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Constraints and prospects of utilising mountain pastures in Gilgit-Baltistan, Pakistan

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Abstract

In the mountain regions of northern Pakistan, pasture-based animal husbandry is a substantial element of people's livelihood. To study the implications of herding strategies on rangeland utilization patterns, individual interviews with 90 herders and 10 group interviews with five to eight herders per group, respectively, were conducted in three valleys each of Pakistan's Gilgit-Baltistan region. Data collection targeted number and species of animals kept, livestock management practices and seasonal pasture use and included GIS-based participatory mapping of spring, summer, autumn and winter pastures of yak, small ruminants and cattle. Households kept 10 yaks on average, along with 4 cattle and 15 small ruminants. Herding practices varied between valleys and seasons and were influenced by topographic as well as social factors. Full-time herding led to a more uniform distribution of yaks on pastures than part-time herding and unattended grazing, but in small ruminants promoted higher animal numbers near camp-sites. Many livestock keepers perceived rangeland degradation as a veritable challenge and identified lack of herding labour as one important problem. Training programmes for young herders, strengthening of group herding schemes and prevention of lowland pasture conversion into farmland were suggested as effective countermeasures.

Keywords: Livestock herding, Mountain pastures, Participatory mapping, Ruminants, Seasonal transhumance

Introduction

The northern areas of Pakistan lie at the junction of the Karakoram, Western Himalaya and Hindu Kush mountain ranges. More than 1.4 million people live in this region, 84% thereof in rural areas with 73% of these dwellers engaged in crop and livestock farming (Government of Gilgit-Baltistan 2020). Of the 72.5 thousand square kilometre area of the administrative territory of Gilgit-Baltistan, only 1% is cultivated with crops while 52% are mostly mountainous rangelands, 4% forests, and the remaining land consists of mountains and barren land (Khan 2003). Hence, it is understandable that agricultural activities, and in particular rangeland-based livestock production, provide up to 40% of annual household income in northern Pakistan (Rahim and Beg 2010; Khan et al. 2013). Livestock-keeping in Gilgit-Baltistan faces the typical challenges of mountainous regions, such as difficult topography, rapidly changing weather patterns, seasonally limited fodder availability and severe winter temperatures (Ali and Butz 2003; Kreutzmann 2012; Khan et al. 2013). Although official statistics have to be viewed with caution because they are often based on extrapolation, the total number of herbivorous livestock in Gilgit-Baltistan increased from to 1.92 to 2.62 million head from 2006 to 2019, with a steep rise in the numbers of cattle, goats and donkeys (+50% each); moderate increases in the numbers of sheep and yaks (+13% each); and a decline of approximately 20% in camel numbers (Government of Gilgit-Baltistan 2020). About 80% of Gilgit-Baltistan's domestic herbivores are grazing mountainous pastures during the vegetation period (Kreutzmann 2015; Khan et al. 2016), with no or only little external inputs provided. The overall annual increase of about 2.8%

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in livestock numbers and their strong dependence on rangelands (Government of Gilgit-Baltistan 2020) exerts high grazing pressure on the latter (Gura 2006; Rahman et al. 2008), even though regional differences in livestock population growth undoubtedly exist across the ten administrative districts of Gilgit-Baltistan. Already in the late 1990s, about 2 million domestic herbivores were grazing on 5.2 million hectares of high mountain rangelands in Gilgit-Baltistan. At that time, Khan (2003) cautioned that the resulting average annual stocking rate of approximately 0.7 sheep units[1] per hectare was three times higher than the stocking rate proposed for low potential rangelands. High stocking rates typically decrease vegetation cover and accelerate soil erosion, especially on steep, dissected slopes; moreover, not only quantity but also quality of the herbaceous vegetation may be negatively affected, along with livestock productivity (Beg 2010; Gentle and Thwaites 2016; Lv et al. 2019). According to a recent study in the Trans-Himalaya region, grazing patterns markedly modify the effects of climate change phenomena, in particular warming and drought, on biomass yield and vegetation cover (Kohli et al. 2021). Grazing patterns are a result of the various strategies that local livestock keepers apply to utilize and manage the harsh and spatio-temporally highly variable high mountain environment (Kreutzmann 2004, 2012; Khan et al. 2013), and until today environmental adaption shapes herd composition, herd movements and grazing decisions (Kreutzmann 2015). Being an important building block of the regionally dominant system of combined mountain agriculture that also comprises crop cultivation and off-farm income generation (Kreutzmann 2015), local livestock husbandry also relies on cultural, social and economic factors, such as intra- and inter-household cooperation for herding, community regulations for pasture and livestock management, labour availability and market demand for livestock products (Schmidt 2000; Ali and Butz 2003; Omer et al. 2006; Rahman et al. 2008; Kreutzmann 2015).

Since the late 1970s, the northern areas of Pakistan underwent major changes—especially the opening of the Karakoram Highway that links the region to the rest of Pakistan and to China greatly improved the regional mobility and communication infrastructure (Kamal and Nasir 1998; Government of Gilgit-Baltistan 2020). While facilitating movement of local products and people to other regions of Pakistan, the highway also enhanced competition for local agricultural products on regional markets and increased opportunities for female empowerment as well as regional out-migration to acquire education and employment (Duncan et al. 2006; Kreutzmann 2015; Cook and Butz 2020). Other stimuli for change were and are activities of government departments and non-governmental initiatives to improve irrigation channels, local roads and micro-hydroelectric schemes (Duncan et al. 2006; Government of Gilgit-Baltistan 2020). These opportunities not only affected labour division within and between households but also changed the role, practice and reputation of livestock keeping (Kreutzmann 2015).

Flanked by effects of climate change, the ongoing livelihood transformations threaten the sustainable management of rangelands in Gilgit-Baltistan, especially at ecologically sensitive higher altitudes (Kreutzmann 2015; Godde et al. 2020; Kohli et al. 2021). While grazing management and stocking densities recently received substantial scientific attention on the Qinghai-Tibetan Plateau region in China (Dong et al. 2015; Miao et al. 2015; Du et al. 2017; Mipam et al. 2019), only few empirical studies (Butz 1996; Kreutzmann 2012, 2015; Khan et al. 2013; Wu et al. 2013) analysed the interdependency of high-altitude livestock grazing and sustainable rangeland management in the Karakoram, Western Himalaya and Hindu Kush region. Approaching the topic from a qualitative angle, these studies described transhumance routes and seasonal grazing areas for different livestock species and different mountain communities, respectively (Butz 1996; Ehlers and Kreutzmann 2000, Kreutzmann 2015). Especially for mountainous spring and summer pastures that provide the basis for individual animal growth, production and reproduction, annual stocking rates and seasonal stocking densities are a useful indicator for the intensity of rangeland use (Jordan et al. 2016; Altmann et al. 2018; Lv et al. 2019; Godde et al. 2020). As demonstrated by Turner et al. (2005), the cumulative product of livestock numbers and grazing hours in a given time period—that is stocking density—is modulated by the way livestock is supervised on pasture: a strong spatial concentration of grazing was observed for unattended animals, whereas full-day herding effectively dispersed grazing animals and an intermediate impact was generated by the herd-release mode, where animals are accompanied to pasture in the morning, then left to graze on their own and eventually brought back to their night resting place by the herder in the evening. However, globally and in the region, labour needed for herding animals is getting scare, especially if alternative income opportunities exist, because of the harsh working conditions, high workload and rather low remuneration of the herding duty (Kreutzmann 2013; Schlecht et al. 2020).

