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Ecosystem service dependence in livestock and crop-based production systems in Asia's high mountains

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ABSTRACT

Globally, in semi-arid and arid landscapes, there is an ongoing transition from livestock-production systems to crop-production systems, and in many parts of Asia's arid mountains, mining for minerals is also increasing. These changes are accompanied by a change in the generation and quality of ecosystem services (ES), which can impact human well-being. In this study, to better understand the impacts of such transitions, we quantified ES in two crop-based and three livestock-based production systems in the arid and semi-arid landscapes of the High Himalaya and Central Asia, specifically in the Indian Himalaya, Kyrgyz Tien Shan, and Mongolian Altai. Our results showed 1) high economic dependence (3.6–38 times the respective annual household income) of local farmers on provisioning ES, with the economic value of ES being greater in livestock-production systems (7.4–38 times the annual household income) compared to crop-production systems (3.6–3.7 times the annual household income); 2) ES input into cashmere production, the main commodity from the livestock-production systems, was 13–18 times greater than the price of cashmere received by the farmer; and 3) in the livestock production systems affected by mining, impacts on ES and quality of life were reported to be negative by majority of the respondents. We conclude that livestock-based systems may be relatively more vulnerable to degrading impacts of mining and other ongoing developments due to their dependence on larger ES resource catchments that tend to have weaker land tenure and are prone to fragmentation. In contrast to the general assumption of low value of ES in arid and semi-arid landscapes due to relatively low primary productivity, our study underscores the remarkably high importance of ES in supporting local livelihoods.

1. Introduction

Natural ecosystems across the world are getting modified either due to human use and resource extraction, or through changes in land-use practices (Foley et al., 2005). Changes in land-use can impact the generation and quality of ecosystem services (ES) and human-well-being (Metzger et al., 2006). Often, studies focus on changes in ES related to major land-use changes, such as appropriation of natural ecosystems for agriculture or for urban areas (for eg. Hamann et al., 2015). However, more subtle changes in land-use can also impact ES, but have received less attention.

An important ongoing change in land-use taking place globally, especially in semi-arid and arid landscapes, is the transition from livestock-dominated production systems to crop-dominated ones (Galvin, 2009). Traditionally, livestock-production was the primary mode of subsistence in these landscapes, adapted to accommodate climatic uncertainties and spatio-temporal variation in the availability of essential ES such as forage and water (Dong et al., 2011). Two predominant narratives have commonly driven policies underlying this change from livestock to crop based systems around the world: 1) the tragedy of the commons, implying that livestock-production systems in communal lands were responsible for overgrazing and overstocking pastures (Saberwal, 1996; Agrawal and Saberwal, 2004), and 2) the narrative that viewed the migratory livestock production lifestyle as being

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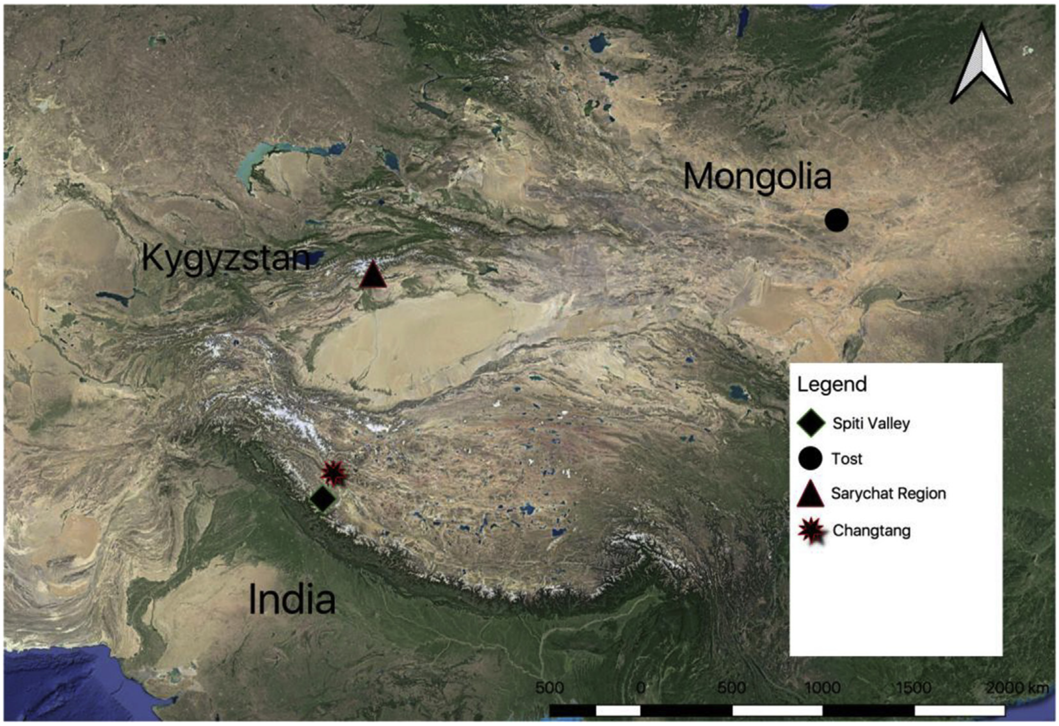

Fig. 1. Map of the study sites in India (Spiti valley and Changtang), Kyrgyzstan (Sarychat region), and Mongolia (Tost).

primitive, with sedentarization being the attempt to 'modernize' it (Saberwal, 1996; Webber, 2008). Some governments encouraged this shift as it permitted delivery of services, facilitated better control and taxation, while eliminating cross-border migrations (Scott, 1998). For example, in the Changthang plateau in India, availabe pasturelands decreased due to the sealing of international border following a war in 1962, and the remaining land had to be shared with incoming Tibetan refugees who were also dependant on livestock-production, thus reducing per capita availability of pastures (Namgail et al., 2007), encouraging a shift from a livestock-production system to a crop-dominated production system.

Such shifts in land-use are presumably accompanied by a change in the ES used and produced by the different production systems. However, these changes in ES use have received little attention in semi-arid and arid landscapes due to their low productivity and the perception that they are poor suppliers of ES (Castro et al., 2018). While there have been studies on the social and ecological impacts of such land use transition (for eg. Upton, 2012), there is limited understanding of the accompanying change in ES dependence. A study conducted in the water-stressed inner Mongolia region in China, for example, reported that ES utilization patterns changed from a complete dependence on ES from pasturelands, such as forage for livestock and medicinal plants, to a complete dependence on ES for crop production such as water, and soil fertility (Fan et al., 2014). This change resulted in water shortage due to high consumption in the croplands (Fan et al., 2014).

Livestock-production relies on ES such as forage and water for livestock, and results in products such as milk, meat, wool, leather and manure (Sala et al., 2017). As a natural resource management system, livestock-production can potentially support ES such as wildlife conservation, tourism, and raw materials like medicinal plants (MA, 2005). Crop-production, on the other hand, makes use of services such as soil fertility, pollination services, and pest and disease control services, while producing food for humans and livestock (Deng et al., 2016). Some crop-production systems may also have tourism value and some can support a relatively restricted assemblage of wildlife and biodiversity, especially if they are managed for conservation as in the case of biodiversity-friendly coffee or cocao (Bose et al., 2016).

