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Spatio-temporal patterns of herbage availability and livestock movements: A cross-border analysis in the Chinese-Mongolian Altay

Greta Jordan[2], Sven Goenster[2], Tsevegmed Munkhnasan[3], Alimu Shabier[4], Andreas Buerkert[2] and Eva Schlecht[1*]

Abstract

Due to increasing population and the recent implementation of policies to intensify the use of land and water resources, the transhumant pastoral systems in the Chinese-Mongolian Altay-Dzungarian region are rapidly changing, leading to modifications of herd size, herd composition and spatial distribution of livestock grazing. This may have major consequences for the supply and quality of rangeland biomass. Despite similar topographic settings, the socio-political framework for Chinese and Mongolian pastoralists differs significantly, leading to differences in rangeland utilization. To substantiate these claims, the long-distance transhumance routes, frequency of pasture changes, daily grazing itineraries and size of pastures were recorded by means of GPS tracking of cattle and goats on 1,535 (China) and 1,396 (Mongolia) observation days. The status quo of the main seasonal pastures was captured by measuring the herbage offer and its nutritive value in 869 sampling spots.

In the Altay-Dzungarian region, small ruminant herds covered up to 412 km (Mongolia) and grazed on up to nine pastures per year (China). In Mongolia, the herds' average duration of stay at an individual pasture was longer than in China, particularly in spring and autumn. Herbage allowance at the onset of a grazing period (kg dry matter per sheep unit and day) ranged from 34/17 to 91/95 (China/Mongolia). Comparing crude protein and phosphorous concentrations of herbage, in China, the highest concentrations were measured for spring and summer pastures, whereas in Mongolia, the highest concentrations were determined for autumn and winter pastures.

Based on our data, we conclude that regulation of animal numbers and access to pastures seemingly maintained pasture productivity in China, especially at high altitudes. However, this policy may prohibit flexible adaptation to sudden environmental constraints. In contrast, high stocking densities and grazing of pastures before flowering of herbaceous plants negatively affected rangeland productivity in Mongolia, especially for spring and summer pastures.

Keywords: Altay Mountains, Cattle, Goats, GPS tracking, Grazing itineraries, Herbage allowance, Transhumance

Background

In the Chinese and Mongolian Altay-Dzungarian region, the prevailing harsh continental climate with its periodic severe winters, called *dzud* in the Mongolian language, is considered to be a major challenge for local herders, and lead over centuries to a well-adapted animal husbandry system characterized by a high degree of herd mobility and herder flexibility in both countries (Morrison 1999; Behnke et al. 2011; Liao et al. 2014b; Reid et al. 2014; Middleton et al. 2015). While the topographic conditions of the Altay-Dzungarian region are similar on both sides of the Mountain range, the social and economic context of Chinese and Mongolian pastoralists could hardly be more different. This reflects the different historical-cultural background as well as the significant political and economic transformation processes of the last decades, which severely challenge the transhumance system in both

* Correspondence: tropanimals@uni-kassel.de
[1]Animal Husbandry in the Tropics and Subtropics, University of Kassel and Georg-August-Universität Göttingen, Steinstr. 19, 37123 Witzenhausen, Germany
Full list of author information is available at the end of the article

countries (Angerer et al. 2008; Liu et al. 2013; Hilker et al. 2014; Liao et al. 2014b; Martin et al. 2014).

During the last decades in the Chinese part of the Altay-Dzungarian region, laws and policies were implemented to intensify livestock production while reducing the rate of land degradation (Brown et al. 2008; Conte and Tilt 2014; Gongbuzeren et al. 2015; Hua and Squires 2015). Measures directly affecting the transhumance systems included state-sponsored fencing programmes and regulations on herd management such as herd size and duration of pasture utilization (Brown et al. 2008; Yeh 2009). Other political programmes aimed at the settlement of pastoralists (Harris 2010; Hua and Squires 2015). Besides such planned interventions in the transhumance system, increasing urban expansion, intensified cropping and local mining activities progressively hamper the accessibility of rangeland (Squires et al. 2009; Kreutzmann 2013a; Conte and Tilt 2014; Liao et al. 2014b).

In the Mongolian part of the Altay-Dzungarian region, privatization of the formerly state-owned livestock triggered an increase in livestock numbers and a change in herd composition (Lise et al. 2006; Lkhagvadorj et al. 2013b; Lkhagvadorj et al. 2013a; Saizen 2013). Additionally, the transition from a centrally planned to a market economy put considerably more responsibility on individual herders for careful use of pasture resources, access to markets, maintenance of infrastructure for seasonal movements and watering places and preparation of winter fodder (Janzen 2005; Fernández-Giménez and Le Febre 2006; Zhen et al. 2010). Nevertheless, informal/traditional norms allow Mongolian pastoralists to use pastures flexibly to cope with climate hazards (Upton 2010; Fernández-Giménez et al. 2011; Addison et al. 2013; Saizen 2013).