[1] See Materials and Methods section for calculation of sheep units

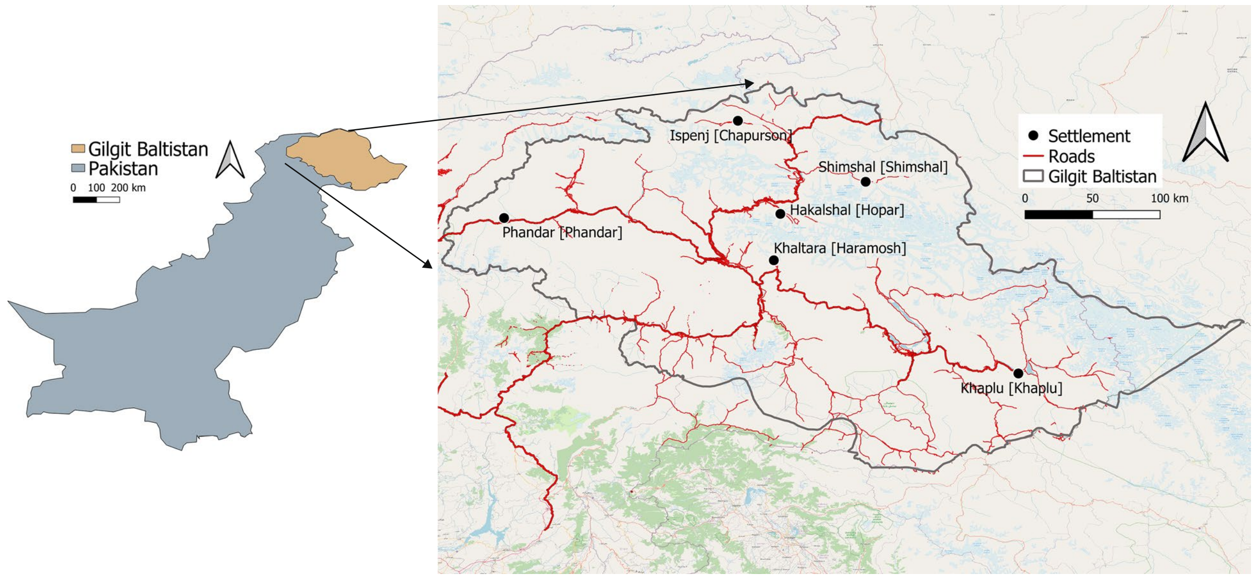

Fig. 1 Map of Pakistan with Gilgit-Baltistan (small inset, left), and topographic map of Gilgit-Baltistan (right) with six major settlements (black dots) indicating the location of each of the six study valleys (names given in the rectangular brackets). Modified from Open Street Map, 2021

In view of these findings, the current study investigated if different herding modes influence rangeland utilization patterns on high mountain pastures in the Gilgit-Baltistan region, in particular during the vegetation period in spring and summer, and which constraints local livestock keepers are facing in this regard.

Materials and methods

Area and study sites

Gilgit-Baltistan (Fig. 1) is situated in the extreme north of Pakistan (between 35–37°N and 72–75°E); it borders Xinjiang Province of China to the northeast, India to the east and Afghanistan to the north and west. The region is dominated by the mountain ranges of the Karakorum, the Hindu Kush and the Himalaya, with more than 700 peaks above 6000 m and five above 8000 m in altitude, including K2 (8611 m). Most of the region's surface is situated at >1500 m above sea level (asl), with more than half located at >4500 m asl (Khan 2003). Climatic conditions vary widely, ranging from the monsoon-influenced moist temperate zone in the western Himalaya to the arid and semi-arid cold desert in the northern Karakoram and the Hindu Kush, with daily mean temperatures ranging from −10°C in winter to +35°C in summer (Awan 2002).

Of the region's total land area of 72,496 km^2, only 1% is cultivated with staple and cash crops including perennials (Khan 2003). While annual precipitation rarely exceeds 200 mm at lower altitudes, pastures situated >3500 m asl receive substantial snowfall during winter, with annual precipitation summing up to 2000 mm (Awan 2002). In contrast to general global patterns, significant increases have regionally been observed in winter mean and maximum temperatures, and consistent decreases in summer maximum temperatures (Fowler and Archer 2006).

The vast majority of Gilgit-Baltistan's cattle, sheep, goats and yaks are kept in combined mountain agriculture systems and their grazing is managed in seasonal transhumant movements: from the farmers' principal homes in lower lying valley bottoms, the animals are taken to mountain ranges during spring and summer time to first graze on medium and later on high altitude pastures, for approximately 5 months of the year (Ehlers and Kreutzmann 2000; Khan 2003).

To study patterns and challenges of rangeland utilization, six valleys, namely Chapurson[2] (north, bordering Afghanistan), Haramosh (centred, close to Gilgit), Hopar (centred, close to Karimabad), Khaplu (east, bordering the Indian part of Kashmir), Phandar (west, bordering Khyber Pakhtunkhwa region) and Shimshal (north, bordering China), were selected (Fig. 1). Due to the high engagement of their population in crop-livestock mountain agriculture, these valleys had been suggested for study by the regional livestock department in Gilgit. Each valley hosts several villages or smaller settlements (in the following subsumed under 'settlements'), but while the valleys of Khaplu, Phandar and Hopar are linked to

[2] Spelling of place names follows *Manzoom, A. and A. Hussain. 2016. Atlas of Gilgit-Baltistan, revised edition. Gilgit, Pakistan.*

regional markets through a good road network, the other three valleys are distant from major traffic axes, with high risk of blockage of their access roads in case of landslides, storms or meltwater floods. The mobile phone network is reliable in Hopar, Khaplu and partly in Shimshal, while it is difficult to access in the other valleys. Tourism is booming in Phandar, Hopar and Shimshal, with the two latter communities actively organizing trekking and mountaineering expeditions.

Herder interviews and group discussions

A research permit that covered all aspects of this study was issued by the Government of Gilgit-Baltistan (No-Misc-44/2850-95-2018). Rangeland management patterns and herding strategies of the local livestock keepers were studied in all six valleys from May to November 2018, whereby data was retrieved for the year 2017. In Hopar, Phandar and Shimshal (HPS), family-based herding of livestock prevailed, whereby 'family' also includes close relatives or members of the same lineage living in the same or a close-by settlement. In HPS, 30 male and female livestock keepers were randomly sampled per valley, based on a name list of all households provided by the local livestock department. The individual interview with the household's main herder comprised 40 open questions about family members involved in herding, years of herding experience of the main herder, numbers, age categories (newborn, young and adult) and species composition of his/her own livestock holding (further on termed 'flock'), use of seasonal pastures, species- and season-specific herding times and herding modes, perception of the herding tasks, rangeland conditions and measures suggested for future livestock and rangeland management. Conversation always took place in Urdu language which was spoken and understood by the herders and the interviewing scientist. Answers were noted on paper and later transcribed, codified and entered into a database.

In the valleys of Chapurson, Haramosh and Khaplu (CHK), several livestock keepers, not necessarily related by family ties, were taking turns in herding all livestock at settlement level (further on termed 'group herding'). Therefore, in three, four and three villages of Chapurson, Haramosh and Khaplu valley, respectively, one focus group discussion (FGD) each was conducted with five to eight of these herders who had been recommended by elders. The FGD participants were asked the same 40 questions as the individually interviewed persons but replied to them collectively; in consequence, cumulative numbers for the jointly managed livestock were obtained per group (further on termed 'herd').

For standardization and comparability, all animal numbers collected in individual interviews and FGDs were converted to sheep units (SU) using the conversion factors proposed by Hu and Zhang (2006): 5.0, 4.0, 1.0 and 0.9 for adult (> 1 years of age) individuals of cattle, yaks, sheep and goats; 2.5 for young cattle and yaks (< 1 year); and 0.4 for newborn and young small ruminants.

Due to inter-annual as well as regional variation in the start and end of the vegetation period and that of very low ambient temperatures or snowfall, respectively, the unanimous definition of the four distinguished seasons posed a certain problem with respect to delimiting the exact calendar months: commonly, however, spring related to the period April–May or April–June, summer to June–August or July–August, autumn to September–November and winter to December-March.

Participatory mapping of pasture utilization

In combination with the individual interviews and the FGDs, respectively, all interviewees also participated in an electronic mapping exercise. A preceding exploration (Hameed et al. 2018) had identified seasonal pasture areas per settlement and valley, and high-quality images of all pasture areas had been downloaded from Google Earth version 7.1.8.3036 prior to the interviews. The Google Earth images were geo-referenced in QGIS version 3.6.2 (QGIS Development Team 2012) by creating four geo-referenced points per image using the WGS 84 coordinate reference system (World Geodetic System 2020, with Authority EPSG 4326). On a laptop operating Microsoft Windows 10, Google Earth images were opened in QGIS and herders were asked to locate the pastures grazed by their yaks (Y), small ruminants (SR: sheep and goats) and cattle (C) on these geo-referenced images. Thereby, we relied on the assurance that the delineated pasture areas, though common property (Kreutzmann 2015), were predominantly utilized by the livestock of the specific family (HPS) or herder group (CHK). Information about each species' grazing areas was carefully registered along the indicated demarcation lines and directly entered into QGIS as single polygon shapefile. The mapping exercise resulted in a maximum of 3 (species[3]) times 4 (seasons) polygons per family (HPS) or group (CHK), respectively, if all three livestock species were kept and grazed throughout the year. Area information obtained in the interviews were overlaid in QGIS to identify seasonal pasture overlap between livestock species per valley. Area information was exported to a database to relate the standardized animal numbers (SU, see above) to the interview-based information on sojourn time of animals on seasonal pastures (in days, d) and the polygon surfaces (ha) depicting species-specific

[3] Although sheep and goats are two different species, we use the term *species* here to distinguish between yaks, cattle and small ruminants.