Livestock-production has been practised in the semi-arid and arid mountains of Central Asia and the high Himalaya for several millennia, with the first evidence of livestock-rearing in Central Asia dating back to the 6000 years before present (Spengler et al., 2014). The earliest records of livestock-production on the Tibetan plateau are from 8200 years before present (Brantingham et al., 2007). Traditionally, the livestock reared here were sheep, goat, cows, horses, yaks, and donkeys. While livestock-production was the primary livelihood strategy, some supplementary crop-production was also practiced at relatively lower altitudes. From archeological data it is suspected that cereal grains were grown in Central Asia around 4000 years before present (Spengler et al., 2014) and crop-produciton on the Tibetan Plateau dates back to 5500 years before present (Guedes et al., 2014). However, since the 1980's and 1990's, livestock-production systems started shifting to settled crop-production systems across the region (Namgail et al., 2007). In addition to these changes, the pastures of the existing livestock-dominated systems are under pressure from mining (Upton, 2012).

We aimed to understand the differences in ES used under crop-production and livestock production systems in the semi-arid and arid landscapes of Asian mountains. We economically valuated of the provisioning ES used by people in four sites – Spiti Valley (crop-production system) and Changtang (both livestock-production and crop-production systems) regions of the Indian Trans-Himalayas, Tost Mountains (livestock-production) in Mongolia's Altai range, and the Sarychat (livestock-production) landscape in the Tien Shan Mountains of the Kyrgyz Republic. In two of our study sites (Sarychat and Tost) where mining was prevalent, we also documented its impact on the main ES as perceived by the local people. In Changtang and Tost, cashmere was a primary source of livelihood for the livestock dependent communities. This underwool of goats has a global demand and its production has a significant influence on local livelihoods as well as biodiversity across Central Asia (Berger et al., 2013). We therefore examined the value of ES used in the production of cashmere, and compared it to its market price, to assess the importance of ES in the production of this global commodity. Our results show the high dependence of local communities on ES, which are especially undervalued in arid and semi-arid ecosystems.

2. Methods

2.1. Study site

Spiti Valley: Spiti Valley (31°35′ to 33°0′ N and 77°37′ to 78°35' E, area = 7589 km^2), hereafter referred to as Spiti, is a cold desert mountainous region with altitude ranging from 3350 m to 6700 m in the Indian Trans-Himalayas Fig. 1. Temperatures range from −40 °C in peak winter to over 30 °C in peak summer. Precipitation occurs mainly in the form of snow in winter, which starts to melt in late March. The landscape is rocky, with steep slopes largely dominated by grasses and shrubs. There are around 14,000 inhabitants in Spiti. Crop-production is the primary livelihood generating activity for majority of the population. The main cash crop across the Valley is green pea (*Pisum sativum*). Apple (*Malus pumila*) is also a cash crop grown at relatively lower altitudes (c. 3300 m) of the valley. Barley (*Hordeum vulgare*), wheat (*Tricitum sp.*) and black pea (a local variety of non-commercial pea) are grown as well.

The livestock reared are sheep (*Ovis aries*), goat (*Capra hircus*), donkey (*Equus asinus*), yak (*Bos grunniens*), cattle (*Bos indicus*), dzomo (yak-cattle hybrid), and horses (*Equus caballus*). Livestock are occasionally used for meat and other products such as milk, butter, manure and wool, with the exception of horses and donkeys that are not consumed. Every community has access to grazing pastures around the settlement. Local people have traditional grazing and collection rights in the pastures but cultivation is not permitted.

Changtang region, Ladakh, India (32°69′ to 34°16′ N and 77°63′ to 79°09' E, area = 9500 km^2): The geographical and climatic features of this region are similar to Spiti, although the eastern part of Changtang is a high-altitude rolling plateau Fig. 1. Changtang is contiguous with Spiti to the south-east. Two kinds of communities live in the Changtang, those that primarily depend on crop-production and those that depend on livestock-production, whose combined population is about 31,000 people (Leh district, Government of India, 2015). Crop-producing communities have permanent settlements with crop land and some livestock. Main income for livestock-production communities comes from the sale of cashmere. They move their settlements four to twelve times a year, based on the availability of forage for livestock.

Land for crop-production is owned by families while pasturelands are owned by the government but managed by the local communities based on historical and traditional land tenure rights. The livestock reared are similar to those in Spiti Valley. The crops grown include green pea, black pea, barley, wheat, mustard (*Brassica sp.*), and vegetables like turnip (*Brassica rapa subsp.*). Henceforth, Changtang's crop-producing communities are referred to as Changtang (cp) and the livestock producing communities as Changtang (lp).

Tost Mountains, Mongolia (43°N, 100°E; area = 1700 km^2)**:** The Tost Mountains, hereafter referred to as Tost, are located in the South Gobi Province Fig. 1. Tost is an extension of the Altai Mountains and a westward extension of the desert valleys. Temperature in winter can go as low as −20 °C and in summer it can go up to 38 °C. Altitude varies from 1000 m to 2500 m. Precipitation is between 100 and 250 mm, most of which is received in the form of snow. The vegetation types include desert steppe and semi-desert grasslands. Various sources place the number of herding households living in the study area between 68 and 90, although according to our estimates, 68 households is more likely. They move seasonally and live in gers, which are portable tents made of sheep wool, canvas, and wooden structures for support. Nomadic herders lease land from the government. The livestock reared are goats, sheep, camels (*Camelus bactrianus*) and horses, with their main income derived from the sale of cashmere. Crop-production is largely absent. The South Gobi Province is impacted by mining, primarily for coal, gold and copper (Jackson, 2015). As of 2009, 12% (560) of the total mining licenses (4521) issued in the Gobi were issued in the South Gobi province and out of these 560 licenses, 16% of the total licenses were issued in Gurvantes Soum, where the Tost Mountains are located (Snow Leopard Conservation Fund; Snow Leopard Trust and Panthera, 2009).

Sarychat region, Kyrgyz Republic (41°65′ to 42°36′ N and 77°93′ to 79°73' E, area = 9197 km^2)**:** The study area, hereby referred to as Sarychat, is located in the Tien Shan mountains, within the Issyk Kul region of the Kyrgyz Republic Fig. 1. Altitude ranges from 2000 m to over 7000 m above msl. Vegetation consists of arid grasslands, wet meadows, and tundra cushion plants interspersed with barren rock at higher altitudes (Jumabay-Uulu et al., 2014). Average annual precipitation is approximately 295 mm, with almost half of it falling between June to August. Mean temperatures range from 15 °C in summer to −17 °C in winter. There were two communities within our study area dependent on livestock production, Ak-shiyrak and Enylchek, which had 40 and 25 households, respectively (Jumabay-Uulu et al., 2014). Livestock included sheep, goats, horses, cows and yaks.

Kyrgyzstan is rich in mineral resources with deposits of molybdenum, iron ore, aluminum, tin, mercury, rare earth metals, and gold (Honkonen, 2013). Kyrgyzstan's biggest gold mine, the Kumtor Gold mine, is located in the Sarychat region (Honkonen, 2013).