Recent rangeland studies in both countries mainly focused on different interacting drivers of declining herbage yields and herbage quality such as increasing livestock numbers, changes in livestock species, reduction of livestock mobility, reduction of affordable and good quality winter fodder, privatization of rangeland, alteration of traditional rangeland management, rural labour outmigration to cities and changing climate either in China or in Mongolia (Glindemann et al. 2009; Kakinuma et al. 2013; Liu et al. 2013; Yamamura et al. 2013; Bruegger et al. 2014; Hilker et al. 2014; Ma et al. 2014; Khishigbayar et al. 2015). Despite marked differences between China and Mongolia, both countries struggle with designing effective rangeland strategies, policies and programmes that allow to sustain rangeland productivity on the basis of fine-tuned pasture management and planning for disaster mitigation (Addison et al. 2012; Sasaki et al. 2012; Schönbach et al. 2012; Kreutzmann 2013a; Wang et al. 2013; Hilker et al. 2014; Khishigbayar et al. 2015).

To the best of our knowledge, the present case study is the first to undertake a three-year-long comparison of rangeland utilization strategies between China and Mongolia by means of GPS tracking of herds and concomitant determination of herbage offer and quality. We hypothesized that, despite similar natural conditions, the differences in recent socio-political and socio-economic developments on both sides of the border have a large impact on the local transhumance systems in the Altay-Dzungarian region and on rangeland utilization as indicated by herbage offer and quality. To test this hypothesis, the present case study aimed at (i) examining the spatio-temporal mobility patterns of pastoral herds including long-distance transhumance routes and daily grazing itineraries, number of utilized pastures and size of pastures and (ii) monitoring the herbage offer and its nutritive value on the main seasonal pastures in both countries.

Study area

The study was conducted in Qinghe county, Xinjiang Uyghur Autonomous Region, China (area, 15,760 km^2; inhabitants, 64,300; livestock number, 286,500; 2011) and in Bulgan county, Khovd province, Mongolia (area, 8,105 km^2; inhabitants, 9,018; livestock number, 154,058; 2012), which are only about 100 km apart. Both comprise parts of the central Altay Mountains and the Dzungarian Desert Basin (45° to 47° N, 89° to 91° E). In the administrative centres of both counties, which are located in the transition zone between the mountain range and the basin, long-term average minimum/maximum annual air temperatures of −34/24 °C for China (1958 to 2007, Qinghe 46°40′28 N, 90°22′59 E, 1,253 m) and −32/26 °C for Mongolia (1963 to 2014, Bulgan, 46°05′19 N, 91°32′41 E, 1,182 m) were recorded. The average rainfall per year amounts to 174 mm (standard deviation (SD) 50) and 75 mm (SD 34) with a coefficient of variation of 29 % and 45 %, respectively. During the study period (2013 to 2014), the annual air temperature and the annual rainfall averaged 3 °C and 162 mm in Qinghe compared to 4 °C and 50 mm in Bulgan, respectively. In contrast to the drier conditions in the desert steppe, the relatively wetter climate at the alpine belt was characterized by an average minimum/maximum annual air temperature of −33/26 °C in China (C) and −40/23 °C in Mongolia (M) and an average annual rainfall of 160 mm (C) and 305 mm (M) at an altitude of 2,121 m (C) and 2,432 m (M), respectively (Figure 1).

Over millennia, the environmental conditions of the study area shaped a pastoral system that can be described as classical mountain nomadism with seasonal transhumance between pastures in the desert steppe (C, from 1,194 to 1,366 m; M, from 1,528 to 1,938 m - winter); mountain steppe (C, from 1,432 to 1,576 m; M, from 1,603 to 2,025 m - spring; C, from 1,031 to

