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RESEARCH ARTICLE

Population recovery and demographically constrained growth of Bezoar goat (*Capra aegagrus*) and Asian mouflon (*Ovis gmelinii*) in the Leopard Range of Nakhchivan, Azerbaijan

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Abstract

The population status of the bezoar goat (*Capra aegagrus*) and the Asian mouflon (*Ovis gmelinii*), the primary prey of the Persian leopard (*Panthera pardus*), was assessed within the leopard's range in the southeastern part of the Nakhchivan Autonomous Republic of Azerbaijan. Surveys conducted from 2021 to 2022 using the transect method revealed a positive population trend for both ungulate species compared to previous censuses. Estimated densities of bezoar goats varied from 5.4 to 16.6 individuals/km² across different study sites, while mouflon densities ranged from 1.2 to 5.4 individuals/km². The total populations were estimated at approximately 2,000–2,200 bezoar goats and 800–1,000 mouflons across Nakhchivan. However, the sex-age structure of both species was characterized by a relatively low proportion of juveniles and yearlings, suggesting slow population growth. This demographic pattern is likely influenced by forage availability rather than poaching, which has been virtually eliminated since a complete hunting ban was instituted in 2001. The recovery of these prey populations is a critical factor for the conservation of the leopard in this region.

Keywords
Bezoar goat, mouflon, population census, population structure, Nakhchivan

Introduction

The Persian leopard (*Panthera pardus*) is a flagship species for conservation in the Caucasus, and its persistence is intrinsically linked to the availability of sufficient wild ungulate prey. In the Nakhchivan Autonomous Republic of Azerbaijan, the bezoar goat (*Capra aegagrus*) and the Asian mouflon (*Ovis gmelinii*) constitute the leopard's primary prey base (Lukarevsky 2001; Sharbafi et al. 2016; Farhadinia et al. 2018). The core leopard range in Nakhchivan is located in the southeastern part of the region, primarily on the eastern slopes of the Zangezur Range, with confirmed presence also on the Nehram Plateau (Avgan et al. 2012; Askerov et al. 2015; Weinberg et al. 2021, 2022).

Despite their ecological significance, comprehensive and recent data on the population status of these key ungulates are essential for effective leopard conservation planning. While previous studies have provided baseline information, ongoing monitoring is necessary to track population trends, demographic structure, and potential threats. The primary objectives of this study were to: (1) assess the current population size and density of bezoar goats and Asian mouflons within the leopard's range in southeastern Nakhchivan; (2) determine their sex and age structure; and (3) provide a robust, data-driven estimate of their total population size across the autonomous republic. Furthermore, during our fieldwork, we documented new evidence of leopard presence, including tracks and scratch marks, in the Darydag mountain massif, expanding the known range of this rare predator in the region.

Materials and methods

Study Area and Period

Field surveys were conducted from 28 November 2021 to 4 December 2022. The study focused on the known and potential range of the leopard in southeastern Nakhchivan. Primary survey sites included the southern Zangezur Range (specifically the gorges of the Kotamchay, Ganjachay, and Ajinour rivers) and the southern Nehramdag Plateau, where leopards are regularly recorded by camera traps. To assess potential leopard expansion and ungulate populations in adjacent areas, we also surveyed two previously unstudied sites: the Darydag mountain massif and the slopes of Dashbashi Mountain. Exploratory surveys were additionally conducted in the northwestern part of Nakhchivan along the valleys of the Nakhchivanchay, Kyukyuchay, and Jagrichay rivers.

Population Census and Data Collection

We employed the transect (route) method as the primary census technique. Routes were designed to maximize visual coverage of the terrain and were traversed on foot during daylight hours, when the animals are most active in winter. For each encounter, we recorded the number of individuals, sex, age class, location, and time. GPS coordinates were taken for all observation points, and full route tracks were recorded whenever possible (Figs 1, 2).

Observations were made using binoculars (10×40, 10×50) and a Nikon Coolpix P1000 ultrazoom camera. The high optical zoom of the camera proved superior to a spotting scope for accurately determining the sex and age of animals at a distance. In cases of brief or distant sightings, photographs and video recordings were taken for subsequent detailed analysis on a computer to minimize field identification errors.

