Towards the survival of Tibetan argali in India

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Project Report 2006-2007

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Abstract

Tibetan argali is one of the endangered species of wild sheep occurring in small and scattered populations across the high altitude Tibetan plateau and Transhimalayan rangelands. One of the largest populations of argali occurs in the Tso Kar basin area of eastern Ladakh India. The last updates on the status and distribution of argali in India were reported a decade ago. A number of factors threaten the future survival of Tibetan argali in India. We thus initiated this project with three main objectives. First, to update the status and distribution of argali in India. Second, to assess the distribution of livestock and pasture use by herders on the Tso Kar basin intensive study area. Third, to estimate the multiple scale resource selection process by argali in the study area. The answers to these questions may assist in identifying the threats and propose conservation and management actions for existing argali populations in India.

The study included surveys, interviews and literature reviews to identify and understand the past range of argali and nomads' movement and pasture use patterns of their livestock. Kernel density estimations (KDE) were used to estimate the range used by livestock and the grazing pressure. Ecological Niche factor Analyses (ENFA), bias-reduced logistic regression and Fuzzy correspondence analyses (FCA) were used to answer habitat and resource selection questions.

The latest estimate of argali population is about 680 to 820 animals in India against the earlier estimate of 200. Especially, there are more argali in Ladakh and in several new areas, against the earlier small estimate and range. These updates reveal that the earlier estimate was not due to small populations of argali but non inclusion of areas under survey and lack of intensive surveys in the already identified areas. The Tso Kar basin is avoided by herders during summer to save the pasture for winter. The herders use the area in four main seasonal pastures during winter and 29 camping sites out of which 3 sites are semi permanent with accessibility to shelter against cold both for the nomads' families and livestock and year round availability of water. Hence these semi permanent camping sites experience the maximum grazing pressure during winter. The spatial determinant associated with altitude in the area, predicts argali habitat and resource selection by argali. These determine the range of other topographic variables and forage characteristics selected by argali. The selection of feeding patches in the selected range of altitude and topography is mainly characterised by their greenness and the quality of plant groups. Adjusting to changing forage quality, argali display an opportunistic feeding strategy, selecting grasses in early spring and switching to forbs later in summer. Livestock grazing appears to be the main existing threat to argali. Other threats are identified and conservation actions are proposed.

Introduction

Tibetan argali (*Ovis ammon hodgsoni)*, is one of the two argali subspecies categorised as endangered in the red list of IUCN (international Union of Conservation of nature now World Conservation Union). It is the argali subspecies with the widest distribution, *c*.2.5 million km^2 across the Tibetan plateau and its margins (Shackleton 1997, Schaller 1998). However, the populations are small and patchy (Schaller 1998, Fox *et al.* 1991). In terms of political boundaries, Tibetan argali are known to occur in Tibet (China), India, Nepal and Bhutan (Fox and Johnsingh 1997). The population status reports claim *c.* 7000 individuals surviving on the Tibetan plateau and its margins in small populations (Schaller 1998). In India, *c.* 200 animals were believed to occur in Ladakh and Sikkim until the recent surveys (Fox *et al.* 1991, Fox and Johnsingh 1997). Most of these estimates have been based on past surveys and secondary information and clearly lack latest updates. Within India, Chundawat and Qureshi (1999) estimated *c.* 11,000 km^2 of potential argali habitat in eastern Ladakh through GIS maps prepared based on surveys and secondary information but argali have been encountered only occasionally in these large tracts identified as suitable habitat.

Hunting for trophy and meat, introduction of livestock to the areas in habited by argali, disease introduced from livestock, and lack of protection are among the important factors that are believed to affect their survival over their range (Schaller 1998, Bhatnagar and Wangchuk 2001, Harris Chapter In press). Although, hunting has been prohibited over most of the argali range since 1980s, apparently the argali population have not recovered following the ban. Most of the argali range has been subjected to traditional nomadic pastoralism for several millennia (Schaller 1998). However, these areas have undergone radical transformation due to political as well as socioeconomic changes and increased developmental activities that followed (Bhatnagar *et al.* 2007, Namgail *et al.* 2007, Hagalia 2005, Singh *et al.* submitted, Fox *et al.* 2008). Such important changes have resulted in modified traditional pasture use patterns and increased human and livestock populations all over the area and hence increased conservation pressure on argali (Bhatnagar *et al.* 2006, Namgail *et al.* 2007). Taking into account these factors and changes, latest updates on the status of argali in these areas are urgently required. To date, most available information about Tibetan argali comes from comparative studies on Tibetan plateau ungulates (Fox *et al.* 1991, Fox and Johnsingh 1997, Harris and Miller 1995, Schaller 1998, Namgail *et al.* 2004, Shrestha *et al.* 2005) and from recent habitat use studies that focus on the impact of livestock (Namgail *et al.* 2007, Singh 2008).

In the context of limited knowledge and risk of local extinction, conservation of argali remains a challenge. More basic ecological information about their habitat and resource use should aid to understand their survival requirements and to provide baseline for further management policies. Hence, we initiated one of the first efforts to undertake detailed habitat selection studies on Tibetan argali (*Ovis ammon hodgsoni*) with the following goals:

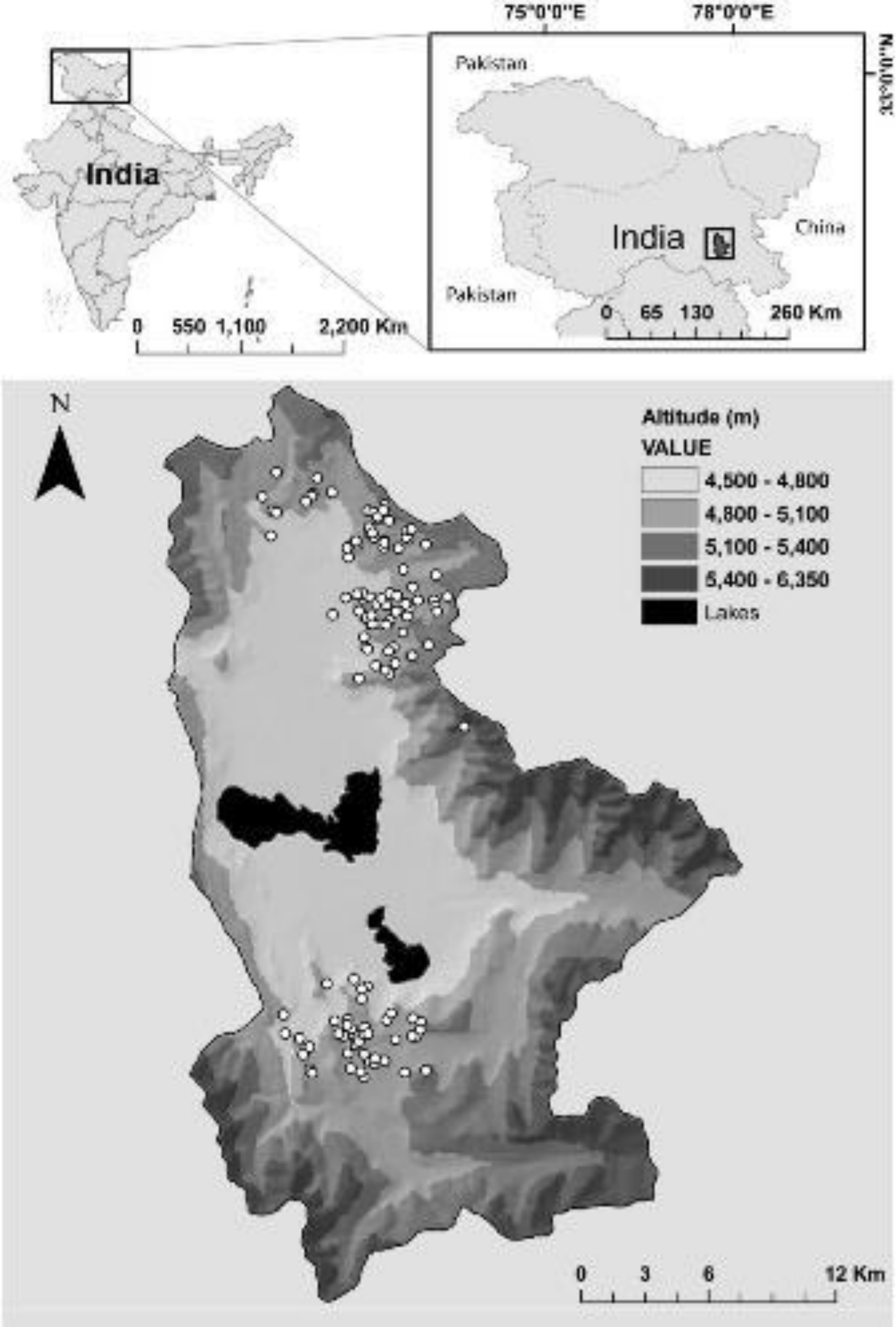
- Update the status and distribution of Tibetan argali in India
- Distribution of Livestock and pasture use in prime argali area, the Tso Kar basin in eastern Ladakh
- To understand the multi-scale resource selection process to unveil the primary factors determining the survival and growth

Finally, we intend to review the threats and propose conservation actions.

Intensive study area

The intensive study area, known as Tso Kar basin, (*c.* 650km^2) (Figure 1) is situated in the Changthang region of eastern Ladakh, India (32°15'N, 78°00'E). The altitude ranges from 4550 to 6371m. The main feature of the study area is enclosed basin with two lakes, a smaller freshwater lake called Starsapuk Tso (4km^2) and larger sale water lake called Tso Kar (16km^2). The lakes are surrounded by rolling hills, broad valleys and alluvial plains. The climate is characteristic of high altitude cold desert ecosystems with temperatures oscillating from -40°C (min. winter) to 25°C (Max. summer) and a mean annual precipitation of about 200mm. Most of the precipitation occurs in the form of snow. Strong winds are a general feature of the landscape. The vegetation can be broadly categorised into scrub formations, desert steppe and marsh meadows. The major plant communities include *Caragana-Eurotia, Artmeisia-Tanacetum, Stipa-Oxytropis-Alyssum,* and *Carex melanantha-Leymus secalinus.* The parts of the study area at very high altitudes (5000m) have sparse fell-field communities with moss or cushion-like growth forms, e.g. *Thylacospermum caespitosum, Arenaria bryophylla, Androsace sarmentosa* and a variety of lichens. Stream banks and marsh meadows around both the lakes (except areas of borax and salt deposits) exhibit characteristics sedge-dominated vegetation represented by species of *Carex spp., Kobresia spp., Scirpus spp., Triglochin sp., Pucciniella sp., Ranunculus sp., and Polygonum spp.* (Rawat & Adhikari 2005). About 150 argali inhabit the Tso Kar basin region. Other wild ungulates found in the region include a population of over 300 kiangs (*Equus kiang)* and 50 blue sheep or bharal (*Pseudois naur)* (Fox 2004).

Figure 1: Altitude range in the Tso Kar basin (intensive study area) in eastern Ladakh, India. White dots represent argali locations during the study period.