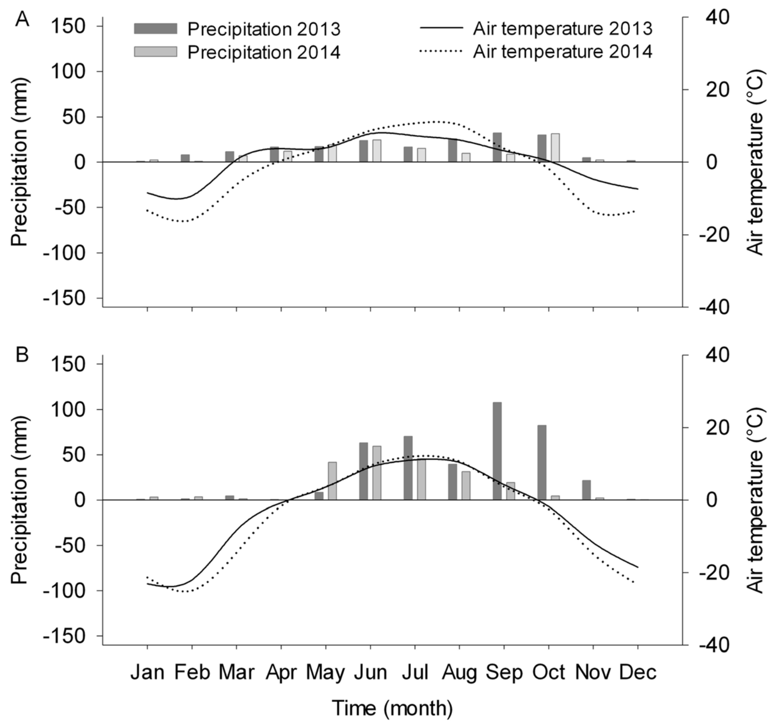

Figure 1 Average monthly precipitation amount (mm) and air temperature (°C) of the Chinese (**a**, at an altitude of 2,121 m) and the Mongolian summer pasture (**b**, at an altitude of 2,432 m) in the alpine belt of the Altay Mountains in 2013 and 2014

1,328 m - autumn); floodplains of the Bulgan river in Mongolia (from 1,133 to 1,161 m - autumn); and the alpine belt (C, from 1,981 to 2,943 m; M, from 2,392 to 3,097 m - summer). To facilitate comparison between years and countries, each season's length was set at three months.

In China, the spring and autumn pastures are characterized by the *Stipa caucasica* and *Anabasis brevifolia* community and the *Halimodendron halodendron* and *Convolvulus gortschakovii* community, respectively. The *Agropyron cristatum* community; the *Festuca ovina*, *Festuca altaica* and *Phlomis tuberosa* community; and the *Juniperus sabina* and *Larix sibirica* community prevail in the summer pasture. Whereas, the *S. caucasica* and *A. brevifolia* community and the *Nanophyton erinaceum* community are predominant in the winter pasture. In Mongolia, the *Caragana leucophloea* community prevails in the spring pasture, the summer pasture is characterized by the *A. cristatum* community and the *F. altaica* community, and the autumn pasture by the *Salix turanica*, *Caragana spinosa* and *Populus laurifolia* community and the *Phragmites australis* community. The *S. caucasica* and *A. brevifolia* community dominates in the winter pasture.

Transhumant pastoralism in the Chinese as well as in the Mongolian Altay-Dzungarian region is characterized by resembling a consistent sequence of seasonal pastures and comparable soil properties (Jordan et al. 2015). Besides similar geographic settings, the Chinese and Mongolian study region is also characterized by a similar sequence of seasonal pastures, spatially fixed for generations. The spring pastures in desert steppes or at mountain foothills are of major importance for the herds' reproduction. In summer, the animals graze at the alpine meadows. At the summer pastures, higher precipitation amounts and soils richer in organic carbon and nutrients favour higher herbage yields and quality, which is of importance to fatten the animals and for dairy production. Decreasing temperatures in autumn force herds to move back to flood plains and desert steppes which play an important role for building up further body reserves for the winter. Winter pastures at the desert steppes feature relatively low biomass yields, but their accessibility is ensured due to relatively low snow cover; nevertheless, late winter and early spring are known as bottlenecks of animal nutrition.

Even though the agro-ecological environment is similar, the political context could not be more different. In the Chinese Altay-Dzungarian region, the start date for transhumance movements to any seasonal pasture (pastures used only in a specific season, i.e. spring, summer, autumn and winter), the duration of stay on a pasture, the location and size of a household's pastures and the animal numbers per household are defined by the local government (Squires et al. 2010). A (household's) pasture is always in state ownership and in the study region is normally an unfenced but clearly delimited rangeland management unit for grazing assigned to an individual herder household; in the whole of Qinghe county, there was only one fenced winter pasture for cattle. Representatives of the local government followed the herders year-round to ensure their compliance with the mentioned regulations. However, the prescribed dates of transhumance movements to the seasonal pastures were often circumvented by sending un-herded livestock ahead (especially cattle, horses and camels). In Mongolia, in contrast, the timing of transhumance movement is determined by social and environmental factors (start of school holidays, weather conditions, herbage yield and water availability). The compliance with regulations of traditional rangeland utilization and the number of animals kept are largely self-controlled by the individual herder and a communally nominated 'major' herder elected by the local herders themselves (Upton 2010).

