard distribution range, although their numbers have contracted, limiting them to the extreme northern parts of the country—their distribution range extends from Khunjerab in the north to Swat district, Azad Jammu and Kashmir (AJK) to the south, and Chitral district to the west (Hess et al., 1997). In Pakistan, the ibex are well adapted to rough terrain and live above the tree line at an altitude range of 3500–5000 m in precipitous mountainous ranges (Roberts, 1977). They predominantly inhabit rocky mountainous regions, cliffs, open meadows, and low-elevation areas during heavy snowfall in winter (Fedosenko and Blank, 2001). The species mostly avoid areas of dense forest; during high-temperature periods in summer, it likes shaded areas beneath rocks or vegetation, and lives and remains near steep and escape terrain (Fedosenko and Blank, 2001). Globally, the species was recently declared 'Near Threatened' in the IUCN red data book (Reading et al., 2020). It is receiving limited attention in Pakistan where native population trends throughout its distribution range cannot correctly define its conservation status (Sheikh and Molur, 2005). The overall population status of ibex in Pakistan is unknown. Studies related to the population status of ibex *do* exist (Ahmad et al., 2020; Khan et al., 2016, 2020), but they are limited to small portions of the species' range.

Estimating the density or abundance of mountain ungulates is arduous and not generally conducted using statistically robust methods (Huapeng et al., 1997). The rough terrain they inhabit, the remoteness of the area, climate, financial support, logistics, commitment, technical capacity, low species density, their group-living habits, and the absence of clear identification marks on individuals, make population estimation a challenging task (Singh and Milner-Gulland, 2011; Wingard et al., 2011). The accurate population estimation of ungulate species is highly important for their conservation, although most existing methods are difficult to implement in mountainous areas (Pal et al., 2021). For example, distance sampling is a widely used method for the population and density estimation of large herbivorous species in tropical and temperate forests (Buckland et al., 2017), but meeting this method assumptions are difficult in mountainous areas (Corlatti et al., 2015; Suryawanshi et al., 2012). The distance sampling method was used by Wingard et al. (2011) in Mongolia for the density estimation of argali and found this method to be imprecise even in relatively accessible mountainous terrain. An alternative is aerial surveys, but they are expensive and unsafe in mountainous areas (Tumursukh et al., 2016). Suryawanshi et al. (2012) standardized the double-observer technique for the population estimation of mountain ungulates in the Himalayas; it was initially established by Forsyth and Hickling (1997) for the Himalayan tahr *(Hemitragus jemlahicus)*. The principle of the double-observer technique is based on the theory of capture-mark-recapture (CMR) (Forsyth and Hickling, 1997). A capture-recapture history can be built for each observed individual or group, and data can be analyzed in a CMR-like fashion (Williams et al., 2002).

Successful strategies for managing wide-ranging species need reliable information on population and density trends (Marques et al., 2001). This study was conducted in the ibex range of the Himalaya, Karakoram, and Hindu Kush mountain ranges in northern Pakistan using the double-observer technique to determine the spatial density of this key ungulate species. Secondary data was also collected for the un-surveyed area to develop a single density map for the species' entire distribution range in northern Pakistan. This study aims to construct the first-ever range-wide density map of ibex in Pakistan, based on empirical data. The spatial density pattern identified through this study will aid conservation planning for ibex across its range in Pakistan.

2. Materials and methods

2.1. Study area

This study was conducted in the ibex distribution range (Reading et al., 2020) in Gilgit-Baltistan (GB), AJK, and district Chitral of Khyber Pakhtunkhwa (KP) province in northern Pakistan (Fig. 1). Additionally, new areas reported as probably suitable habitat for ibex (Ali et al., 2021) and suggested by wildlife department officials were also searched for ibex occupancy, especially in GB. The study area fell in the Karakoram, Himalayas, and Hindu Kush mountain ranges, connecting with China to the north, Afghanistan to the west, and India to the east. It is characterized by narrow valleys, steep, rugged, and high mountain peaks, and highland plateau (Abbas et al., 2013). The mountain ecosystem in the study area supports a unique diversity of flora and fauna. Climatic conditions vary widely across the study area, ranging from the Himalayas to the cold, semi-arid deserts of the northern Karakorams and the Hindu Kush, to a monsoon-influenced, moist temperate zone in the west. Winter rainfall and snowfall contribute to glacier ice accumulation and the recharge of groundwater resources (Abbas et al., 2013). Four vegetation zones are identified along with altitudinal ascents: alpine meadows, sub-alpine scrub zones, alpine dry steppes, and permanent snowfields (Hameed et al., 2020). Large mammalian carnivore species found in the study area include the common leopard *(Panthera pardus),* snow leopard, Himalayan lynx *(Lynx lynx),* wolf, brown bear, and Asiatic black bear *(Ursus thibetanus).* Large-sized prey species are represented by markhor, blue sheep, ibex, Marco Polo sheep, musk deer, and Ladakh urial. The livestock reared by locals in the study areas includes domestic goat (*Capra hircus*), sheep (*Ovis aries*), cow (*Bostaurus indicus*), yak (*Bos grunniens*), horse (*Equus caballus*), and donkey (*Equus asinus*).