Methods

Status and distribution of argali

This status and distribution report is based on our own recent surveys, a literature review and personal communication with wildlife department officials and local nomads and residents. Specifically, very recent status reports (i.e. Namgail *et al.* In review, Chanchani *et al.* In review) were referred and updated with information from this detailed study on argali ecology (Singh 2008) and personal communication regarding unpublished surveys. The detailed surveys in the Tso Kar catchment (Figure 2) were conducted through repeated counts carried out from predetermined vantage points and survey walks every four days during daylight hours. The surveys in Gya Miru and Tso Moriri region of eastern Ladakh were carried out monthly, during summer of 2007 (Figure 2).

Livestock use of the area

To document movement patterns and preferred habitat use of pastoralists, we studied the *Samad* group during 2006-2007, using 6 land use surveys, interviews of nomads and officials of the Wildlife Protection, Sheep, and Animal Husbandry departments of Jammu and Kashmir stet, India. We conducted semi-structured interviews of local Nomads, Tibetan Refugees (TRs) and government officials. We also evaluated the reports on socio-economic surveys (Hagalia, 2004; Anon, 2007) and obtained the livestock data from the Sheep and Animal Husbandry departments. The information on pasture use, migration patterns and socio-economic changes was given by 6 elderly people from the community; the community head '*Goba*', - the '*Lama*' (priest) and 10 young educated herders. Information on family size and livestock holdings was obtained from an adult member of the family (Samad n=22 nomads, 10 TRs, Korzok n=20 nomads, 10 TRs). We report livestock in terms of sheep (or goat) units (SU), and converted yaks and horses on the basis of 1 yak = 4 SU, 1 horse = 6 SU, as suggested by (long *et al.* 1999). Information on time spent (number of days) at particular seasonal locations and pastures were obtained from the *Goba*.

Preparation of pasture use maps

GPS locations of herder camps were reported to generate a map of camp site locations in the Tso Kar catchment. We used the Digital Elevation Model (DEM, Surface Radar Topography Mission) of Ladakh region and based on the information collected from herders on seasonal patterns, created seasonal pasture polygons. The area of seasonal pastures was estimated using the 'Area tool' in 'Hawth's tool extension' of ArcGIS 9.2 (ESRI Inc.). Areas > 5,300m, lakes and snow peaks were excluded from the analysis. Nearest distance to water source from the camp site was estimated using 'near' function in the analyses toll in ArcGIS.

Habitat selection by argali at different scales

Habitat

Habitat use by argali was determined through repeated surveys which were conducted from 13 vantage points every four days, at 15 minute intervals, using 15 x 45 spotting scopes. These vantage points were determined during previous reconnaissance surveys to allow a complete overview of the study area. We noted the new groups sighted during the scan survey for the identifying the habitat level questions. The observations of argali groups covered the entire daylight period, i.e. between 06.00 and 19.00 hrs, and lasted on average 1.5 hrs each. The feeding group locations were recorded using a GPS and plotted on the map. We estimated altitude, slope, aspect, ruggedness, distance from flat terrain (distance of the group to the nearest 10° slope) and NDVI (Normalized Difference Vegetation Index) of the observed group feeding location to assess habitat characteristics at this scale (see below for details on the definition of habitat variables).

Table 1: Environmental variables estimated to assess habitat selection of Tibetan argali. For each variable, we indicate the range and the mean (± S.E.) values observed at argali feeding sites.

Variable	Estimation	Spring			Summer	
		Range	mean	S.E.	mean	S.E.
Altitude (m)	Field validation and digital elevation model (DEM)	4633-5573	4798	18	4933	14
distTslp (m)	Classification of DEM slope raster into slope.and10° and classification of nearest distance to a group	0-988	315	48	318	20
ndvi	MODIS (250m) images with $ndvl = \frac{IR(band4) = R(band3)}{IR(band4) + R(band3)}$ (IR: Infared band, R=Red band)	0.07-0.22	0.13	0.01	0.14	0.00
northness	DEM transformed into northness – cos(aspect)	-1 to +1	-0.03	0.13	-0.08	0.07
sari	$\frac{\text{Std.Dev of slope*variety of aspect}}{\text{Std.Dev of slope+variety of aspect}}$	1.04-4.7	3.04	0.16	3.05	0.06
Slope(°)	Field validation and DEM	0.84-29.7	13.3	1.46	13	0.5

Definitions of habitat variables

The spatial variables were analysed in ArcGIS 9 (ESRI Inc.). A Digital Elevation Model (Demment and van Soest 1985) was obtained from SRTM (Surface Radar Topography Mission, 90m resolution data) for the Ladakh region. Terrain variables extracted from DEM included altitude, slope, aspect transformed into 'northness' (cos (aspect)) and a Slope-Aspect Ruggedness Index (SARI) (Nellemann and Fry 1995, Jepsen *et al.* 2005). SARI is an index that combines the attributes of slope and terrain heterogeneity and provides high index values where terrain is simultaneously rugged and steep. The index was estimated using the formula for SARI (see Table 1). Distance to slope (distTslp) was estimated as the minimum distance between an argali and the nearest flat area (i.e. a

slope <10°). We reclassified the slope raster in ArcGIS (ESRI Inc.) to identify areas with slope > and <10°.

We used the normalized difference vegetation index (NDVI) (Pettorelli *et al.* 2005) as an index of vegetation biomass, estimated from the MODIS scene of the Tso Kar region on 20 August 2007. NDVI is calculated as the differences between the red and near-infared channels divided by their sum. August is the period during which the vegetation biomass is at its peak and is the end of the growing season (Karnieli *et al.* 2006, Ito *et al.* 2006, Mueller *et al.* 2008).

Resources

Feeding patch

We indentified group feeding patches as sites where >50% of the argali from the same group had been feeding for more than three consecutive scans (i.e. minimum 30 minutes). A total of 130 feeding sites were sampled for vegetation parameters. Feeding patches parameters were estimated after animals had left the site by laying six $10m^2$ plots, randomly disposed within a 25-m radius circle around the observed centre of the feeding location. The radius was decided after several observations on group size and foraging movements of the groups. For each of the six plots for every plant group (graminoids, forbs and shrubs), vegetation height (cm) and percentage of green material were estimated visually at the plant group level. We used four vegetation height categories (0-2, 2-4, 4-6 and 6-8 cm). Vegetation cover was estimated using the point intercept method based on four 0.5 X 0.5m plots embedded with 20 metal pins. Plants groups that touched the pins were recorded as "hits". Percent cover was calculated by dividing the number of hits for each plant group class by the total number of pins in the plot. Plant biomass was estimated for plant groups, by clipping plants 1cm above the ground in two of the 1 x 1 m randomly chosen plots and using the average. Fresh weight was noted for each plant group the same day using Pesola spring scale (capacities of 10g, 30g and 100g; Pesola Inc.). Plant samples were dried in the field before being transferred to laboratory facilities to measure dry weight.

To evaluate selection for feeding patches, this sampling design was repeated by measuring the same parameters using the same number of plots at a distance empirically by observing the feeding behaviour of groups – larger distances (250 and 500m) generally corresponded to movements among patches (see Compton *et al.* 2002; Hurme *et al.* 2005; Young *et al*;. 2006 for a similar design).

Forage categories

We collected five fresh pellets groups from argali groups every 2 weeks. Pellets were first dried in the field and later air dried in the lab before grinding.

Data analyses

Preparation of grazing pressure map for livestock

We recorded the number of families residing per campsite, livestock holding per family (SU), and time spent per camp site (number of days). Hence, grazing pressure was estimated as a function of sheep unit days (SUD) per camp site. A greater clustering of camp sites is assumed to increase pressure in the impact zone by additive effect of all camp sites. Each nomad campsite was assigned a weight (SUD/campsite) which we used to generate the intensity of use for the point using kernel density estimation (KDE). We used fixed kernel estimation using the Gaussian kernel function to estimate the density around the point (Silverman 1968; Seaman & Powell 1996). The smoothing parameter was chosen using least squares cross validation (LSCV) method (Worton 1995). As in the context of 'home range' analysis, the density at any location is also an estimate of time spent there, which we estimated as SUD/campsite. Hence, for camp locations, the 50% volume contour (VC) will show the area with higher pressure and intensity progressively reduced towards the edge (95% VC). In the home range context, it will show that these are the 'core zones' – areas that are important due to some key resources (snow free pastures, lower altitude, and seasonal water).

Statistical analyses

All analyses were implemented in R2.7.0 (R Development Core Team, 2008)

Habitat selection by argali

Habitat

To assess the habitat scale selection, we used Ecological Niche Factor Analysis (ENFA; Hirzel *et al.* 2002, Calenge 2006) in R using the 'adehabitat' library to explore the differences between used and available sites for argali. ENFA is a multivariate method that investigates the difference between used and available sites in both the average (called marginalization) and the range of variation (called specialization) of the different environmental variables. ENFA works best if the distribution of variables is close to symmetric, so we used Box –Cox transformation family (Hirzel *et al.* 2002, Venable and Ripley 2002). Slope and NDVI variables were transformed using square-roots. In ENFA, the first axis accounts for the marginality, i.e. the difference between the mean habitats used vs. available. Slope and NDVI variables were transformed using square-roots. In ENFA, the first axis accounts for the marginality, i.e. the difference between mean habitats used vs. available. Specialization is the ratio of variance of the available habitats to that of habitats used, and is accounted on all axes. We randomly sampled availability using the 'Random point generator' in the Hawth's tools extension of ArcGIS (ESRI Inc.), taking the whole study area as available excluding the high summits with snow. A randomly chosen set of data is expected to have a specialization value of 1

(Hirzel *et al.* 2002) with higher values indicating the extent of specialization. Eigenvectors can be used as for other multivariate methods to interpret the specialization and marginality axes (Hirzel *et al.* 2002).

Resources

Feeding patch

To assess the selection at the feeding patch scale, we developed logistic regression models for matched case-control studies (Hosmer and Lemeshow 2000, Compton *et al.* 2002), also referred to as conditional logistic regression, with the following predictor variables: plant group biomass, cover % green tissue and height. Cover and biomass were included as separate variable due to no significant correlation among them. It could likely be due to presence of plant groups as dry but with significant cover, or green with less cover, as in case of many grasses and shrubs during spring, when they are in early stages of growth, with less biomass but same cover and green biomass increases with the progress of growing season. Also cover could be an important variable in terms of delineation of feeding patches from a distance. Because our study is 1-1 matched, the conditional maximum likelihood estimates and standard errors were obtained by the following settings: the sample size equals the number of case-control pairs used, covariates are estimated with the differences between the variables (Feeding – random), and the value of the response variable is equal to 1 (Hosmer and Lemeshow 2000). Using such settings, a bias occurs when only positive values are observed for predicator variable, as maximum likelihood estimates are not bounded (Heinze and Schemper 2002). To remove this bias we used the brlr library in R, which implements the penalized likelihood approach proposed by Firth (1993).

To assess the presence of plant groups in both random and feeding sites we used fuzzy correspondence analysis (FCA; Chevenet *et al.* 1994, see also Hauser *et al.* 2003). This method is derived from multiple correspondence analysis, and allow the analyses of species affinity to different categories of a given variable (in multiple correspondence analysis, observation belong to a unique category for each categorical variable). The affinity scores are used to calculate the frequency distribution of the categories within variables. In our case the variables were grasses, forbs and shrubs and categories were absence, dry and green. The feeding and random sites were the categories. The modalities (green, dry and absence) were then used for joint scaling of the main variable i.e. graminoids, forbs and shrubs. We used the library ade4 in R (Chessel *et al.* 2004).