In the study region, most livestock herds consist of sheep and goats complemented by cattle and horses, and sometimes by camels or/and yaks. Bovids on both sides of the border are of the same types, namely fat-tail sheep, cashmere goats and Turano-Mongolian cattle. Each livestock species grazes separately, except for sheep and goats. None of these animals are actively herded; only sheep and goats are sporadically checked to assure the utilization of assigned (on the basis of governmental or traditional regulations) pasture and to avoid mixing of different herds. In the early evening, sheep, goats and cattle return to the herder's camp. During winter, the livestock herds are separated into cattle herds and other livestock (goats, sheep, horses and camels). The cattle stay in the floodplains in the vicinity of villages, whereby in China some of them grazed in a fenced plot, and receive additional fodder in form of hay, while the remaining livestock is moved far into the desert plain.

Methods

Livestock-related data collection

From a previous baseline survey covering >150 herder households in each country (Munkhnasan et al. 2014), it appeared that groups of 30 to 50 or even more families utilized the same seasonal pastures and connecting tracking routes. From the baseline survey households, one typical herder family per country was chosen and asked for its willingness to participate in the current study. This family practised the classical seasonal transhumance between lowland and mountain pastures and its herd was of average size and country-specific species composition. From May to September, its pastoral movements were personally accompanied. The study herder in China was of Kazakh ethnicity (as all other herders in the study region), whereas in Mongolia the study herder was Mongolian (Torguud tribe, the predominant ethnicity in the study region). Between 2012 and 2014, the herd studied in China averaged 428 sheep units (SU) with a SD of 43 (cattle = 125, goats = 21, sheep = 242, horses = 40, camels = 0) and that in Mongolia 1,004 SU (SD 117; cattle = 342, goats = 173, sheep = 190, horses = 263, camels = 37), whereby one cattle equals 5 SU, one goat 0.9 SU, one sheep 1 SU, one horse 5 SU and one camel 7 SU (Zizhi and Degang, 2011). Differences between both countries were particularly large for the number of sheep (C, $n = 242$; M, $n = 190$) and goat heads (C, $n = 23$; M, $n = 192$).

Given the importance of cattle and goats for the provision of food and income to the herder families, and their major economic and social value, GPS tracking of livestock was limited to these two species. Butt (2010) and Moritz et al. (2012) reported that one GPS-tracked animal per herd may be sufficient to study the general movements and grazing patterns of the entire herd over long periods of time. Therefore, per herd, one representative female cow and male goat, both of middle social rank, were equipped with a GPS collar (GPS PLUS Globalstar, VECTRONIC Aerospace GmbH, Berlin, Germany) to record the herd's temporal and spatial mobility. Date, time, altitude, longitude and latitude were stored at 1-min intervals from May to September and at 16-min intervals from October to April in the years 2012, 2013 and 2014. From May to September, each animal was carrying the collar for a minimum of three days per seasonal pasture, whereas from September to May the collared animals were tracked continuously. In addition, the transhumance routes between the seasonal pastures were tracked. This resulted in a total track number of $n_{\text{Cattle}} = 602$ and $n_{\text{Small ruminants}} = 933$ in China and $n_{\text{Cattle}} = 644$ and $n_{\text{Small ruminants}} = 752$ in Mongolia. The difference in track numbers between both countries and species is explained by accidental discharge of battery before the end of an observation period and the temporary loss of one GPS collar. For the calculation of the length and duration of transhumance movements and the duration of stay on pastures, missing GPS data were substituted by herder's information. During the first year of study, a brief survey on animal numbers, way of transportation to seasonal pastures and course of transhumance routes was conducted along the main transhumance axis on each side of the border.

Sampling and chemical analysis of above-ground herbaceous biomass

At each seasonal pasture, herders were asked (with the help of satellite images) to which pasture they would move next; subsequently, the pasture was visited for herbage sampling before the herders' actual movement.

Prior to the herders' arrival at each seasonal pasture, the initial above-ground herbaceous biomass was determined. At each seasonal pasture, a regular grid of 500 m × 500 m and a list of the GPS coordinates of each grid point (=sampling point) was created in QGIS 1.4 (Quantum GIS Development Team, 2010, QGIS Geographic Information System, Open Source Geospatial Foundation Project). At each of these sampling points, which in the field were located by a hand-held GPS device (HOLUX M-241, Holux Technology Inc., Hsinchu, Taiwan), a spot with representative herbaceous cover and composition was chosen within a radius of 4 m. Then a sampling frame (50 cm × 50 cm) was placed on the ground, and the above-ground herbaceous vegetation was clipped to 1 cm above the soil surface, whereby dead plant material was excluded. Additionally, further spots were sampled at every 500 m along the itinerary of the GPS-collared cattle and goat. The number of sampled spots per pasture was set on the basis of the herbage heterogeneity of each pasture.