Table 1 Species-specific number of animals kept per family and average years of herding experience of herders in six valleys of Gilgit-Baltistan, Pakistan. Values depict arithmetic mean and standard error of the mean (SEM)

Valley	Interviews (*n*)	Yaks (*n*)	Goats (*n*)	Sheep (*n*)	Cattle (*n*)	Herding experience (years)
Individual interviews						
Hopar	30	10.6	18.3	22.0	3.8	25.3
Phandar	30	11.1	13.3	19.3	5.3	21.6
Shimshal	30	8.7	9.2	10.5	4.2	29.2
SEM		*0.50*	*1.05*	*1.24*	*0.23*	*1.26*
P ≤		*n.s.*	*0.001*	*0.001*	*0.05*	*0.05*
Group interviews						
Chapurson	3	11.9	3.7	24.2	10.7	22.1
Haramosh	4	30.4	85.7	52.9	14.1	25.1
Khaplu	3	14.9	31.9	44.4	9.0	20.4
SEM		*3.36*	*12.57*	*8.17*	*1.51*	*1.07*
P ≤		*n.s.*	*0.01*	*n.s.*	*n.s.*	*n.s.*

n.s. not significant

seasonal grazing areas. In this way, seasonal stocking densities (SU*d/ha) were estimated (Jordan et al. 2016).

Data processing and statistical analysis

All spatial raw data (polygons) was overlaid in QGIS 3.6.2 on a Google Earth image using the WGS 84 coordinate reference system. An individual layer was created for each animal species and each season—for example, in a valley where grazing was practised in all four seasons, 12 layers were created, each comprising the spatial information supplied by 30 individual interviewees in the case of Hopar, Phandar and Shimshal, and by the participants of three, three and four focus groups in Chapurson, Khaplu and Haramosh. The season-specific area grazed by different livestock species was calculated in QGIS using the *field calculation function*. To calculate the overlapping grazing area of different species, the QGIS *geoprocessing tool function* was used. The QGIS *intersection function* was used to generate polygons of differently stocked areas across species and seasons. The resulting information was exported into SPSS 20.0 software (SPSS Inc., Chicago, IL) to calculate the proportion of overlapping areas, as well as of lightly stocked areas, which we defined as being utilized by ≤25% of flocks or herds in a settlement, and heavily stocked areas (utilized by ≥75% of flock or herds in a settlement). According to the Kolmogorov–Smirnov test, some of the continuous variables showed non-normal distribution of residuals. Differences between valleys were therefore investigated with chi-square test in case of categorical variables and ANOVA in case of continuous variables, thereby acknowledging that probabilities are indicative only for non-normally distributed data. Significance was declared at $P \leq 0.05$. Since the location-specific differences in herding animals per family or per group necessitated different modes of data acquisition (individual *versus* group interviews), statistical tests were only applied within the HPS and the CHK cluster, respectively. To limit fragmentation of the highly scattered dataset, intra- and inter-valley differences between livestock species and seasons, respectively, were also not investigated. Results on sizes and composition of livestock flocks and herds, areas grazed, sojourn time on seasonal pastures and estimated stocking densities are depicted as arithmetic mean and standard error of the mean (SEM), while only the mean per valley is reported for aggregated variables such as species' overlapping grazing areas and share of heavily or lightly stocked pastures.

Results

Livestock species and grazing management

Overall, herders in Haramosh valley had an average herding experience of 25 years and, on family basis, kept the largest number of animals with on average 30 yaks, 50 sheep, 85 goats and 14 cattle (Table 1). Yak keeping was also prominent in Khaplu, Chapurson and Phandar, whereas small ruminants were mainly kept in Khaplu, Hopar and Chapurson. The longest average herding experience of 29 years and the smallest average flock size of 32.6 ruminants per family were encountered in Shimshal.

In HPS, the average trekking time from the settlements to the seasonal pastures (Additional file 1: Appendix Table 1) differed significantly ($P \leq 0.001$) between spring (7 to 21 h) and summer pastures (12 to 25 h) and between

Table 2 Number of days that the herders and their yaks, small ruminants and cattle spent on spring and summer pastures in three valleys of Gilgit-Baltistan with family-based herding. Values depict arithmetic mean and standard error of the mean (SEM); $n=30$ interviewees per valley

Valley	Sojourn time (d)					
	Yak	Yak herder	Small ruminants	Small ruminant herder	Cattle	Cattle herder
Spring pastures						
Hopar	49	25	39	15	n.a.	n.a.
Phandar	48	3	40	19	35	16
Shimshal	58	21	39	21	39	3
Mean	52	27	39	18	37	10
SEM	*1.0*	*1.6*	*1.0*	*1.5*	*1.1*	*1.9*
P ≤	*0.001*	*0.001*	*n.s.*	*n.s.*	*n.s.*	*0.001*
Summer pastures						
Hopar	131	65	120	49	131	44
Phandar	148	99	119	77	96	65
Shimshal	107	43	151	40	109	21
Mean	129	69	130	55	112	43
SEM	*2.5*	*4.0*	*2.3*	*3.3*	*2.4*	*3.1*
P ≤	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*

n.a. not applicable, *n.s.* not significant

all species (Y, SR, C; $P \leq 0.001$). In Shimshal, yak pastures were farthest away from the settlements and according to the interviewees, trekking took on average 21 h (spring) and 24 h (summer) to reach there. In CHK, trekking to spring and summer pastures of yaks lasted 3 to 4 h, with the exception of yak summer pastures in Chapurson (16 h of trekking). Cattle were always grazed at the lower altitude ranges of a seasonal pasture, yaks at the highest (very close to the snow line) and small ruminants in-between. Average time to access small ruminant spring (14 h) and summer (21 h) pastures was longest in Shimshal, followed by the time needed to reach Chapurson summer pasture (15 h).

Except for yaks in Haramosh valley, all animals were taken to spring and summer pastures for grazing and the extraction of milk; the latter was especially relevant in Shimshal and Phandar and to some extent in Khaplu and Hopar. Apart from for Shimshal and Hopar, where herders could choose among several pastures per season, the livestock flocks were taken to one specifically designated grazing area within the communal grazing territory in each season. Designation of pasture areas to families was either decided at village level or by social group[4]. At the herders' level, (family) labour availability, flock size and area of the designated seasonal pasture determined seasonal sojourn time, which in HPS was always longer for the animals than for their herders who did not continuously stay there with the livestock (Table 2).

Mostly, animals were herded by men, though herding arrangements varied between families and valleys, respectively: yaks in Hopar were either herded by the family's principal herder, other family members, or grazed unattended on the spring and summer pastures. The same applied to yaks in Phandar during spring season, while during summer some families hired and paid external herders for yaks, and others grouped their yaks and the families' principal herders took turns in herding them (group herding). In Shimshal, yaks were either attended to by the principal herder, family members or remunerated hired herders from within the valley or left to graze unattended on spring and summer pastures. Small ruminants in Hopar were mostly attended to by family members on spring and summer pastures, and the same applied to small ruminants in Phandar where in summer sometimes also external waged herders were hired. In Shimshal, small ruminants were either attended to by family members or hired herders from within the region. Cattle in Hopar and in Phandar were attended to by the family's principal herder or other family members during spring and summer. Yet, as for small ruminants, waged herders were sometimes hired to herd cattle on summer pastures in Phandar. In Shimshal, cattle were attended to by the principal herder or family members on spring as well a summer pastures. Obviously, in

[4] Social group is defined here as persons seeing themselves relatively closely related through lineage and language.