Forage categories

To form a single composite sample per season, we randomly mixed ten pellet groups from different argali for each season every year (Harris and Miller 1995). We determined the diet using composite samples. Three slides from each composite sample were prepared and 10 non-overlapping fragments were identified. We collected plant species eaten by argali from 20 feeding sites to prepare reference slides. Individual species were grouped into graminoids, forbs and shrubs. We used the percent relative frequency, i.e.

fields with group of a plant divided by the total number of fields with identifiable plant materials of any species (Gill *et al.* 1983).

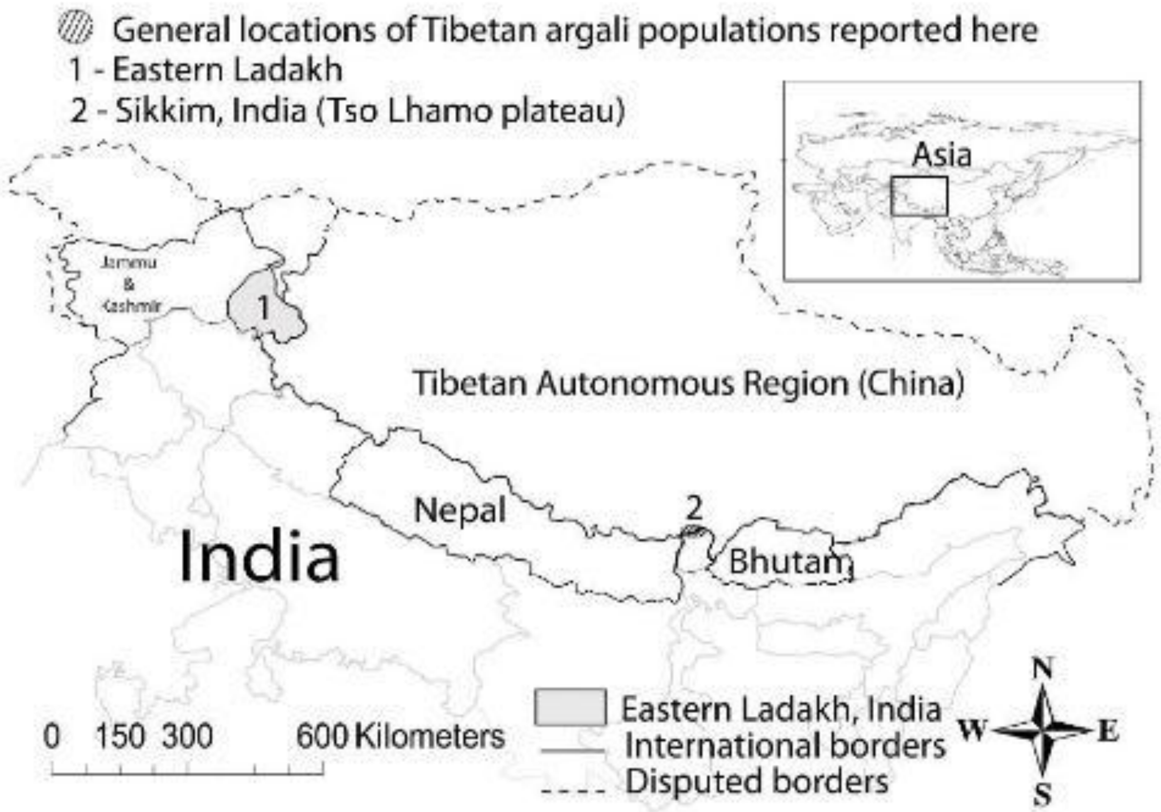
Forage quality

Forage species collected from argali feeding sites were tested for nutrient content. Ten grams of dried plant samples were used for the analyses (n=62). Crude protein (CP), Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF) were estimated for grasses, forbs and shrubs, for the same months for which diet analyses were performed. Crude protein content was analyzed using macro – Kjeldahl acid digestion technique (Association of Official Analytical Chemists 1084), NDF and ADF were analyzed using the method of Goering and van Soest (1970).

Results

Status and distribution of argali in India

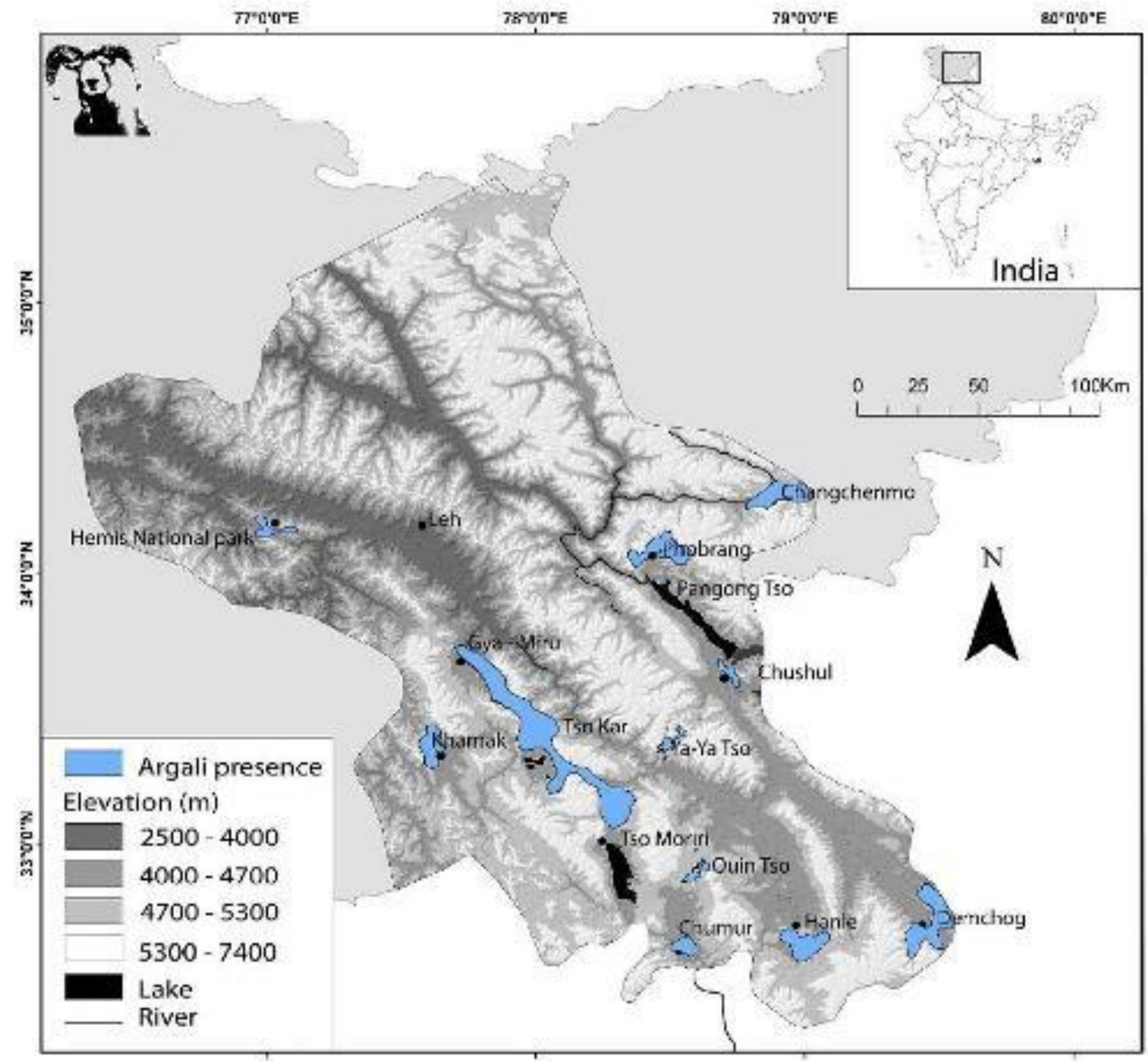
Figure2: Distribution of Tibetan in India.



Within India, Tibetan argalis occur in two widely separated areas where India's territory extends to the north of the Himalaya in the states Jammu and Kashmir and Sikkim (Figure 2). The largest known argali population occurs in eastern Ladakh region of Jammu and Kashmir (Figure 2). In this region, the area containing a relatively large population of argali stretches from Gya Miru Wildlife Sanctuary, through the Tso Kar catchment towards Tso Moriri Lake (Figure 3). The last argali counts estimated about 48 animals in Gya Miru and at most 80 within the adjoining Tso Kar catchment (Namgail *et al.* In review). Our surveys during 2004 to 2007, which covered the entire stretch from Gya Miru to Tso Moriri, indicate a presence of 45 to 50 animals in the Gya Miru Wildlife Sanctuary, 130 to 150 inside the Tso Kar catchment, and 10 to 15 between Tso Moriri and Tso Kar. There are several other areas in Ladakh that reportedly support several small argali populations (Namgail *et al.* In review). Three individuals have been observed in the Hanle Valley, where they were earlier thought to be extinct and 10-15 individuals above the Indus Valley at Denchog near the Chinese border (Figure 2) (Bhatnagar and Wangchuk 2001). Other additional small argali populations exist in the Chumur area (10 to 15), *c.* 70 in Phobrang near north of Pangong Lake, and *c.* 20 in Kharnak (Figure 3)

(Namgail *et al.* In review). An isolated population of about 25 animals survives in the southwest corner of Hemis National Park, where Fox *et al.* (1991a) reported the establishment of a new argali population in the 1970s. Recently, another large population has also been reported in the border area of Changchenmo, which is estimated to include *c.* 150 to 200 animals (Rinchen Wangchuk pers. comm.). In addition, two other small populations of about 20-25 near Ya Ya Tso and another *c.* 10-20 northwest of Quin Tso are also reported (R.S. Chundawat, pers. comm.). Summing all recent surveys and reports, the overall population estimate for Ladakh is *c.* 480 to 620 individuals as listed in Table 1, against the earlier or the recent estimate of 300-360 (Namgail *et al.* In review). A large part of potential Tibetan argali habitat in Ladakh is believed to be devoid of animals. However, intense surveys in this identified potential habitat and inclusion of new areas is required for better estimates of argali populations in Ladakh (Bhatnagar and Wangchuk 2001).

Figure 3: Distribution of Tibetan argali in eastern Ladakh, India.