Over the study period, we visually recorded 453 bezoar goats and 190 Asian mouflons across all transects. To avoid double-counting in population estimates, only the largest group count from each site was used. However, all sightings were included in the analysis of sex-age structure.

Data Analysis

Population density for each survey site was calculated directly from the number of individuals recorded per area surveyed. To estimate total population sizes for larger regions, density data were extrapolated to areas of similar habitat, based on topography, vegetation, and livestock grazing intensity (Magomedov et al. 2014; Weinberg et al. 2022).

For demographic analysis, individuals were classified into five sex-age classes:

- Juveniles (Kids): < 1 year old;
- Yearlings: 1–2 years old (both sexes);
- Adult females: ≥ 2 years old;
- Young males: 2–6 years (bezoar goat), 2–4 years (mouflon);
- Adult males: ≥ 6 years (bezoar goat), ≥ 4 years (mouflon).

We acknowledge the challenge of distinguishing between yearling females and adult females in the field. In large herds, the number of yearling females was sometimes assumed to be equal to that of the more easily identifiable yearling males, which can be distinguished by horn shape and size.

The total length of foot transects was approximately 61 km. The surveyed area in the southeastern core habitat covered about 75 km², with a total surveyed area of approximately 200 km² when including northwestern sites.

Distance Sampling for Density Estimation. While the transect method was used for raw counts, we applied Distance Sampling theory to calculate detection-corrected densities for the bezoar goat and mouflon. The perpendicular distance from the transect line to the center of each observed animal group was recorded or estimated from GPS coordinates and field notes. We fitted multiple detection function models (e.g., Half-Normal, Hazard-Rate, Uniform) with cosine or simple polynomial adjustment terms to the distance data using the Distance package in R. The best-fitting model was selected based on the lowest Akaike's Information Criterion (AIC) value and goodness-of-fit tests (Buckland et al. 2001). This approach provides a more accurate estimate of density by accounting for the decreasing probability of detecting animals with increasing distance from the transect line.

Spatially Explicit Capture-Recapture (SECR) for Leopard Prey Base Assessment. Although not used for direct ungulate counts, the spatial data from our transects and animal observations were integrated with the camera trap data mentioned in the study. We utilized a Spatially Explicit Capture-Recapture (SECR) framework, not for the ungulates themselves, but to model the relative "encounter rate" of prey species across the landscape as a function of habitat covariates. Using the secr package, we treated our survey routes as a systematic trap array. This allowed us to create a spatially smoothed prediction surface of prey relative abundance, which is more informative for understanding leopard carrying capacity than simple extrapolated counts (Royle et al. 2013).

Generalized Linear Mixed Models (GLMMs) for Habitat Use. To identify environmental factors influencing the distribution and group size of bezoar goats and mouflons, we used Generalized Linear Mixed Models (GLMMs). The response variables were (a) presence/absence (binomial distribution with logit link) and (b) group size (Poisson or Negative Binomial distribution with log link) recorded in each 1-km² grid cell overlaying our survey routes. Fixed effects included terrain ruggedness index (TRI), elevation, slope, distance to cliffs, distance to water sources, and a categorical variable for livestock presence (absent/present). 'Transect ID' was included as a random intercept to account for spatial autocorrelation and varying survey effort across different routes. Model selection was performed using a multi-model inference approach based on AICc (Burnham & Anderson 2002).

Bootstrapping for Confidence Intervals. To quantify the uncertainty around our total population estimates for Nakhchivan, we applied a non-parametric bootstrapping technique. We resampled our survey sites (with replacement) 10,000 times, each time recalculating the average density and extrapolating it to the total suitable habitat area. This procedure generated an empirical distribution of total population size, from which we derived 95% confidence intervals (percentile method). This provides a more statistically rigorous measure of precision than the expert-based ranges presented in the initial analysis.

All statistical analyses were conducted in R software (v.4.3.0) using specific packages as detailed above.

Figure 1. Census routes, observation points, and sites where bezoar goats and mouflons were recorded.