In total, 869 spots (C, $n = 359$; M, $n = 510$) were sampled for the main spring, summer, autumn and winter pastures. Whereas the measurements on the pastures took place from 2012 to 2014, those along the animals' itineraries were restricted to 2013 and 2014. Due to logistic constraints, measurements at the winter pastures took place in September, although pastures were not grazed until November/December; all other measurements were made during the utilization period of the respective pasture. At each spot, the vegetation and stone cover, mean vegetation height ($n = 3$) and occurrence of functional plant groups (grasses, herbs and shrubs) were assessed. However, these parameters are not considered in the current study. In addition, environmental variables (altitude, aspect) and the GPS position were measured.

After the total fresh weight of herbaceous biomass was determined directly in the field (portable electronic balance, range 0.1 to 1,000 g, precision 0.1 g), the samples were dried at 60 °C until constant weight to determine the dry weight of above-ground biomass; this mass (available at the start of the grazing season) is further referred to as 'herbage offer' (Allen et al. 2011). Following grinding to 1-mm particle size (FOSS sample mill, Cyclotec™ 1093, Haan, Germany), all samples were read with a XDS-Rapid Content Analyzer NIRsystem (FOSS NIRsystems, Hillerod, Denmark).

The concentrations of dry matter (DM) after drying to weight constancy at 105 °C, of organic matter (OM) after combustion at 550 °C and of phosphorus (P) and calcium (Ca) were determined in a subset of 290 samples following standard procedures (Naumann and Bassler 2004). Using a semi-automated Ankom 200 Fiber Analyzer (Ankom Technology, Macedon, NY, USA), a subset of 179 samples was measured for the concentration of neutral detergent fibre (NDF) and acid detergent fibre (ADF) according to van Soest et al. (1991) following the procedure of Schiborra et al. (2010). Carbon (C) and nitrogen (N) concentrations were determined by a CN analyser (Vario MAX CN; Elementar Analysensysteme GmbH, Hanau, Germany). On the basis of a calibration model (NDF $R^2 = 0.87$, standard error of cross-validation (SECV) = 43 g kg^{-1} DM; ADF $R^2 = 0.90$, SECV = 31 g kg^{-1} DM; N $R^2 = 0.94$, SECV = 1.5 g kg^{-1} DM; OM $R^2 = 0.88$, SECV = 21 g kg^{-1} DM; P $R^2 = 0.72$, SECV = 30 g kg^{-1} DM; Ca $R^2 = 0.95$, SECV = 25 g kg^{-1} DM), the concentration of the respective chemical fractions was predicted in the remaining samples (Reddersen et al. 2013). The concentration of crude protein (CP) was calculated based on the N concentration (CP = N × 6.25, Allen et al. 2011). The above-mentioned parameters were used for the evaluation of the nutritive value of the vegetation ('herbage quality').

Data processing and statistical analysis

All GPS raw data obtained from the tracked animals were corrected for outliers (GPS positions estimated from only three satellites) as well as failed GPS readings (GPS positions were estimated from <3 satellites) and were subsequently merged per season (spring, summer, autumn and winter) and animal species. All data were processed using the software packages ArcGIS 9.2 (ESRI Corp., Redlands, CA, USA) and QGIS; coordinates were converted to UTM grid projection (WGS 1984, 46 N). The horizontal distance covered in long-distance transhumance movements was calculated using Hawth's Analysis Tools extension for ArcGIS. For the calculation of the 'daily walked distance', the horizontal distance was divided by the number of tracking days. On the basis of the GPS tracks, the number of utilized pastures was counted and the duration of stay (time between date of arrival and departure) was determined. A buffer with a 50-m width to both sides of the collared animal's itinerary was placed along the merged tracks. The surface of the resulting area was calculated and defined as 'theoretical utilized pasture area' for the entire small ruminant and cattle herd (Feldt and Schlecht 2016). The theoretical utilized pasture area was divided by the herd's duration of stay to determine the 'theoretical utilized pasture area per day'. The herbage offer and selected herbage quality data (NDF, CP and Ca:P ratio) were spatially interpolated by the Inverse Distance Weighting Method in QGIS 1.4 using a distance coefficient of three. Selected properties of the seasonal pastures as well as of the species-specific theoretical utilized pasture area were extracted from the interpolated herbage offer and herbage quality map.

On the basis of SU in a given theoretical utilized pasture area, the 'herd-related stocking density' (SU ha^{-1}) was calculated. For estimations of stocking densities/stocking rates, the livestock of other herders were neglected, due to the fact that either grazing areas were far off each other or herders confirmed their exclusive utilization of assigned pastures. For the calculation of the 'herd-related stocking rate' (SU * season ha^{-1}), the SU were divided by the summed theoretical utilized pasture area and subsequently multiplied by the length of season (three months). The 'daily herbage allowance per SU' was calculated based on the herbage offer at the pasture divided by the number of SU and duration of stay at the pasture. For the estimation of herbage allowances, autumn and winter data were combined to compare small ruminants and cattle, since cattle stayed on the same pasture during autumn and winter. To assure comparability of the calculation of stocking density and stocking rate as well as herbage allowance across the two countries, the SU of sheep and goats were summarized and defined as 'small ruminants' as they were continuously herded and managed together.