2.2. Survey methods

2.2.1. Double-observer technique

Using the double-observer survey, 25 study sites were surveyed (Fig. 2) within the ibex distribution range in northern Pakistan from 2019 to 2021 with the primary aim of determining the abundance and density of ibex. The surveys were carried out in different seasons (Table 1). Winter and spring are the most suitable survey seasons for the robust population estimation of ibex however in the current study we also conducted surveys in a few sites during summer to observe the new recruitment to the ibex population. The double-observer method is built on the same principles as the two-sample CMR technique (Williams et al., 2002) which capitalizes on the fact that theory allows for population size to be estimated based on just two surveys (Suryawanshi et al., 2012). The double observer method involves two observers scanning and counting the animals while ensuring that both teams do not give any clue to each other about animals sighting. Each study site was further divided into watershed blocks 1) of unequal size that were large enough for the ibex to cross easily in a single day movement; 2) not larger than daily human effort, and 3) that had high ridges as boundaries and were

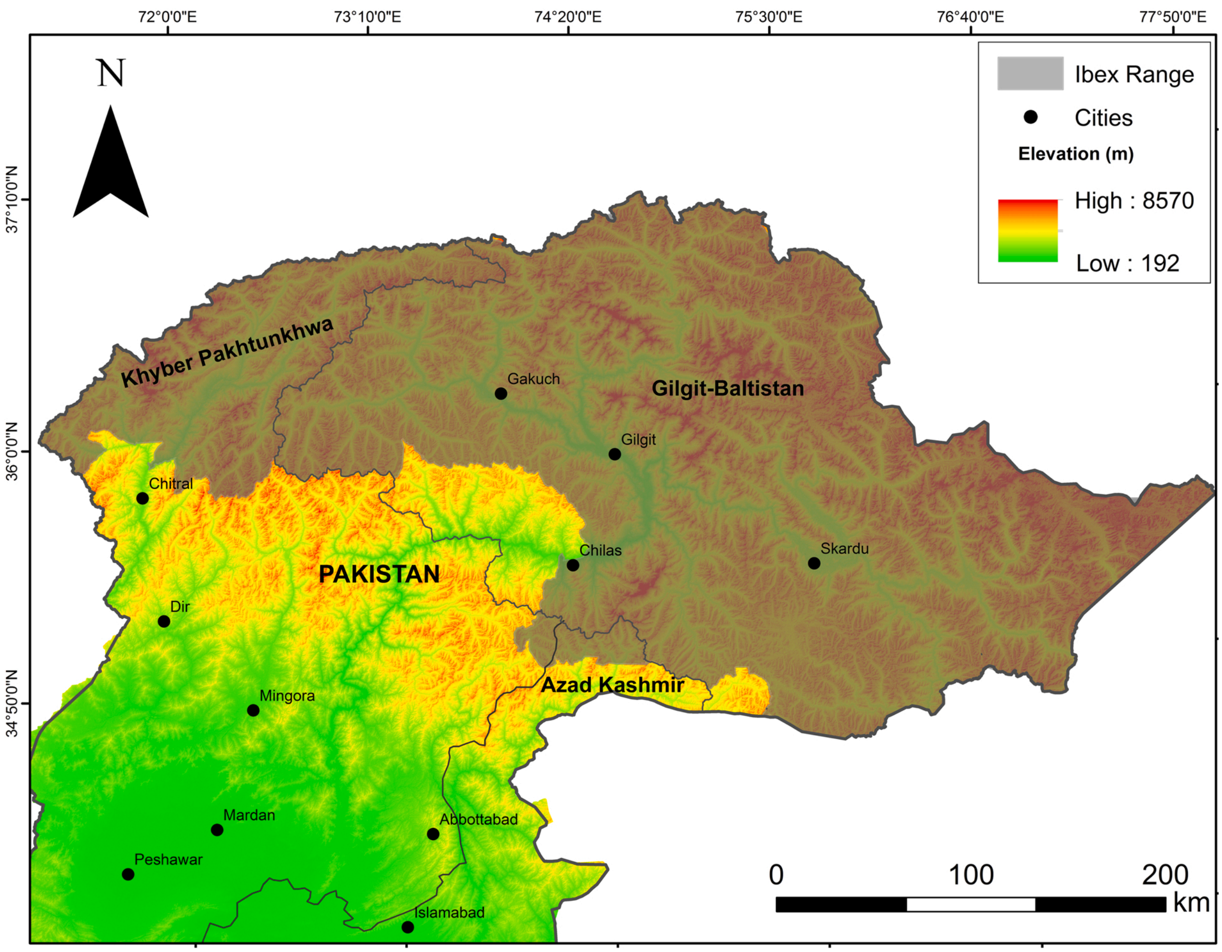

Fig. 1. Geographic distribution range of Himalayan ibex in northern Pakistan (study area).