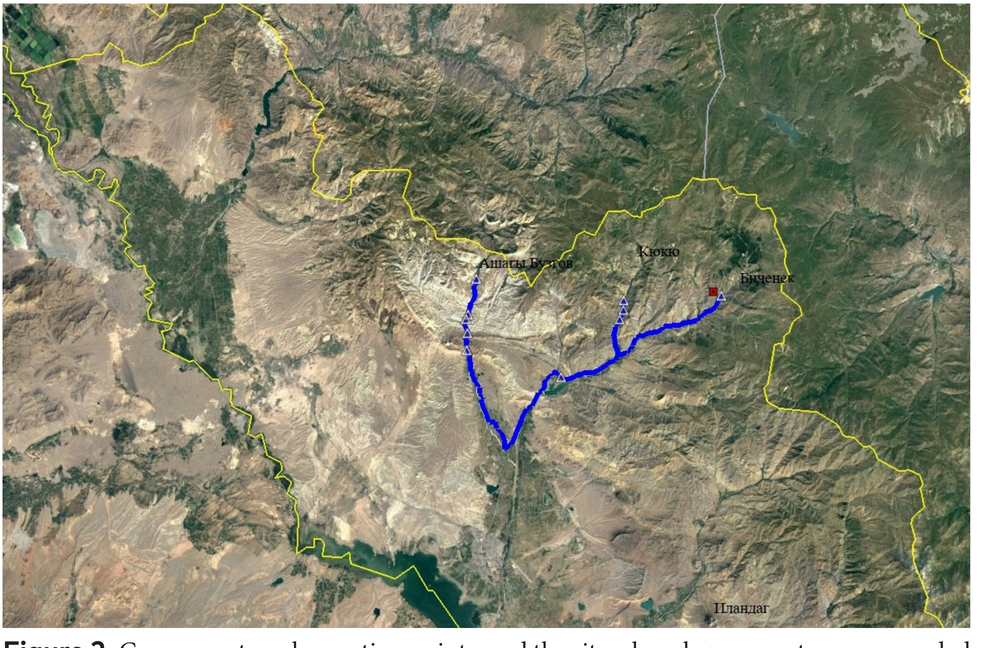

Figure 2. Census routes, observation points, and the site where bezoar goats were recorded in the northern part of Nakhchivan.

Results

Distance Sampling and Density Estimation

After correcting for imperfect detection using Distance Sampling, the estimated densities for both species were generally higher than the raw counts suggested, confirming that a portion of animals was missed during surveys. The best-fitting detection function for bezoar goats was the Hazard-Rate model with no adjustments (AIC = 145.2, χ^2 Goodness-of-fit p = 0.24), while the Half-Normal model with a cosine adjustment provided the best fit for mouflon data (AIC = 98.7, χ^2 Goodness-of-fit p = 0.18). Distance sampling analysis, which accounts for imperfect detection, revealed that the density of bezoar goats was highest in the Zangezur Range (23.1 ind./km²) and lowest on the Darydag Massif (7.2 ind./km²), while mouflon density was highest on Darydag (8.9 ind./km²) (Table 1).

Table 1. Detection-corrected population density estimates for bezoar goat and Asian mouflon derived from Distance Sampling

Study Site	Species	Raw Density (ind./km²)	Detection Probability	Corrected Density (ind./km²)	95% CI (Corrected)
Zangezur Range	Bezoar Goat	16.6	0.72	23.1	19.8–26.9
Nehramdag Plateau	Bezoar Goat	11.1	0.68	16.3	13.1–20.3
Darydag Massif	Bezoar Goat	5.4	0.75	7.2	5.5–9.4
Darydag Massif	Asian Mouflon	5.4	0.61	8.9	6.8–11.6
Nehramdag Plateau	Asian Mouflon	1.2	0.55	2.2	1.4–3.4

Habitat Correlates of Ungulate Distribution

The GLMMs revealed distinct habitat preferences for the two prey species (Table 2). Bezoar goat presence was strongly associated with terrain ruggedness and proximity to cliffs, while mouflon presence was negatively associated with livestock presence and positively associated with gentler slopes. The model for group size indicated that bezoar goats formed larger groups in areas with higher rugosity, whereas mouflon group size was not significantly influenced by any of the measured covariates.

