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Density Pattern of Flare-Horned Markhor (*Capra falconeri*) in Northern Pakistan

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Abstract: Wild ungulates play vital roles in maintaining a balanced ecosystem through herbivory and are also an important determinant of carnivores' density. The flare-horned markhor (*Capra falconeri*) is a threatened wild goat distributed across the mountain ranges of Pakistan, India, Afghanistan, Russia, Turkmenistan, Uzbekistan, and Tajikistan. The remote terrain and fragmented population limit our understanding of the population ecology of markhor, though knowledge of the target species population is vital for making informed management decisions. Therefore, the current study was designed to determine the markhor population across their range in Northern Pakistan and to evaluate the efforts made by the government and non-government organizations for the conservation of markhor. Double-observer surveys were conducted during 2019–2021 in nine major watersheds of Khyber Pakhtunkhwa and Gilgit-Baltistan covering an area of 4664 km^2. Secondary data were collected for unassessed areas to gain a holistic overview of the markhor population and density in the region. Results revealed a markhor population of 7579, with a density of 0.30 animals per km^2 in Northern Pakistan. Our analysis of the double-observer data through the Bayesian behavioral capture–recapture model estimated a population of 5993 individuals (95% CI) of markhor across nine study sites, with a density of 1.28 animals per km^2. A review of secondary data revealed that a population of about 1586 was present in the un-surveyed area (20,033.33 km^2), with a density of 0.08 per km^2. A total of 146 groups of markhor were counted, with a mean group size of 23 (3–58) individuals. There were 109 males and 108 young per 100 females in the population. Among 1936 recorded males, Class I males accounted for 27.74%, followed by Class II (26.45%), Class IV (trophy-size) (23.40%), and Class III (22.42%). The overall detection probability was recorded as 0.87 and 0.68 for the first observer and second observer, respectively. Compared with the past reports, the population of markhor in Northern Pakistan appears to be increasing, particularly in protected areas (PAs) such as national parks and community-controlled hunting areas (CCHAs). Conservation programs, notably trophy hunting and PA networks, appear to be vital in sustaining markhor populations in parts of the species range. We recommend expansion in such programs in the markhor range in order to maintain a viable population of this majestic wild goat in the region.

Keywords: markhor; *Capra falconeri*; Gilgit-Baltistan; Karakoram; population; double-observer; CGNP

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1. Introduction

Wild ungulates (hoofed mammals) are adapted for life in high mountainous areas, particularly the mountain ungulates in the family *Caprinae* [1]. These species play an important role in maintaining ecosystems through nutrient recycling and influencing plant species composition and vegetation structure [2,3]. They are important prey species for

large carnivores [4], and predators' population density depends on their availability [5]. The depletion of ungulate prey is thus a major threat to the survival of carnivores [6]. For example, with the global focus on the conservation of snow leopard (*Panthera uncia*) [7,8], the monitoring of large ungulate species in the snow leopard range is essential because it has been documented that the density of snow leopard increases with an increase in the density of available wild prey species [3].

The population size of many large-sized herbivore species can be an important indicator of their conservation [9]. Therefore, conservation biologists and wildlife managers often try to evaluate management protocols by assessing the population dynamics of wildlife species [10] and also evaluating the management effects in a given area [11]. Wildlife managers identify population trends by estimating the abundance of target species [12,13]. Therefore, knowledge of population trends is vital for assessing or implementing conservation actions. The extinction risk assessment of species at the global or national level depends on strong assessments of species population sizes and trends [8].

Mammal diversity in the northern parts of Pakistan is higher than in other parts of the country [14]. The mountains in Northern Pakistan are home to several species of wild ungulates, including the flare-horned markhor (*Capra falconeri*), Himalayan ibex (*Capra ibex sibirica*), blue sheep (*Pseudois nayaur*), Marco Polo sheep (*Ovis ammon polii*), Ladakh urial (*Ovis vignei vignei*), and Kashmir musk deer (*Moscus cupreus*) [15].

The flare-horned markhor (hereafter markhor) is a wild goat of the family *Bovidae* that lives in the Hindu Kush, Himalayan, and Karakoram ranges [16,17] in Pakistan, India, and Afghanistan and the mountains of Russia, Turkmenistan, Uzbekistan, and Tajikistan in Central Asia [18–20] at an elevation of 600–3600 m [21]. In Pakistan, the distribution range of markhor extends from the mountains of Balochistan to the north of Khyber Pakhtunkhwa and Gilgit-Baltistan [17]. Globally, the markhor was listed as 'Endangered' in the IUCN red list from 1994–2015. However, in 2015, the status of markhor was downlisted to 'Near Threatened' on the IUCN Red List [21]. The main justification behind this downlisting was an increasing population trend (>5000 mature individuals) due to international conservation success in the recovery of the markhor population in protected and sustainable hunting management areas [21]. In Pakistan, very little information is available about the species' range-wide population status as the populations are highly fragmented—they are listed as 'Endangered' on the Mammals National Red List [22]. Markhor is listed in the CITES Appendix I, which includes species threatened with extinction.