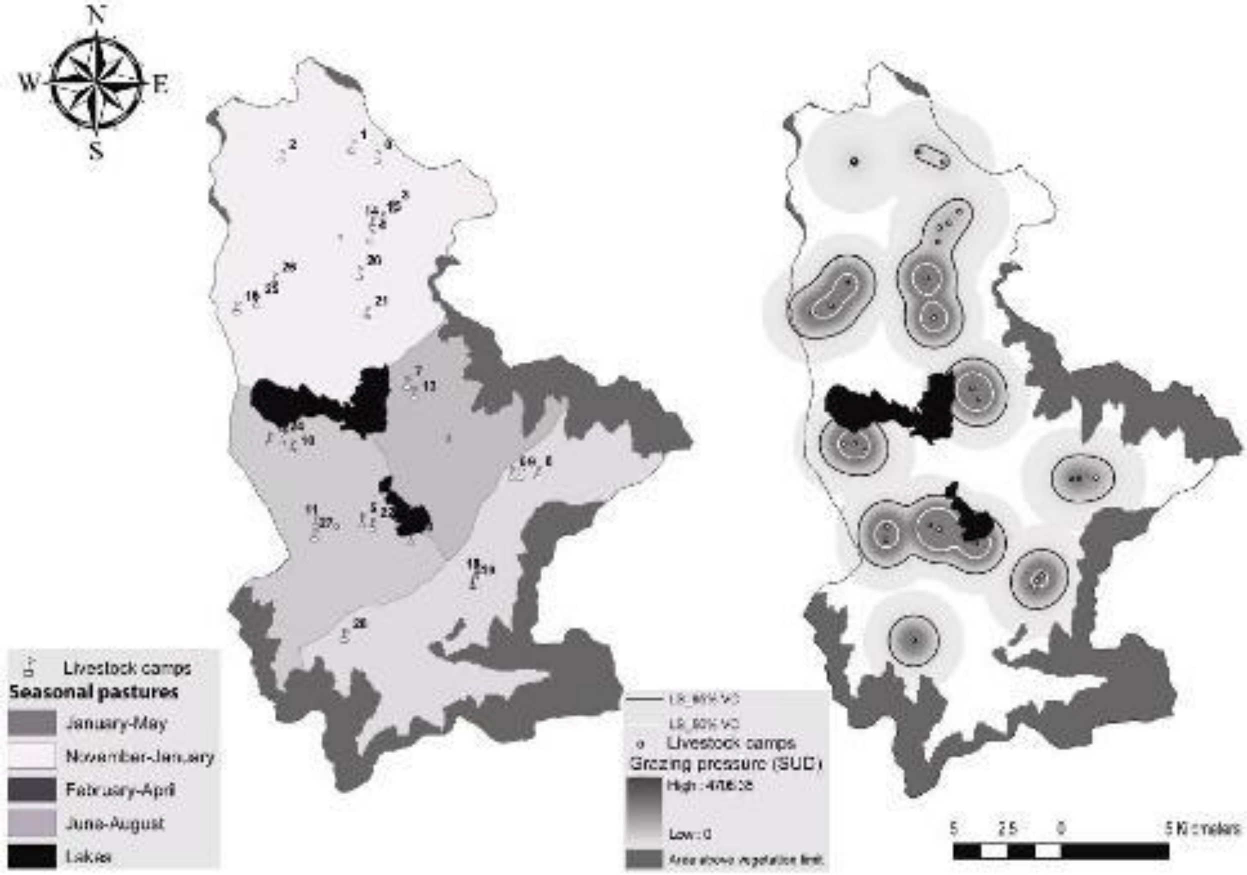


In northern Sikkim (Figure 2), a decade ago, 94 individuals were reported in the Choilung Valley near Lake Gya Tsoma in Khangchendzonga National park (Ganguly-Lachungpa 1996). But this population is currently believed to occur in two subgroups that range across the border between Sikkim and China (Tibet Autonomous Region), with a total of about 180 to 200 animals observed on the Tso Lhamo plateau (Chanchani *et al.* In review). Thus, in contrast to the estimate of *c.* 200 for India from data almost 30 years ago (Fox *et al.* 1991), the currently known argali population for India is *c.* 680-820 animals.

Livestock use of the area

Livestock, movements, camps, factors affecting the movements

Figure 4 maps showing – a) Seasonal pastures in winter, nomads campsites location, b) Utilizing distribution of livestock around campsites, estimated based on grazing pressure (calculated as Sheep unit days (SUD)) along with 50% and 95% Volume Contours (VC) calculated using Kernel density estimation.



The grazing and movement pattern of nomads with their livestock is comprised of fixed spatial movements (same areas every year) and flexible temporal movements (timing for movements is flexible based on environmental conditions). The pastures for winter

grazing inside the immediate Tso Kar basin are divided into four sub areas (see Figure 4a) which are used during November-January, February-April, January-May (emergency grazing area, used during severe snow events), and June-August. January0May area experiences the maximum grazing pressure and hence faces maximum resource exploitation by livestock followed by February-April, June-August and November-January area (Table 2). June-August area is manly used by Korzak nomads throughout summer.

Table 2: Sub areas used inside the study area for grazing. SU-Sheep Units, SUD-Sheep Unit Days, SUD/Km²-Grazing intensity expressed as sheep unit days per square kilometres.

Subarea	Month	Area (Km^2)	Days	SU	SUD	SUD/Km^2
Area 1	Jan-May	99	135	11,156	15,06,060	15,212.73
Area 2	Nov-Jan	200	92	12,321	11,33,532	5,667.66
Area 3	Feb-Apr	68	89	7,814	6,95,446	10,227.15
Area 4	Jun-Aug	112	92	7,376	6,78,592	6,058.85

In total, 29 camps sites are spread over the entire area, with numbered location shown in Figure 4a. Each camp site is used by several local nomad or Tibetan refugee families. Average holdings per family in the study area were 180 and 350 sheep and goats for local nomads and Tibetan refugees, respectively. In 2006 there was a total of 18,477 SU using the Tso Kar basin area over a period of 6 months, centred in the winter season. The estimated grazing pressure in terms of SUD are 20 (Nalbukar), and 21 (Thukje) in the north and northeast part of the basin, 22 (Starsapuk) and 23 (Nyangjung) in the south and 24 (Rigul) in the western part (Table 2, Figure 4a). Camp sites 6, 8, 9, 18, 19 and 28 addition to winter grazing are used for summer by Korzak nomads (another group of nomads) and are hence used all year round.

Habitat selection by argali

Argali habitat use was analysed during spring and summer seasons. Spring habitat use of argali showed both marginality and specialization (Figure 5a). During this season, the first two axes of ENFA explained 82% of the variability in the data (Table3). Alone, the marginality factor accounted for 61.3% of the total specialization. Argali preferentially used habitats at a lower altitude than available (alt score: -0.98; Table 3), but also slightly higher ruggedness and slope values. The second axis of ENFA also accounted for a relatively high specialization (eigenvalue: 4.72) and revealed a use of lower values of slope and NDVI. Overall, argali used a restricted range of altitudes, slopes and NDVI (Figure 5c and Table 3). In addition, argali likely preferred habitats that were closer to flat terrain (distTslp score: -0.33), and that were on south-facing slopes. Finally, SARI had little influence on specialization.

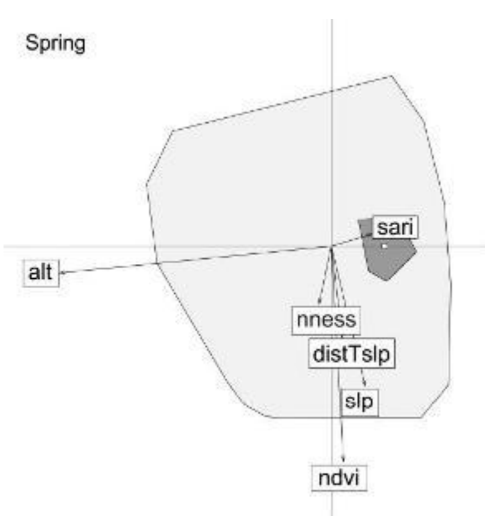
Table 3: Ecological Niche factor Analysis for spring and summer habitat selection of Tibetan argali. Marginality (Mar) and specialization (Spe) are indicated in different columns. Factor scores and the variance explained by the factor (Var_Exp%) are presented. Positive ENFA values indicate that argali preferred locations with higher values of the corresponding variable than the global average.

	Mar		Spe1		Spe2	
	Spring	Summer	Spring	Summer	Spring	Summer
Var_Exp%	61.3	41.5	19.5	25.8	10.1	13.6
altitude	-0.98	-0.66	-0.09	0.2	0.13	-0.67
distTslp	0.04	0.36	-0.33	0.41	0.11	-0.15
ndvi	0.04	0.56	-0.77	0.29	-0.42	-0.65
northness	-0.04	-0.2	-0.2	-0.03	-0.07	0.02
sari	0.15	0.23	0.04	-0.16	0.25	-0.25
slope	0.12	0.17	-0.5	-0.82	0.85	0.21

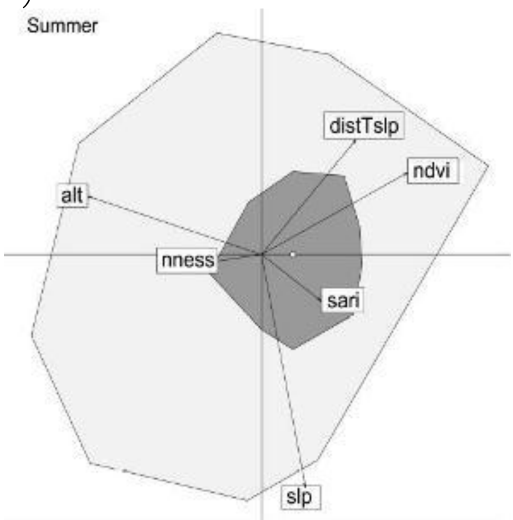
Compared to spring, summer habitat use appeared to be less specialized (Figure 5b). The first two axes explained 67% of the variability. As represented in the first axis, the marginality factor in summer was more complex than in spring although it still represented a high percentage of specialization (42%). Overall, marginality indicated argali preferences for lower altitude, higher NDVI, ruggedness and slope values. Compared to spring, argali used habitats at higher altitudes (alt-score: -0.66; Table 3) in summer and also chose areas closer to slopes (distTslp score: 0.36), and used more south facing slopes. The second axis also contributed highly to the specialization (26% of variability, eigenvalue: 3.64) and was mainly associated with the use of higher values for altitude, slope, NDVI and distTslp variables (indicated by positive values in the specialization axis, Figure 5d).

Figure 5: Ecological Niche Factor Analysis for spring and summer habitat selection of Tibetan argali. The first two panels a & b (spring and summer) show the marginalized (x axes) and specialization (y axes) with the scores of the environmental variables plotted. Used habitat is indicated by dark grey polygons and available habitat by light grey polygons. The last two panels (c-spring and d-summer) display the distribution of use (grey bars) versus (white bars) for all environmental variable (see table 1 for all abbreviations and descriptions).