2.2. Data collection

We used structured interviews and group discussions to identify ES used by local people across the four study sites. We focused on the provisioning ES used by local people. We first had discussions with different stakeholders to understand the use of ES. Following this we developed a questionnaire that was administered to households in each study area. Our questionnaire to evaluate the household value of provisioning services was based on the International Forestry Resources and Institutions (IFRI) field manual (Wertime et al., 2007). ES were defined as the benefits people received from nature. We asked questions about the amount of agricultural produce sold, crops harvested for subsistence, livestock owned (age-sex classification), water used, and collection of forage, firewood, wild plants and dung from the pastures. Interviews have been shown to provide reliable information on harvesting patterns (Jones et al., 2008). In Sarychat and Tost, where mining activities are currently underway, we added questions related to the perceived impacts of mining on ES (questionnaire provided in the supplementary material).

In Spiti, we interviewed members from 30% of the households (HH)

Table 1
Total number of households (HH) interviewed in each study site, the country of the study site, and the production system type are given below. The percentage of households interviewed in each study area is also provided.

Country	Study site	Production system type	% of HH interviewed	No. of HH interviewed
India	Spiti Valley	Crop-production	30%	156
India	Changtang	Crop-production	30%	140
India	Changtang	Livestock-production	80%	39
Mongolia	Tost	Livestock-production	74%	50
Kyrgyzstan	Sarychat region	Livestock-production	50%	40
Total				**425**

in 19 communities/villages based on their willingness to be interviewed. In total, 156 interviews were conducted (Table 1). This included 30 focal group and 126 individual interviews. Communities sampled were distributed throughout the valley, and were chosen based on prior knowledge to ensure fair representation of the coverage of crops grown, livestock reared, and the type and quantity of natural resource collection from the pastures. This included medicinal plants, forage, and wild plants (largely used as food or dye). The data from Spiti were published in Murali et al. (2017). In this paper, for consistency of methods amongst all landscapes, we recalculated the ES related to forage by multiplying the annual forage consumption per species of livestock with the value of forage in the particular landscape.

In Changtang, in the two nomadic livestock-production communities, respondents from 80% of the HH were interviewed. There were 50 crop-production communities, and respondents from 30% of the HH in 12 of them were interviewed. A total of 179 interviews were conducted (Table 1).

In Tost, the herder households depended exclusively on livestock for livelihood, though some income was also derived from the extensive mines surrounding the region. We interviewed people from 50 of the estimated 68 households (Table 1). We also collected information on their perceptions of the impact of mining by asking them if mining had an impact on their lives, and the kind of impact it had.

In the Sarychat region, we interviewed people from 50% of the households in the two livestock-based communities, who were randomly selected, and amounted to 40 interviews. Across all the four study areas, we conducted a total of 425 interviews (Table 1).

2.3. Analyses

2.3.1. Economic value of ES

The ES were classified according to the typology provided by the Common International Classification of ES (CICES) (Haines-Young and Potschin, 2010). In this study, we used economic valuation to assess and compare ES value, as it provides a comparable unit of measurement across ES types (Table 2). Due to country specific values and the GDP variation, we could not compare absolute ES values amongst the countries. Instead we compared the ES value against the household income in each country, which was then compared across countries. The economic value of provisioning services was calculated using the Total Economic Valuation Framework (TEV), proposed by The Economics of Ecosystems and Biodiversity (Kumar and Martinez Alier, 2011). The TEV framework is a well-established instrument used in economic assessments of ES as it expresses value in monetary or other market-based units that allow cross comparison (Pomfret, 2014). Under this framework, provisioning services are assessed using direct use values. We used the market-price-based and replacement cost methods to assess the value of provisioning services. Market-price-based methods are commonly used to assess the value of provisioning services, as they are often sold and the market price reflects their monetary value (Pomfret, 2014).

Crop production: ES that contributed to crop production were evaluated by estimating the quantity of all the crops harvested per year and multiplying them with the market value. The value of external inputs such as chemical fertilizers and pesticides, labor hired, and the price of seeds was subtracted from the value of the crops produced to get the ES value of agriculture.

$$\text{Crop production (cp)} = \Sigma(Cp_1 + Cp_2. + Cp_n) - \text{external inputs}$$

Reared animals and their outputs: The value of livestock outputs per year such as milk, meat, and wool was estimated. External inputs such as vaccinations and the cost of herding were subtracted from this value. The value of the animals themselves was not used as the forage used by the animals was evaluated and considering the economic value of animals would have led to double counting.

$$\text{Reared animals and their outputs} = \Sigma(\text{Livestock outputs}) - \text{external inputs}$$

Forage consumed by livestock: We estimated the annual forage consumed by livestock using standard equations of forage consumption and body size for foregut and hindgut fermenters (Cordova et al., 1978). The total estimated forage consumption was multiplied by the local price of forage in each study area. If local prices for forage were unavailable, we used the regional price.

$$\text{Forage} = \Sigma\ (\text{forage by } ls_1 + \text{forage } ls_2 + \text{forage } ls_3\ /\text{year}) \text{ x price of forage}$$

Where ls = livestock and the numbers in the subscript represent different livestock species.

Water for livestock: In Tost, herders were able to report the amount of water collected for their livestock, which was then multiplied by the local price of water. In the other study sites, the economic value of water consumed by livestock was calculated by multiplying the species-wise annual water consumption (Ward, 2015), with the local price of water. If local prices were unavailable, we used the prices from the closest town.

$$\text{Water} = \Sigma \text{ water consumed by } (ls_1 + ls_2 + ls_n)/\text{year x price of water}$$

Water for household purposes: We asked interviewees to report their daily household water consumption. Most interviewees were able to accurately report this, as water was stored in fixed containers of known volume. This was then multiplied with the local or regional price of water. In the cases where people did not know how much water they used, we used the per capita consumption of water for arid regions (Rodriguez et al., 2016) multiplied by the number of people in the household and the local price of water.

$$\text{HH Water consumption} = \Sigma \text{ water consumed by HHyr}^{-1} \text{ x price of water}$$

Wild plants collected: We estimated the annual household consumption of different wild plants in each study site and multiplied it with the local market price, if they had one, or with the price of the closest substitute. The purpose of the wild plants collected was recorded to identify the market substitute. For example, wild onion collected

Table 2
Methods used and units of measurement for estimating the economic value of provisioning ES used by the local communities in the mountainous landscapes of India, Mongolia and Kyrgyzstan. We used the Total Economic Valuation Framework (Kumar and Martinez Alier, 2011).

