Original study

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# Understanding population baselines: status of mountain ungulate populations in the Central Tien Shan Mountains, Kyrgyzstan

https://doi.org/10.1515/mammalia-2020-0005
Received January 18, 2020; accepted June 18, 2020; published online August 17, 2020

**Abstract:** We assessed the density of argali (*Ovis ammon*) and ibex (*Capra sibirica*) in Sarychat-Ertash Nature Reserve and its neighbouring Koiluu valley. Sarychat is a protected area, while Koiluu is a human-use landscape which is a partly licenced hunting concession for mountain ungulates and has several livestock herders and their permanent residential structures. Population monitoring of mountain ungulates can help in setting measurable conservation targets such as appropriate trophy hunting quotas and to assess habitat suitability for predators like snow leopards (*Panthera uncia*). We employed the double-observer method to survey 573 $km^2$ of mountain ungulate habitat inside Sarychat and 407 $km^2$ inside Koiluu. The estimated densities of ibex and argali in Sarychat were 2.26 (95% CI 1.47–3.52) individuals $km^{-2}$ and 1.54 (95% CI 1.01–2.20) individuals $km^{-2}$, respectively. Total ungulate density in Sarychat was 3.80 (95% CI 2.47–5.72) individuals $km^{-2}$. We did not record argali in Koiluu, whereas the density of ibex was 0.75 (95% CI 0.50–1.27) individuals $km^{-2}$. While strictly protected areas can achieve high densities of mountain ungulates, multi-use areas can harbour meaningful though suppressed populations. Conservation of mountain ungulates and their predators can be enhanced by maintaining Sarychat-like "pristine" areas interspersed within a matrix of multi-use areas like Koiluu.

**Keywords:** conservation; human-use landscapes; hunting concession; mountain ungulates; population baselines; protected areas.

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## 1 Introduction

Mountain ungulates play an important role in maintaining ecosystems by influencing vegetation structure and nutrient cycling (Bagchi and Ritchie 2010). They are critical determinants of large carnivore populations, including the Vulnerable snow leopard *Panthera uncia* (Suryawanshi et al. 2017). However, owing to their remote mountainous habitats and associated challenges in sampling, there is a lack of information regarding mountain ungulate abundance and population trends (Singh and Milner-Gulland 2011). Robust population estimates over time help in determining population trends (Mihoub et al. 2017). Conservation status assessment of any species requires rigorous monitoring of their abundances (Lindenmayer et al. 2013). An initial population reference can aid in framing conservation objectives by helping assess feasibility, concentrate effort, and define time period within which progress can be evaluated (Bull et al. 2014).

Threats from mining, illegal hunting, poorly managed trophy hunting, resource competition, and potential disease transmission from livestock pose conservation threats to mountain ungulates (Berger et al. 2013; Farrington 2005; Mishra et al. 2004; Pratt et al. 2004). Across large parts of Asia's high mountains, livestock account for c.95% of ungulate biomass and few refuges remain for wild ungulates (Berger et al. 2013).

Argali *Ovis ammon*, the world's largest wild sheep, and ibex *Capra sibirica*, a wild goat species, are found across most of Central Asia's mountain ranges. Argali is found in

11 Central and South Asian countries and is classified as "Near Threatened" by the IUCN (Fedosenko and Blank 2008). Argali occur in small and fragmented populations in most of their global distribution range (Ekernas et al. 2016). Ibex is classified as "Least Concern" by the IUCN (Reading and Shank 2008). Both argali and ibex face similar conservation threats such as poaching for subsistence or for use of horns as mounted trophies (Harris and Reading 2008; Khan et al. 2014). Further, exploitative and interference competition from livestock is documented for both species (Bagchi et al. 2004; Namgail et al. 2007). Land-use changes across their Central Asian range, including mining, also threaten their habitats (Farrington 2005; Pratt et al. 2004).

Multi-year population estimates are lacking for both species; thus their trends remain largely unknown (Reading and Shank 2008) with some exceptions such as Tumursukh et al. (2016) for both species from Tost, Mongolia and Frisina et al. (2010) for argali across Mongolia. A few one-time population assessments have been conducted, with estimates ranging from 1.62 to 0.04 ibex $km^{-2}$ and 2 argali $km^{-2}$ to occasional sightings of a few small herds (Ekernas et al. 2016; Frisina et al. 2007; Khan et al. 2016; McCarthy et al. 2008; Schaller and Kang 2008).