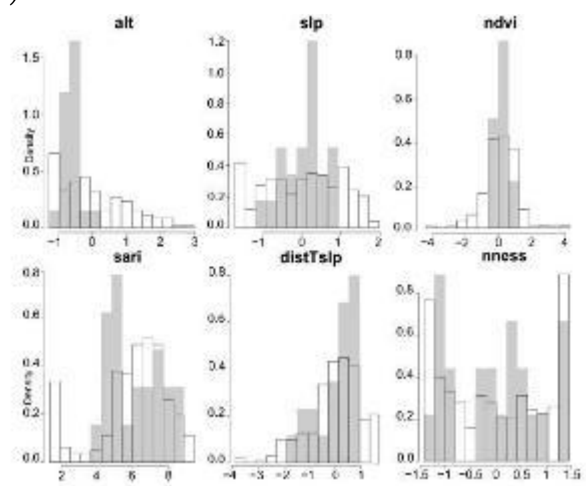
a)



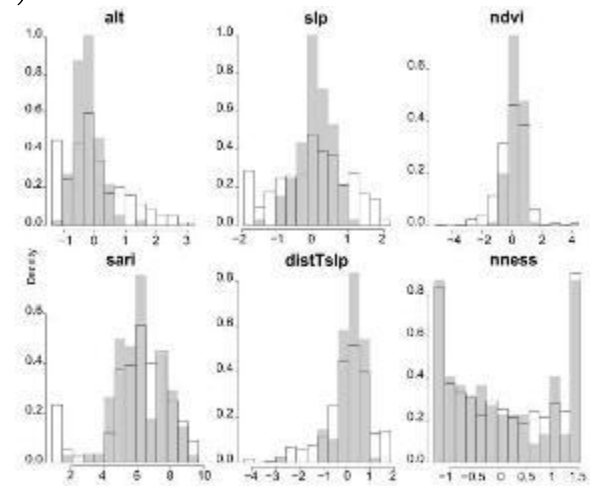
b)



c)



d)



Feeding patches

For both seasons, the percentage of green tissue was higher in feeding sites than in random sites (bias reduced logistic regression models, spring: t=2.64, df=18, P=0.002; summer: t=3.96, df=104, P=0.0001). These differences were not apparent for other vegetation variables (Table 4).

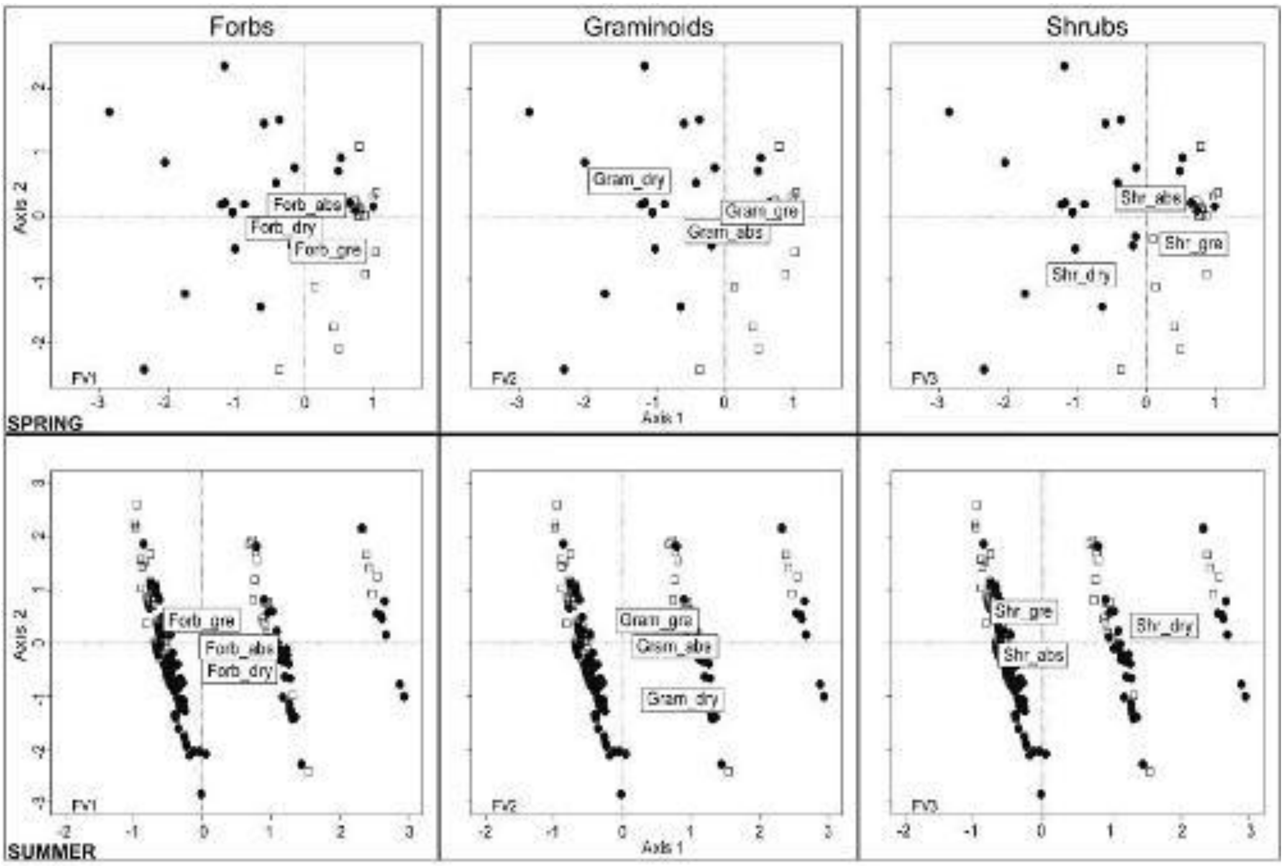
Table 4: Results of 'Bias reduced logistic regression models' at the feeding patch scale of argalis. Parameter estimates and S.E. for vegetation are provided for spring and summer.

	Spring			Summer		
Variables	Estimates	S.E.	t-value	Estimates	S.E.	t-value
biomass	0.30	0.27	1.12	0.09	0.12	0.78
cover	-0.06	0.20	-0.30	0.02	0.07	0.32
% green	0.09	0.04	2.63*	0.20	0.05	3.96*
Plant height	0.16	1.21	0.13	0.98	0.60	1.63

*p<0.05; ***p<0.001.

For both seasons, the fuzzy correspondence analysis showed a clear separation between feeding and random sites (Figure 6). This difference was related to green graminoids and green shrubs during spring and summer, whereas different forb categories did not seem to differ. The first axis was always associated with the presence of green plants.

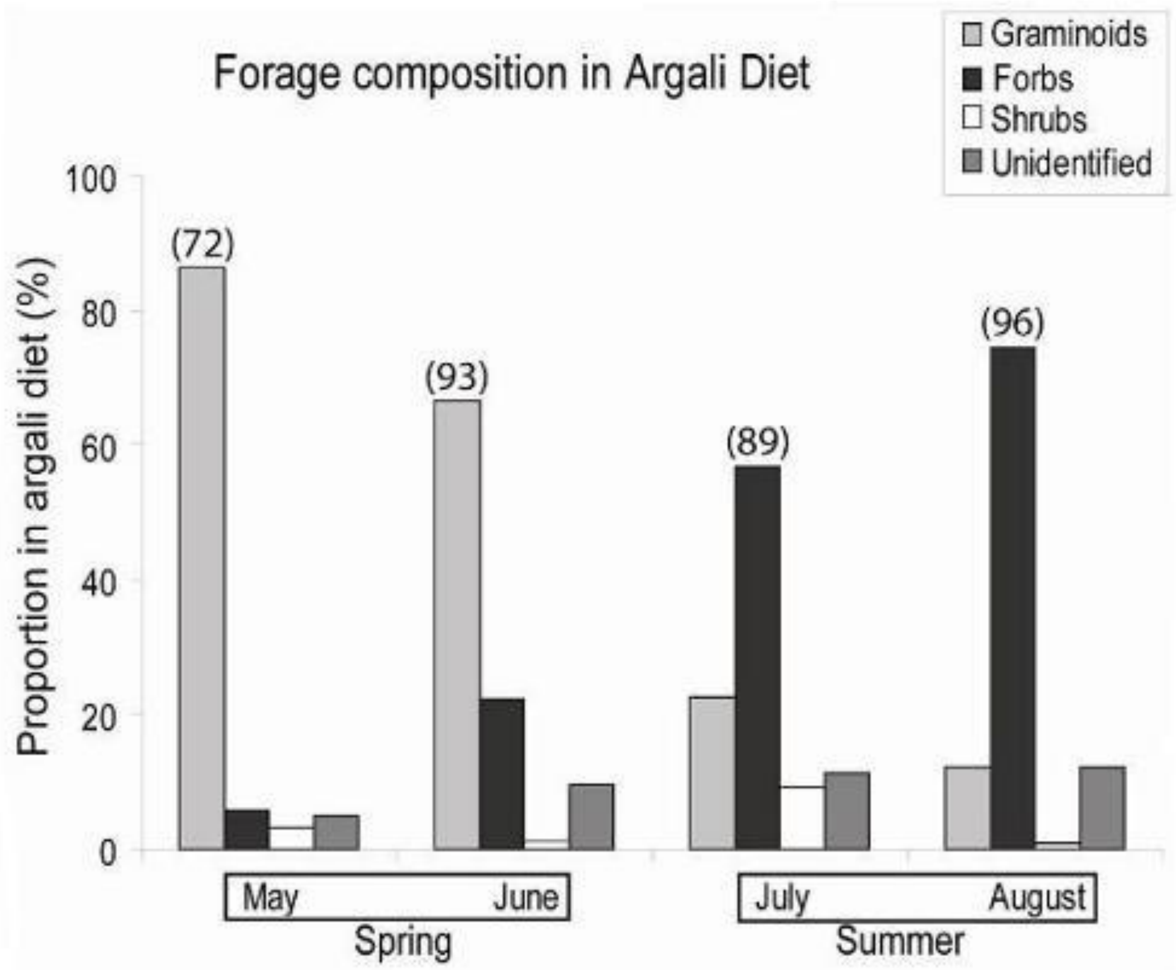
Figure 6: Fuzzy correspondence analysis of vegetation community categories for spring and summer habitat patch selection of Tibetan argali. 'Squares' indicate feeding sites and 'black dots' random sites. Three categories (green, dry and absence) for each of the vegetation communities (graminoids, forbs and shrubs) were considered for the analysis. The first two correspondence axes are presented. Each graph corresponds to one Fuzzy variable (FV).



Forage categories

During spring (here represented by May-June), argali diet comprised mainly graminoids (ca.70%), whereas during summer (represented by July-August) argali used much more forbs (Figure 7). Shrubs were lightly used in both seasons. During spring, graminoids on average (mean±S.E.) contained 16.2±2.6% CP, 70.6±5.3% NDF and 34.6±8.5% ADF, whereas forbs, which were in the early stages of growth, contained 11.4±3.6% CP, 43.5±9.3% NDF, and 28.7±7.1% ADF. The nutrient content changed rapidly with the onset of summer when graminoids contained 7.9±3.4% CP, 82.8±3.5% NDF, and 40.2±3.9% ADF, whereas forbs' CP increased to 24.8±3.5%. The NDF and ADF values for forbs were 33.8±3.1% and 28.9±4.8%, respectively in summer. The CP content in Shrubs also showed a slight increase from 17.5±2.4% in spring to 23.2±2.6% in summer.

Figure 7: Proportion of different plant groups in the spring (May-June) and summer (July-August) diet of Tibetan argali. The analysis is based on 350 micro-histological fragments found in argali faeces (numbers over bars represent the number of fragments checked for each month).