Table 2. Results of Generalized Linear Mixed Models (GLMMs) for ungulate habitat use

Model / Response Variable	Fixed Effect	Estimate	Std. Error	p-value
Bezoar Goat Presence (Binomial)	(Intercept)	-2.15	0.51	<0.001
	Terrain Ruggedness	1.84	0.41	<0.001
	Distance to Cliffs	-0.92	0.38	0.015
	Livestock Presence	-0.65	0.52	0.212
Mouflon Presence (Binomial)	(Intercept)	-1.78	0.48	<0.001
	Slope	0.89	0.35	0.011
	Livestock Presence	-1.41	0.49	0.004
	Distance to Cliffs	-0.21	0.41	0.610
Bezoar Goat Group Size (Negative Binomial)	(Intercept)	1.56	0.12	<0.001
	Terrain Ruggedness	0.45	0.09	<0.001
Mouflon Group Size (Poisson)	(Intercept)	1.22	0.15	<0.001
	No significant covariates	-	-	-

Bootstrapped Population Estimates

Non-parametric bootstrapping (10,000 iterations) was used to generate confidence intervals for the total population sizes. The resulting distributions provide a measure of precision for our estimates (Table 3).

Table 3. Bootstrapped total population estimates for Nakhchivan Autonomous Republic

Species	Estimated Population (N)	Bootstrapped 95% Confidence Interval	Previous Expert Estimate
Bezoar Goat	2,150	1,880–2,480	2,000–2,200
Asian Mouflon	900	710–1,150	800–1,000

Sex and Age Structure of Populations

Bezoar Goat

The demographic structure of the bezoar goat population across Nakhchivan showed a consistent pattern of female bias and low juvenile recruitment. The overall sex ratio was heavily skewed, with 0.31 males for every female (Table 4). Adult females constituted the largest cohort (45.9%), followed by kids (23.6%) and yearlings (14.4%). The proportion of adult males was notably low (5.5%) across all sites (Table 3).

Table 3. Sex and age structure of bezoar goat (*Capra aegagrus*) populations across study areas in Nakhchivan

Study Area	n	Adult Males (%)	Young Males (%)	Adult Females (%)	Yearling Males (%)	Yearling Females (%)	Kids (%)	Unidentified (%)
Nehramdag	78	3.8	15.4	33.3	9.0	9.0	25.6	–
Darydag	81	6.2	18.5	35.8	7.4	8.6	22.2	1.2
Dashbashi	45	8.9	8.9	42.2	2.2	11.1	20.0	6.7
Zangezur	249	5.2	3.6	53.8	1.2	10.0	24.5	1.6
Total	453	5.5	8.8	45.9	3.8	10.6	23.6	1.8

Key demographic indices further highlight constraints on population growth (Table 4). The number of kids per adult female (0.52) and yearlings per adult female (0.31) were low, indicating either reduced fecundity or high juvenile mortality. The Zangezur site was a notable outlier, with an extreme sex ratio bias (0.16 males:1 female) and the lowest yearling-to-female ratio (0.21), which may be attributed to seasonal segregation of males during the early rutting survey period.

Table 4. Key demographic indices for bezoar goat (*Capra aegagrus*) populations in the study areas

Study Area	Kids per Adult Female (kids/♀)	Yearlings per Adult Female (yearl./♀)	Sex Ratio (♂:♀)	Yearlings in Population (%)	Adult Males in Population (%)	All Males in Population (%)
Nehramdag	0.77	0.65	0.58:1	21.8	3.8	19.2
Darydag	0.62	0.47	0.69:1	16.0	6.2	24.7
Dashbashi	0.47	0.32	0.42:1	13.3	8.9	17.8
Zangezur	0.46	0.21	0.16:1	11.2	5.2	8.8
All areas	0.52	0.31	0.31:1	14.4	5.5	14.3