Four subspecies of markhor are documented in Pakistan. The Pir Panjal or Kashmir markhor (*Capra falconeri cashmiriensis*) has corkscrew-shaped horns and is endemic to Kashmir and the northern areas (Chitral, Swat, Upper Dir, and Kohistan districts) of Khyber Pakhtunkhwa. The Astor markhor (*Capra falconeri falconeri*) has one and a half twist, out-flaring horns and is endemic to Gilgit-Baltistan [23,24]. These two subspecies are considered different subspecies of the flare-horned markhor [25]. The third subspecies is the Suleiman markhor (*Capra falconeri jerdoni*), which has tight multi-spiral horns and is endemic to Balochistan [26]. The fourth is the Kabul markhor (*Capra falconeri megaceros*), which has 2–3 straight spiral horns and is endemic to Khyber Pakhtunkhwa (Koh Safed range of the Khyber Valley) and Balochistan [26]. However, the Kashmir and Astore markhor are considered one subspecies, while the Kabul and Suleiman markhor is also considered one subspecies [25]. The Chiltan wild goat (*Capra aegagrus chialtensis*), which is described as a wild goat or rather a hybrid, is considered a fifth subspecies [25]. Apart from this, one subspecies of markhor is the Tajik markhor (*Capra falconeri heptneri*) which is found in Tajikistan, Turkmenistan, Afghanistan, and Uzbekistan [21,27].

The markhor is facing many threats, including deforestation, competition with livestock for food resources, decreased specialized habitat in which to forage, intensified local resource use, habitat fragmentation, increased human population, poaching, largescale development, border fencing [17,20,22], genetically isolated populations due to poor connectivity among subpopulations, hybridization, and low reproductive rates [17] throughout its distribution range. The ongoing war and social conflict make the future of the species

indeterminate [20]. In addition, Khattak et al. [28] documented feral dogs' depredation as an important threat to markhor in Pakistan. Across its distribution range, markhors forage close to domestic goats [29], which are possible carriers of *Mycoplasma capricolum* which caused a fatal pneumonia outbreak in the markhor population [30]. Asia's rangelands and mountains are strongholds for several endemic ungulate species [31], many of which are listed as globally threatened [32], and information related to their population sizes and trends is patchy due to the inaccessibility of their habitats and the absence of strong studies [31]. Several techniques have been established for the monitoring of large herbivores and ungulate species, e.g., distance sampling and strip transects. However, rugged habitats and the lack of sufficient expertise have posed challenges to the reliable estimation and monitoring of wild ungulate populations in Asia's mountains [31]. Many standardized methods for the assessment of wild ungulate populations, such as distance sampling, are difficult to use in mountainous areas because of the impracticality of their assumptions [33]. On the other hand, aerial surveys can be effective but are costly and even dangerous in mountainous areas [34].

The double-observer survey technique was introduced [33] to ensure the reliable population estimation of mountain ungulates. The principles of the technique are based on the theory of capture–mark–recapture [35]. A capture history can be built for each observed individual, and data can be analyzed in a capture–mark–recapture fashion [36]. The method has been successfully applied to mountain ungulates in different regions in the range of the snow leopard [1,8,34]. In Pakistan, the double-observer method has been used for the population estimation of Marco Polo sheep [37], blue sheep [38], and Himalayan ibex [39].

The establishment of protected areas (PAs) with a high level of protection plays an important role in the conservation of threatened species. Across the globe, the number of threatened ungulate species and populations have recovered through PAs and incentive programs that directly benefit the local communities and engage them in the conservation of targeted and non-targeted wildlife species. The current study was designed to determine (1) the markhor population across their range in Northern Pakistan and (2) to assess the impacts of conservation initiatives on the density pattern of markhor. This study was carried out in Northern Pakistan, across three mountain ranges (Karakoram, Hindu Kush, and Himalaya) and two provinces (Khyber Pakhtunkhwa and Gilgit-Baltistan) to determine the range-wide population status of markhor. This study will inform future conservation strategies for the species by providing benchmark population estimates and identifying major strongholds of the species in the country.