Discussion

Status and distribution of argali

Population estimates of Tibetan argali from a decade ago found very low and declining populations. However, more recent surveys in India revealed new argali populations from un-surveyed areas and somewhat larger populations in known areas, especially Ladakh, suggesting the need for more intensive surveys in un-surveyed and surveyed areas. Two large populations (>100 animals) occur in eastern Ladakh (Gya Miru-Tso Kat-Tso Moriri and Changchenmo) and one in Sikkim (Tso Lhamo plateau). These populations can be used as source populations to introduce argali in the potential habitats as well as areas where they had been known to occur in the past. Also, these populations need to be studied in detail to identify the factors affecting their present condition.

Livestock use of the area

As ascertained in discussion with nomads, quality of pastures and water availability are two most important factors that determine the stay duration at a camp site (mean$\pm$S.E., distance of camp site from nearest water source was 818$\pm$394m). According to the nomads, other factors that influence stay duration are disease outbreaks, localized droughts, market locations, festivals and social gatherings. During summer, nomads prefer to stay in the area along the main highway, outside the immediate lakes basin, for easy access to city and transport (see also Hagalia 2004).

Evidence for possible mechanisms of interactions between sympatric wildlife and livestock suggest that higher densities of domestic livestock deplete the density and diversity of wild herbivores in Transhimalayan rangelands by imposing resource limitations through over exploitation and causing interference through direct presence (Mishra *et al.* 2002; Bagchi *et al.* 2004; Namgail *et al.* 2007). Often the livestock groups are also accompanied by herding dogs which harass adult wild herbivores and prey on juveniles and lambs (Namgail *et al.* 2004). It is hence essential to assess the likely interactions between argali and livestock.

The impact of the resource exploitation by livestock on argali can be severe depending on the timing of grazing. During winter, snow free areas are scarce and pastures use is confined to such areas, hence diets are also largely constrained by what is available. The growing season lasts for three months in summer, in Transhimalayan rangelands. It is the time when ungulates are building up their lost energy reserves, and lambing occurs. Herbivores then probably exercise some choice to meet their energy demands, given the higher forage availability and quality (Gordan and Illius 1989; Mysterud 2000; Mishra *et al.* 2004). The competition with livestock for forage and space will therefore be more detrimental, if completion occurs in summer and the danger is more severe in the areas where livestock grazing occurs all year round. If seasonal

changes occur in pasture use patterns due to rising livestock densities, increased pasture demand and local government policies on livestock management, it may increase the chances of direct interactions and overexploitation of the pastures. Such overexploitation and interference might have also resulted in absence of argali from many suitable areas and may have confined them to those areas which are either lightly grazed or livestock free. Extinction of wild ungulate species have been reported from Spiti area (Mishra *et al.* 2002) due to competition with livestock. Past reports claim the occurrence of Tibetan gazelle in Tso Kar basin till the 1980s, which are now absent. In Hanle region of eastern Ladakh, the gazelle population has survived likely to relatively low grazing in winter, and the other small gazelle population (Rique plains) apparently in a livestock free area (Bhatnagar *et al.* 2006a).

Habitat selection by argali

At the broad landscape scale, selection of habitat was mainly determined by topographic characteristics of the landscape and at the finer resource scale, by forage quality. The broad scale selection is determined by predation risk and NDVI and finer scale selection based on greenness in high altitude rangeland systems. In addition, we showed that selection varied on a seasonal scale following changes in resource availability and quality.

Habitat

Habitat choice in early spring in high altitude and alpine ecosystems is expected to be confined to limited areas, which are free from snow or windblown, whereas during summer preferences are expected to widen as more habitat becomes available. Our results follow this pattern, with a combination of altitude, slope, and distance to slope determining spring habitat selection by argali. As low altitude areas became snow free earlier than higher sites in the study area, argali moved from relatively lower areas in spring towards higher altitudes in summer. The increased use of higher altitudes in summer is linked to the later plant phenology at these sites (Schaller 1998, Kala and Mathur 2002). However, there is a limit to movements to higher elevation and slope values, as argali preferred intermediate values of these variables, confining their movements in the narrow belt of sparse vegetation of the low and high hills. The preference for intermediate range of NDVI also supports this trend. This pattern could be the result of two limiting factors. First, although low flat steppes contain patches of high plant biomass (Rawat and Adhikari 2005), they are also disturbed by people and occasionally horses in summer (Fox2004). Second, high areas could also be avoided because they are above vegetation limit (>5200m till 5900m). In addition, predation and presence of other large herbivores such as kiangs in the lower areas prevent argali from using them. The high biomass areas around the lakes are also used throughout winter by thousands of livestock. This excessive grazing may also reduce the quality of the vegetation, although being higher in biomass. Early summer is the time of lambing in argali, when both lambs and lactating ewes are exposed to an increase risk of predation. Thus, the increased use of slopes in summer likely provides a better view of the area to scan for wolves and could also be linked to the flight escape strategy of argali, which is to run towards the slopes (Schaller 1977). The preferred habitat use of argali thus

appears to be a compromise between disturbances, forage and safety (see Hamel and Côté 2007).

Resources

Feeding Patch
The intermediate range of habitat variables altitude, slope and NDVI selected by argali limited the choice of feeding patches within this range.

The plant growing season in alpine environments is short, generally occurring from May to July in our study area. Feeding patch selection by several ungulates in alpine environments has been explained by individuals tracking new emerging plant growth (Skogland 1984, Mårell and Edenius 2006), which has higher nutritive quality in terms of available energy and protein, is easy to browse, and contain low amount of secondary compounds (Albon and Langvatn 1992, van Soest 1994). Over the growing season, the proportion of fiber increases and energy, nutrient levels, and digestibility decrease as the plant age (Hudson and White 1985). In homogeneous high altitude rangelands, percent green tissue can be considered as an indicator of forage quality, which initially increases and then decreases as the growing season progresses (this study, Sinclair 2095, Schaller 1998). We can then hypothesize that the percentage of green tissue in plants is used by argali to select feeding patches, allowing them to build up the energy reserves lost during winter. Argali in the Transhimalayan rangelands of Nepal have also been shown to prefer quality over abundance throughout the summer (Shrestha *et al.* 2005).

Reade-off between quality and quantity may lead herbivores to select diets of intermediate quality in order to maximise their overall rate of nutrient assimilation (Wilmshurst *et al.* 1995). However, in circumstances where forage quantity is not a constraint, when animals occur in low densities, herbivores should select food items with maximum nutrients that are most limiting for their growth and/or reproduction (e.g. Demment and van Soest 1985, Duncan and Gordon 1999). Alternatively, herbivores in environments with low biomass but high quality as in the arctic, trade-off quality for a more favourable energy return (Van der Waal *et al.* 2000). Given the low abundance of argali in the study area and their use of habitats with few competitors, argali select forage quality over quantity. In support, several studies have demonstrated a close relationship between food quality, growth rates, body size and have shown that variation in body size appears to be associated to the length of time animals have access to high quality forage during summer in temperate and subarctic areas (Klein 1964, Saether 1985, Langvatn and Albon 1986).

Forage categories
Graminoids are dominant in the steppe and rangeland ecosystems (Schaller 1998). With the progression of the short growing season after snow melt, graminoids undergo rapid growth followed by forbs, and dwarf shrubs. However, the nutrient content of graminoids decreases with the progression of the summer, whereas forbs retain more

nutrients till autumn (Schaller 1998, Rawat and Adhikari 2005). With this temporal variability, ungulates generally adopt a mixed diet at the large temporal scale but a selective diet during the short windows of high quality resources (Harris and Miller 1995, Schaller 1998, Shrestha *et al.* 2005). With their intermediate body size, argali are expected to have high energy requirements and should use plants according to their energy content, provided they are readily available. This has been observed in blue sheep *(Pseudois naur)* in Indian and Nepalese Transhimalayan (Mishra *et al.* 2004, Shrestha *et al.* 2005). In our case, we showed that argali used mainly graminoids in spring and forbs in summer.

During the growing season, protein content in graminoids and forbs ranged from 6 to 16% and from 12 to 26%, respectively. Comparisons among forages harvested in late summer in Tibetan Chanthang and our results indicated that forbs had the highest crude protein, followed by graminoids and shrubs (this study, Long *et al.* 1999). Although micro-histological analyses of faeces did not indicate a common use of shrubs for the whole summer, they do contain green tissue early in the season, which correspond to high quality resources; however shrubs also accumulate secondary compounds (e.g. phenols) quickly. Because they are relatively more prominent compared to graminoids and forbs, shrubs could be used as cues by argali to delineate green patches from a distance (e.g. Renken *et al.* 2008).

Threats to Tibetan argali

Based on the personal observations, results of research, review of literature and direct interviews with the wildlife department officials and local livestock herders, we identified a number of factors that likely threaten the survival of Tibetan argali across its range, these include:

Hunting and military presence

Tibetan argali was the most referred trophy species in Ladakh (Fox *et al.* 1991, Bhatnagar and Wangchuk 2001), with such hunting permitted up until 1975 (Namgail 2003). Argalis were also hunted by army personnel during large military presense of the 1960's - 1980's along the Indo-Chinese border, and it seems that this led to substantial decreases in its population in eastern Ladakh (Fox *et al.* 1991). Recognising the decline in argali populations, hunting was formally prohibited in 1980 (J & K Wildlife Protection Department), but it is difficult to infer what argali populations were before this period. Despite the ban on hunting, it is apparently still a problem in some areas of military presence along their Himalayan border regions.

Livestock

Overgrazing and competition with livestock has been identified as a major threat to wild ungulate herbivores in the Indian Transhimalaya (Mishra *et al.* 2001), with significant increases in livestock populations apparent in both Ladakh and Sikkim in recent decades

(Bhatnagar and Wangchuk 2001, U. Lachungpa pers. comm.). Government promotion of *cashmere* productions has supported substantial increases in pashmina goat populations in Ladakh (Bhatnagar and Wangchuk 2001, Singh 2008). Competition with livestock is therefore an important conservation issue, with competition for space and forage believed to be producing negative consequences for many argali populations (Singh 2008). Shrestha *et al.* (2005) have also indicated a possible dietary overlap between the wildlife and the livestock in the argali range in Nepal. Within India's Gya Miru Wildlife Sanctuary, argali have been shown to shift to more marginal areas (steeper, less productive sites) when livestock (sheep and goats) were moved into their habitat (Namgail *et al.* 2007). In nearby Tso Kar basin, argalis appear to be negatively affected by livestock herding in Gansu Province of western China (Harris and Bedunah 2001, Harris and Pletscher 2002). Disturbances to argali associated with herding activities are not limited to livestock. For example, livestock herders are often accompanied by herding dogs, which chase and harass argali and sometimes kill their lambs.

Disease transmission through livestock

Although evidence is lacking for Tibetan argali, other argali subspecies such as Gobi and Altai argali are reported to have been infected by livestock-introduced diseases such as pasteurellosis, rinderpest, malignant anthrax (Sapozhnikov 1976, R P Reading pers.comm.). Although, Harris (2008) dismisses high disease risks for Tibetan argali (citing genetic resistance), considering their small and patchy populations amid a sea of domestic sheep and goats, the dangers for small population extinction should be of concern (Caughley 1994). Blue sheep population die-offs from disease have, for example, been reported from Pakistan (Wodford 2007).