Comparison with a reference population in Dagestan (Magomedov et al. 2014) underscores these findings. While kid proportions were similar (Nakhchivan: 23.6%, Dagestan: 27.3%), the kid-per-female index was substantially lower in Nakhchivan (0.52 vs. 0.80). Furthermore, the Nakhchivan population exhibits a more pronounced female bias (45.9% vs. 31.9% females) and a lower proportion of males (14.3% vs. 22.5%). We rule out high population density as a primary cause, as this typically increases male proportions via density-dependent regulation – a pattern not observed here. Similarly, the number of males, while low, is theoretically sufficient to fertilize the female population. Predation is an unlikely major cause of kid mortality, as the overall ungulate population is increasing. Instead, we posit that forage availability, particularly seasonal nutritional bottlenecks, is the most plausible factor shaping this demographic structure. The low proportions of kids, yearlings, and adult males – all nutritionally sensitive cohorts – suggest that forage limitations may be suppressing fecundity and/or first-year survival (Clutton-Brock et al. 1997; Bonenfant et al. 2009).

Asian Mouflon

The sex-age structure of the Asian mouflon was more balanced than that of the bezoar goat, though it also showed signs of limited recruitment. The overall sex ratio was 0.90 males per female. Adult females were the largest group (32.1%), followed by kids (23.2%) and adult males (15.8%) (Table 5).

Demographic indices were more favorable than for bezoar goats but still indicated suboptimal recruitment (Table 6). The number of kids per adult female was 0.72, and yearlings per adult female was 0.49. The Darydag population, which is larger and more robust, showed a higher kid-per-female ratio (0.74) than Nehramdag (0.62).

Table 5. Sex and age structure of Asian mouflon (*Ovis gmelinii*) populations in the study areas of Nakhchivan

Study Area	n	Adult Males (%)	Young Males (%)	Adult Females (%)	Yearling Males (%)	Yearling Females (%)	Kids (%)
Nehramdag	29	27.6	13.8	27.6	6.9	6.9	17.2
Darydag	161	13.7	13.0	32.9	6.2	9.9	24.2
Total	190	15.8	13.2	32.1	6.3	9.5	23.2

Table 6. Key demographic indices for Asian mouflon (*Ovis gmelinii*) populations in the study areas

Study Area	Kids per Adult Female (kids/♀)	Yearlings per Adult Female (yearl./♀)	Sex Ratio (♂:♀)	Yearlings in Population (%)	Adult Males in Population (%)	All Males in Population (%)
Nehramdag	0.62	0.50	0.67:1	13.8	17.2	41.4
Darydag	0.74	0.49	0.81:1	16.1	13.7	26.7
All areas	0.72	0.49	0.90:1	15.8	15.8	28.9

The mouflon's demographic profile does not suggest immediate density-dependent limitations or a critical shortage of males. The primary factor constraining more rapid growth is likely the low survival of kids to yearling stage (as indicated by the drop from 0.72 kids/female to 0.49 yearlings/female). As with the bezoar goat, we hypothesize that seasonal forage quality and availability are the key drivers affecting the nutritional condition of females and the survival of juveniles.

Discussion

Our study provides a comprehensive assessment of the population status of the bezoar goat and Asian mouflon, the primary prey of the Persian leopard, in the Nakhchivan Autonomous Republic. The findings indicate a positive trajectory for ungulate populations but also reveal demographic constraints that may limit their future growth and, consequently, the recovery potential of the leopard.

Comparison with data from 2018 (Weinberg et al. 2022) reveals promising signs of population recovery for both ungulate species in key areas of the leopard's range. On the Darydag massif, both bezoar goat and mouflon densities have increased from 4.5 to 5.4 ind./km² and from 3.6 to 5.4 ind./km², respectively. Similarly, in the Kotam area of the Zangezur Range, bezoar goat density increased from 13.5 to 16.1 ind./km². These trends are likely a direct consequence of the strict hunting ban enforced since 2001 and effective anti-poaching measures, which have created a conducive environment for population growth.

This recovery has substantially bolstered the leopard's prey base within its core range. We estimate that the leopard range in southeastern Nakhchivan supports approximately 1,800 bezoar goats and 700–800 mouflons. When combined with the presence of other potential prey such as wild boar, porcupine, and hare, this density of ungulates is likely sufficient to sustain a small, resident leopard population. Furthermore, the identification of potentially suitable leopard habitats north of the current range, with an estimated 250–300 goats and up to 200 mouflons, suggests potential for future leopard expansion.