All resulting data were compared between locations (China, Mongolia), species (cattle and goat for GPS tracks; cattle and small ruminants for herbage-related data) and seasons (spring, summer, autumn and winter). To assess the statistical relations between herbage offer and quality data and GPS-tracked data, the non-parametric Spearman's rank correlation coefficient (r_s) was calculated. Statistical analyses were performed with RStudio Inc. (Version 0.98.1103, Boston, MA, USA); differences were viewed as statistically significant at $P \leq 0.05$.

Results

Seasonal herd movements and pasture utilization

The altitude range captured within the seasonal transhumance movement varied between 1,031 and 2,943 m (China) and between 1,122 and 3,097 m (Mongolia). The overall annual distances covered by seasonal movements were similar between the countries whereas across countries differences were observed between cattle and small ruminant herds due to different management practices. The average (2012 to 2015) annual length of transhumance routes serving the movements between the seasonal pastures of cattle amounted to 219 km (SD 5.1, $n = 29$, China) and 244 km (SD 10.4, $n = 8$, Mongolia), whereas small ruminants covered a transhumance distance of 395 km (SD 136.2, $n = 28$, China) and 412 km (SD 97.0, $n = 23$, Mongolia).

The number of utilized pastures differed between countries and species, particularly for cattle herds. While the cattle herd in China visited up to nine pastures over the year, only four pastures were visited in Mongolia, mainly due to different numbers of autumn pastures. In contrast to that, a similar pattern of seasonal pasture use was observed for the two small ruminant herds (Table 1).

Throughout the year, the herds spent more time on a specific pasture in Mongolia than in China which applied in particular to cattle and was mainly due to the longer sojourn of the Mongolian herd at the spring and autumn pastures. The sojourn of the two small ruminant herds on the individual pastures followed a similar pattern in both countries. Their average duration of stay at a pasture was shorter than for cattle due to a higher number of pastures grazed by small ruminants in autumn and winter (Table 1). Additionally, in China, the herds' sojourn (small ruminants and cattle) was longer at places with lower herbage allowance ($r_s = -0.75$, $P < 0.001$). In China, the duration of sojourn (arrival as well as departure date) was regulated by the local government. Nevertheless, information gathered from herders about arrival and departure dates of their animals deviated by 3 to 112 days from the official dates during the study period.

Generally, the daily walked distance differed numerically between seasons; longer distances were observed during spring (China) and summer (Mongolia) and shorter ones in autumn and winter. The annual average for the daily walked distance of cattle was 5 km day^{-1} in China compared with 12 km day^{-1} in Mongolia. For small ruminants, similar average daily walked distances were observed in China and Mongolia (10 and 9 km, respectively; Table 1). The daily walked distance was mainly influenced by herbage offer and for the cattle was slightly negatively correlated with the latter variable ($r_s = -0.40$, $P = 0.005$) across both countries, whereby this inverse relationship was stronger on the Mongolian side of the Altay ($r_s = -0.62$, $P = 0.001$).

Considering the size of the utilized pastures throughout the year, the theoretical utilized pasture area per day of the Chinese cattle herd (73 ha day^{-1}) was more than twice that in Mongolia (34 ha day^{-1}), whereas the theoretical utilized pasture size of Chinese small ruminants was only slightly larger (+18 %) than that of small ruminants in Mongolia. In contrast, the theoretical utilized pasture area during autumn and winter in China was about 19 times larger for the cattle herd and 9 times larger for the small ruminant herd than that in Mongolia. Comparing the different species within China and Mongolia, the theoretical utilized pasture area of cattle was always smaller than that of small ruminants, especially during winter, except for the autumn pastures. The largest differences were observed for the winter pastures of cattle which were 44 and 17 times smaller than the ones of small ruminants in China and in Mongolia, respectively (Table 1). Herbage offer was an important

Table 1 Average number of utilized pastures, duration of stay at an individual pasture, grazed area per day, daily walked distance and herd-related stocking rate of cattle and small ruminants/goats at the main seasonal pastures in China and Mongolia between 2012 and 2014. Given values are mean values with the corresponding one standard deviation (SD) and number of samples as specified for each variable (*n*)