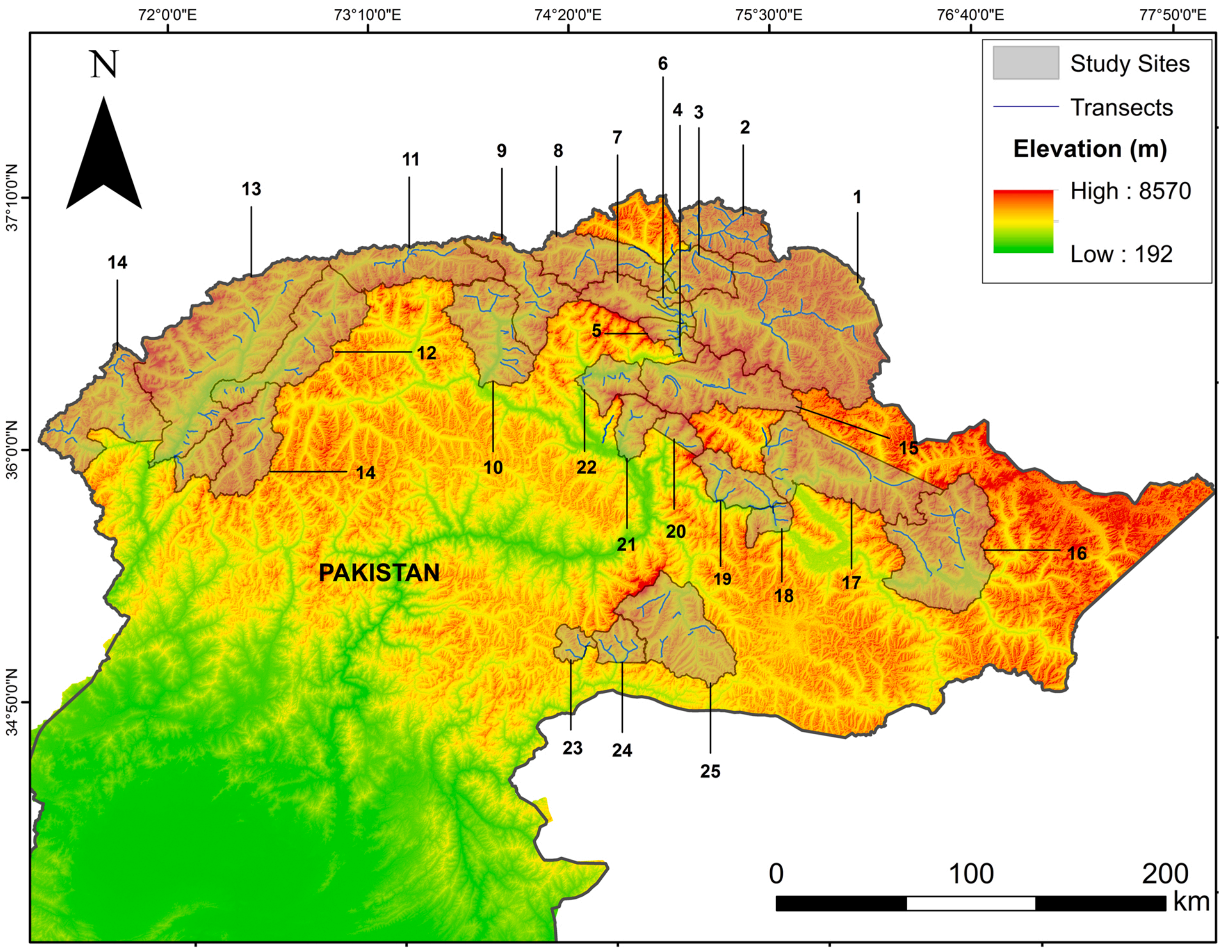

Fig. 2. Study area map showing survey sites where the double-observer survey was conducted for the population estimation of Himalayan ibex in northern Pakistan. 1 = Shimshal, 2 = Khunjerab National Park (KNP), 3 = Khunjerab Village Organization (KVO), 4 = Gulmit, 5 = Gulkin and Hussaini, 6 = Khyber, 7 = Passu, 8 = Chipurson, 9 = Qurumber National Park (QNP), 10 = Ishkoman, 11 = Broghil National Park (BNP), 12 = Mastuj Wildlife Range (WR), 13 = Booni Wildlife Range (WR), 14 = Chitral Wildlife Division (WD), 15 = Hoper-Hisper, 16 = Thalay and Hushey, 17 = Basha Baraldu, 18 = Skoyo-Karabathang-Basingo (SKB), 19 = Astak Tormak, 20 = Haramosh, 21 = Bagrote, 22 = Rakaposhi, 23 = Surgan Valley, 24 = Shounter, 25 = Astore.

difficult for animals to cross. Mountain ungulates are difficult to identify based on their coat pattern, however, the logic of applying the capture-recapture method as the double-observer method was that mountain ungulates can be identified based on their herd composition, herd size, herd sighting location, time of herd sighting, etc. (Khanal et al., 2020). The individual group of ungulate become the units that is being 'marked' and 'recaptured' in the double-observer method.

Both observers scan the surrounding area while walking along predefined trails and observations were made mostly during dawn and dusk (Ahmad et al., 2020). In keeping with the double-observer method, our teams were divided into observers A and B and separated by time or space. In the case of spatial separation, both observers started walking in the same block at the same time but different tracks while in the case of temporal separation both observers started tracking at the same trail but the distance was maintained between the two observers (Second observer began trekking the block 15 min after the first observer) (Tumursukh et al., 2016). Each observer team was equipped with binoculars (10 × 50 Pentax XCF), a spotting scope (20 × 60 Swarovski), DSLR camera (for photography of herds and associated habitats), and GPS device (Garmin 62 S). Both observers scanned the areas with binoculars every 100 m. On sighting herds, they would identify the species, count the individuals, and classify them by body size and horns. Observed ibex individuals in each herd were categorized as female (>2 years), young (<2 years), and male. At the end of the day, both sets of observers would cross-tally their data using herd sighting location, composition, time, and unique characteristics, such as male-only herds, to verify unique and common herds and avoid double-counting (Khanal et al., 2020).

2.2.2. Secondary data collection

We covered 46 % of the ibex range in our field surveys and obtained secondary data about the population of the targeted species for the remaining part of the range. The double observer survey was not carried out in the remaining parts due to various constraints such

Table 1
Chronology of double observer surveys conducted for Himalayan ibex population estimation in Pakistan.