Table 3 Proportion (%) of yak, small ruminant and cattle flocks (HPS) and herds (CHK), respectively, that are either fully herded or herd-released on spring and summer pastures in six valleys of Gilgit-Baltistan

Valley	Season	Interviews (*n*)	Yaks		Small ruminants		Cattle	
			Herded	Herd-release	Herded	Herd-release	Herded	Herd-release
Individual interviews								
Hopar	Spring	30	95	5	95	5	0	0
	Summer		98	2	71	29	97	3
Phandar	Spring	30	62	22	83	17	71	29
	Summer		77	11	98	2	94	6
Shimshal	Spring	30	34	64	44	56	88	12
	Summer		44	55	76	24	88	12
Group interviews								
Chapurson	Spring	3	100	0	0	0	0	0
	Summer		100	0	61	39	75	25
Haramosh	Spring	4	0	0	79	21	85	15
	Summer		0	0	100	0	77	23
Khaplu	Spring	3	68	32	100	0	100	0
	Summer		31	69	40	60	100	0

Where the sum of species-specific flocks (HPS, above) and herds (CHK, below) managed by full-day herding (herded) and in herd-released mode is less than 100%, the reminder share signifies the proportion of flocks or herds pasturing on their own (unattended grazing). For autumn and winter pastures, please refer to Additional file 1: Appendix Table 2

Chapurson, Haramosh and Khaplu, if herded, all species were attended to by group herders. Cattle were always grazed close to the settlements and often brought back to this point on a daily basis so that family members could milk the cows. Cattle herding was mostly managed by female household members who were also involved in dung collection for fuel. An exception was cattle herding on the summer pastures of Hopar and Chapurson, which required 8 to 9 h of trekking to be reached (Additional file 1: Appendix Table 1); here, family members stayed with the herders to milk and produce milk products.

With almost 5 months, the animals' sojourn lasted longest on summer pastures (Table 2) and was of nearly equal length (129 d and 130 d) in yaks and small ruminants. Sojourn time was shorter on spring pastures (52 d and 39 d in yaks and small ruminants) and shortest on winter pastures (data not shown). An exception was Shimshal, where yaks spent nearly 5 months on remote winter pastures close to the Chinese border. The interviewed herders' sojourn time on pastures in the year 2017 was longest on the summer pastures of yaks (69 d) and small ruminants (55 d; $P \leq 0.001$). Shortest stays prevailed on spring pastures of yaks, with significant differences between valleys ($P \leq 0.001$).

In HPS, the average time per day spent on herding (Additional file 1: Appendix Table 1) differed significantly between valleys for yaks ($P \leq 0.01$ in spring, $P \leq 0.001$ in summer) and small ruminants ($P \leq 0.001$ in spring and summer) but not for cattle ($P > 0.05$). In spring, yaks and small ruminants were generally herded for 5 to 8 h per day, although in some valleys small ruminants were released after the yaks and collected and brought back earlier also. Cattle were given ample time per day to graze on spring (6 h) and summer pastures (10 h) in all valleys.

As illustrated in Table 3, the herding mode varied with season, species and valley. Although herded in almost all valleys during spring and summer, the share of herded yaks varied considerably, and in Haramosh, yaks were not herded at all. The herd-release mode was widely practised for yaks in Shimshal (covering 55% of all yaks) and Khaplu (33%) but not relevant in Hopar, Phandar and Chapurson. Unattended grazing of yaks was primarily practised in Haramosh (100%) as well as in Phandar (17%) during spring and autumn (Additional file 1: Appendix Table 2) but was irrelevant in Shimshal (2%).

Small ruminants were herded in every valley and season (Table 3, Additional file 1: Appendix Table 2), whereby herding covered the majority of sheep and goats in Phandar and Hopar but less than two-thirds of small ruminants in all other valleys. On summer pastures, small ruminants were herded predominantly in Phandar (98%), Haramosh (100%) and Hopar (71%), while on autumn pastures the herd-release mode prevailed for small ruminants in Shimshal (63%) and Haramosh (53%). Free grazing of sheep and goats was

Table 4 Area grazed (ha) in spring and summer season per flock of yaks (Y), small ruminants (SR) and cattle (C) in six valleys of Gilgit-Baltistan. Values depict arithmetic mean and standard error of the mean (SEM)

Valley	Interviews	Spring			Summer		
	(*n*)	Y	SR	C	Y	SR	C
Individual interviews							
Hopar	30	145	12	n.a.	672	113	46
Phandar	30	695	268	180	1733	522	568
Shimshal	30	810	521	51	1269	702	51
	SEM	*42.9*	*32.0*	*12.5*	*84.8*	*42.4*	*38.1*
	P ≤	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*	*0.001*
Group interviews							
Chapurson	3	1483	n.a.	n.a.	5970	536	1147
Haramosh	4	292	385	153	1039	281	225
Khaplu	3	337	109	126	2047	462	219
	SEM	*222.4*	*66.0*	*31.9*	*763.9*	*42.3*	*170.9*
	P ≤	*0.05*	*0.05*	*n.s.*	*0.01*	*0.01*	*0.05*

For species-specific flock sizes at herder household level, please refer to Table 1. Since group herding was practised in Chapurson, Haramosh and Khaplu, group pasture areas were divided by the number of herders joining their livestock to calculate the area grazed per flock

n.a. not applicable because animals grazed near settlements, *n.s.* not significant

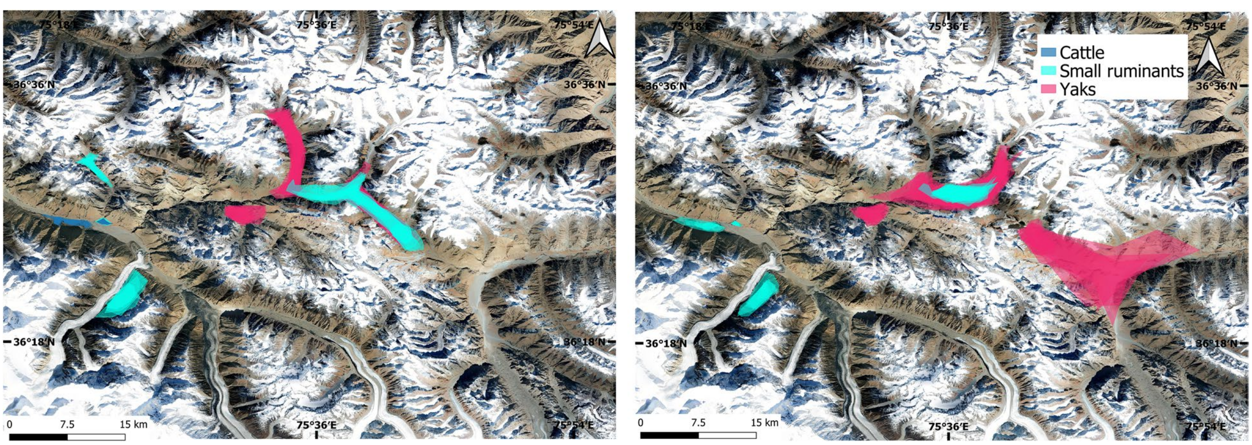

Fig. 2 Areas mapped by herders on a Google Earth Image (2019) as spring (left) and summer (right) pastures for yaks, small ruminants and cattle in Shimshal valley of Gilgit-Baltistan. Please note the coordinates marked in black colour along the image borders. While saturated polygon colours signify overlap of various families' flocks, transparent areas are utilized by one or a few families' flocks only

only practised in Haramosh and Khaplu during winter season (Additional file 1: Appendix Table 2). Cattle were also predominantly herded in all valleys and seasons (Table 3), with highest shares in Hopar, followed by Shimshal, Khaplu and Phandar. Year-round herd-release mode was important for cattle in Haramosh (31% of village herds), Shimshal (17% of family flocks) and Phandar (18% % of family flocks). In contrast, unattended grazing of cattle was only found in Haramosh during winter (Additional file 1: Appendix Table 2).