2. Materials and Methods

2.1. Study Area

This study was conducted in nine different study sites in the markhor distribution range falling in two administrative regions (Khyber Pakhtunkhwa and Gilgit-Baltistan) of Northern Pakistan (Figure 1, Table 1). In Khyber Pakhtunkhwa, the survey was conducted in Chitral Gol National Park (CGNP), the buffer zone of CGNP, and Chitral Wildlife Division (Chitral WD), while in Gilgit-Baltistan, it was carried out in six valleys, including Haramosh, Sikandarabad, Danyor (Jutal, Jaglot Gooro, and Danyor), Skoyo Karabathang Basing (SKB), Astak Tormik, and Bagrote (Figure 1). In Chitral, the winter is cold, with temperatures ranging from 11 to 2 °C. The winter is severe, with frequent snowfall. Summertime is considered pleasant, with a mean temperature of 28 °C [40]. In Gilgit-Baltistan, the overall climate varies greatly from tropical desert to barren and arid desert. The average annual rainfall is less than 20 mm, and temperatures are between 40 °C in summer and –10 °C in winter. Natural vegetation is divided into four distinct categories—sub-tropical scrub forest, dry temperate broadleaved forest, mountain dry temperate coniferous forest, and northern dry scrub forest [14]. The mammalian species found in the area are represented by the common leopard (*Panthera pardus*), snow leopard, Himalayan lynx (*Lynx lynx*), Asiatic

black bear (*Ursus thibetanus*), wolf (*Canis lupus*), red fox (*Vulpes vulpes*), Himalayan ibex, and markhor.

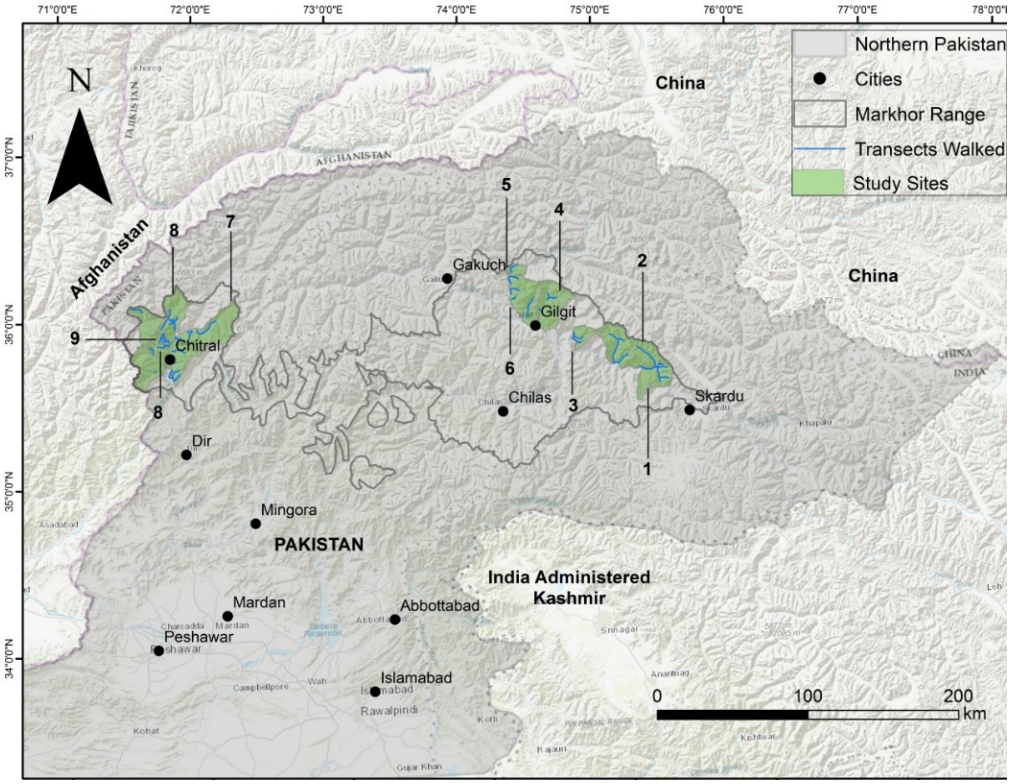

Figure 1. Map showing the distribution of markhor in the northern areas of Pakistan and sites where the double-observer survey was carried out. 1 = SKB; 2 = Astak Tormik; 3 = Haramosh; 4 = Danyor; 5 = Sikandarabad; 6 = Bagrote; 7 = Chitral WD; 8 = CGNP buffer; 9 = CGNP.

Table 1. Study sites where double-observer surveys were conducted for different ungulate species.