Kyrgyzstan is a largely mountainous country consisting of the Tien-Shan and the Pamir-Alay mountain ranges and 70% of its land is listed as hunting concessions while 48% is also pastureland to graze livestock (Nordbø et al. 2018). A particularly important region in Kyrgyzstan is the Central Tien Shan landscape which covers an area of c. 13,201 $km^2$ of mountain habitat (GSLEP 2019). This is nestled within the larger Tien shan region. The size of the Tien Shan influences weather patterns in the region, whilst melt water from the peaks and glaciers feed great rivers of the region such as Syr Darya, Ili river, and the Tarim river. This water and the sediments within form the basis for the agriculture of the region and nurture its pastures. The entire Central Tien Shan region is potential mountain ungulate habitat. It is thus critical to understand mountain ungulate population baselines in the Central Tien Shan in order to inform mountain ungulate conservation.

We worked in two adjoining regions of the Central Kyrgyz Tien Shan mountains, namely, (i) Sarychat-Ertash Nature Reserve (hereafter Sarychat) – a 720 $km^2$ strictly protected nature reserve with minimal anthropogenic disturbance – and (ii) Koiluu Valley (hereafter Koiluu), an area with a variety of human use, to develop population baselines for this region's argali and ibex. To our knowledge, this will be the first population estimates for these species from this region that include estimation of sampling error and detection probability. Additionally, our survey areas are within the Central Tien Shan Landscape which has been identified by the Kyrgyz Government and recognized by Global Snow Leopard and Ecosystem Protection Program (GSLEP) as one of their priority landscapes for conservation in the high mountains of South and Central Asia. Our study helps the management of this priority landscape by providing robust population baselines for two of the most important ungulate species in the region.

With strict protection and minimal disturbances, we expected Sarychat to have population densities that could be considered representative of pristine (lacking anthropogenic impact) regions of the Kyrgyz Tien Shan. Population densities from Koiluu, on the other hand, were expected to be lower due to hunting and other pressures. Our density estimates can also serve as references to compare the impacts of future conservation actions and emerging threats.

# 2 Materials and methods

## 2.1 Study area

Sarychat (N 41 897907°, E 78 562724°) is a protected area and a critical part of the Issyk Kul Biosphere Reserve of Kyrgyzstan. It sits in the upper reaches of the Uch-Kol river basin in the Central Tien Shan mountains. The altitude ranges from 2000 m to 5500 m above sea level. Vegetation types consist of arid grasslands, wet meadows, and tundra cushion plants (Zlotin 1997). The climate is continental and cold. Mean monthly temperatures in June and January are +4.2 °C and −21.5 °C, respectively. Annual precipitation is around 295 mm (SER 2007). Situated in the Central Tien Shan landscape (13,201 $km^2$), Sarychat and Koiluu are within one of 24 priority landscapes for snow leopard conservation (GSLEP 2019).

After Sarychat's declaration as an official *Zapovednik* (Nature Reserve) in 1995, only a small portion in the buffer zone of the park (outside our study area) is being grazed seasonally by livestock (predominantly yaks). There are two villages near the reserve, Uch-Koshkon and Ak-Shyirak, with the nearest one being around 4 km by road from the reserve. Over a dozen individuals from these villages work as rangers within the reserve, and livestock herding (sheep and horses) outside the reserve is the main source of income for the villages.

The majority of Koiluu Valley (N 42 161995°, E 78 818354°) falls under a licenced hunting concession for ibex and argali. Around 10 livestock herders use this valley year round to graze their approximately 1000 livestock including sheep, goats, horses, cows, and yaks. Each herder has at least one permanent house in the area. These permanent houses are scattered throughout the valley. Part of Koiluu is contiguous with a section of Sarychat (see Figure 1). The vegetation, climate, rainfall, altitude, and topography are similar to Sarychat. The nearest village to this valley is Enilchek, which is about 20 km away from the entrance of the valley.