Natural threats due to small populations

Many wild sheep and goat species are particularly vulnerable to extinction due to three main factors: genetic isolation, specialized habitat requirements, and low reproductive rate (Shackleton 2997). From the studies and observations in Ladakh as well as on the Tibetan plateau it is evident that Tibetan argali occur in many isolated populations throughout its range (Fox *et al.* 1991, Namgail 2003, Schaller 1998). Under the small populations' paradigm, the small populations are more vulnerable to environmental stochasticity, such as vagaries of the weather in terms of excess snow and drought that can result in fluctuations in food supply and deaths of animals (Caughley 1994).

Tourism

Due to their scenic beauty, Ladakh attracts an increasing number of tourists every year. In providing facilities for tourists and better access to these areas, many development actions such as road construction and the establishments of camping sites are taking place in both regions of India (Rawat *et al.* 2006, Tambe and Lachungpa 2003). Such activities not only destroy habitat, but also disturb wildlife, and instances of tourists in vehicles chasing after wild animals (N J Singh, pers.obs.) serves to illustrate the problem. Although such activities are more prevalent at the margins of argali habitat, there is potential for some effects on argali.

Suggested conservation actions for argali in India

The banning of hunting in India has apparently not led to a recovery of argali populations (Namgail *et al.* In review). It thus appears that actions more than hunting restrictions will be required to conserve and restore Tibetan argali. Based on the threats outlined above, the following recommendations are given for the conservation and management of argali in India.

Livestock competition and disturbance

Addressing grazing competition from livestock basically means allocating sufficient forage carrying capacity to argali for their survival and reproduction. And this means adjusting to annual changes in forage productivity due to the variable climate. Because current ranges are so small, the freeing of areas from livestock grazing that are important to argali is a viable option. This has been tested successfully for blue sheep in the Spiti area of northern Himachal Pradesh, India, and is now being tried in the Gya Miru Wildlife Sanctuary (Y V Bhatnagar, unpub.data). It has been observed in eastern Ladakh, that small argali and gazelle populations mainly exist in areas free of livestock in summer (Bhatnagar *et al.* 2006, Singh 2008). Hence, restricting the grazing patterns in wildlife areas to only non summer seasons is also a possible option provided the livestock densities are not so high as to lead to overexploitation.

Control of herders' dogs

In areas of critical argali habitat, especially for lambing, the presence of herding dogs that chase argali needs to be strictly controlled.

Disease transmission

Disease transmission between livestock and argali (either way) should be investigated to better identify the risks. Once a disease is identified, vaccinations or other curative measures should be applied in a timely fashion to prevent its spread to wild or domestic populations. Preventing close contact would be one of the benefits of freeing small areas from livestock. Such measures could help to reduce the risk of small populations of argali being wiped our due to a disease carried by livestock. This measure would be viable, once the areas are freed from livestock, which is suggested in one of the earlier points.

Campsite designation, road construction and regulation of off-road driving

The J & K Departments of Wildlife Protection and Tourism need to coordinate better in locating sites for camping and discouraging tourists from camping at will. This will prevent proliferation of garbage and destruction of pastures. Road are being constructed in most of the protected areas for easy access. Road construction should be designed ensure minimum off-road access.

Conservation associated with military areas and personnel

Military personnel need to be made aware of the conservation status of argali and should be discouraged from hunting. Land mines need to be removed from critical argali areas in both Sikkim and Ladakh.

Design of protected areas

Effective design of protected areas needs to incorporate various crucial attributes and ecological knowledge such as size and boundary, landscape heterogeneity, suitable habitat, seasonal and annual home ranges, migrations, connecting corridors and networks. Transboundary reserves should be encouraged where argali populations span border regions as in Changchenmo area of eastern Ladakh and Tso Lhamo plateau of northern Sikkim.

Sampling using habitat selection models

The use of resource selection functions to prepare habitat suitability maps and using stratified random sampling to survey argali based on the based on these maps reduced the survey and sampling effect by almost 60% in one Ladakh study area (Singh *et al.* submitted). Such methods have important implications for designing the future surveys and monitoring programmes. Although the method has been used in a small area in eastern Ladakh recently, it can be applied to sample argali throughout its range. The discovery of new argali populations in the Ladakh region over the last 20 years directs the attention towards the sampling of un-surveyed suitable areas for argali. This will especially be the case in the large areas of un-surveyed argali range on the Tibetan plateau. Thus the previous estimate of 200 argalis in Ladakh reflects primarily a lack of sampling rather than such a low population, and we propose a similar exercise to eventually take place throughout the Tibetan plateau. An important conservation action would be to identify all suitable areas by making precise habitat suitability models and stratifying the high suitability areas to sample and survey argali.

Conclusion

To address the major threats, detailed studies on argali ecology and factors affecting their survival in the small pockets of remaining habitat are required. In particular, competition with livestock must be properly understood through studying patterns of year-round use and resource exploitation by both argalis and livestock. Other factors influencing argali, such as tourism and developmental activities in the argali habitat, must be controlled to minimize threats to the species. In designing conservation and management programs, such acquired ecological knowledge will prove invaluable in helping to assure the continued survival of argali.

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References

Albon, S.D. & Langvatn, R. (1992). Plant phenology and the benefits of migration in a temperate ungulate. *Oikos* 65, 502-513.

Association of Official Analytical Chemists. (1984). Official methods of analyses. Association of Official Analytical Chemists, Washington, D.C.

Bagchi, S., Mishra, C. & Bhatnagar, Y.V. (2004). Conflicts between traditional pastoralism and conservation of Himalayan ibex *(Capra sibirica)* in the Transhimalayan mountains. *Animal Conservation*, 7, 121-128.

Bhatnagar, Y.V. * Wangchuk, R. (2001). Status of large mammals in eastern Ladakh & Nubra. In Anon. 2001. Conserving biodiversity in the Transhimalaya: New initiatives for field conservation in Ladakh. First Annual technical Report (1999-2000), Wildlife Institute of India, Dehradum, India.

Bhatnagar, Y.V., Wangchuk, R. & Mishra, C. (2006a). Decline of the Tibetan gazelle *(Porcapra picticaudata)* in Ladakh, India. *Oryx*, 40, 229-232.

Caughley, G. (1994). Directions in conservation biology. *Journal of Animal Ecology*, 63, 215-244.

Chessel, D., Dufour, A.B. & Thioulouse, J. (2004). The ade4 Package – I: One-Table Methods. *R News* 4, 5-10.

Chevenet, F., Dolédec, S. & Chessel, D. (1994). A fuzzy coding approach for the analysis of long-term ecological data. *Freshw.Biol.* 31, 295-309.

Chetri, M & Pokharel, A. (2005). Status and distribution of blue sheep, Tibetan argali and the kiang in Damodar Kunda Area, Upper Mustang, Nepal. *Our Nature*, 3:56-62.

Chundawat, R.S. & Qureshi, Q., (1999). Planning wildlife conservation in Leh and Kargil district of Ladakh, Jammu & Kashmir, Wildlife Institute of India, Dehradun, India.

Chanchani, P. (2007). Habitat and use and food selection by wild and domestic ungulates in Sikkim Transhimalaya. Master thesis in Wildlife Science, Saurashtra University, Rajkot, India. Pp 1-97.

Compton, B.W., Rhymer, J.M. & McCollough, M. (2002). Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology* 83, 833-843.

Demment, M.W. & van Soest, P.J. (1985). A nutritional explanation for body-size patterns of ruminant and non-ruminant herbivores. *Am. Nat.* 125, 641-672.

Duncan, A.J. & Gordon, L.J. (1999). Habitat selection according to the ability of animals to eat, digest and detoxify foods. *Proc. Nutr. Soc.* 58, 799-805.

Fedosenko, A.K, Blank, D.A, (2005). *Ovis ammon*. Mammalian species No. 773, pp1-15.

Fox, J.L. and A. Manandhar. (1994). Biodiversity conservation and protected area management: Shey-Phoksundo National park. Project Design Report to USAID, Nepal. Devres, Inc. Wash. D.C. Pp42.

Fox, J.L. & Johnsingh, A.J.T. (1997). Country report for India. In Wild sheep and goats and their relatives – status survey and conservation action plan for Caprinae: 215-231. Shackleton, D.M. (Ed.). IUCN, Gland, Switzerland and Cambridge, U.K.: IUCN/SSC Caprinae Specialist Group.

Fox, J.L. (2004). The Tso Kar Basin; conservation of a Tibetan plateau ecosystem in the Changthang highlands of Ladakh, India. Annual Project background and progress report. Institutional cooperation programme in Natural resource ecology and Management, between the Wildlife Institute of India, Dehradun, India and University of Tromø, Tromø, Norway. 30pp.

Fox, J.L., Nurbu, C. and Chundawat, R.S. (1991a). Tibetan argali (O*vis ammon hodgsoni*)establish a new population. *Mammalia* 55:448-552.

Fox, J.L., Nubru, C. and Chundawat, R.S., (1991b). Mountain ungulates of Ladakh, India. *Biological Conservation* 58: 167-190.

Fox, J.L., K. Dhondup and T. Dorji. (2008). Tibetan antelope and new rangeland management activities in and around the Chang Tang Reserve. Report to Tibet Autonomous Region Forestry Bureau. Univ. of Tromø, Norway.

Fox, J.L. Ciren Yangzong, Kelsang Dondhup, Tsechoe Dorji and C. Richard. In press. Biodiversity conservation and pastoralism in the Tibetan Chang Tang; coexistence or conflict? Journal of International Tibetan Studies Association.

Firth, D. (1993). Bias reduction of maximum likelihood estimates. *Biometrika* 80, 27-38.

Ganguly-Lachungpa, U. (1996). Unusual congretation of Nayan (*Ovis ammon Hodgsoni*) Blyth at Gya Tsona, North Sikkim. *Journal of Bombay Natural History Society*. 93-292.

Gill, R.B., carpenter, L.H., Bartmann, R.M., baker, D.L. & Schoonveld, G.G. (1983). Fecal analysis to estimate mule deer diets. *J. Wildl. Manage*. 47, 902-915.

Goering, H.K & van Soest, P.J. (1970). Forage fiber analyses (apparatus reagents, procedures, and some applications.). *Agric. Handbook* 379, ARS USDA, Washington, D.C.

Gordon, I.J. & Illius, A.W. (1989). Resource partitioning by ungulates on the Isle of Rhum. *Oecologia,* 79, 383-389.

Hagalia, W. (2004). Changing rangeland use by the nomads of Samad in the highlands of eastern Ladakh, India. MS dissertation, Agricultural University of Norway, Ås, Norway.

Hamel, S. & Côté, S.D. (2007). Habitat use patterns in relation to escape terrain: Are alpine ungulate females trading-off better foraging sites for safety? *Can. J. Zool.* 85, 933-943.

Harris, R.B. (1993). Wildlife conservation in Yeniugou, Qinghai Province, China. Ph.D. dissertation, University of Montana, Missoula, 326 pp.

Harris, R.B. & Miller, D.J. (1995). Overlap in summer habitats and Tibetan Plateau ungulates. *Mammalian* 59:197-212.