			China				Mongolia			
			Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Pastures (*n*)	Cattle	Mean	2	2	4	1	1	2	-	1
		SD	1.0	0.0	0.5	0.0	0.0	0.0	-	0.0
		n	4	4	7	2	2	4	-	2
	Small ruminants	Mean	3	2	3	1	2	2	1	3
		SD	1.5	0.0	0.8	0.0	0.0	0.0	0.0	0.0
		n	5	6	9	3	4	4	3	5
Duration of stay per pasture (days)	Cattle	Mean	21	38	11	167	45	32	-	247
		SD	0.2	0.8	1.9	16.8	19.3	5.4	-	14.3
		n	55	102	72	334	38	47	-	412
	Small ruminants	Mean	28	43	23	140	42	32	77	57
		SD	1.3	7.1	1.7	42.9	11.4	0.0	23.2	18.5
		n	124	135	198	411	190	126	84	269
Daily pasture area (ha)	Cattle	Mean	22	6	77	1	8	22	-	4
		SD	15.2	3.1	11.0	0.6	3.9	3.1	-	0.7
		n	70	101	72	334	38	47	-	416
	Small ruminants	Mean	36	18	68	63	66	25	8	73
		SD	26.8	2.0	13.6	41.4	20.6	2.8	2.3	40.4
		n	110	135	149	482	190	126	100	269
Daily walked distance (km)	Cattle	Mean	6	6	5	3	11	15	-	8
		SD	2.0	1.3	0.8	0.6	2.3	3.6	-	2.2
		n	70	101	72	334	38	47	-	416
	Small ruminants	Mean	12	9	10	9	11	12	6	8
		SD	1.8	1.6	2.6	3.3	3.2	3.0	0.4	1.6
		n	110	135	149	482	190	126	100	269
Stocking rate (SU* season ha^{-1})	Cattle	Mean	1.3	2.1	0.4	1.7	3.5	1.6	-	0.8
		SD	1.1	1.2	0.1	0.9	0.7	0.5	-	0.0
		n	70	101	72	334	38	47	-	416
	Small ruminants	Mean	1.1	1.5	0.5	0.3	0.6	1.3	2.1	0.3
		SD	1.1	0.7	0.2	0.3	0.3	0.3	0.8	0.1
		n	110	135	149	482	190	126	100	269

driver for the theoretical utilized pasture area: The area used per day was negatively correlated with the average herbage offer at the pasture site across all species ($r_s = -0.43$, $P = 0.013$), whereby the correlation was higher if only cattle were considered ($r_s = -0.53$, $P = 0.044$).

Seasonal (three-month) stocking rates (SU ha^{-1}) ranged from 0.32 and 0.31 for Chinese and Mongolian small ruminants during winter to 3.48 for Mongolian cattle during spring. Comparing both countries, seasonal stocking rates of cattle were lower in the Chinese spring and autumn pastures, whereas stocking rates of small ruminants were only lower in the Chinese autumn pastures. Particularly, Mongolian spring pastures evinced high cattle stocking rates, while for small ruminants high rates were observed during summer (China) and autumn (Mongolia). Comparing the stocking rates of cattle and small ruminants within each country, Chinese and Mongolian cattle pastures featured always higher stocking rates over the course of the year, with the exception of the Chinese autumn pastures of cattle (Table 1).

Quantity and quality of herbage

The herbage offer ranged from 847 (winter pasture) to 1,685 kg DM ha^{-1} (summer pasture) in China. At the Mongolian sites, a wider range of herbage offer from 535 (summer pasture) to 1,868 kg DM ha^{-1} (autumn pasture; Table 2) was recorded. Compared with Mongolia, Chinese pastures were characterized by a higher herbage offer with the exception of the autumn pastures; the largest difference was observed for the summer pastures where herbage offers were three times higher on the Chinese side (Table 2). Considering all seasonal pastures, overall average herbage offer was about 18 % higher in China than in Mongolia. Comparing average herbage offers available to each livestock species between both countries, Chinese cattle utilized pasture areas with lower herbage offers (−14 %) than those utilized by cattle in Mongolia, whereas the herbage offers on pasture areas utilized by Mongolian small ruminants were 29 % lower than the respective Chinese values. Comparisons between livestock species within each country indicated lower herbage offers on pasture areas utilized by cattle than by small ruminants (−24 %) in China, whereas in Mongolia cattle utilized pasture areas with 22 % higher yields than areas utilized by sheep and goats (Figure 2).

Yearly average herbage allowances (kg DM SU day^{-1}) amounted to 20 (Mongolia) and 50 (China) for cattle and 52 (Mongolia) and 65 (China) for small ruminants (Figure 3). The herbage allowance on all seasonal pastures was higher in China compared with Mongolia, except for the spring pasture of small ruminants, where the Chinese value was 33 % lower. Despite the high herbage offer in the summer season, the lowest herbage allowance was determined for the summer pastures, while high herbage allowances prevailed at spring and autumn/winter pastures. Comparisons of herbage allowances between livestock species within each country showed higher values for Chinese cattle than for small ruminants, except for the autumn pasture on which herbage allowance for cattle was considerably lower than for small ruminants. In contrast, in Mongolia, all pastures of cattle were characterized by a lower herbage