ES	Economic valuation method (Kumar and Yashiro, 2014)	Unit price
Cultivated crops	Market price based approach	Kg HH^{-1} yr^{-1}
Reared animals and their outputs	Market price based approach	Number of livestock/HH
Wild plants, algae and their outputs	Replacement cost method	Kg HH^{-1} yr^{-1}
Water for household purposes	Replacement cost method	Litres HH^{-1} yr^{-1}
Fibres and other materials from plants, algae and animals for direct use or processing	Market price based approach and replacement cost method	Kg HH^{-1} yr^{-1}
Materials from plants, algae and animals for agricultural use	Replacement cost method	Kg HH^{-1} yr^{-1}
Plant and animal based resources	Replacement cost method	Kg HH^{-1} yr^{-1}

from the pastures did not have a market value, but in the place of wild onion households would buy cultivated onion. We used the prices of onion to estimate the price of wild onion. Similarly, one plant was collected to be used as a red dye. The value of this was calculated by using the price of the red dye available in the market.

$$\text{HH wildplant consumption} = \Sigma\,(wp_1 \text{ x price of } wp_1)\ \text{HHyr}^{-1} + (wp_2 \text{ x price of } wp_2)\ \text{HHyr}^{-1} + (wp_n \text{ x price of } wp_n)\text{HHyr}^{-1}$$

Where wp = wildplants and numbers in the subscript represent different wildplant species.

Animal based resources: We estimated the annual household usage of animal dung and multiplied it by the local price of dung.

$$\text{Animal dung} = \text{animal dung HHyr}^{-1} \text{ x price of animal dung}$$

Fuel wood: Annual household consumption of fuel wood was estimated through interviews. The economic value of fuel wood was then calculated by multiplying it with the local price of fuel wood.

$$\text{Fuel wood} = \text{fuel wood HHyr}^{-1} \text{ x price of fuel wood}$$

Total economic value: The total economic value was estimated by adding the economic value of all individual provisioning services.

We derived values for household income by asking the respondents for all their different income sources (employment, agriculture, livestock products sold) and adding them to estimate the average income in each study site.

The Shannon diversity index was used to explore the diversity in ecosystem service use in each study site. The Shannon diversity index was calculated using the economic value of the ES in each site. All analysis and graphics were generated using the open source statistical software R (R Core Team, 2013).

Cashmere was the primary market commodity produced by the livestock-production systems in Tost and Changtang. We assessed the ES input into the production of 1 kg of cashmere and compared it with its market value. ES input was calculated as the annual consumption of water and forage per goat multiplied by the average number of goats needed to produce 1 kg of cashmere (on average 6 goats produce 1 kg of cashmere (Misra et al., 2018)).

$$\text{ES input} = (\Sigma\,(\text{water consumed by LS/yr} + \text{forage consumed by LS/yr})_n) / 6$$

3. Results

3.1. Identification of provisioning ES used by the communities

The most used ES in the crop-production systems was water, which was used by 100% of the respondents in both Spiti and Changtang (cp). The other highly used ES in this system were crop production, used by 82% of the respondents in Spiti and Changtang (cp); reared animals and their outputs used by 86% of the respondents in Spiti and 87.8% of the respondents in Changtang (cp); fibers from animals and plants for direct use or processing used by 100% of the respondents in Spiti and 43.7% of the respondents in Changtang (cp); and materials from plants and animals for agricultural use used by 80% of the respondents in Spiti and 100% of the respondents in the Changtang Table 3.

The most used ES in the livestock-production system were water, reared animals and their outputs, and materials from plants and animals for agricultural use, which were used by 100% of the respondents in Changtang (lp), Tost, and Sarychat. Animal-based resources were used by 100% of the respondents in Tost and Changtang (lp), and 86% of the respondents in Sarychat. Wild plants and their outputs were used by 100% of the respondents in Changtang (lp), 76% in Tost, and 70.5% in Sarychat.

Water was the only ES used by all respondents in both production systems (Table 3). All respondents practiced livestock rearing in the livestock-production system in Changtang, Tost, and Sarychat while none of the respondents practiced crop-production. In both the crop-production systems, more than 85% of the respondents also kept livestock. More than 70% of the respondents from the livestock-production system used wild plants and their outputs as compared to the crop-production system where up to 41% of the respondents used wild plants and their outputs. Table 3lists all the provisioning services used in the two production systems in the four landscapes with the percentage of respondents using these services.

3.2. Economic value of ES used

The estimated average value (± SE) of ES used by households was lower in the crop-production systems as compared to the livestock-production systems. In Spiti (crop-production) it was 3964 ± 335 USD/HH/yr and 15083 ± 1656 USD/HH/yr in the Changtang crop-production system. In the livestock-production systems the average value of ES was higher, with economic value of household ES use being the highest in Tost at 150100 ± 13290 USD/HH/yr, followed by the Changtang (lp) at 79303 ± 9204 USD/HH/yr, and 25544 ± 5236 USD/HH/yr for the Sarychat (Table 4). Forage for livestock was the service with the highest economic value in all five-study areas (Table 4). In the crop-production system of Spiti, it contributed relatively the lowest to the total value of ES (57%) while in the other study areas, it contributed to more than 90% of the total ES economic value (Table 4). ES related to crop-production was the highest for Spiti, contributing 28% of the total ES economic value.

Forage for livestock, crop-production, and outputs of reared animals were the economically highest valued ES in the crop-production systems. In the livestock-production systems the highest economically valued services were forage for livestock, reared animals and their outputs and plant and animal based resources. Water and Medicinal plants were the least economically valued services in both production systems.

While there were minimal differences in the kinds of ES valued between the two production systems, there were differences in the total value of ES, with the value being lower in the crop-production systems as compared to the livestock-production systems. The total ES was 3.6 times the annual household income in Spiti (HH income = 1092 USD/HH/yr), and 3.7 times the annual household income in Changtang (cp) (HH income = 4087 USD/HH/yr) as compared to 26.1 times the annual household income in Changtang (lp) (HH income = 3042 USD/HH/yr), 38.7 times the annual household income in Tost (HH income = 3881 USD/HH/yr), and 7.4 times the annual household income in Sarychat (HH income = 3450 USD/HH/yr) (Fig. 2).

3.3. Ecosystem service diversity

There was a greater diversity of ES used by the crop-production systems as compared to the livestock-production systems. The diversity of ES used by the crop-production system in Spiti was highest (1.31), followed by Changtang (cp) (0.45). The diversity of ES used by the livestock-production systems was lower with the system in Tost having the least diversity (0.16). The diversity index for Changtang (lp) (0.25) and Sarychat (0.24) were higher than Tost but lower than both the crop-production systems.

3.4. ES contribution to cashmere production

The economic value of ES input into producing cashmere in Tost was estimated at 704 USD/kg and it was 495 USD/kg in Changtang (lp). Farmers in the two livestock-production systems sold cashmere at an average of 39 USD/kg in Tost, and 36 USD/kg in Changtang (lp).

Table 3
List of provisioning services used by local people in each of the five study systems in four mountainous landscapes of Asia – the Trans-Himalayas (Spiti and Changtang), the Altai (Tost), and the Tien Shan (Sarychat). The first row header identifies the study area. Under each study area, the first column lists the provisioning services used, classified according to the Common International Classification of Ecosystem Services (Haines-Young and Potschin, 2010). The second column shows the percentage of respondents that used the respective ES.