Study Blocks	Area Size (km^2)	Month/Year	Effort (km)
Chitral WD	1930	Jan 2020	113
Astak Tormik	801	Apr 2019	62
Bagrote	523	Dec 2020	16
Haramosh	142	Apr 2019	15
SKB	335	Jan 2021	44
CGNP	79	Jan 2020	23
CGNP buffer zone	279	Jan 2020	32
Sikandarabad	87	Dec 2020	10
Danyor	488	Jan 2021	43
Total	**4664**		**357**

2.2. Data Collection

2.2.1. Double-Observer Survey

The double-observer survey was conducted in nine valleys (study sites) within the distribution range of markhor in Northern Pakistan with the primary aim of determining the animal population and density (Figure 1). Surveys were conducted in April 2019, December 2019–January 2020, and January 2021, covering an area of 4664 km^2 (about 19% of the known markhor range in Northern Pakistan) by walking a total of 44 transects of the length of 357 km (Table 1). The mean transect length was 8.1 km ranging from 0.9 to 23 km (SD = 5.53). Study blocks were identified based on natural watersheds and high ridges. The tough, rugged terrain was delineated as boundaries as there was little chance of crossing into the next block during the survey period. In the double-observer

technique, two observers (teams) scan and count animals simultaneously by keeping a spatial or temporal distance between them to ensure that they do not give each other any clue about animals or herd locations. This approach allows population estimates based on just two surveys [33]. The identification of individual mountain ungulates is difficult due to the absence of unique identification marks, but herds can be identified based on specific identification features such as herd size, the age-sex composition of a herd, location of the sighted herd, distance to herd, name of the pasture where the herd was encountered, and time at which group was observed [41]. The unit is 'marked' and 'recaptured' in the double-observer survey as the individual group [42]. Following the assumptions of Suryawanshi et al. [33] of the double-observer method, the team was divided into two sets of observers—observers A and observers B. A temporal distance of about 15 min was maintained between observers A and B while walking through the watershed. Each team was equipped with a spotting scope (20 × 60 Swarovski), binoculars (10 × 50 Pentax XCF), DSLR camera, and GPS device (Garmin 62S). Observed animals in each herd were categorized as female (>2 years), young (<2 years), and male. Males were classified into four different age classes; Class I (2 1/2 years), Class II (3 1/2), Class III (4 1/2), and Class IV (5 1/2), based on their horn size [24]. At the end of the day, both observers compared their data on herd size and sex/age, time of the sighting, and other specific characteristics and herd composition (e.g., male groups only). These data were used to confirm common (recapture) and unique herds and avoid double counting [41].

2.2.2. Secondary Data Collection

Secondary data on markhor populations in the watersheds not covered by the direct surveys were obtained from the published literature [24,43–46] and wildlife department officials. The purpose was to project a single density map of the species across its distribution range.

2.3. Data Analysis

The data obtained for each study through the double-observer survey were arranged in a capture–mark–recapture pattern. Three formats were used depending on herd sightings. A code of '11' was used if a herd was sighted by both observers, '10' if sighted by observer A, and '01' if sighted by observer B. The data were analyzed in a Bayesian behavioral capture–recapture model (BBRecapture package) using the software R [47] to estimate each study site's markhor population. We followed Suryawanshi et al. [8] and Khanyari et al. [42] for the estimation of the number of markhor groups, mean group size, total population, confidence intervals (CIs), and detection probability for both observers.

Markhor density within each study site was calculated by dividing the estimated population by the total site area. The density map was developed in ArcGIS 10.8 (ESRI, Redland, CA, USA) to depict low- (0.00–0.12 animals per km^2), medium- (0.13–0.24), and high-density areas (>0.24).

3. Results

3.1. Markhor Sighting Record

In the current study, markhor herds were observed in seven blocks at 133 locations (Table 2); none were found in Bagrote or Astak Tormak. The sightings comprised single animals to as many as 111 in a herd. Most of the larger herds were observed in CGNP and its buffer areas. Of the observed herds, about 95.5% were mixed herds (consisting of male, female, and young).

Table 2. Estimated population of markhor in different study sites using the double-observer technique.