S.NO	Study Sites	Size (km^2)	Year	Season	Effort (km)
1	Astak-Tormak valleys, Gilgit-Baltistan	801	Apr-19	Spring	62
2	Astore valley, Gilgit-Baltistan	1955	Sep-20	Summer	73
3	Bagrote valley, Gilgit-Baltistan	523	Dec-20	Winter	16
4	Basha-Baraldu valleys, Gilgit-Baltistan	1513	Apr-19	Spring	110
5	Broghil National Park (BNP), Khyber Pakhtunkhwa	1515	Aug-20	Summer	62
6	Booni Wildlife Range, Khyber Pakhtunkhwa	5764	Jan-20	Winter	92
7	Chipurson valley, Gilgit-Baltistan	1261	Aug-20	Summer	74
8	Chitral Wildlife Division, Khyber Pakhtunkhwa	2444	Jan-20	Winter	113
9	Gulkin-Hussaini valleys, Gilgit-Baltistan	229	Jan-20	Winter	20
10	Gulmit valley, Gilgit-Baltistan	167	Dec-20	Winter	19
11	Haramosh valley Gilgit-Baltistan	304	Apr-19	Spring	15
12	Hoper-Hisper valleys, Gilgit-Baltistan	1534	Nov-20	Winter	70
13	Ishkoman valley, Gilgit-Baltistan	1566	Aug-20	Summer	87
14	Khyber valley, Gilgit-Baltistan	117	Dec-20	Winter	14
15	Khunjerab National Park (KNP), Gilgit-Baltistan	1061	Aug-20	Summer	143
16	Khunjerab Village Organization (KVO), Gilgit-Baltistan	939	Dec-20	Winter	93
17	Mastuj Wildlife Range, Khyber Pakhtunkhwa	1959	Jan-20	Winter	69
18	Passu valley, Gilgit-Baltistan	785	Jan-20	Winter	42
19	Qurumber National Park (QNP), Gilgit-Baltistan	1259	Aug-20	Summer	55
20	Rakaposhi valley, Gilgit-Baltistan	617	Apr-19	Spring	21
21	Shimshal valley, Gilgit-Baltistan	5269	Nov-20	Winter	177
22	Shounter valley, Azad Kashmir	452	Dec-18	Winter	50
23	Skoyo-Karabathang-Basingo (SKB), Gilgit-Baltistan	335	Jan-21	Winter	44
24	Surgan valley, Azad Kashmir	266	Dec-19	Winter	27
25	Thalay and Hushey valleys, Gilgit-Baltistan	2672	Apr-19	Spring	104
Total		**35,307**			**1647**

as financial and logistic constraints. For some sites, we were unable to obtain NOC from the security agency due to the sensitivity of the area. Secondary data was collected with the purpose to develop a single density map for the species and to determine ibex population in areas where the double-observer survey was not conducted. Secondary data was obtained from wildlife census data available from wildlife department officials.

2.3. Data analysis

The ibex population in each study site was estimated using the mark-recapture feature of the BBRecapture package (R Core Team, 2019). Following Suryawanshi et al. (2012), we analyzed the number of groups, group sizes, age-sex composition, and sighting locations to evaluate whether a herd had been re-sighted by observer B. The data was arranged in the form of '10' if the group was sighted by observer A only, '01' if sighted by observer B only, and '11' if recorded by both (Tumursukh et al., 2016). We modelled the detection for the two observer groups separately—mt model; i.e. the detection probability varied across the two surveys. To estimate the number of groups ($\hat{G}$) of ibex in each study area, we fit the mt model using the function BBRecap with a uniform prior (Khanyari et al., 2021). We used the mt model because we expected the detection probability to be different across the two surveys (Suryawanshi et al., 2012).

We performed 10,000 MCMC iterations with a burn-in of 1000 followings (Suryawanshi et al., 2021). The estimated detection probability by model mt for occasions one and two was interpreted as the detection probability for observer teams A and B. We estimated the total population (N_{est}) for ibex within each study site as a product of the estimated number of groups ($\hat{G}$) and the estimated mean group size (μ). To estimate the confidence intervals (CI) of the population using the variance in the estimated number of groups and the mean group size, we generated a distribution of estimated group size by bootstrapping it 10,000 times with replacement. The distribution of the estimated population (Nest) was generated by multiplying 10,000 random draws of the estimated number of groups ($\hat{G}$) weighted by the posterior probability and draws of mean group size (μ). The median of the resultant distribution was the estimated population (Nest), and the 2.5 and 97.5 percentiles were used as the boundaries of the 95 % CI (Suryawanshi et al., 2021).

The density of ibex within each study site was calculated by dividing the estimated population within each study site by the total area of the corresponding study site. The density map for the species was projected in ArcGIS 10.8. Density across the range was categorized into low- (0–0.09 animals/km^2), medium- (0.10–0.28), and high-density (>0.28), and plotted on the map. The categorization of density was based on the average density value (0.20 per km^2) of ibex throughout its range in Pakistan. Sites with density of "< 1/2 average" were categorized as low while those areas with density of "average ± 1/2 average" were categorized as medium. Areas with density "> 1.5 x average" were categorized as high-density areas.

Table 2
Population structure of Himalayan ibex in different study sites in Northern Pakistan.