Sarychat and Koiluu have very similar landscape, habitat, and climatic conditions; they are also neighbouring valleys in the same

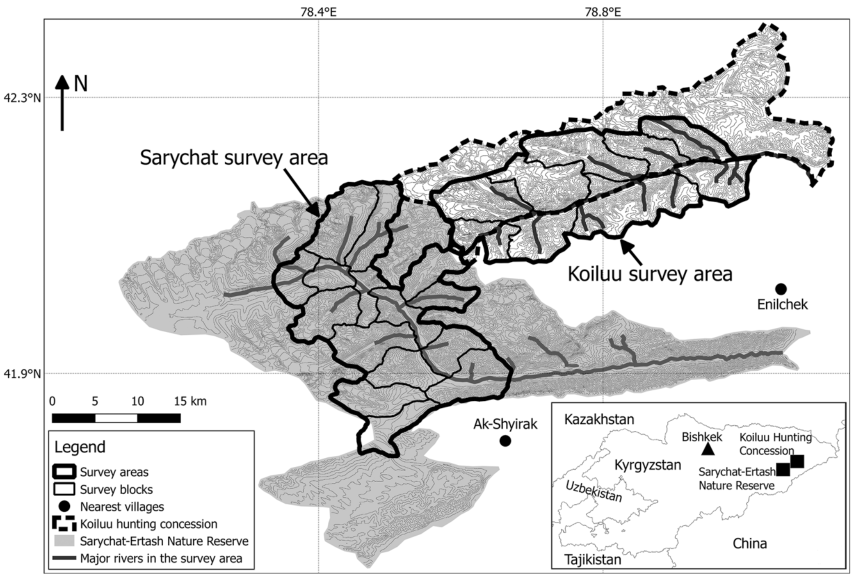


**Figure 1:** Map showing the Sarychat-Ertash Nature Reserve (the boundary includes the buffer and core zones of the park), the Koiluu Hunting Concession, and the surveyed area in each of them. Nearly all of the survey area in Sarychat was within the core zone. The Koiluu survey area is the entire Koiluu valley (drained by the Koiluu river) which forms a major component of the Koiluu Hunting Concession. The inset map displays Kyrgyzstan and situates its capital Bishkek (triangle) and our study sites of Koiluu Hunting Concession (upper dark square) and Sarychat-Ertash Nature Reserve (lower dark square).

mountain range hence we consider them to be comparable. Both areas are drained by a relatively broad and undulating central river valley (more typical of argali habitat) connecting to numerous relatively narrow and rugged side valleys (typical ibex habitat) (see Figure 2).

## 2.2 Ungulate surveys

The surveys were conducted in late autumn (October) 2017. We used the double-observer method (Forsyth and Hickling 1997; Suryawanshi et al. 2012) to survey 573 $km^2$ (34.4% including the buffer zone) of Sarychat and 407 $km^2$ (49.4%) of Koiluu (Figure 1). This method is based on the principles of mark-recapture theory. It is difficult to identify individual mountain ungulates; however, their groups, even if temporary, can be identified during sampling based on characteristics such as group size, age-sex composition, and location. The unit being "marked" and "recaptured" in double-observer technique is the individual group. Proportionate to the total population, there are very few single individuals. Broadly, the method involves two teams searching for and counting animals simultaneously or sequentially in the same region, while ensuring they do not cue each other on the locations of the animals.

Both Sarychat and Koiluu were further divided into smaller blocks to allow for ease of survey. The shape and size of blocks depended on the terrain and the logistics of accessing and surveying the area. Blocks varied in size from c. 20 $km^2$ to c. 55 $km^2$. Each block was surveyed keeping three main assumptions in mind: (1) that entire visual coverage of each block was possible during the survey, (2) two individual teams, each with the same number of observers (often two or occasionally one person) surveyed the area independently, and (3) the ungulate groups could be identified individually based on the age-sex composition of a herd, its location, and any other peculiarities that the teams could note. The population-specific data collected was group size, species, and group detection or non-detection by each observer team.

Each observer team had a pair of binoculars or spotting scope to find ungulate groups and classify them. In Sarychat, 15 blocks were surveyed along 115.5 km survey trails, resulting in a total of 231 survey kilometres (2 teams). In Koiluu, eight blocks were surveyed along 84.5 km, resulting in a total of 169 survey kilometres. Surveys were done on horseback, in cars, and on foot. Care was taken to use car and horseback as a means of transport between survey locations, while the surveys themselves were conducted on foot. Survey trails were predetermined using topographic maps of the area. Ridgelines or valleys were generally the preferred route of the trails as they provided the best view. Often, trails followed the topography of the landscape and weren't straight lines. Effort was made to start all surveys at sunrise, in order to control for the effect of time of day on both activity and grouping patterns of the study species (Fattorini et al. 2019). Each block was surveyed by two teams following the recommendations of Suryawanshi et al. (2012), with the second team starting the survey c. 15–30 min after the first. Each team comprised of either a single or two observers and care was taken to keep same number of observers per team per survey to standardize effort. In total eight observers were involved in the surveys. To ensure independence, we used only trained and/or experienced observers who had been part of previous double-observer surveys and/or taken part in a workshop that was held prior to the surveys. Additionally, teams were instructed not to spend too much time at one spot regardless of spotting a group. The teams ensured they deployed similar survey efforts on all surveys.