Variables	CGNP	CGNP Buffer	Chitral WD	Sikandarabad	SKB	Danyor	Haramosh	Total
No. of herds recorded by team A	20	4	19	0	0	3	0	**46**
No. of herds recorded by team B	6	2	2	0	0	2	0	**12**
No. of herds recorded by both teams	26	13	24	2	4	5	0	**74**
Estimated no. of groups	56	20	47	2	4	12	5	**146**
Mean group size	44.26	30.47	57.82	3	10.75	9.1	5.8	**23.02**
Estimated population	2479.0	609.0	2718	6	43	109	29	**5993**
±95% confidence interval	2047.6–2976.2	458.9–801.0	2096.1–3499.7	4.0–16.0	26.0–81.0	68.20–194.40	18.0–46.0	
Total area (km^2)	78.61	279	1930	86.76	335	488	142	**3339.4**
Detection probability of team A	0.81	0.81	0.89	0.70	0.80	0.64	0.83	**0.78**
Detection probability of team B	0.63	0.72	0.54	0.70	0.80	0.57	0.83	**0.68**
Density/km^2	**31.54**	**2.18**	**1.41**	**0.07**	**0.13**	**0.22**	**0.20**	**1.79**

3.2. Markhor Population and Density

The analysis yielded an estimated population of 5993 individuals (95% CI). The mean density was 1.28 individuals per km^2 (1.79 in sighting blocks). The highest population was estimated in Chitral WD where the estimated population was 2718 animals (95% CI 2096–3500), followed by CGNP (2479 animals, 95% CI 2048–2976), CGNP buffer area (609, 95% CI 459–801), and Danyor (109, 95% CI 68–194) (Table 2). The lowest population of markhor was estimated in Sikandarabad and Haramosh where a population of 6 (95% CI 4–16) and 29 (95% CI 18–46) individuals was estimated, respectively (Table 2). The highest markhor density was estimated in CGNP at 31.54 animals per km^2, while the lowest was estimated in Sikandarabad (0.07) (Figure 2, Table 2).

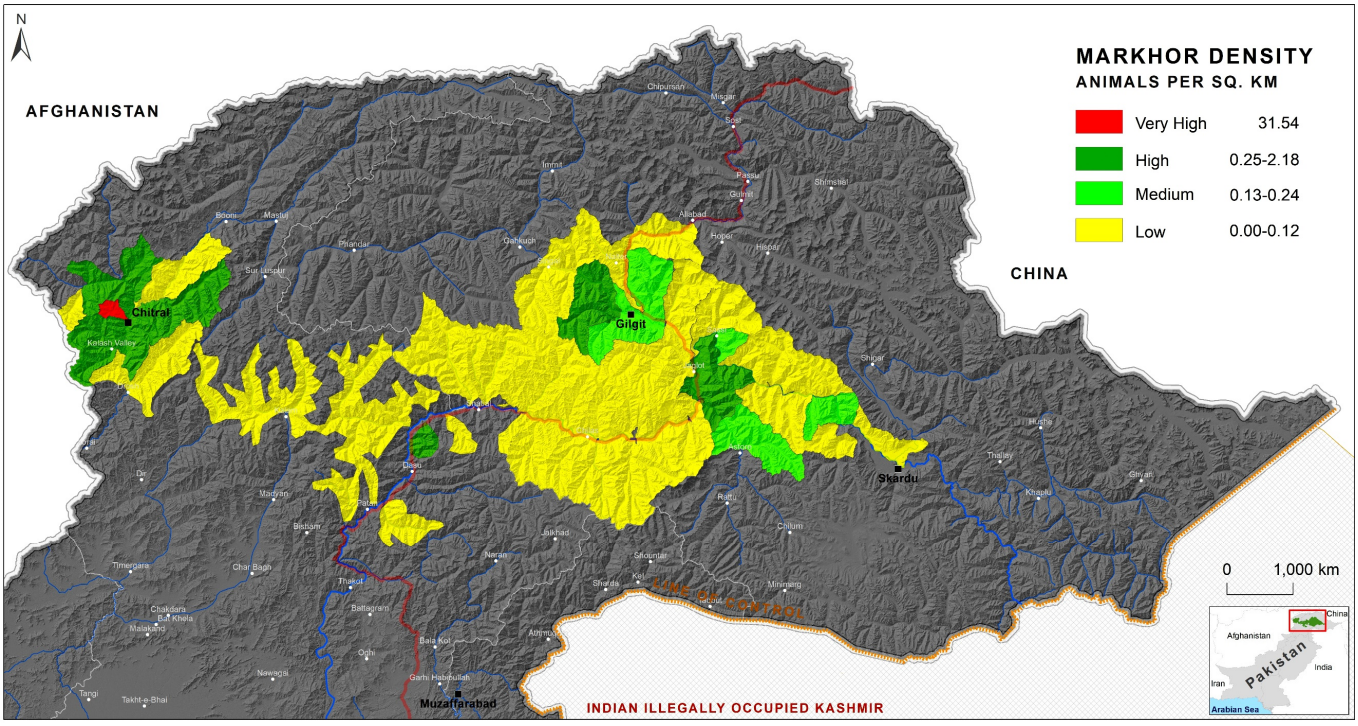

Figure 2. Range-wide density pattern of markhor in Northern Pakistan.