Study sites	No. of herds sighted by A	No. of herds sighted by B	No. of herds sighted by A and B	Estimated no. of herds	Mean herd size	Estimated population	95 % confidence interval	Detection probability (A)	Detection probability (B)	Density/km^2	Ratio to 100 females	
											Male	Young
Astak-Tormak valleys, Gilgit-Baltistan	6	0	0	18	9.50	171	38.0–725.9	0.51	0.07	0.21	205	132
Astore valley, Gilgit-Baltistan	3	2	2	13	3.57	46	17.1–127.3	0.46	0.39	0.02	42	38
Bagrote valley, Gilgit-Baltistan	1	1	0	2	19.00	38	1.0–80.0	0.59	0.59	0.07	83	133
Basha-Baraldu valleys, Gilgit-Baltistan	9	0	5	16	20.00	320	216.0–502.5	0.85	0.34	0.21	85	106
Broghil National Park (BNP), Khyber Pakhtunkhwa	7	8	8	32	6.04	193	135.8–300.0	0.48	0.51	0.14	59	94
Booni Wildlife Range, Khyber Pakhtunkhwa	3	4	30	38	17.90	681	550.4–807.4	0.85	0.88	0.12	55	100
Chipurson valley, Gilgit-Baltistan	6	1	2	16	5.22	84	31.0–211.1	0.58	0.25	0.07	50	64
Chitral Wildlife Division, Khyber Pakhtunkhwa	21	3	31	58	20.20	1172	1010.4–1347.5	0.88	0.58	0.48	70	128
Gulkin-Hussaini valleys, Gilgit-Baltistan	8	3	14	28	25.20	706	481.0–961.3	0.78	0.61	3.08	85	61
Gulmit valley, Gilgit-Baltistan	2	0	6	8	16.25	130	70.0–230.6	0.86	0.67	0.78	72	38
Haramosh valley Gilgit-Baltistan	0	0	1	2	23.00	46	1.0–95.0	0.59	0.59	0.15	42	50
Hoper-Hisper valleys, Gilgit-Baltistan	4	1	15	21	17.75	373	278.0–474.0	0.88	0.75	0.24	88	93
Ishkoman valley, Gilgit-Baltistan	8	3	2	29	3.23	94	42.7–246.1	0.41	0.22	0.06	47	35
Khyber valley, Gilgit-Baltistan	2	0	7	9	41.30	372	210.0–617.2	0.87	0.70	3.18	88	91
Khunjerab National Park (KNP), Gilgit-Baltistan	15	5	7	41	16.48	676	392.0–1167.7	0.56	0.31	0.64	118	76
Khunjerab Village Organization (KVO), Gilgit-Baltistan	6	4	18	30	11.92	358	291.0–443.2	0.78	0.72	0.38	61	59
Mastuj Wildlife Range, Khyber Pakhtunkhwa	16	10	23	57	6.55	373	303.0–468.7	0.68	0.57	0.19	53	48

(*continued on next page*)

Table 2 (*continued*)

Study sites	No. of herds sighted by A	No. of herds sighted by B	No. of herds sighted by A and B	Estimated no. of herds	Mean herd size	Estimated population	95 % confidence interval	Detection probability (A)	Detection probability (B)	Density/km^2	Ratio to 100 females	
											Male	Young
Passu valley, Gilgit-Baltistan	4	0	9	14	15.76	221	91.0–418.2	0.90	0.64	0.28	72	71
Qurumber National Park (QNP), Gilgit-Baltistan	5	2	6	16	7.15	114	60.3–200.8	0.68	0.51	0.09	20	85
Rakaposhi valley, Gilgit-Baltistan	7	0	4	11	10.22	112	68.0–226.7	0.78	0.31	0.18	75	80
Shimshal valley, Gilgit-Baltistan	18	3	3	49	16.37	802	382.6–1943.0	0.49	0.15	0.15	90	56
Shounter valley, Azad Kashmir	1	0	0	6	18.00	108	2.0–378.0	0.45	0.22	0.24	50	40
Skoyo-Karabathang-Basingo (SKB), Gilgit-Baltistan	0	0	12	12	11.75	141	107.0–179.7	0.92	0.92	0.42	93	62
Thalay and Hushey valleys, Gilgit-Baltistan	25	0	1	43	7.15	308	172.0–724.0	0.68	0.05	0.11	85	202
Total/*average*	**177**	**50**	**206**	**569**	***15.00***	**7639**		***0.68***	***0.48***	***0.48***	***75***	***81***

3. Results

3.1. Ibex sightings

A total of 25 different study sites covering an area of about 35,307 km^2 were surveyed (1647 km of transects) (Table 1). Ibex were sighted at 430 locations across 24 study sites—Surgan Valley was the exception.

3.2. Estimated population

Our analysis estimated a population of 7639 ibex in the surveyed area, with a density of 0.21 animals/km^2 (Table 2). The largest population was estimated in the Karakoram-Pamir range, followed by the Hindu Kush and Himalayan ranges. Study site-wise, the largest population was estimated for Chitral WD, with an estimated population of 1172 (95 % CI, 1010.4–1347.5). This was followed by Shimshal (802 animals, 95 % CI, 382.6–1943.0), Gulkin-Hussaini (706.0, 95 % CI, 481.0–961.3), Booni WR (681, 95 % CI, 550.4–807.4), KNP (676, 95 % CI, 392.0–1167.7), Khyber (372, 95 % CI, 210.0–617.2), and KVO (358, 95 % CI, 291.0–443.2) (Table 2). The smallest populations were estimated for Bagrote (38, 95 % CI, 1.0–80.0), Astore (46, 95 % CI, 17.1–127.3), and Haramosh (46, 95 % CI, 1.0–95.0) (Table 2). The highest density of ibex was estimated for Khyber (3.18 animals/km^2), Gulkin-Hussaini (3.08), Gulmit (0.78), KNP (0.64), and KVO (0.38), while the lowest densities were estimated for Astore (0.02), Ishkoman (0.06), Bagrote (0.07), and QNP (0.09) (Table 2, Fig. 3).