Harris, R.B., D.H. Pletscher, C.O. Loggers, and D.J. Miller. (1999). Status and trends of Tibet's Plateau mammalian fauna, Yeniugiu, China. *Biological Conservation* 87:13-19.

Harris R.B., Ali, A. and C. Loggers. (2005). Trend monitoring of large mammals: two case studies. *Acta Theriologica Sinica*. 25: 319-325.

Harris, R.B. and D.H. Pletscher. (2002). Incentives toward conservation of argali *Ovis ammon*: A case study of trophy hunting in western China. *Oryx* 36: 373-81.

Harris, R.B. & Bedunah, D.J. (2001). Sheep vs. sheep: Argali and livestock in western China. Final report to National Geographic Society, University of Montana.

Harris, R.B. Argali on the Tibetan plateau (Chapter 2). Argali biology and conservation. Denver Zoological Foundation. (In press).

Hausner, V., Yoccoz, N.G. & Ims, R.A. (2003). Selecting indicator traits for monitoring land use impacts: birds in northern coastal birch forests. *Ecol. Appl.* 13, 999-1012.

Heinze, G. & Schemper, M. (2002). Solution to the problem of separation in logistic regression. *Stat. Med.* 21, 2409-2419.

Hirzel, A.H., Hausser, J., Chessel, D. & Perrin, N. (2002). Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? *Ecology* 83, 2027-2036.

Hosmer, D. & Lemeshow, S. (2000). Applied logistic regression. A Wiley-Interscience Publication, John Wiley & Sons Inc, new York, NY.

Hudson, R.J. & White, R.G. (1985). Computer simulation of energy budgets- In: Hudson, R.J. and White, R.G. (Ed), Bioenergetics of Wild herbivores CRC Press, pp 261-290.

Hurme, E. Monkkonen, M., Nikula, A., Nivala, V., Reunanen, P., Heikkinen, T & Ukkola, M. (2005). Building and evaluating predictive occupancy models for the Siberian flying squirrel using forest planning data. For. *Ecol. Manage.* 216, 241-256.

Ito, T.Y., Miura, N., Lhagvasuren, B., Enkhbileg, D., Takasuki, S., Tsunekawa, A. & Jiang, Z. (2006).

IUCN – World Conservation Union. (2004). The IUCN Red List of threatened species. Available: "http://www.iucn.org/themes/ssc/red-lists.htm" via web.

Jackson, R. and J.L. Fox. (1997). Report on the fourth SLIMS training workshop. International Snow leopard Trust, Seattle, WA.

Jepsen, J.U., Madsen, A.B., Kalsson, M. & Groth, D. (2005). Predicting distribution and density of European badger (*Meles meles*) setts in Denmark. *Biodivers. Conserv.* 14, 3235-3253

Kala, C.P. & Mathur, V.B. (2002). Patterns of plant species distribution in the Transhimalaya region of Ladakh, India. *J. Veg. Sci.* 13, 751-754.

Karnieli, A., Bayasgalan, M., Bayarjargal, Y., Agam, N., Khudulmur, S. & Tucker, C.J. (2006). Comments on the use of vegetation health index over Mongolia. *Int. J. Rem. Sen.* 27, 2017-2024.

Klein, D.R. (1964). Range related differences in growth of deer reflected in skeletal ratios. *J. Mammal.* 45, 226-235.

Langvatn, R. & Albon, S.D. (1986). Geographic clines in body weight of Norwegian red deer: a novel explanation of Bergmann's rule? *Holarct. Ecol.* 9, 285-293.

Long, R.J., Apori, S.O., Castro, F.B. & Orskov, E.R. (1999). Feed value of native forages of the Tibetan Plateau of China. *Anim. Feed. Sci. Technol.* 80, 101-113.

Mårell, A. & Edenius, L. (2006). Spatial heterogeneity and hierarchical feeding habitat selection by reindeer. *Arct. Antarct. Alp. Res.* 38, 413-420.

Mishra, C., Prins, H.H.T., van Wieren, S.E. (2001). Overstocking the Transhimalayan rangelands of India. *Environmental Conservation* 28: 279-283.

Mishra, C. van Wieren, S.E., Ketner, P., Heitkonig, I.M.A & Prins, H.H.T. (2004). Competition between domestic livestock and wild bharal (*Pseudois nayur*) in the Indian Transhimalaya. *J. Appl. Ecol.* 41, 344-354.

Mishra, C., van Wieren, S.E., Heitkonig, I.M.A. & Prins, H.H.T. (2002). A theoretical analysis of competitive exclusion in a Trans-Himalayan large herbivore assemblage. *Animal Conservation*, 5, 251-258.

Mueller, T., Olson, K.A., Fuller, T.K., Schaller, G.B., Murray, M.G. & Leimgruber, P. (2008). In search of forage: predicting dynamic habitats of Mongolian gazelles using satellite – based estimates of vegetation productivity. *J. Appl. Ecol.* 45, 649-658.

Mysterud, A., Larsen, P.K., Ims, R.A. & Østbye, E. (1999). Habitat selection by roe deer and sheep: does habitat ranking reflect resource availability? *Can. J. Zool.* 77, 776-783.

Mysterud, A. (2000). Diet overlap among ruminants in Fennoscandia. *Oecologia*, 124, 130 137.

Namgail, T. (2003). Gya-Miru: last refuge of the Tibetan argali. *Sanctuary Asia.* 23: 16-21.

Namgail, T., J.L. Fox and Y.V. Bhatnagar (2004). Habitat segregation between sympatric Tibetan argali *Ovis ammon hodgsoni* and blue sheep *Pseudois nayaur* in the Indian Trans-Himalaya. *Journal of Zoology*, 262:57-63.

Namgail, T., J.L. Fox and Bhatnagar, Y.V. (2007). Habitat shift and time budget of the Tibetan argali: the influence of livestock grazing. Ecological Research, DOI10.1007/s11284-006-0015-y.

Namgail, T., J.L. Fox and Bhatnagar, Y.V. In review. Status and conservation of the endangered Tibetan argali in Ladakh, India.

National Biodiversity and Action plan (NBSAP) (2003). Sikkim State Biodiversity and Action plan. 14p.

Nellemann, C. & fry, G. (1995). Quantitative analysis of terrain ruggedness in reindeer winter grounds. *Arctic* 48, 172-176.

Pettorelli, N., Vik, J.O., Mysterud, A., Gaillard, J.M., Tucker, C.J. & Stenseth, N.C. (2005). Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends Ecol. & Evol.* 20, 503-510.

Rawat, G.S., Fox, J.L, et al. (2006). Rangeland production ecology and habitat use by wildlife and livestock in Tso Kar basin, eastern Ladakh. "Natural Resource Ecology and management" – an Institutional Cooperation between the Wildlife Institute of India & the Department of Biology, Faculty of Science, University of Tromsø, Norway supported by NORAD.

Rawat, G.S. & Adhikari, B.S. (2005). Floristic and distribution of plant communities across moisture and topographic gradients in Tso Kar basin, Chanthang plateau, eastern Ladakh. *Arctic, Antarctic and Alpine Research*, 37, 539-544.

Reading, R.P., S. Amgalanbaatar, G.J. Wingard, D. Kenny, and A. DeNicola. (2005). Ecology of argali in Ikh Nartin Chuluu, Dornogobi Aimag. Erforschung Biologischer Ressourcen der Mongolei (Halle/Saale) 9: 77-89.

Renkin, W.J., Howery, L.D., Ruyle, G.B. & Enns, M.E. (2008). Cattle generalise visual cues from the pen to the field to select initial feeding patches. *Appl. Anim. Behav. Sci.* 109, 128-140.

Saether, B.E. (1985). Annual variation in carcass weight of Norwegian moose relation to climate along a latitudinal gradient. *J. Wildl. Manage.* 49, 977-983.

Sapozhnikov, G.N. (1976). Wild sheep (genus *Ovis*) of Tadjikistan. Dornish Press, Dushanbe, United Soviet Socialist republics (in Russian).

Schaller, G.B. (1977). Mountain monarchs: wild sheep and goats of the Himalaya. University of Chicago Press, Chicago.

Schaller, G.B., Gu, B.Y. (1994). Ungulates in Northwest Tibet . National Geographical Research & Exploitation. 10 (3): 266-293.

Schaller, G.B. (198). Wildlife of the Tibetan Steppe, University of Chicago Press, Chicago.

Seaman, D.E. & Powell, R.A. (1996). An evaluation of the accuracy of kernel density estimators for home range analysis. *Ecology*, 77, 2075-2085.

Shackleton, D.M. (ed) (1997). Wild sheep and goats and their relatives, IUCN, Gland, Switzerland and Cambridge, UK.

Shrestha, R., P. Wegge, et al. (2005). Summer diets of wild domestic ungulates in Nepal Himalaya. *Journal of Zoology*, 266:111-119.

Sinclair, A.R.E. (1975). Resource limitation of trophic levels in tropical grassland ecosystems. *J. Anim. Ecol.* 44, 497-520.

Singh, N.J., Yoccoz, N.G., Bhatnagar, Y.V., Fox, J.L. Using resource selection functions to sample rare species in high altitude ecosystems: A case study with Tibetan argali. *Submitted.*

Singh, N.J., Bonenfant, C., Yoccoz, N.G., Cote, S.D. Proximate and ultimate causes of sexual segregation in Eurasian wild sheep, the Tibetan argali. *Submitted.*

Singh, N.J. (2008). Animal – Habitat relationships in high altitude rangeland. PhD. Thesis. University of Tromsø, Norway.

Silverman, B.W. (1986). *Density estimation for statistics and data analysis.* Chapman and hall, London, UK.

Skogland, T. (1984). Wild reindeer foraging-niche organization. *Hol. Ecol.* 7, 345-379.

Tambe, S., Lachungpa, U. (2003). Sikkim Biodiversity and Action plan. Pg 1-900

van der Wal, R., Madan, N., van Leishout, S., Dormann, C., Langvatn, R. & Albon, S.D. (2000). Trading forage quality for quantity? Plant phenology and patch choice by Svalbard reindeer. *Oecologia* 123, 108-115.

Venerables, W.N. & Ripley, B.D. (2002). Modern applied statistics with S Plus. Springer.

Ward, A.E. (1924). The mammals and birds of Kashmir and the adjacent hill provinces. *Journal of the Bombay Natural History Society* 29: 879-887.

Wilmshurst, J.F., Fryxell, J.M. & Hudson, R.J. (1995). Forage quality and patch choice by wapiti (*Cervus elaphus*). *Behav. Ecol.* 6, 209-2217.

Woodford, M.H. (2007). Debilitating skin disease in Blue sheep in Khunjerab national Park, Northern Area, Pakistan. Caprinae newsletter. IUCN/SSC Caprinae Specialist Group Pp. 5-6.

Worton, B.J. (1989). Kernel methods for estimating the utilization distribution home range studies. *Ecology*, 70, 164-168.

Young, J.K., Andelt, W.F., Terletzky, P.A. & Shivik, J.A. (2006). A comparison of coyote ecology after 25 years: 1978 versus 2003. *Can. J.Zool.* 84, 573-582.