Based on secondary data, the total population of markhor in an un-surveyed area of 20,033 km^2 was about 1586, with an average density of 0.08 per km^2. The high-density areas of markhor in the un-surveyed area included Kiagah (1.90 animals per km^2), Ramgaht (0.79), Doyan (0.72), Bonji (0.54), and Henzal (0.37) (Supplementary Materials and Figure 2). Most of the un-surveyed areas fell in the low-density class (Figure 2).

3.3. Estimated Number of Groups and Group Size

The estimated number of markhor groups was 146, with a mean group size of 23 (3.00–57.82 individuals). The numbers of markhor groups observed by team A, team B, and both teams are shown in Table 3. The largest number of estimated groups was recorded in CGNP (56 groups) and Chitral WD (47), while the smallest numbers were found in Sikandarabad (4), SKB (4), and Haramosh (5). The highest mean estimated group size was observed in Chitral WD (57.82 animals/herd), followed by CGNP (44.26 animals/herd) and CGNP buffer (30.47 animals/herd). The lowest number of animals per herd was found in Sikandarabad (3 animals/herd) and Haramosh (5.8 animals/herd) (Table 3).

Table 3. Sex ratio and fecundity in markhor population in Northern Pakistan.

	Ratio to 100 Female Individuals	
Study Block	**Male**	**Young**
Chitral WD	151	208
CGNP	146	144
CGNP buffer	100	181
Haramosh	67	67
SKB	55	41
Sikandarabad	150	50
Danyor	91	67

3.4. Detection Probability

The overall detection probability was 0.87 and 0.68 for the first observer and second observer, respectively. The highest detection probability of observer A was recorded in Chitral WD (0.89), followed by Haramosh (0.83), CGNP and buffer area (0.81 each), and SKB (0.80). In the case of observer B, the highest detection probability was observed in Haramosh (0.83), followed by SKB (0.80), CGNP buffer (0.72), and Sikandarabad (0.70) (Table 3).

3.5. Sex Ratio

The male-to-female ratio for markhor across the surveyed areas was estimated as 109 per 100 females, while the young-to-female ratio was estimated as 108 per 100 females (Table 3). The highest male-to-female ratio was observed in Chitral WD, Sikandarabad, and CGNP, while the highest young-to-female ratio was recorded in Chitral WD, CGNP buffer, and CGNP (Table 3).

3.6. Male Population Structure

A total of 1936 male markhors of different classes were observed in this study (Table 4). Class I males accounted for about 27.74%, followed by Class II (26.45%), Class IV (23.40%), and Class III (22.42%). The highest number of trophy-sized males (Class IV) was observed in CGNP (225 individuals), followed by Chitral WD (180), CGNP buffer (32), and Danyor (8) (Table 4). A photograph of male markhor of Class III is given in Figure 3.

Table 4. Age structure of male markhors in Northern Pakistan.

Study Site	Class I (%)	Class II (%)	Class III (%)	Class IV (%)	Total
Chitral WD	257 (29.7)	238 (27.5)	191 (22.1)	180 (20.8)	866
CGNP	236 (27.5)	216 (25.2)	181 (21.1)	225 (26.2)	858
CGNP buffer	31 (20.7)	44 (29.3)	43 (28.7)	32 (21.3)	150
Haramosh	3 (37.5)	2 (25)	2 (25)	1 (12.5)	8
SKB	0	0	6 (50)	6 (50)	12
Sikandarabad	0	1 (25)	2 (50)	1 (25)	4
Danyor	10 (26.3)	11 (28.9)	9 (23.7)	8 (21.1)	38
Total	**537 (27.7)**	**512 (26.4)**	**434 (22.4)**	**453 (23.4)**	**1936**

Figure 3. Markhor photographed in CGNP (photo credit: Abdullah Khan).

4. Discussion

This study provides the first-ever range-wide density estimates of markhor in Pakistan, constructed on empirical data. The double-observer technique has been used successfully for mountain ungulates in Pakistan [37–39] and in neighboring countries such as India [3], Nepal [48], Bhutan [49], and Kyrgyzstan [42]. This technique has not been used for the population assessment of markhor, except by Michel et al. [27], who carried out a double-observer survey for markhor in a small area in Tajikistan. Previous population assessments in Pakistan were carried out in limited parts of the species' distribution range using the point count/vantage point method. The double observe method was tested for the first time during the current study in two administrative regions: Khyber Pakhtunkhwa province and Gilgit-Baltistan. We estimated the population of markhor in the surveyed area to be about 5993 individuals with a density of 1.28 individuals per km^2. The high density was documented in study blocks of Chitral (CGNP and buffer area of CGNP). In Gilgit-Baltistan, we estimated a population of about 187 individuals across six different study sites with a density range from 0.07 to 0.22 animals per km^2. The density of markhor varies from region to region depending upon the protection level measures and quality of available habitats.