Adult males, adult females, and young (defined as yearlings and kids combined), were classified based on morphological characteristics described by Schaller (1977). For ibex, females are grey-brown with less distinctive white under parts (compared to males), have thin parallel horns that are wide apart at the base, and dark markings on the legs. The males have distinctive thick, scimitar-shaped horns that diverge and curve backwards. A distinctive feature of ibex, including females, is the presence of a beard. Argali females, like ibex, have horns with similar separation at the base but diverge much more towards the tips. For the males, the horns are much thicker and curve outwards from a closer base on top of the head. Both sexes are generally grey-

**Figure 2:** Top: Koiluu Valley, Below: Sarychat-Ertash Nature Reserve (with a group of argali in the central, relatively broad, and undulating valley, as shown by the arrows). Photo credit: KS.

brown in the summer and turn whitish in the winter. For both species, kids lack horns and yearlings have newly developing horns.

## 2.3 Data analysis

The total number of argali and ibex groups was estimated using the two survey mark-recapture in the "BBRecapture" package that uses the Bayesian framework in R statistical and programming environment (Fegatelli and Tardella 2013, Version 3.3.4, R Core Team, 2018). Following Suryawanshi et al. (2012), the analysis was conducted on the number of groups. Group size, age-sex composition, and location of sighting were used to assess whether or not a group was re-sighted by the second team. A group was coded "11" if recorded by both teams, "10" if only the first team recorded it, and "01" if only the second team recorded it. We modelled the detection for the two teams separately ("mt" model). To estimate the number of groups ($\hat{G}$) of each ibex and argali in our study areas, we fit the "mt" model using the function BBRecap with a "uniform prior" for each species. We used the "mt" model because detection probability was expected to be different across the two surveys (Suryawanshi et al. 2012). We used uninformed uniform priors because this is the first effort to use this method in these landscapes for argali and ibex. We did 10,000 mcmc iterations with 1000 burn-in. Further details on model fitting are available in Fegatelli and Tardella (2013).

The estimated detection probability by model "mt" for occasion one and two was interpreted as the detection probability for observer teams one and two. We estimated the total population of each ungulate species ($N_{est}$), as a product of the estimated number of groups ($\hat{G}$) and the estimated mean group size ($\mu$). To estimate the confidence intervals of their population using the variance in 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. A distribution of estimated population for each ungulate species ($N_{est}$) was generated by multiplying 10,000 random draws of estimated number of groups ($\hat{G}$) weighted by the posterior probability and draws of mean group size ($\mu$). The median of the resultant distribution was the estimated ungulate population ($N_{est}$) and the 2.5 and 97.5 percentiles were used as the confidence intervals.

We conducted 10,000 bootstraps to assess the 95% confidence intervals of the proportion of individuals of different age-sex classes (adult male, adult female, and young) using herd as the sampling unit. The median values were used as the estimates, while the 0.025 and 0.975 quartiles were used as 95% confidence intervals.

We estimated densities by dividing the estimated abundance by the total area sampled. Total area sampled was obtained by adding up areas of all the surveyed blocks. The area demarcated was the visible areas for each block (see Figure 1). Area of blocks was obtained by demarcating them on a GIS platform (i.e. Google Earth Pro) post-survey by the team of surveyors.