Rangeland utilization patterns

In comparison to cattle and small ruminants, yaks were always kept on the largest pastures (Table 4), but the size of the utilized area differed between valleys in all seasons ($P \leq 0.001$), especially in summer (Figs. 2, 3 and 4). In spring, a family's flock of yak grazed an average of 1483 ha in Chapurson, which was almost double the area available to family yak flocks in Phandar and Shimshal and much larger than the area grazed by yaks in the remaining villages. On the winter pastures of Shimshal near the Chinese border, yaks grazed on an average of 5113 ha per family flock, whereas yaks were mostly stall-fed in

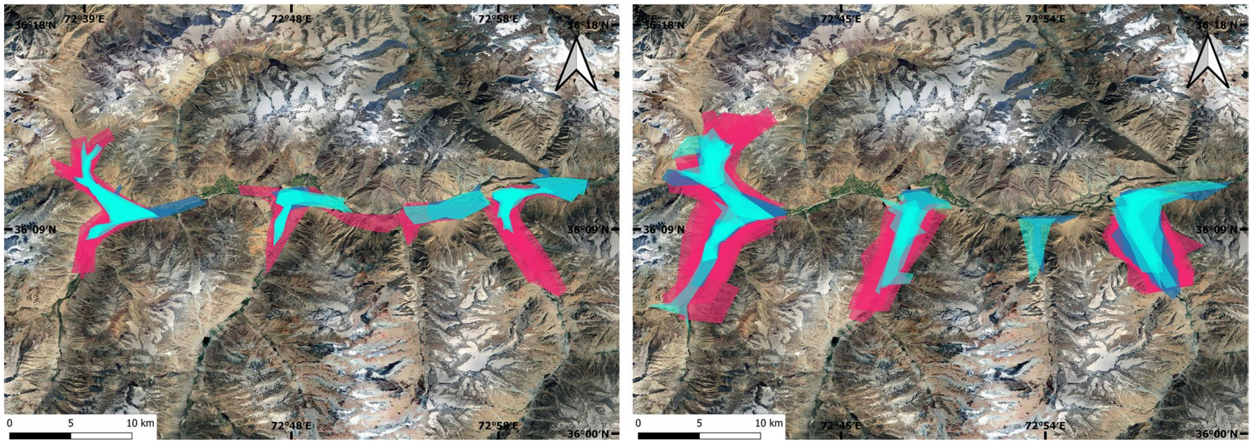

Fig. 3 Areas mapped by herders on a Google Earth Image (2019) as spring (left) and summer (right) pastures of yaks (pink), small ruminants (turquoise) and cattle (blue) in Phandar valley of Gilgit-Baltistan. Please note the coordinates marked in black colour along the image borders. While saturated polygon colours signify overlap of various families' flocks, transparent areas are utilized by one or a few families' flocks only

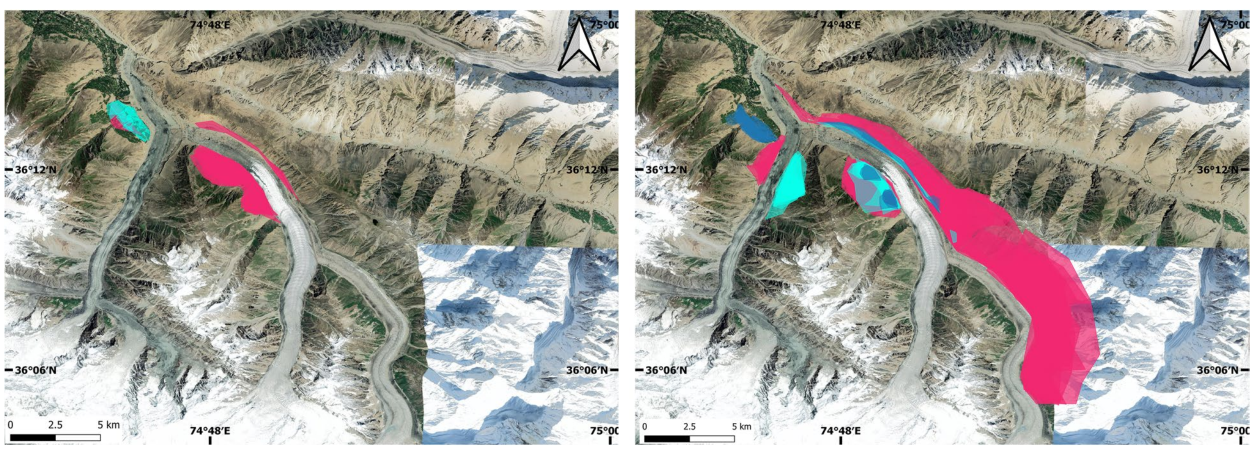

Fig. 4 Area mapped by herders on a Google Earth Image (2019) as spring (left) and summer (right) pastures of yaks (pink), small ruminants (turquoise) and cattle (blue) in Hopar valley of Gilgit-Baltistan. Please note the coordinates marked in black colour along the image borders. While saturated polygon colours signify overlap of various families' flocks, transparent areas are utilized by one or a few families' flocks only

the other valleys during winter. All seasonal pastures of small ruminants differed significantly between valleys ($P \leq 0.001$): whereas Shimshal valley provided vast grazing areas in spring and summer (Table 4 and Fig. 2) as well as in autumn (Additional file 1: Appendix Table 3), small ruminants in Hopar remained near settlements in spring (Fig. 4), with only 12 ha per family flock available for daily grazing, and the same trend was observed in autumn. In Chapurson, small ruminants and cattle were grazed close to the settlements in all seasons except summer. Across seasons and valleys, cattle utilized smaller grazing areas than the other species, whereby the sizes of spring and summer pastures, respectively, differed between valleys ($P \leq 0.001$). Largest were the summer pastures, averaging 1147 ha and 568 ha per family cattle flock in Chapurson and Phandar (Fig. 3), slightly more than 200 ha per family cattle flock in Haramosh and Khaplu, and barely 50 ha in Shimshal (Table 4).

In spring, species-specific grazing areas did not overlap in Chapurson and Hopar (Fig. 4) but in all other valleys ($P \leq 0.001$). Yaks and small ruminants shared 22% of their spring grazing area (Fig. 5a) in Khaplu, 16% in Shimshal, 1% in Haramosh and 14% Phandar. Similarly, yaks and cattle shared grazing area in Khaplu (22%), Phandar (9%) and Haramosh (6%). Grazing areas of small ruminants and cattle overlapped in

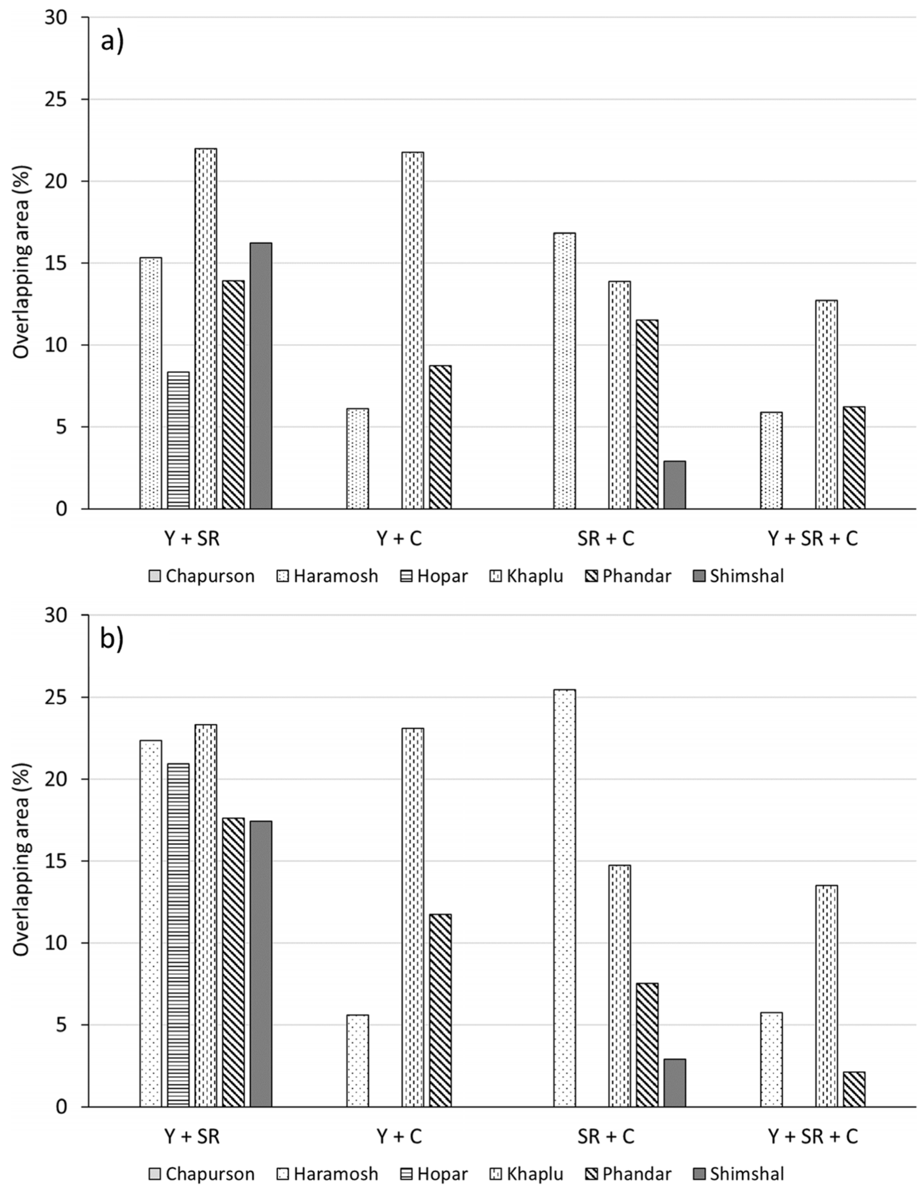

Fig. 5 Average area overlap (in % of total area grazed) between yaks (Y), small ruminants (SR) and cattle (C) on spring (**a**) and summer (**b**) pastures of six valleys in Gilgit-Baltistan