Study area	Spiti Valley (Cp)		Changtang (Cp)		Changtang (Lp)		Tost (Lp)		Sarychat (Lp)	
ES	ES named	% use	ES named	% use	ES named	% use	ES named	% use	ES named	% use
Cultivated crops	Crops include green pea, barley, apple, black pea, wheat.	82	Crops include barley, green pea, black pea, mustardturnips, wheat, potatoescauliflo-wer, alpha-alpha (for livestock).	90	No crops cultivated	0	No crops cultiva-ted	0	No crops cultivated	0
Reared animals and their outputs	Livestock include sheep and goat for wool, meat from all livestock except donkeys and horses, yak hair used to make ropes, cow and dzomo for milk, butter and cheese.	86	Livestock reared are sheep, goats, donkey, yak, cow, dzomo (a yak-cow hybrid), and horses. Goats reared for commercially valuable cashmere, sheep for wool, cow and dzomo for milk, yaks for wool and animal-based energy. All livestock except donkeys and horses for meat.	87.8	Livestock reared are sheep, goats, donkey, yak, cow, dzomo (a yak-cow hybrid), and horses. Goats reared for commercially valuable cashmere, sheep for wool, cow and dzomo for milk, yaks for wool and animal-based energy. All livestock except donkeys and horses for meat.	100	Livestock reared are goat, sheep, camel, cow, and horse. Goats are reared for commercially valuable cashmere, sheep for wool. The milk and meat of all animals are consumed.	100	Livestock reared are sheep, goat, cow, horse,yak. Reared for wool, milk, and meat.	100
Wild plants, algae and their outputs	Wild onion, mushroom, rhubarb, and green leafy plants to eat.	26	Wild onion, mushroom, rhubarb, stinging nettle, local green leafy vegetables.	41.3	Wild onion, mushroom, rhubarb, stinging nettle, local green leafy vegetables.	100	Wild onion.	76	Blackberry, mushroom, wild onion, and rhubarb.	70.5
Wild animals and their outputs	Not used.	0	Not used.	0	Not used	0	Wolves for skin and organs used in traditional medicince, ibex and argali horn to rid corrals of parasites and protect the corral, Lagomorph pellets for use in traditional medicine.	30	Wolves for organs in traditional medicine and selling their skin. Hunting concessions. Use of Golden eagles in Tourism.	9
Surface water	Water for household and agricultural purposes. Snow melt. Water for downstream users.	100	Water for household and agricultural purposes. Water for downstream users.	100	Water for household and agricultural purposes. Water for downstream users.	100	Surface water ocassionally used for livestock and household purposes.	100	Water for household purposes, for livestock, and for downstream users as well.	100
Ground water	Not used.	0	Not used.	0	Not used	0	Mostly dependant on ground water which is accessed by wells.	100	Ground water recharge for downstream users.	0
Fibres and other materials from plants, algae and animals for direct use or processing	Medicinal plants, plants for dyes, plants for roofing.	100	Medicinal plants, plants for dyes, plants for roofing	43.7	Medicinal plants, plants for dyes, plants for roofing	0.04	Medicinal plants.	60	Medicinal plants.	45.5
Materials from plants, algae and animals for agricultural use	Animal dung as fertilizer, wild plants as fertilizer, forage for livestock.	80	Animal dung as fertilizer, wild plants as fertilizer, forage for livestock.	100	Forage for livestock	100	Forage for livestock.	100	Forage for livestock.	100
Plant-based resources	Wood for heating.	70	Wood for heating.	70.4	Wood for heating	100	Wood for heating.	100	Wood for heating.	25
Animal-based resources	Animal dung for heating.	70	Animal dung for heating.	67.7	animal dung for heating	100	Animal dung for heating.	100	Animal dung for heating.	86.4
Animal-based energy	Yak to plough the land, donkey to transport materials.	39	Horses used for herding, ploughing, and transport, yak for ploughing the land, donkey to transport material	42.5	Horses used for herding, ploughing, and transport, yak for ploughing the land, donkey to transport material	100	Horses used for herding and transport.	42	Horses used for herding and transport.	63.6

Table 4
Economic value of ES in the five study systems. The first column lists the ES, while the second column shows their respective value in USD/HH/yr. The third column indicates the percentage contribution of individual ES value to the total ES value. Total ES value is mentioned first, followed by the value of individual services.

Site	Spiti (Lp)		Changtang (Cp)		Changtang (Lp)		Tost (Lp)		Sarychat (LP)	
	ES value (USD/HH/yr)	Contribution to total ES (%)	ES value (USD/HH/yr)	Contribution to total ES (%)	ES value (USD/HH/yr)	Contribution to total ES (%)	ES value (USD/HH/yr)	Contribution to total ES (%)	ES value (USD/HH/yr)	Contribution to total ES (%)
Total ES	3964 ± 334.8		15083 ± 1656		79303 ± 9204		150100 ± 13290		25544 ± 5236	
Cultivated crops	1092 ± 42	27.5	282 ± 43	1.9	0		0		0	
Outputs of reared animals	523 ± 46.2	13.2	929 ± 67	6.2	3042 ± 437	3.8	3881 ± 360	2.6	1182 ± 177	4.6
Wild plants and their outputs	8 ± 1	0.2	80.9 ± 12.8	0.5	233 ± 35.9	0.3	20 ± 9.1	0.01	35 ± 6	0.1
Medicinal plants	3.4 ± 0.3	0.1	0	0	0	0	6 ± 2	0	2.1 ± 0.6	0
Water for HH use	9 ± 0.7	0.2	3.5 ± 0.1	0.02	3.4 ± 0.2	0	9 ± 0.7	0	12.3 ± 0.9	0.05
water for agriculture/livestock use	26 ± 3.6	0.7	38 ± 3	0.3	99.2 ± 12.1	0.1	524 ± 59	0.3	71 ± 11	0.3
Plants for roofing/livestock fibre for housing	142 ± 16	3.4	2.5 ± 0.6	0.02	0	0	13 ± 7.2	0	0	0
Fodder for livestock	1960 ± 208	49.4	13550 ± 1606	89.8	75025 ± 8848	94.6	145381 ± 13027	96.9	24073 ± 5115	94.5
Plant and animal based resources	201 ± 17	5.1	197 ± 23	1.3	900 ± 151	1.1	206 ± 16	0.1	169 ± 25	0.7

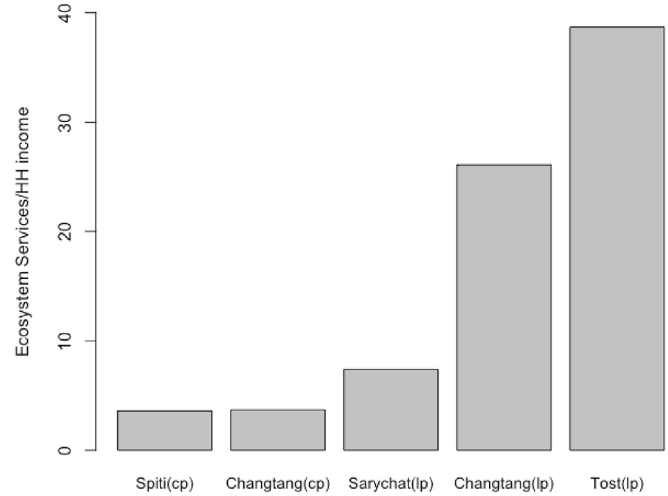

Fig. 2. Total ecosystem service value in comparison to household income. The ratio of ES to household income (ES/household income) is shown on the y-axis. The study sites and their production systems are shown on the x-axis. Changtang (cp) refers to the crop-production system and Changtang (lp) to the livestock-production system in the Changtang, respectively.