# 3 Results

In Sarychat, double-observer survey estimates of ibex and argali abundance were 1294 (95% CI 963–1919) individuals and 885 (95% CI 787–1077) individuals, respectively (Figure 3). In Koiluu, we did not observe any argali. We recorded ibex with an abundance of 317 (95% CI 259–493) individuals (Figure 3). The mean group size of ibex in Koiluu was higher than that of ibex in Sarychat (Figure 3) Table 1 summarises different parameters such as detection probabilities, estimated number of groups, mean group size, and age-sex ratios of each of the populations and species. The estimated densities of ibex and argali in Sarychat were 2.26 (95% CI 1.68–3.34) individuals $km^{-2}$ and 1.54 (95% CI 1.37–1.88) individuals $km^{-2}$ respectively (Figure 4). Collectively, the ungulate density in Sarychat was 3.80 (95% CI 3.05–5.23) individuals $km^{-2}$. The density of ibex in Koiluu was 0.75 (95% CI 0.64–1.21) individuals $km^{-2}$ (Figure 4). The male to female ratios for all the populations were similar (see Table 1). While the young to female ratios for both the ibex populations were comparable, this was surprisingly low for argali in Sarychat (Table 1).

# 4 Discussion

We provide robust population estimates of ibex and argali from the Central Tien Shan. These can serve as population references for future analysis. Considering the confidence intervals around our estimates, it should be possible to detect a decline of 25% and 18% in the ibex populations of Sarychat and Koiluu, respectively, and an 11% decline in the argali population of Sarychat. However, the reliability with which population declines can be detected will partly depend on the uncertainty in the subsequent population estimates.

Collectively, wild ungulate densities were 5.06 times higher in Sarychat than in Koiluu. Sarychat's ibex density was three times higher than in Koiluu (Figure 4). Despite relatively high density of argali in Sarychat and connectivity between these two areas, we were unable to find any argali in Koiluu. This is worrying as argali have previously been reported from Koiluu (pers. comm. KZ).

Sarychat's ibex density was among the highest compared to published estimates, whilst its density in

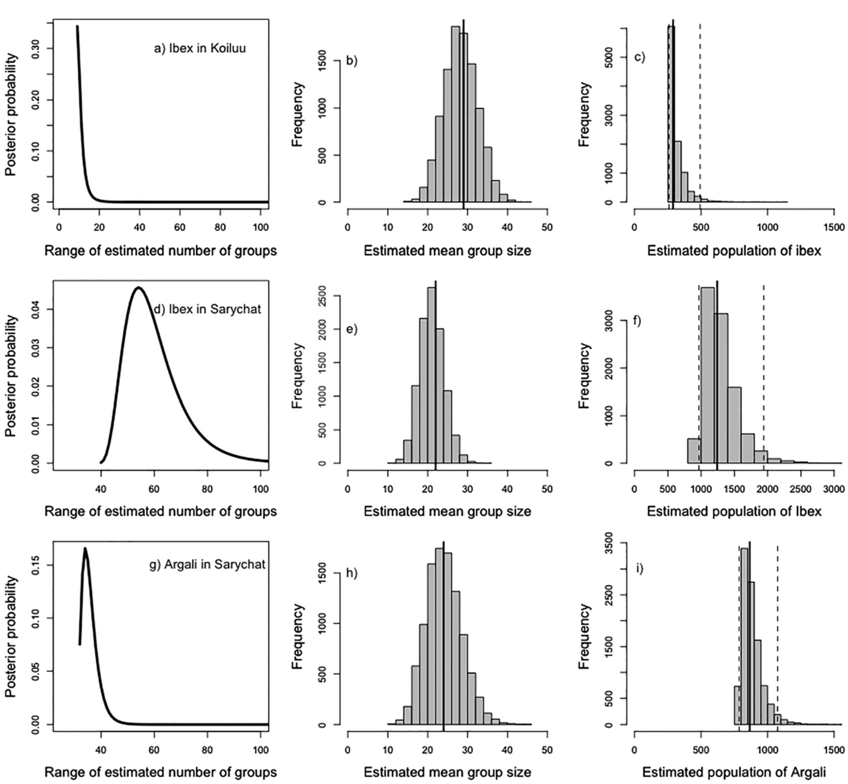


**Figure 3:** (a, d, g) The posterior probability distribution estimated by the mt model for the range of number of Koiluu ibex groups, Sarychat ibex groups, and Sarychat argali groups respectively. (b, e, h) Histogram of 10,000 bootstrapped means of Koiluu ibex group size, Sarychat ibex group size, and Sarychat argali group size respectively. The vertical solid line indicates the median. (c, f, i) Histogram of the estimated Koiluu ibex, Sarychat ibex, and Sarychat argali population. The solid line indicates the median and the dotted lines indicate the 95% CI.