Based on secondary data, about 2603 individuals (density = 0.06/km^2) across a total area of 41,828.71 km^2 were recorded in un-surveyed areas in the ibex distribution range in northern Pakistan. Using this data, the highest population was found in Misgar Valley, where about 500 animals were present with a density of 0.40 individuals/km^2 (Supplementary materials and Fig. 3). Other un-surveyed areas with high populations included Biafo-Hisper (300 individuals with a density of 0.11), Shigar (300 individuals with a density of 0.33), and Kharmang (200 individuals with a density of 0.08). Most un-surveyed areas fell in the low-density class, while only a few sites fell in the medium- and high-density class (Fig. 3).

3.3. Detection probability and sex ratio

Observers A sighted a total of 177 herds of ibex, while observers B sighted 50. Both observers sighted 206 herds (Table 2). Only a single individual was sighted at some locations, while the largest herd observed was 102 in Hushey-Thalay Valley. Of the observed herds, about 75 % were classified as a mixed herd (having male, female and young) while 19 % and 6 % herds were classified as female (only female individuals) and male herds (only male individuals). The total estimated groups of ibex in the surveyed area were 569, while the estimated mean group size of ibex across 24 study sites was 15 individuals (5.22–41.0) (Table 2). The average detection probability was 0.68 (0.41–0.92) and 0.48 (0.22–0.88) for observers A and B, respectively (Table 2). The average male-to-female ratio across the surveyed areas was estimated to be 75 per 100 females, while the young-to-female ratio was estimated to be 81 per 100 females (Table 2).

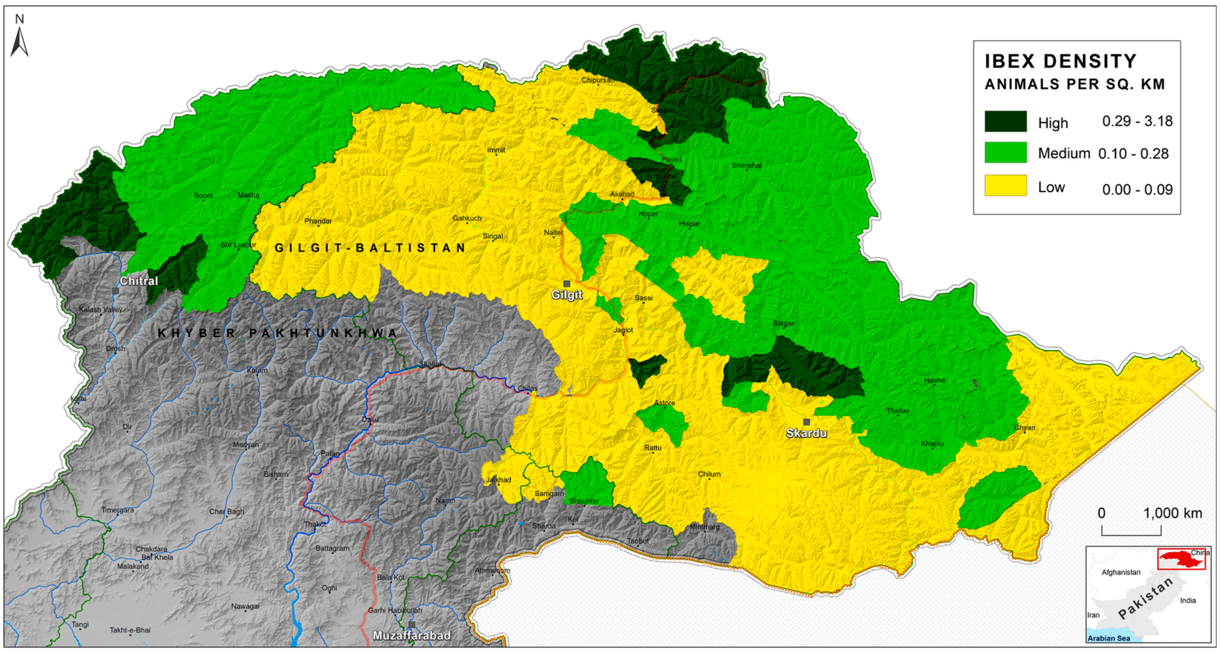

Fig. 3. Density pattern of Himalayan ibex in northern Pakistan.

4. Discussion

The main objective of the current study was to assess the range-wide population and density pattern of ibex across northern Pakistan. We covered about 46 % of the range through extensive double-observer surveys and collected data from concerned wildlife departments for the remaining parts to develop a single-density map. Ibex are the most common and widely distributed ungulate species in northern Pakistan (Hess, 1990). They were rampantly poached throughout their range in GB before the introduction of the country's trophy hunting program in 1995 (Shackleton, 2001). However, poaching then decreased (Jackson and Hunter, 1996), leading to a rise in ibex numbers. Monitoring the populations of wildlife species through robust scientific methods is vital for the evaluation of the success of conservation programs, and also for assessing the conservation of species from a trophy hunting perspective (Singh and Milner-Gulland, 2011). The double-observer approach for population estimation uses the mark-recapture framework (Caughley, 1974). This method has been proven effective in the study of ibex in the harsh and rugged terrain of our study area. It was developed as a more robust and rigorous method based on CMR to address gaps in the monitoring of mountain ungulate species in rugged terrains (Suryawanshi et al. (2012).