3.5. Impacts of mining

In Tost, 6% of the HH interviewed were employed by mining industry and in Sarychat, among our respondents, there were no people employed by the mining industry. In Tost, 95.8% of the respondents felt that mining had negative impacts on ES, while 4.2% felt that it had no impact on ES. In Sarychat, 75.6% of the respondents felt that mining had negative impacts on ES, 19.8% felt that it had no impact, and 4.7% felt it had a positive impact. Mining was perceived to negatively impact pasturelands, water, air, livestock, and human health and positively impact income (Table 5). Perceived negative impacts on pasturelands included pollution of grazing lands, reduction of grazing pastures, fragmentation of grasslands due to road networks, and soil collapse in exploratory mining areas.

Table 5
The ES that are perceived to be impacted by mining, the kind of impact, and the nature in which the respondents expected to be impacted, in Tost and Sarychat.

ES	Percieved impact	Nature of impact
Pasture lands	negative	Pollution of grazing land Reduction of grazing pastures Fragmentation of grasslands due to road networks Soil collapse in exploratory mining areas
Water	negative	Reduction in ground water level, drying up of surface water, pollution of ground and surface water, reduction in precipitation Drying up of surface water Pollution of ground and surface water Reduction in precipitation Pollution of precipitation
Air	negative	Pollution of air with dust
Livestock	negative	Respiratory ailments Pollution of meat (stomach lining turns black, this makes it difficult to sell the meat)
Health	negative	Respiratory ailments
Income	positive	Increase in household income

4. Discussion

4.1. ES use in crop-production and livestock-production systems

We found that the primary difference between the two production systems was not as much in the types of ES used, but rather the extent of use in terms of the proportion of people using ES and the quantity of ES used. In the livestock-production systems, there were a higher proportion of ES users as compared to the crop-production systems. For example, in the livestock-production systems, all the respondents used the ES belonging to CICES classes (Haines-Young and Potschin, 2010) wild plants, materials from plants and animals for agricultural use, reared animals and their outputs, animal-based energy, and plant and animal-based resources. On the other hand, in the crop-production systems, water was the only ES used by all respondents in both sites, and materials from plants and animals for agriculture were used by all respondents in one of the sites. Sedentary crop-production systems are likely to have better access to markets, better infrastructure development, better employment opportunities, and more government support, that reduces their use of the local ES as compared to livestock-production systems, especially nomadic systems (Dong et al., 2011). Both in Spiti and Changtang (cp), there were permanent village settlements with good connectivity that offered better access to markets as compared to the livestock-production systems, which were nomadic. Further, the government offered facilities and subsidies such as infrastructure, hospitals, firewood (as in the case of Spiti) etc, that reduced dependence on local ES.

There were also greater variations in user dependence within the livestock-production systems as compared to the crop-production systems. In Changtang (lp) there was a greater proportion of people using several ES (all respondents used 7 ES), closely followed by Tost (all respondents used 5 ES), and finally Sarychat (all respondents used 3 ES). The two communities in Sarychat were semi-nomadic, with permanent village settlements where most of the inhabitants stayed, while the herders moved seasonally with the livestock, as compared to the other two sites, where people were completely nomadic. The presence of a permanent village makes it easier for the government to supply services (Ikeya, 2017) that reduces local ES dependence. For example, electricity was used for heating in Sarychat in contrast to the other two livestock-production systems, where animal dung or wood was used for heating. In addition, Sarychat had easier access to external markets as their closest town was 3 h by car, as compared to Changtang (lp) where the closest town was about an 8-h drive.

It is likely that Changtang (lp) had the highest proportion of users of ES, as most people were nomadic, and had limited external support, making them more reliant on ES (Goodall, 2004). Incidentally, our two sampled villages represent the last two remaining nomadic villages in all of Ladakh (Ahmed, 1997).

In Tost, although nomadic, the government infrastructure has been built around offering support to nomadic pastoralists as is the case in large parts of Mongolia (Dierkes, 2012). Therefore, it is likely that certain ES were substituted or replaced, such as wild plants, which can be substituted by vegetables and medicine bought at the *soum*, which is the permanent administrative center for each province. Contrastingly, in the crop-production system, there were fewer variations in local ES users. It is likely that employment opportunities, access to markets, and external government support were similar in both these systems. In addition to the socio-economic factors driving these patterns in differences in local ES use, it is also likely the local system conditions, i. e the supply of ES can affect use (Burkhard et al., 2012).

4.2. Economic value of ES

The total economic value of the ES used differed between the livestock-production and crop-production systems. Our results also showed that ES used in crop-production systems were more diverse than the livestock production systems. However, as most of the ES were used by both systems, the diversity patterns were driven by evenness, with the higher diversity sites being more even than the lower diversity sites. This difference was largely due to forage for livestock. Forage for livestock was the highest valued service in all five sites, contributing to more than 90% of the total ES in every study site except Spiti where it contributed to 45% of the total ES value. In the livestock production systems, the mean livestock holding per household (Tost (mean $\pm$ SE) = 369 $\pm$ 33, Changtang lp = 303 $\pm$ 36, Sarychat = 94 $\pm$ 14)) was higher than the crop-production systems (Spiti valley = 4.5 $\pm$ 0.5, Changtang cp = 45 $\pm$ 6), which accounted for the much higher values in ES in the livestock-production systems.

4.3. ES input into cashmere production

The economic value of ES input into the production of cashmere, the primary market commodity from the livestock-production systems in large parts of Asia (Berger et al., 2013), was a staggering 18 times the price of cashemere that the local farmers obtained in Tost, and 13 times the price in Changtang (lp).

The extremely high dependance on forage in the livestock-systems indicates that they could be more vulnerable to changes in the landscape such as ecosystem degradation, fragmentation, and climate change as compared to the crop-production systems. Vulnerability of livestock-production systems to fragmentation in arid and semi-arid landscapes have been well-documented (Hobbs et al., 2008; Galvin, 2009). Fragmentation can lead to a loss of access to forage and water, that could lead to possible over-use of natural resources (Hobbs et al., 2008). Crop-production systems, concentrated in space, are less likley to be impacted by changes in the pastures as many of the ES that crop-production depend on are derived 'in-situ'. Although they do depend on the ecosystem for ES such as water, pest control and disease control, they do not require access to large unfragmented areas.

4.4. Mining in livestock-production systems

One of the biggest causes of landscape change in the livestock-production systems is mining, which especially impacts Tost and Sarychat (Pomfret, 2014). In our study areas affected by mining, respondents perceived mining impacts to be negative and affecting crucial ES such as pasture availability, water, and air. Income was recognized to be the single positive benefit from mining, even though it benefitted only 6% of the respondent HH in Tost, and none of the HH interviewed derived benefits from in Sarychat. Mining compensations offered to affected people are often one-time payments, while the ES benefits tend to last entire lifetimes, and have bequest value as well. In addition to the monetary value of the land, people also have traditional and cultural attachment to it. These multiple, renewable or long-lasting values are rarely accounted for in compensation packages. Accurately accounting for the true value of ES in compensation packages would probably render mining in these landscapes even economically unprofitable.