**Table 1:** Information about mountain ungulate populations in Sarychat and Koiluu.

| | Sarychat Ertash Nature Reserve | | Koiluu Hunting Concession |
|---|---|---|---|
| **Species** | **Argali** | **Ibex** | **Ibex** |
| Minimum count | 787 | 863 | 259 |
| No. of blocks | 15 | 15 | 8 |
| *P*1 | 0.74 | 0.51 | 0.69 |
| *P*2 | 0.61 | 0.36 | 0.61 |
| Obs 1 total | 644 | 682 | 140 |
| Obs 1 groups | 10 | 19 | 2 |
| Obs 2 total | 379 | 463 | 128 |
| Obs 2 groups | 5 | 10 | 2 |
| Common groups | 17 | 11 | 5 |
| Total groups | 32 | 40 | 9 |
| Mean group size | 22 | 25 | 29 |
| Prop male | 0.34 (0.19–0.56) | 0.27 (0.18–0.39) | 0.29 (0.17–0.37) |
| Prop female | 0.51 (0.33–0.63) | 0.48 (0.37–0.61) | 0.48 (0.44–0.54) |
| Prop young | 0.15 (0.09–0.19) | 0.24 (0.17–0.31) | 0.23 (0.19–0.29) |
| M:F | 0.66 | 0.57 | 0.60 |
| Y:F | 0.29 | 0.50 | 0.48 |

These include detection probabilities (*P*1 = first observer; *P*2 = second observer), individual ungulates seen by each observer (Obs 1 total and Obs 2 total), Individual number of groups seen by each observer (Obs 1 groups and Obs 2 groups), number of groups seen by both, i.e. recaptures (Common groups), mean group size, proportion of male, female, and young with 95 % confidence intervals. M:F and Y:F displays the male to female ratio and the young to female ratio respectively using the estimated proportional values for each age-sex class.

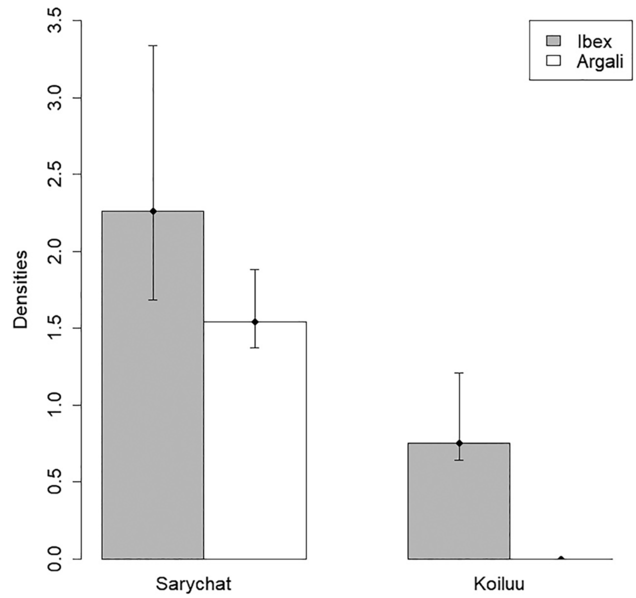


**Figure 4:** Estimated density of ibex and argali in Sarychat-Ertash Nature Reserve and Koiluu Hunting Concession in the Central Tien Shan landscape of Kyrgyzstan.

Koiluu was similar to those in other human-use landscapes. McCarthy et al. (2008) reported a density of 1.62 ibex km$^{-2}$ from Sarychat, but our estimates cannot be statistically compared because they surveyed a small area (141 km$^2$) and used total count method (Singh and Milner-Gulland 2011). Suryawanshi et al. (2012) and Tumursukh et al. (2016) recorded ibex densities of 0.35 individuals km$^{-2}$ in Pin Valley (India) and 0.64 individuals km$^{-2}$ in Tost (Mongolia) using double-observer. Pin and Tost are human-use landscapes with intensive livestock grazing and have comparable ibex densities to Koiluu. Detection probabilities for both these studies ranged between 0.34 and 0.70, which are similar to ours (Table 1).