Based on the double-observer technique, we estimated a population of 7639 individuals of ibex with a density of 0.21 animals/km^2 across 25 different survey sites. Spatial variation in the density across the study blocks has been observed. In KNP, we recorded a density of 0.64 animals/km^2. This was in contrast to Ahmad et al. (2020) who recorded 0.40 animals/km^2 and Khan et al. (2014) who reported 0.04–0.71 animals/km^2 in some watersheds of KNP using a fixed-point count method. In the KVO area, Ahmad et al. (2020) reported a density of 1.32 animals/km^2, while this study estimated a density of 0.38/km^2. Rahman and Jaffar (2016) recorded a higher ibex density of 0.26 in Chipursan Valley as compared to the density we documented in the current study. The possible reason for this may be the time difference in both surveys—we surveyed in summer while Rahman and Jaffar (2016) conducted theirs in winter. In Hushey Valley, Raza et al. (2015) reported high density, but we cannot compare our estimate because they used the total count method (Singh and Milner-Gulland, 2011).

Density estimates for ibex across its global range are variable, depending on habitat quality and protection level. Throughout the ibex distribution range, high density has been mostly documented from the protected areas. For example, Tumursukh et al. (2016) documented a density of 0.75 ibex/km^2 in the Tost Local Protected Area of Mongolia. Suryawanshi et al. (2012) recorded ibex density of 0.35 individuals/km^2 in Pin Valley National Park, India. Khanyari et al.'s (2021) documented ibex density of 0.75 and 2.26 individuals/km^2 in Koiluu and Sarychat protected areas of Kyrgyzstan. In the current study, the estimated density range from 0.02 to 3.18 ibex/km^2 and suggests that area with a high level of protection (KNP) or area managed by local communities such as Khyber Valley, KVO, Gulmit, Gulkin Hussaini, and Chitral WD have the highest densities.

Ali et al. (2021) have identified suitable habitats for ibex in Pakistan. High-density areas identified in this study lie within good habitat predicted in this study, however, we find that a major chunk of suitable habitat supports the species in low densities. This is probably because of lack of conservation work in these areas, poor control over poaching, and higher stress on habitat. In the current study, a high density of ibex was either found in protected areas with high levels of protection (e.g., KNP) or in areas where trophy hunting programs exist (e.g., Chitral WD, Khyber Valley, Passu Valley, Gulmit, Gulkin-Hussaini, KVO, and SKB). This shows that trophy hunting plays an essential role in the conservation of mountain ungulates in northern Pakistan. Similarly, the increase in the population of markhor in district Chitral, Pakistan, has been attributed to the establishment of Chitral Gol National Park (CGNP) and two game reserves. Due to the establishment of game reserves, local communities also play an active role in the conservation of markhor, blue sheep, and ibex in the area, as they receive benefits through trophy hunting programs. Economic incentives through trophy hunting play an important role in changing human attitudes toward large carnivore species (Mishra et al., 2003) and enable locally supported conservation actions.

Survey season is an important factor that can potentially influence the detection of wild ungulates and their density estimates. The majority of surveys during the current study were carried out in November-April, which is the most appropriate time for sighting ibex in northern Pakistan. During this time ibex occupy lower elevations, make larger herds, and human disturbance is minimal in the habitat (Schaller, 1977). Winter is the rut season when animals aggregate; spring is time for fresh sprouting and attracts animals towards pastures. Surveys in three valleys (Chipurson, Ishkoman, and QNP) in summer (July-August) yielded lower detection and low population estimates. Summer is a time of higher disturbance in the ibex habitat due to increased grazing and tourism activities. Grazing by livestock on shared resources with wild herbivores causes competition for food and reduces forage availability for wild herbivores (Bagchi et al., 2003). During summer, the locals in the study area move to the upper reaches of watersheds along with their livestock and stay there for a few months of summer. During this period their livestock uses the pastures at middle elevations and competes with ibex for forage or displaces them altogether (Bagchi et al., 2004). As a result, the ibex herds are pushed to extreme elevations and in inaccessible areas, thus reducing the chances to find them. Similarly, the study carried out by Bhandari et al. (2022) in Nepal found a negative correlation between ungulate and domestic livestock abundance. Summer is also the post-lambing season when females with their newborns move to remote and secure areas (Schaller, 1977). In consideration of these factors, we believe that our study has underestimated the population in these valleys. Factors like the availability and distribution of food resources, predation risk, and biological events significantly impact the shaping of wild ungulate group sizes (White et al., 2012). We estimated 569 herds of ibex in the surveyed area, with a mean group size of 15 individuals (5.22–41). Ahmad et al. (2020) estimated ibex mean group sizes of 19.0, 16.5, and 16.07 in the Gojal watershed, KVO, and KNP areas of GB respectively. We estimated corresponding figures of 24.56, 11.92, and 16.46 ibex per herd, respectively. Another study by Khanyari et al. (2021) reported the estimated mean group size of ibex as 25 and 29 in Sarychat and Koiluu (Kyrgyzstan), respectively. In Tost Local Protected Area (Mongolia), mean group sizes of 5.24 and 5.04 were documented for 2012 and 2013, respectively, by Tumursukh et al. (2016). According to a study conducted by Han et al. (2019) in the Eastern Tien-Shan Mountains, Xinjiang, China, the ibex group sizes ranged from 1 to 201 individuals, but groups of 1–5 animals were most frequent. The commonly accepted argument for large ungulate aggregation is that it decreases predation risk by increasing predator detection and the dilution effect (Roberts, 1996). Solitary animals spend more time scanning for risk while foraging compared to animals foraging in groups (Berger and Cunningham, 1998).