4.5. Limitations of the study

We used economic value as a proxy for ES use in our study. However, we would like to emphasize that economic value alone is an insufficient indicator of overall value of ES. Economic values of ES are based on local pricing and prices are based on a range of external factors which do not necessarily reflect value. For example, the price of water is most often set by the optimal volumetric pricing rule that requires that the water price be set equal to the marginal cost of water supply (Grafton et al., 2015). Different countries and regions use different versions of this method to charge for water. Irrigation water involves a volumetric water charge to cover operation and maintenance costs, and a per hectare water charge to recover the public investment in off-farm irrigation infrastructure (Dinar and Subramanian, 1997). In India, a volumetric rate per estimated volume of water consumed is used in areas with pumped irrigation and tubewells (Dinar and Subramanian, 1997). However, the price of water is different from the value of water, which is infinite, as water is essential for survival. Non-monetary valuation techniques explore other aspects of why people value ES.

We assessed only provisioning services in this study. However if we were to include regulating and cultural services, the economic value of ES is likely to have been much higher in each of these systems, although the qualitative differences in economic value of ES between the two types of systems might not have changed. Future work in these systems could address regulating and cultural services, explore differences in their use between livestock-production and crop-production systems, and the trade-offs between provisioning and regulating services.

5. Conclusions

Our study shows the high importance of ES for people in both crop and livestock based production systems in arid and semi-arid landscapes. Intensified harvest of provisioning services in either of the production systems can lead to a trade-off with regulatory services such as soil fertility and prevention of soil erosion. This especially applies to livestock-production systems, where the costs of rearing large herds are heavily subsidised by the natural ecosystem, but in turn can also place immense pressure on it. Traditionally, mobility among pastoralists was a livelihood strategy to distribute the pressure across a larger resource area, and prevent over-grazing (Dyson-Hudson and Dyson-Hudson, 1980). However, over the last few years, a number of factors such as the increased demand for cashmere have led to increasing herd sizes, or mining has led to decreased pasture availability, leading to pasture degradation (Upton, 2012). This is also evident on the Tibetan plateau, where rangeland degradation is thought to have increased dust storms, increased soil erosion, reduced C and N storage capacity of the soil, decreased soil fertility, and intensified desertification (Harris, 2010).

Finally, although the livestock-production systems used more ES, it is important to highlight that both crop-production and livestock-production systems in our study were heavily dependent on local ES, with fodder contributing to the highest economic value in both systems. The dependence of rural communities on local ES in arid and semi-arid regions are often underreported and undervalued as these systems are seen as low productivity systems, assumed to have little ES value (Castro et al., 2018). However, globally, the dependence of rural communities on local ES is particularly high in these regions due to a lack of alternative employment opportunities (Castro et al., 2018).

While the comparison of the extent of ES contribution to human well-being across studies is difficult due to variations in the kind of ES measured and methods used, it is generally accepted that provisioning services are crucial to rural livelihoods, contributing to both economic and livelihood security (Fisher et al., 2014). Some scholars have also argued that local provisioning services can provide pathways out of poverty (Kumar and Yashiro, 2014). Therefore, effectively managing them, based on the needs of the production systems, is crucial to both human well-being and ecosystem integrity.

CRediT authorship contribution statement

Ranjini Murali: Conceptualization, Methodology, Data curation, Writing - original draft. **Purevjav Ikhagvajav:** Methodology, Writing - review & editing. **Venera Amankul:** Methodology, Writing - review & editing. **Kubanych Jumabay:** Methodology, Writing - review & editing. **Koustubh Sharma:** Methodology, Writing - review & editing. **Yash Veer Bhatnagar:** Methodology, Writing - review & editing. **Kulbushansingh Suryawanshi:** Methodology, Writing - review & editing. **Charudutt Mishra:** Conceptualization, Methodology, Data curation, Writing - review & editing.

Declaration of competing interest

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

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Appendix A. Supplementary data

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References

Agrawal, A., Saberwal, V.K., 2004. Whither South asian pastoralism? An introduction. Nomadic Peoples 8 (2), 36–53.
Ahmed, M., 1997. The salt trade: rupshu's annual trek to Tsokar. In: Ladakh: History, Culture and Development between Himalaya and Karakoram. Recent Research on Ladakh 8. Proceedings of the Eight Colloquium on the International Association for Ladakh Studies. Aarhus University Press, Aarhus, pp. 32–48.
Berger, J., Buuveibaatar, B., Mishra, C., 2013. Globalization of the cashmere market and the decline of large mammals in Central Asia. Conserv. Biol. 27 (4), 679–689.
Bose, A., Vira, B., Garcia, C., 2016. Does environmental certification in coffee promote "business as usual"? A case study from the Western Ghats, India. Ambio 45 (8), 946–955.
Brantingham, P., Gao, X., Olsen, J., Ma, H., Rhode, D., Zhang, H., Madsen, D., 2007. A short chronology for the peopling of the Tibetan Plateau. In: Madsen, D., Fahu, C., Xing, G. (Eds.), Late Quaternary Climate Change and Human Adaptation in Arid China. Elsevier, Amsterdam, Netherlands.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012. Mapping ecosystem service supply, demand and budgets. Ecol. Indicat. 21, 17–29.
Castro, A.J., Quintas-Soriano, C., Egoh, B.N., 2018. Ecosystem services in dryland systems of the world. J. Arid Environ. 159, 1–3.
Cordova, F.J., Wallace, J.D., Pieper, R.D., 1978. Forage intake by grazing livestock: a review. J. Range Manag. 31 (6), 430–438.
Deng, X., Li, Z., Gibson, J., 2016. A review on trade-off analysis of ecosystem services for sustainable land-use management. J. Geogr. Sci. 26 (7), 953–968.
Dierkes, J. (Ed.), 2012. Change in Democratic Mongolia: Social Relations, Health, Mobile Pastoralism, and Mining 25 Brill.
Dinar, A., Subramanian, A., 1997. Water Pricing Experiences: an International Perspective. The World Bank, USA.
Dong, S., Wen, L., Liu, S., Zhang, X., Lassoie, J.P., Yi, S., Li, X., Li, J., Li, Y., 2011. Vulnerability of worldwide pastoralism to global changes and interdisciplinary strategies for sustainable pastoralism. Ecol. Soc. 16 (2).
Dyson-Hudson, R., Dyson-Hudson, N., 1980. Nomadic pastoralism. Annu. Rev. Anthropol. 9 (1), 15–61.
Fan, M., Li, W., Zhang, C., Li, L., 2014. Impacts of nomad sedentarization on social and ecological systems at multiple scales in Xinjiang Uyghur Autonomous Region, China. Ambio 43 (5), 673–686.
Fisher, J.A., Patenaude, G., Giri, K., Lewis, K., Meir, P., Pinho, P., Rounsevell, M.D., Williams, M., 2014. Understanding the relationships between ecosystem services and poverty alleviation: a conceptual framework. Ecosys. Servc (7), 34–45.
Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., 2005. Global consequences of land use. Science 309 (5734), 570–574.
Galvin, K.A., 2009. Transitions: pastoralists living with change. Annu. Rev. Anthropol. 38 (1), 185–198.
Goodall, S., 2004. Changpa nomadic pastoralists: differing responses to change in Ladakh, North-West India. Nomadic Peoples 8 (2), 191–199.
Grafton, Q., Chu, L., Kompas, T., Ward, M., 2015. Volumetric water pricing, social surplus and supply augmentation. In: Understanding and Managing Urban Water in Transition. Springer, Dordrecht, pp. 401–419.
Guedes, J., Lu, H., Li, Y., Spengler, R., Wu, X., Aldenderfer, M., 2014. Moving agriculture onto the Tibetan plateau: the archaeobotanical evidence. Archaeol. Anthropol Sci 6