Haramosh (17%), Khaplu (14%) and Phandar (12%). The area shared by all three species amounted to 13% of grazed pastures in Khaplu and 6% in Phandar and Haramosh. In summer, yaks and small ruminants shared grazing areas (Fig. 5b) in Khaplu (23%), Haramosh (22%), Hopar (21%), Phandar (18%) and Shimshal (17%), whereas a substantial overlap of yak and cattle grazing areas was only observed in Khaplu (23%). Small ruminants and cattle shared summer grazing areas mainly in Haramosh (25%) and Khaplu (15%), whereas pastures of all three species only overlapped in Khaplu (14%).

Estimated stocking densities of yaks on spring pastures (Table 5) differed between valleys ($P \leq 0.001$), being higher in Haramosh and Khaplu than in Hopar and Chapurson, and being low in Shimshal and Phandar. Estimated stocking densities of yaks on summer pastures were also different between valleys ($P \leq 0.01$), with the highest values calculated for Haramosh (0.29 SU*d/ha), and the same was true for autumn and winter stocking densities of yak in Haramosh (Additional file 1: Appendix

Table 5 Estimated seasonal stocking densities (SU*d/ha) of yaks (Y), small ruminants (SR) and cattle (C) on spring and summer pastures in six valleys of Gilgit-Baltistan. Values depict arithmetic mean and standard error of the mean (SEM)

Valley	**Interviews**	**Spring**			**Summer**		
	(*n*)	**Y**	**SR**	**C**	**Y**	**SR**	**C**
Individual interviews							
Hopar	30	0.74	0.62	*n.a.*	1.45	1.83	2.24
Phandar	30	0.14	0.23	0.26	0.16	0.44	0.25
Shimshal	30	0.10	0.09	0.80	0.13	0.15	2.31
	SEM	*0.047*	*0.046*	*0.062*	*0.191*	*0.125*	*0.226*
	P ≤	*0.001*	*0.001*	*0.01*	*0.01*	*0.001*	*0.001*
Group interviews							
Chapurson	3	0.26	n.a.	n.a.	0.02	0.34	0.10
Haramosh	4	1.76	1.82	4.41	0.29	0.86	0.56
Khaplu	3	0.95	3.33	7.47	0.09	0.33	0.47
	SEM	*0.245*	*0.477*	*1.984*	*0.061*	*0.119*	*0.097*
	P ≤	*0.01*	*0.01*	*n.s.*	*n.s.*	*n.s.*	*n.s.*

n.a. not applicable because animals grazed near settlement, *n.s.* not significant

Table 6 Share (%) of heavily (an area utilized by ≥ 75% of the flocks or herds) and lightly (an area utilized by ≤25% of the flocks or herds) stocked spring and summer grazing areas of yaks and small ruminants across six valleys in Gilgit-Baltistan

Valley	**Yaks**				**Small ruminants**			
	Spring		**Summer**		**Spring**		**Summer**	
	Heavily stocked	**Lightly stocked**	**Heavily stocked**	**Lightly stocked**	**Heavily stocked**	**Lightly stocked**	**Heavily stocked**	**Lightly stocked**
Individual interviews								
Hopar	60	10	47	13	53	16	63	6
Phandar	72	7	63	11	53	12	50	18
Shimshal	58	13	47	14	50	27	51	21
SEM	*2.3*	*0.8*	*2.8*	*1.0*	*2.6*	*1.6*	*2.6*	*1.8*
P ≤	*0.05*	*0.01*	*0.05*	*n.s.*	*n.s.*	*0.001*	*n.s.*	*0.001*
Group interviews								
Chapurson	6	54	23	42	n.a.	n.a.	13	61
Haramosh	55	21	49	25	49	15	37	18
Khaplu	66	15	45	33	68	8	42	21
SEM	*10.8*	*9.6*	*6.9*	*6.8*	*11.3*	*4.6*	*7.6*	*8.4*
P ≤	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*0.05*	*n.s.*	*n.s.*	*0.05*

n.s. not significant

Table 4). For small ruminants, higher seasonal stocking densities were estimated for spring and autumn as compared to summer pastures, with significant differences between valleys in all seasons ($P \leq 0.001$). Estimated stocking densities of cattle were significantly different between valleys on spring ($P \leq 0.01$) as well as on summer pastures ($P \leq 0.001$).

Across valleys, areas on spring and summer pastures that were utilized by ≥75% of the studied herds (highly stocked areas) were found in those valleys where high animal numbers and long sojourn times prevailed and mixed species grazing was common (Table 6). The prevalence of highly stocked spring and summer areas in Haramosh was mainly due to the limited availability of pastures in this narrow valley.

Herders' perceptions of challenges to rangeland utilization

When asked about actual and potential problems of herding and mountain rangeland utilization, and about respective reasons and possible strategies to mitigate problems, shortage of workforce, especially of skilled and experienced herders, was mentioned frequently

Table 7 Herders' view of challenges and problems related to herding and rangeland management, underlying reasons and possible mitigation measures as identified in 30 individual interviews each in Hopar, Phandar and Shimshal valley, and in three, four and three focus group discussions in Chapurson (C), Haramosh (H) and Khaplu (K) valleys in Gilgit-Baltistan

Challenges and problems	Problems identified by n respondents in				Reasons	Suggested mitigating measures
	Hopar	Phandar	Shimshal	Group discussions[a]		
Herding						
Shortage of skilled labour	10	15	29	C1, C2, C3, K3	Young generation involved in education and tourism, business/jobs; family members must also work on farmland.	Restructuring of school schedules, training programmes for young herders, herding incentives in cash and kind, joint herding.
Animal herding is a tough and time-consuming job	5	4	27	C1, C2, C3, K1, K3	Harsh climate, year-round duty.	Training for herders, incentives in cash and kind.
Lifestyle changes, people are less tough and lazier	18	11	23	C1, C2, K3	Infrastructure development, quest for luxuries.	Training for herders, incentives in cash and kind.
Livestock keeping is no more a family business	2	24	19	C3, H1, H4, K1, K3	Family engagement in other work, low prices of milk products.	Markets for products, training in making good-quality milk products.
Climate change (closure of roads, washing away of bridges)	9	5	1	C2, K2, K3	Not known	
Rangeland/pastures						
Productivity of pastures is low	21	24	3	C2, K1, K2, K3	Mismanagement, concentrated grazing.	Pasture rehabilitation plans.
Management issues (overgrazing, overexploitation)	25	27	10	All valleys	No (clear) management system, no taxation, no one's property.	Animal grazing fees.
Rapid increase in tourism	17	11	22	H2, H3, K2	Camping, expeditions.	Tourism guidelines development.
Climate change (erratic rains, soil erosion)	9	5	1	C2, K2, K3	Not known.	
Conversion of pasture areas into farmland	21	18	12	C1, C2, H1, H4, K1, K2, K3	Farming provides more (cash) income than herding.	Policies for land use, community organizations taking care of such matters.
No access to traditional cross border pastures due to political issues	0	0	16	C2, C3	Political decisions.	Providing access to cross border areas.