Information about markhor population and density pattern across their range is patchy. A density of 2.91–3.12 animals per km^2 was documented by Bhatnagar et al. [20] from an area of 120 km^2 of Jammu and Kashmir. In Tajikistan, a mean density of 2.84 animals per km^2 was documented by Michel et al. [27] in 2014, while Broghammer et al. [50] documented a mean density of 3.4 individuals per km^2 for several study sites in Tajikistan in 2017. We cannot compare our study results with the aforementioned density of markhor from different regions due to the differences in the survey methodologies.

The largest population was estimated in Chitral: 5806 animals in CGNP, the buffer of CGNP, and Chitral WD. According to wildlife department officials, about 67 individuals were present in the remaining (un-surveyed area) valleys of this district (DFO Wildlife Chitral Pers. Comm.). Compared with historical records, our estimates suggest an increasing trend in the population of CGNP. Before the establishment of CGNP, a maximum number of 520 animals in CGNP area were recorded by Aleem [51]. The area was established as a national park in 1984. The CGNP's estimated markhor population during 1985–1986 was 160–300 animals. Arshad [52] documented 373 in 2003 and 590 in 2005–2006. Ali [53] confirmed the increasing population trend, recording a total of 612 animals in 2006, with an annual growth rate of 7.7%. The Chitral area has been observed to be a markhor stronghold, with an increasing population trend. We documented an increase in Chitral's markhor population and attribute it to the establishment of CGNP and two community-managed game reserves called Tooshi-Sasha Community-Managed Game Reserve (TSCMGR) and Gehraite-Golain Community-Managed Game Reserve (GGCMGR), in addition to active protection measures taken by wildlife departments and communities. These game reserves fall within Chitral WD, covering an area of about 1150 km^2 (GGCMR = 950 km^2 and TSCMGR = 200 km^2). The establishment of these game reserves allowed local communities to play an active role in markhor conservation—they receive benefits through trophy hunting programs. Moreover, a proposal has been submitted for the establishment of a community-based conservancy program in CGNP's buffer area (DFO Wildlife Chitral Pers. Comm.). Similarly, the increasing trend in the population of markhor in Tajikistan is attributed to the expanding network of protected areas and the establishment of trophy hunting reserves. The population of markhor was about 350 individuals in 1997, but due to the increased level of protection in already existing protected areas, the establishment of more conservancies in 2005, and the trophy hunting program commencing in 2014, the population of markhor increased to 1901 in 2017, and 85% of markhors were in the conservancy areas [54].

Combining the markhor populations estimated through the double-observer method and from data obtained from the published literature and Gilgit-Baltistan wildlife officials, a total population of about 1238 individuals can be assumed across the species range in Gilgit-Baltistan. Haider et al. [24] reported a population of about 1087 individuals. There was a sharp decline in markhor populations in Gilgit-Baltistan up to the mid-1990s, but community-based conservation efforts led to an eventual increase [24]. Most of the high markhor densities were observed in community-based conservation areas. The social and economic benefits of trophy hunting have persuaded local communities to become stewards of wildlife populations, especially of the highly prized markhor [24,55].

In this study, we recorded detection probabilities of 0.87 and 0.68 for observers A and B, respectively, though in some study sites, it was the same for both observers. Using the double-observer technique to study mountain ungulates, most researchers have reported high detection probabilities for observer A [34,38,39,42]. In most of these studies, the low detection of the second observer is attributed to the escape behavior of wild ungulates due to the first observer. In this study, the same detection probabilities of both observers across almost all study sites may be attributed to high protection levels and relatively low poaching pressures as the study was conducted in mostly protected areas or community-controlled hunting areas (CCHAs). Michel et al. [56] used the double-observer technique for the markhor survey in Tajikistan and reported very low detection probabilities for

observer B. This low detection probability was linked with the escape behavior of markhor because of the first observer team.