The social organization of the observed groups shows that about 75 % of the ibex herds in the study area were mixed herds. The numbers of individuals counted in mixed herds were normally larger than male or female herds (Han et al., 2019). Mostly ibex form mixed herds during rut season (November-December), and after rut season they split into male and female herds (Wang et al., 2018). However, there are still a significant number of males and females that stay in mixed-sex groups throughout the year (Fedosenko, 2003). In the present study, seven individuals were observed as a single individual across six study sites. Most (5) of the solitary ibex were identified as males (Class IV = 3, Class II and I = 1) while on one occasion it was identified as an adult female. The possible explanation for solitary individuals could be due to predator attacks that dispersed the herd, human disturbance or male searching for receptive females (Han et al., 2019), or old or sick individuals abandoned by their herd (Zhu et al., 2016). The average detection probability recorded by observer A's (0.68, 0.41–0.92) in the present study was higher than observer B's (0.48, 0.22–0.88). Similarly, Ahmad et al. (2020) also recorded high detection probabilities for observer A in KNP, Gojal (Khyber, Passu, Gulmit, and Gulkin-Hussaini in our study), and Socterabad (KVO), respectively in northern Pakistan. In regions other than Pakistan, the higher detection probabilities for observer A were also recorded by Tumursukh et al. (2016), Khanyari et al. (2021), and Suryawanshi et al. (2021) for ibex in Mongolia, Kyrgyzstan, and India, respectively. The overall higher detection of observer A in the present study showed that the sighting of the first observer by ibex affected the detection probability of observer B in the double-observer method. Ibex are sensitive to human presence—this sensitivity may be attributed to observer A provoking ibex retreat behaviour (Suryawanshi et al., 2012). Observer detection rates are also influenced by animal activity patterns and factors like climate, topography, survey time, and observer efficiency (Thompson, 2004).

In our study, the overall ratio of males and young per 100 females across the surveyed area were recorded as 75 and 81, respectively. This showed that the overall population of ibex in our study area was female-biased. Although, in some study sites, the ratio of males (KNP, 118 males per 100 females), young (Hushey-Thalay, 202 young per 100 females; Chitral WD, 128; and Bagrote, 133), or both males and young (Astak Tormak, 205 males and 132 young) were observed to be higher than females. Similar results were obtained by Ahmad et al. (2020) for the KVO and Gojal watersheds (Khyber, Gulmit, Passu). However, they recorded a low ratio of males to females in the KNP area, while our study recorded a higher ratio (about 20 %). This difference could be due to variations in population size, as Ahmad et al. (2020) estimated a population of 473 ibex, while we estimated a population of 676 individuals. Other possible reasons for this higher ratio of males in KNP could be factors like bans on selective hunting such as trophy hunting and other illegal hunting of large-size males due to the high level of protection in KNP. Khanyari et al. (2021) recorded the ibex population as female-biased in two different study sites in Kyrgyzstan, while Tumursukh et al. (2016) documented a higher ratio of females to males and young in Mongolia. The populations of mountain ungulates are generally known to be female-biased (Berger and Gompper, 1999). Not only are males excessively preyed upon (Berger and Gompper, 1999), but as polygynous species, ibex males incur greater expenses during the rut than females, lowering male survival. Factors such as the hunting of prime-aged males can further exacerbate the female bias.

The population size of large carnivore species depends on the availability of wild ungulates (Karanth et al., 2006; Suryawanshi et al., 2017). Ibex in northern Pakistan are an important source of food for snow leopards and other large carnivores such as the wolf. According to Jackson and Ahlborni (1984), adult snow leopards require about 1.3–2.0 kg of food per day, and 600–900 kg of prey species biomass are required for one adult snow leopard for one year. Oli (1994) documented a ratio of 1:114–159 for snow leopards vs. blue sheep, by weight. Considering the mean weight of ibex to be 60 kg (Hess, 1990) and of snow leopards to be 40 kg (Oli, 1994), the estimated biomass of ibex in the current study is 614,520 kg (surveyed area biomass = 458,340 kg, un-surveyed area biomass = 156,180 kg). Following the formula of Oli (1994) for predator-prey ratios, we estimated that the ibex populations in northern Pakistan could support a population of adult snow leopards ranging from 97 to 135 (surveyed area = 72–101, un-surveyed area 25–34).

5. Conclusions and recommendations

This study estimates a population of 7639 ibex in a 35,307 km^2 surveyed area, with a density of 0.21 animals/km^2. High densities of ibex in northern Pakistan are found mostly in protected areas with high levels of protection, such as KNP, or areas where trophy hunting programs exist, such as Chitral WD, KVO, Khyber, Gulmit, Gulkin-Hussaini, Passu, and SKB. This illustrates the role of trophy hunting programs in the conservation of mountain ungulates and consequently, carnivore species in the area. The density map provides an objective rationale for extended protection in northern to safeguard key populations of ibex. A conservation and protection effort needs to be initiated in low-density areas to help recover the declining populations in those areas. The effectiveness of protected areas need to be enhanced to protect higher concentrations of ibex. We also recommend that study on habitat partitioning between ibex and other sympatric species should be conducted in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is available in the MS.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2022.e02288.

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