[a] Numbers 1, 2, 3 and 4 associated with a valley ID represent the group discussion number in which the respective issue was reported

(Table 7). The harsh and time-consuming nature of the herding tasks, the general thrive of society for a more comfortable lifestyle, low prices for animal products and the diminishing trend to organize livestock keeping as a family business were also mentioned very often, especially in Chapurson and Shimshal, and to a lesser extent in Phandar, Hopar and Khaplu. Poor physical infrastructure and difficult access to remote pastures due to dangerous terrain were identified as reasons for strenuous and long treks to grazing areas in Shimshal and Chapurson and reportedly reduced family members' willingness to accompany the animals. Besides, the percentage of individuals engaged in mountaineering expeditions for tourists was considered high in Shimshal and Hopar, reducing workforce available for herding tasks. To this added an increasing interest of the younger generation and other (non-herding) family members to study and pursue other work, eventually resulting in acute shortage of herders and a decreasing number of people engaging in year-round livestock keeping. The last aspects were especially underlined by interviewees in Chapurson, Khaplu and Phandar. Rearranging school schedules to free more time for young herders, and organizing specific programmes to teach and train herding tasks, providing in-kind or cash rewards to young herders for performing the herding duty by governmental or non-governmental organizations, promoting joint (group or village) herding, and establishing appropriate markets for livestock products were identified as suitable mitigation strategies by the respondents (Table 7). Low productivity of mountain pastures, changes in rangeland utilization patterns, such as too early start of spring grazing or too long summer grazing on high altitude pastures, spatially concentrated grazing, and conversion of low-lying spring and late autumn pasture areas into farmland were depicted as important problems of rangeland management. Pasture rehabilitation plans and the introduction of pasture utilization fees on the basis of animal units were among the proposed counter-measures (Table 7). The latter measure is already practised in Shimshal, where the collected fees are used to pay for joint herding, maintenance of pastures and of installations such as corrals or pens. Further proposed solutions included the establishment of guidelines for (mountaineering) tourists and of policies for communal land use that prevent conversion of pastures into farmland. Lastly, herders of Shimshal also suggested that providing access to historical pasture areas along and across the international border with China could reduce pressure on the valley's rangelands.

Discussion

Livestock and grazing management

During the past decades, livestock husbandry systems in Gilgit-Baltistan underwent multiple and changing social-ecological conditions as well as the respective management responses of livestock keepers have been documented in detail (Nüsser et al. 2012; Kreutzmann 2015). Especially in regions characterized by a high spatial variability of rangeland primary production and inter- as well as intra-annual variation in climatic and weather conditions, herders seek to optimize the use of rangeland resources by carefully choosing season-specific grazing areas (Roe et al. 1998; Ehlers and Kreutzmann 2000; Krätli et al. 2013; Kreutzmann 2015; Schlecht et al. 2020). Herd mobility, seasonal as well as diurnal, is a key strategy in this respect and allows dealing with the great spatio-temporal variation in feed quality and availability (Dost 2003; Kreutzmann 2011; Turner and Schlecht 2019). Knowledge of the spatial heterogeneity of rangelands, and of the botanical composition and season-specific forage offer of particular grazing areas, is therefore essential for herders' management decisions. Furthermore, mobility patterns of herds reflect livestock owners' year-long herding experience, as well as tradition, cultural and social factors, intra- and inter-household cooperation and communal agreements on rangeland management (Kreutzmann 2004, 2009, 2015; Parajuli and Paudel 2016). Other aspects are the physical accessibility of pastures, water availability and presence or absence of predators (Rasool et al. 2000; Dangwal 2009; Khan and Rahman 2009), which in the study area mainly consisted of foxes, wolves and very rarely leopards.

The average distance of movements to the seasonal pastures and the time period herders spent there to herd different animal species indicated that supervision time was first allocated to the most important livestock species, namely yak, in Hopar, Phandar and Chapurson. Time spent by herders on seasonal pastures of small ruminants and cattle varied widely between valleys and seasons but was not markedly different from the sojourn time of yak herders during the summer season. This is due to the fact that at that moment all species grazed the high altitude summer pastures that are far away from the settlements (Ehlers and Kreutzmann 2000; Kreutzmann 2015). Next to remoteness, the practice of milking and milk transformation as well as other tasks at temporary campsites and adjacent hay-making plots also affect herders' time on seasonal pastures (Mishra et al. 2001; Parajuli et al. 2013). Furthermore, activities in the family's permanent settlement where crop cultivation and harvest require repeated visits during the vegetation period (Ehlers and Kreutzmann 2000; Kreutzmann 2015) shorten the pasture sojourn time of herders as compared to that of their livestock. As far as the daily surveillance of livestock on the seasonal pastures was concerned, a high proportion of fully herded animals was found in Hopar, Chapurson and Phandar during all seasons and in Khaplu during spring and autumn. In contrast, unattended spring and summer season grazing was predominantly found in yaks at Haramosh and Hopar. A high share of supervised herds underlines the importance of the specific livestock for the households and sufficient labour availability (Kreutzmann 2015; Wu et al. 2016). Unattended grazing of livestock, in contrast, greatly reduces diurnal herd mobility and may increase stocking densities around campsites (Turner et al. 2005; Altmann et al. 2018; Turner and Schlecht 2019) but also enhance the risk of livestock mortality through predation (Sangay and Vernes 2008).

Lack of a year-round availability of herding labour, in particular of skilled and experienced persons, was a frequently mentioned problem in the (group) interviews; to this adds the hardship and time-demanding facet of this task. Other studies from Buthan (Derville and Bonnemaire 2010) and Gilgit-Baltistan (Jasra et al. 2016) also revealed that instances increase where grazing animals are supervised by less experienced herders or persons allocating little time to herding. According to our respondents, the regional labour shortage problem emerged with the establishment and expansion of the road network and reliable market links in the last decade of 20th century, and the introduction of educational reforms in the early twenty-first century (Kreutzmann 2015). In agreement with Wu et al. (2014), the interviewees also observed that members of the younger generation are often reluctant to concentrate on herding as a profession. This is especially due to the fact that remuneration of mountain agriculture, and in particular of pastoral activities, is often low in comparison to off-farm activities and in view of the hard physical work and long working hours (Kreutzmann 2013; Legeard et al. 2014; Schlecht et al. 2020). Similarly, already three decades ago, a study from northern India suggested that the observed decline in yak numbers was due to the desire of the younger generation for an easier and more relaxed lifestyle (Pal 1993). Group herding of several families' livestock is a proven way to overcome labour shortage (Schlecht et al. 2020), enhancing the livestock keepers' flexibility to adjust to specific socio-economic conditions (Ehlers and Kreutzmann 2000; Davies and Hatfield 2007; Kreutzmann and Schütte 2011; Li and Huntsinger 2011). For instance, in Chapurson valley, when principal herders had to work on their agricultural land during parts of spring and summer season, they arranged for a substitute herder to supervise their animals. While in CHK group herding was an established scheme, diverse herding strategies were also combined in HPS that did not only involve the main herder but also other family members as well as hired herders from outside the community or were partly organized as a larger group's task, which agrees with reports by Kreutzmann (2015). While group herding bears the advantage of reducing labour costs and, if practised in a team, enhances flexibility of the involved livestock keepers in case of emergency, potential challenges are its reliable implementation, equal distribution of tasks across all group members, knowledge sharing, leadership and agreement on rules such as on day-to-day herd management and movements (Altmann et al. 2018; Ulambayar and Fernández-Giménez 2019; Schlecht et al. 2020).

Rangeland utilization patterns

On average, the estimated seasonal stocking densities on medium (spring) and high (summer) altitude pastures ranged from values <0.1 SU*d/ha to 7.5 SU*d/ha across the studied valleys and livestock species. These values compare well with seasonal stocking densities on mountain pastures in Mongolia reported by Jordan et al. (2016) and Altmann et al. (2018). Furthermore, the estimates are also in line with optimal seasonal stocking densities elaborated by Dong et al. (2015) for alpine grassland of the Qinghai-Tibetan Plateau in China. However, one has to be careful when interpreting the estimated seasonal stocking densities: on the one hand, spring and summer seasons in particular were not clearly defined with respect to their start and end, as explained in the methods' section. On the other hand, attribution of a certain grazing area to a specific family or group does not mean that no other animals can graze in this area, because all pastures are common land (Kreutzmann 2015). Nevertheless, participatory mapping exercises have successfully been used elsewhere to assess rangeland utilization patterns and stocking densities (Turner et al. 2005; Bauer 2009; Wario et al. 2015; Altmann et al. 2018); therefore, the present values may serve as indicators for mountain pasture areas threatened by degradation processes due to high use intensity (Altmann et al. 2018). The species-specific differences in seasonal stocking densities determined in our study valleys can be explained by differences in livestock numbers, surface of assigned pasture areas and herding modes. Yaks are often given ample time to graze and distribute on pastures during the day, as they are released earliest and brought back last when managed in herd-release mode (Mishra et al. 2001; Ali and Butz 2003; Kreutzmann 2012). This was also observed in Khaplu and Shimshal valleys where herd-release mode prevailed for yaks, which were oriented to a particular pasture in the morning after which herders attended to small ruminants for the rest of the day. Cattle were frequently grazed on pastures near permanent homes or campsites where cows could be milked easily, with the area of those pastures being often small and of limited carrying capacity (Kreutzmann 2012; Barsila et al. 2015). Furthermore, high stocking densities were also estimated for yaks and small ruminants on (mid-altitude) spring (as well as autumn) pastures in various studied valleys. This can be explained by the presence of snow at higher elevations in these seasons, which constrains herd movements (Kreutzmann 2012, 2015; Du et al. 2017). To this add a relatively lower biomass offer and reduced grazing time due to shorter day length in these seasons as compared to summer (Kreutzmann 2012, 2015; Miao et al. 2015). In consequence, warm-season (that is summer) pastures can often tolerate higher stocking densities than dry and cold season alpine grasslands (Dong et al. 2015). In this context, it must be admitted that a major shortcoming of our study is the lack of data on forage biomass offer at the different seasonal pastures: while Altmann et al. (2018) combined participatory mapping of animals' grazing areas with determination of biomass production, this was not feasible in the current study where not just one site and one season but a multitude of sites and all season of the year were covered by the mapping approach.