The markhor population in Pakistan shows a well-balanced sex ratio structure. The hunting of selective males in the population results in a low ratio of males to females [57]. In our study, the high ratio of males to females indicated that illegal hunting or poaching targeting adult males is very low [27]. The main reason for this is active protection by relevant wildlife departments and the involvement of local communities. In the current study, we documented a high ratio of young to female (108:100) for markhor. A high ratio of young to females in the markhor population was also documented by Michel et al. [56] in Tajikistan (117:100) and Haider et al. [24] in the Gilglit-Baltistan region of Pakistan (112:100). This high ratio of young indicates a high reproduction rate and survival of kids [56].

The most important factor contributing to the high ratio of male markhor is the trophy hunting program through which local communities are actively involved in the protection and conservation of markhor, a high-price trophy animal in Pakistan compared to Himalayan ibex and blue sheep. In this study, a total of 1936 males of different age classes were observed at various study sites. About 23.4% of males were trophy-sized (Class IV). Hunting of trophy-size males could have a huge impact on the population size and structure of the target species if the trophy quota is not allocated based on ground truth. In Pakistan, the trophy hunting quota is allocated at 1–2% of the target population for sustainable harvesting [58]. In the case of markhor, two trophy-size males could be harvested if the total population is about 150 individuals, and about 8 trophy-size males were observed in two consecutive winters. Our results show that there are enough trophy-size males available for suitable harvesting, particularly in the Chitral region, but most of the trophy-size males are present in protected areas such as CGNP and buffer areas of CGNP where trophy hunting is not allowed as per the wildlife act. Therefore, the current harvesting ratio of trophy-size males in both Chitral (three trophies each year) and Gilgit-Baltistan (four trophies each year) is sustainable and should not have a disastrous impact on the structure of and ratio of the male population.

The trophy hunting of markhor was allowed to promote the conservation of endangered species through community-based conservation programs after the 10th meeting of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in 1997 [58]. Trophy hunting programs give residing communities direct benefits. Successful community-based markhor hunting conservancies are well-established in Pakistan, where 80% of hunting fees are invested in participating communities [29,58,59]. Markhor trophy hunting is currently taking place in 8 of the 15 CCHAs in Gilgit-Baltistan, namely Kargah, Sakwar-Jutial-Barmas, Harmosh-Sassi, Sikandarabad, Bunji, Dashkin-Mushkin-Turbuling, Doyan, and SKB.

A total of four markhor trophies are harvested in Gilgit-Baltistan each year, usually one per catchment, with an interval of one to several years [24]. Moreover, the establishment of TSCMGR and GGCMGR in Chitral WD contributed significantly to markhor conservation. A maximum of three markhors are hunted through trophy hunting programs in these two community-managed game reserves each year.

The Chitral Wildlife Department has proposed the establishment of a new conservancy in the buffer area of CGNP to strengthen markhor conservation in Chitral—the buffer area has a sufficiently large population, with a density of 2.18 animals per km^2. The relevant department proposes a trophy allowance of one animal per year (DFO Wildlife Chitral Pers. Comm.).

Markhor trophy hunting also takes place in Kiagah Valley of district Kohistan (Khyber Pakhtunkhwa) where the population has increased since the valley's establishment as a community-managed game reserve in 2005. A total of 74 markhors were present in the valley during 2005 which expanded to a population of 291 in 2018 [43]. However, the surrounding valleys had no community conservation programs, so poaching and human interference directly affected the population and led to a significant decrease [43].

In mountain ungulates, the ratio of kids to females is important for determining the fecundity rate, while the ratio of yearlings to females is critical for calculating the chances of kids reaching the yearling stage [60]. In this study, we recorded a high ratio of young to females (108 per 100 females), which indicates a high reproductive rate and survival rate of young in the study area. Markhor inhabits lower elevations than blue sheep and Himalayan ibex. Higher elevations have minimal plant cover and severe temperatures due to heavy snowfall. The opposite is true of lower elevations [43]. The high survival rate of young markhors may be due to food availability and the moderate temperatures of lower elevations.

5. Conclusions

This study concludes that Pakistan's markhor population is increasing, particularly in protected areas such as CGNP, its buffer zone, and CCHAs. The increasing population trend, particularly in the Chitral area, is due to the active protection measures of the Wildlife Department and the involvement of local communities in conservation activities through trophy hunting programs. Based on our findings, we recommend that more surveys be carried out in other areas of the markhor's distribution range using the double-observer technique, e.g., Kumrat Valley (Upper Dir), Kalam Valley (Swat), and the valleys of district Kohistan. In addition to this, we also recommend that future surveys should be carried out through the double-observer and vantage point method to test the validity of both survey methods. The trophy hunting program should be extended to other areas after extensive population surveys. In addition, the protected area network should be extended to include high markhor density areas.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su14159567/s1, Secondary data obtained from published literature and concerned Wildlife Officials.

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