The estimated density of argali from our survey is among the highest reported from its global distribution. McCarthy et al. (2008) reported 2.82 argalis km$^{-2}$ using total count from 141 km$^2$ in Sarychat which is again not directly comparable with our survey. Tumursukh et al. (2016) reported 0.08 argali km$^{-2}$ in Tost using double-observer. Wingard et al. (2011) reported 1.63 argali km$^{-2}$ in Ikh Nart Nature Reserve (Mongolia) using distance sampling, which is similar to our argali density in Sarychat. However, the uncertainty of their estimate was much wider (0.59 individuals km$^{-2}$ – 3.28 individuals km$^{-2}$). Detection probabilities from Tost and Ikh Nart ranged between 0.28 and 0.60, which is comparatively lower than our detection probabilities of 0.74 and 0.61 (Table 1). Given our experience in the field (i.e. we were able to uphold the field assumptions of the method) and based on the estimated detection probability for each team (range 0.36–0.74 for both species), we are confident that the double-observer method can be reliably used in the Central Tien Shan mountains.

All three surveyed ungulate populations were female-biased. Mountain ungulate populations are known to be primarily female biased (Berger and Gompper 1999). Not only are males disproportionately preyed upon (Berger and Gompper 1999), but being polygynous species, argali and ibex males expend higher costs than females during rut, reducing male survival. Factors like selective hunting of prime-aged males can further aggravate the female-bias (Michel et al. 2015). Comparable male to female ratios across our survey areas maybe because of proximity and movement of animals between them. We propose annual monitoring of male to female and young to female ratios along with population density to inform hunting quotas. Data on trends in these ratios will help identify the impact of hunting on the demography of the ibex (Milner et al. 2007).

Another interesting result is the relatively low young to female ratio (0.29) for argali in Sarychat (Table 1). Ekernas (2016) suggest that argali populations with young to female ratios <0.5 are potentially declining. Our surveys were conducted in October. It would be important to know young to female ratio in spring, soon after the critical winter, to better understand young survival. Also, mean ibex group size in Koiluu was slightly higher than Sarychat (Table 1). While the evidence suggests hunted populations may have larger groups (Pulliam and Caraco 1984), further research is needed to understand the relation between group size and hunting in these species.

Wild ungulates are known to be a key determinant of wild carnivore populations (Karanth et al. 2006; Suryawanshi et al. 2017). Sarychat's wild ungulate densities can support predators including the snow leopard, wolf *Canis lupus*, and Eurasian lynx *Lynx lynx*. Given that 70% of Kyrgyzstan's land area is characterized as hunting concession and 7% is given protected status, our results suggest that mountain ungulates across Kyrgyzstan are at much suppressed population levels. The mechanisms driving the reduction of population in human-use landscape could be exploitative competition from livestock (Bagchi et al. 2004), disturbance from herding dogs (Namgail et al. 2007) and unregulated trophy hunting (Rosen et al. 2012). With comparable habitat, topography, and close proximity, we speculate the lower ungulate densities in Koiluu are driven by human activities. Nevertheless, the reasons for different densities could be more complex and need concerted studies.

## 5 Conclusion

Our study shows that while strictly protected areas can achieve high densities of mountain ungulates, multi-use areas can harbour meaningful though suppressed populations. Multi-use areas need to be managed with specific goals for conservation, such as maintaining a certain minimum population of mountains ungulates. Given this understanding, conservation efforts should be prioritized towards having strictly protected areas like Sarychat interspersed amongst multi-use landscapes like Koiluu to promote conservation of mountain ungulate alongside humans across the Central and South Asian mountains.

**Acknowledgments:** We extend our heartfelt thanks to Mirbek, Temirbek and Askat, the three rangers that accompanied us during our surveys in Sarychat. It is their tireless effort that ensures the protection of spaces like Sarychat. We are also thankful to the Department of Biodiversity Conservation and Protected Area Department of the State Agency on Environment Protection and Forestry under the Government of Kyrgyzstan for providing us with the necessary permits to conduct these surveys. A special thanks to Trisha Gupta for taking her time out to comment on our work.

**Author contributions**: KS, KZ and MK conceived the idea of the study. MK, KZ, SL, and KS conducted the field work. KS and MK conducted the data analysis and contributed to the first draft of the manuscript. CM helped develop the ideas, guided the analysis, and contributed to the writing of the manuscript. KZ and SL edited and commented on the manuscript. All authors helped in editing the draft.

**Research funding**: This study would not have been possible without the funding provided by the National Geographic Collaboration Grant and British Ecological Society. MK was supported by the Ravi Shankaran Inlaks Foundation Grant.

**Conflict of interest statement**: The authors declare no conflicts of interest.

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