When relating the share of lightly and heavily stocked areas to the percentage of yaks and small ruminants that were fully herded or managed in herd-release mode, respectively, it appeared that spring and summer season herding of yaks resulted in a fairly even distribution of animals on pastures. Accordingly, the estimated high values for spring and summer season stocking densities of unattended yaks in Haramosh confirm observations of Turner et al. (2005) on effects of unattended grazing; in this particular valley, they were promoted by high animal numbers and a spatially restricted grazing area. Surprisingly, a high percentage of heavily stocked areas was also found where herding of small ruminants prevailed, while lower estimates of small ruminant stocking densities were related to the herd-release and unattended grazing modes. The latter was best exemplified in Shimshal where, across seasons, low stocking densities were determined for a system dominated by herd-release mode. In Hopar, where reportedly more than 95% of small ruminants were herded during spring season, high stocking densities were primarily due to the limited area available for grazing, confining animals to the vicinity of livestock keepers' homes. Despite the above-mentioned lack of biomass data, tolerating an overlap of the grazing areas of different ruminant species or even grazing them together may enhance pasture utilization and reduce the burden of herding (Kreutzmann 2011; Kreutzmann et al. 2011; Khan et al. 2013). Multi-species grazing improves exploitation of forage resources, with bulk and roughage feeders (cattle, yaks), selective grazers (sheep) and intermediate browsers (goats) utilizing different feeding niches (Van Soest 1994, Dumont et al. 2020). It has been demonstrated recently that multi-species grazing supports higher stocking densities on temperate (lowland) grasslands than grazing with only one species (Dumont et al. 2020; Jerrentrup et al. 2020).

Challenges of rangeland utilization

Many of the interviewed herders perceived pasture conditions as poor due to heavy stocking, much of which was traced back to the unavailability of herding labour and in particular skilled labour, but also to time constraints and herders' leisure behaviour. Another factor mentioned in Shimshal and Chapurson was the (historical) closure of the national borders with China that restricts herd mobility since many decades already (Kreutzmann 2015). In line with other studies (Uniyal et al. 2005; Bagchi and Ritchie 2010; Singh et al. 2013; Kreutzmann 2015; Jasra et al. 2016), regionally increasing off-farm income earning opportunities were also identified as a challenge to sustainable herd and rangeland management. For the latter aspect, also climatic constraints were relevant: at middle-elevation catchments of the Karakoram, streamflow of the Indus tributaries is primarily controlled by (high) winter snow inputs at high altitudes (Forsythe et al. 2017). Very warm temperatures during the study period (July 2018) provoked accelerated snow melting and increased water flow rate in the downwards streams so that herders of Shimshal could not cross these with their animals to reach the high altitude summer pastures. They were thus forced to graze their livestock in a restricted mid-altitude valley for a few weeks (first author's own observation). Other studies confirmed that climate change enhances the pressure on the already dwindling yak populations by reinforcing degradation of high-altitude pastures and enhancing shortage of feed (Gyamtsho 2000; Maiti et al. 2014). Further causes of pasture degradation perceived by the herders and confirmed by literature were the increase in livestock numbers (Government of Gilgit-Baltistan 2020), lack of well-defined grazing regulations or lack of their stringent implementation (Schmidt 2000; Jasra et al. 2016), changing rangeland utilization patterns such as too early start of spring grazing or too long summer grazing on high altitude pastures and in consequence prolonged periods of high livestock numbers in these areas, which can accelerate rangeland degradation (Alvi and Sharif 1995; Beg 2010; Khan et al. 2013). The different mitigation measures proposed by the interviewees were mainly calling for action of governmental or non-governmental organizations, a proposition also witnessed in other pastoral contexts (Tenzing et al. 2017; Soma and Schlecht 2018). Yet, especially in Shimshal, own initiatives of the herders seemed to effectively address some of the challenges related to sustainable rangeland management.

Conclusion

Based on participatory approaches, the current study investigated if different modes of livestock management, and in particular herding, impact the utilization of high mountain pastures in six different valleys of Gilgit-Baltistan, and which constraints the herders are facing in this regard. It appeared that lack of (herding) labour is perceived as a major constraint, which is often mitigated by employing waged labour or organising group herding. However, allocating herding time to livestock did not necessarily lead to a spatially homogenous distribution of grazing animals, because the herders in charge needed to survey different animal groups at a time. Such constraints enhance the risk of rangeland degradation and consequently challenge the sustainability of the current livestock systems. Offering training programmes to interested young herders, strengthening group herding schemes, developing attractive markets for livestock products, collecting pasture utilization fees for investment in rangeland management and implementing policies that prevent farmland conversion of pastures near settlements could effectively address the constraints of grazing high mountain rangelands in Gilgit-Baltistan and neighbouring regions.

Abbreviations

C: Cattle; CHK: Chapurson, Haramosh and Khaplu; FGDs: Focus group discussions; HPS: Hopar, Phandar and Shimshal; SEM: Standard error of the mean; SR: Small ruminants; SU: Sheep unit; Y: Yaks.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13570-022-00253-5.

Additional file 1: Appendix Table 1. Time needed to reach pastures, time spent on herding and proportion of herders attending yaks (Y), small ruminants (SR) and cattle (C) on spring and summer pastures in six valleys of Gilgit-Baltistan. Values depict arithmetic mean and standard error of the mean. **Appendix Table 2.** Proportion (%) of yaks, small ruminants and cattle managed in herded and herd-release mode[1] on autumn and winter pastures in six valleys of Gilgit-Baltistan. **Appendix Table 3.** Area grazed (ha) in autumn and winter season per flock[1] of yaks (Y), small ruminants (SR) and cattle (C) in six valleys of Gilgit-Baltistan. Values depict arithmetic mean and standard error of the mean (SEM). **Appendix Table 4.** Seasonal stocking densities (SU*d/ha) of yaks (Y), small ruminants (SR) and cattle (C) on autumn and winter pastures in six valleys of Gilgit-Baltistan. Values depict arithmetic mean and standard error of the mean (SEM).

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Authors' contributions
AB and ES secured funding and conceptualized the study; AB, AH and ES developed the methodology. AH carried out fieldwork under supervision of MT; AH also analysed all data and compiled the manuscript's first version, with supervision provided by ES. ES completed the manuscript writing after AH passed away. AB and MT contributed to the manuscript with substantial comments, suggestions and edits. AB, MT and ES read and approved the final draft of this manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials
Descriptive statistics of all data generated or analysed during this study are included in this article and its supplementary information files. Detailed data will be provided upon request by email to the corresponding author.

Declarations

Ethics approval and consent to participate
This research received an ethics approval from the ICDD, consent from Gilgit-Baltistan Livestock and Dairy Development Department and a research permit from the Government of Gilgit-Baltistan (No-Misc-44/2850-95-2018). The research included survey and interview data. Before conducting interviews, all interviewees were informed about the purpose of the research and how the results would be used; they were only interviewed upon oral consent to participate. The database was entirely anonymized before analysis.

Consent for publication
The widow of late Asif Hameed gave written consent that this manuscript can be published, which was drafted as part of his PhD thesis.

Competing interests
The authors declare that they have no competing interests.

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