Despite the positive trend in overall numbers, a notable feature of both ungulate populations is their skewed sex-age structure, characterized by low juvenile recruitment. For the bezoar goat, the demographic indices are particularly concerning: a highly skewed sex ratio (0.31♂:1♀), a low kid-to-female ratio (0.52), and a very low yearling-to-female ratio (0.31). This structure is markedly different from the more balanced population in Dagestan, where the kid-per-female ratio is 0.80 (Magomedov et al. 2014).

The mouflon population exhibits a more balanced sex ratio (0.90♂:1♀) and a higher kid-per-female ratio (0.72) than the bezoar goat. However, the halving of the ratio from kids (0.72) to yearlings (0.49) per female indicates high juvenile mortality in the first year, which is a key factor limiting population growth.

We can rule out several potential causes for these demographic patterns. First, poaching has been effectively eliminated and is not a factor. Second, high population density typically leads to an increase in the proportion of males, a pattern not observed here; therefore, density-dependence is an unlikely primary cause at present. Third, the number of males in both populations, while low for bezoar goats, is theoretically sufficient to fertilize all available females. Finally, significant predation pressure is doubtful as the sole cause, as it would not allow for the observed overall population increases.

We posit that the most plausible explanation for the observed demographic structure is forage availability. The low proportions of kids, yearlings, and adult males – all cohorts with high nutritional demands or susceptibility to resource stress – point towards seasonal nutritional bottlenecks. The challenging, arid environment of Nakhchivan likely experiences periods of limited forage quality and quantity, which can suppress female fecundity and disproportionately affect juvenile survival (Clutton-Brock et al. 1997; Bonenfant et al. 2009). This pattern resembles that of the Dagestan tur, a species adapted to harsh mountain environments where single offspring are the norm, suggesting a similar adaptation to resource limitations in Nakhchivan's ungulates.

The continued recovery of bezoar goat and mouflon populations is a conservation success story demonstrating the effectiveness of legal protection. Our total population estimates of 2,000–2,200 bezoar goats and approximately 1,000 mouflons for Nakhchivan suggest significant progress. Furthermore, these populations have not yet reached their carrying capacity in most areas, with potential for further expansion, particularly for mouflons in the foothills of Darydag and the central Zangezur ridges.

However, the identified demographic constraints signal that future growth may be slow and could be susceptible to additional pressures. The primary conservation challenge is to maintain the quality of the ungulates' habitat. The overlap of mouflon habitats with winter pastures and cereal fields presents a potential for human-wildlife conflict. Any future increase in livestock grazing pressure could further constrain forage availability for wild ungulates, exacerbate the nutritional limitations we hypothesize, and ultimately limit the prey base for the leopard.

Therefore, while the current prey base is likely sufficient for the existing leopard population, achieving further recovery of both the leopard and its ungulate prey will require a focused strategy on habitat management, mitigating anthropogenic pressures, and continuing long-term monitoring to track these demographic trends.

Conclusions

Populations of bezoar goat and Asian mouflon within the leopard's range in Nakhchivan show a positive trend, with increasing densities in key areas like Darydag and the Zangezur Range, largely due to effective protection. The leopard's prey base in its core range is robust, supporting an estimated 1,800 bezoar goats and 700–800 mouflons, which is sufficient for a small leopard population.

A critical finding is the constrained demographic structure of both ungulate species, characterized by low juvenile-to-female ratios. This is likely driven by limited forage availability rather than poaching, predation, or density-dependence, and it may slow future population growth. The total estimated populations for Nakhchivan are 2,000–2,200 bezoar goats and ~1,000 mouflons, with potential for further expansion if habitat quality is maintained. Future conservation efforts must focus on habitat management and mitigating human-wildlife conflict to ensure the long-term recovery of both the prey species and the Persian leopard. Further research is needed in the central, northern, and northwestern parts of the republic for a complete assessment.

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