(3), 255–269.
Haines-Young, R., Potschin, M., 2010. The links between biodiversity, ecosystem services and human well-being. Ecosys Ecol: New Synthesis (1), 110–139.
Hamann, M., Biggs, R., Reyers, B., 2015. Mapping social–ecological systems: identifying 'green-loop' and 'red-loop' dynamics based on characteristic bundles of ecosystem service use. Global Environ. Change (34), 218–226.
Harris, R., 2010. Rangeland degradation on the Qinghai-Tibetan plateau: a review of the evidence of its magnitude and causes. J. Arid Environ. 74 (1), 1–12.
Hobbs, N.T., Galvin, K.A., Stokes, C.J., Lackett, J.M., Ash, A.J., Boone, R.B., Reid, R.S., Thornton, P.K., 2008. Fragmentation of rangelands: implications for humans, animals, and landscapes. Global Environ. Change 18 (4), 776–785.
Honkonen, T., 2013. Challenges of mining policy and regulation in central asia: the case of the Kyrgyz Republic. J. Energy Nat. Resour. Law 31 (1), 5–32.
Ikeya, K., 2017. Introduction: studies of sedentarization. Senri Ethnol. Stud. (95), 1–15.
Jackson, S.L., 2015. Imagining the mineral nation: contested nation-building in Mongolia. In: Nationalities Papers 43. Cambridge University Press, pp. 437–456 3.
Jones, J., Andriamarovololona, M., Hockley, N., Gibbons, J., Milner Gulland, E., 2008. Testing the use of interviews as a tool for monitoring trends in the harvesting of wild species. J. Appl. Ecol. 45 (4), 1205–1212.
Jumabay-Uulu, K., Wegge, P., Mishra, C., Sharma, K., 2014. Large carnivores and low diversity of optimal prey: a comparison of the diets of snow leopards Panthera uncia and wolves Canis lupus in Sarychat-Ertash Reserve in Kyrgyzstan. Oryx 48 (4), 529–535.
Kumar, P., Martinez-Alier, J., 2011. The Economics of Ecosystem Services and Biodiversity: an International Assessment. Economic and Political Weekly. pp. 76–80.
Kumar, P., Yashiro, M., 2014. The marginal poor and their dependence on ecosystem services: evidence from South asia and sub-saharan africa. In: von Braun, J., Gatzweiler, F.W. (Eds.), Marginality: Addressing the Nexus of Poverty, Exclusion and Ecology. Springer Netherlands, Dordrecht, pp. 169–180.
Leh District, Government of India, 2015. Demographics. Accessed [12.1.2019]. URL. https://leh.nic.in/about-district/demography/.
MA, 2005. Ecosystems and Human Well-Being. Island Press, Washington, D.C., USA Washington D.C.
Metzger, M., Rounsevell, M.D.A., Acosta-Michlik, L., Leemans, R., Schröter, D., 2006. The vulnerability of ecosystem services to land use change. Agric. Ecosyst. Environ. 114 (1), 69–85.
Misra, A., Longnecker, M.P., Dionisio, K.L., Bornman, R.M., Travlos, G.S., Brar, S., Whitworth, K.W., 2018. Household fuel use and biomarkers of inflammation and respiratory illness among rural South African Women. Environ. Res. 166, 112–116.
Murali, R., Redpath, S., Mishra, C., 2017. The Value of Ecosystem Services in the High Altitude Spiti Valley, Indian Trans-himalaya. Ecosystem Services, pp. 28.
Namgail, T., Bhatnagar, Y.V., Mishra, C., Bagchi, S., 2007. Pastoral nomads of the Indian Changthang: production system, landuse and socioeconomic changes. Hum. Ecol. 35 (4), 497.
Pomfret, R., 2014. The Economies of Central Asia 318 Princeton University Press.
R Core Team, 2013. R: A Language and Environment for Statistical Computing.
Rodriguez, R.D.G., Pruski, F.F., Singh, V.P., 2016. Estimated per capita water usage associated with different levels of water scarcity risk in arid and semiarid regions. Water Resour. Manag. 30 (4), 1311–1324.
Saberwal, V.K., 1996. Pastoral politics: gaddi grazing, degradation, and biodiversity conservation in Himachal Pradesh, India. Conserv. Biol. 10 (3), 741–749.
Sala, O.E., Yahdjian, L., Havstad, K., Aguiar, M.R., 2017. Rangeland Ecosystem Services: Nature's Supply and Humans' Demand. Rangeland Systems. Springer, Cham, pp. 467–489.
Scott, J.C., 1998. Seeing like a State: How Certain Schemes to Improve the Human Condition Have Failed. Yale University Press.
Snow leopard conservation fund, Snow Leopard Trust, Panthera, 2009. Mining and snow leopard conservation: tost-tosonbumba mountains of Gurvantes soum, South Gobi, Mongolia. Available at. http://www.snowleopardnetwork.org/bibliography/Mining%20Report.pdf.
Spengler, R., Frachetti, M., Doumani, P., Rouse, L., Cerasetti, B., Bullion, E., Mar'yashev, A., 2014. Early agriculture and crop transmission among Bronze Age mobile pastoralists of Central Eurasia. Proc. Biol. Sci. 281 (1783), 20133382.
Upton, C., 2012. Mining, resistance and pastoral livelihoods in contemporary Mongolia. In: Dierkes, J. (Ed.), Change in Democratic Mongolia: Social Relations, Health, Mobile Pastoralism and Mining. Brill, Netherlands, pp. 223–248.
Ward, D., 2015. Water requirements of livestock. Ministry of agriculture, food, and rural affairs, Governmnet of Canada. http://www.omafra.gov.on.ca/english/engineer/facts/07-023.htm.
Webber, M., 2008. Primitive accumulation in modern China. Dialect. Anthropol. 32 (4), 299–320.
Wertime, M., Ostrom, E., Gibson, C., Lehoucq, F., 2007. International Forestry Resources and Institutions (IFRI) Research Program: Field Manual, Version 13. Centre for the Study of Institutions, Population, and Environmental Change, Indiana University, USA.