Table 2 Duration of stay at the seasonal pasture as well as average yield and concentrations of dry matter (DM), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP), phosphorus (P) and calcium (Ca) for herbage at the main seasonal pastures in China and Mongolia between 2012 and 2014. Given values are mean values with the corresponding one standard deviation (SD) and number of samples (*n*)

		China				Mongolia			
		Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Duration of stay (days)	Mean	25	43	18	154	43	32	77	135
	SD	1.1	7.0	3.8	16.3	3.1	0.0	23.2	70.0
	n	179	237	270	745	227	173	84	680
Herbage offer (kg DM ha^{-1})	Mean	1,418	1,685	1,121	847	1,201	535	1,868	555
	SD	896.5	747.2	864.6	656.2	820.7	419.3	835.1	338.0
	n	44	219	31	65	60	326	28	96
DM (g kg^{-1} FM)	Mean	449	359	447	428	513	571	384	386
	SD	131.3	129.5	93.5	89.8	127.2	159.4	59.6	116.9
	n[a]	44	194	30	56	57	290	22	91
OM (g kg^{-1} DM)	Mean	853	891	822	869	917	891	891	811
	SD	35.9	26.9	59.8	34.1	22.3	33.3	22.5	67.9
CP (g kg^{-1} DM)	Mean	136	121	71	85	118	108	83	111
	SD	26.6	17.2	27.5	23.5	19.6	30.8	14.9	18.1
NDF (g kg^{-1} DM)	Mean	528	467	586	525	470	552	586	410
	SD	64.9	44.6	98.5	64.3	87.4	53.3	53.1	88.1
ADF (g kg^{-1} DM)	Mean	360	325	397	367	286	298	339	239
	SD	54.6	38.3	92.3	43.2	44.2	46.8	33.9	69.5
P (g kg^{-1} DM)	Mean	2.1	2.0	1.2	1.3	1.7	1.3	1.2	1.3
	SD	0.3	0.2	0.4	0.5	0.4	0.3	0.2	0.4
Ca (g kg^{-1} DM)	Mean	8.0	10.5	15.3	17.8	8.1	7.1	7.9	31.1
	SD	5.3	2.9	10.8	8.7	3.9	3.6	3.3	14.8

FM fresh matter

[a]For the following quality parameters, the numbers (*n*) are equal in the corresponding column

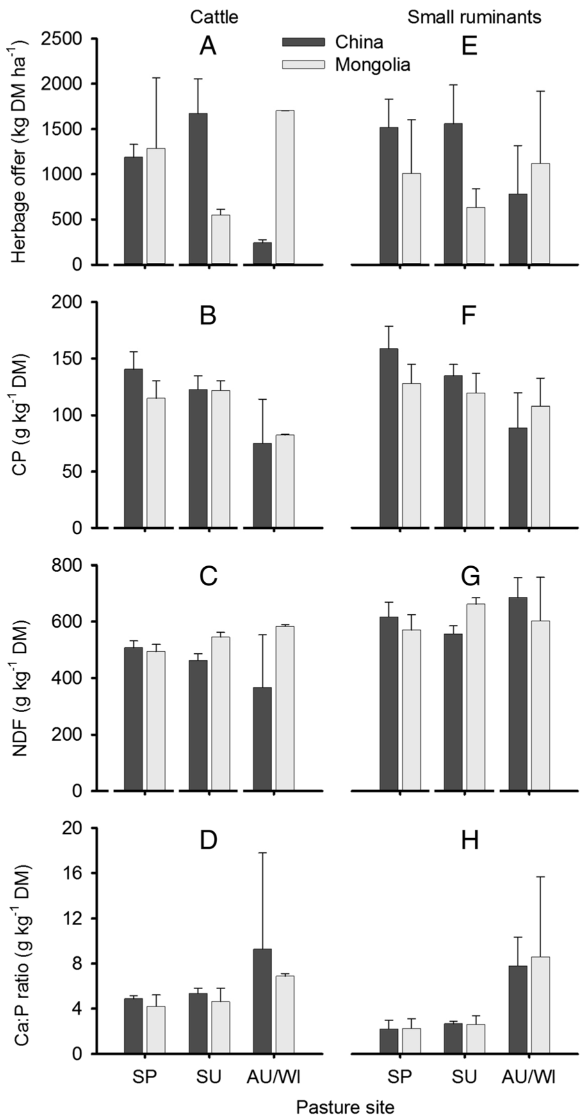

Figure 2 Herbage offer and concentrations of neutral detergent fibre (NDF), crude protein (CP) and calcium/phosphorus ratio (Ca:P) for herbage at the main spring (SP), summer (SU) and autumn/winter (AU/WI) cattle (**a** to **d**) and small ruminant (**e** to **h**) grazing grounds in China and Mongolia (collected between 2012 and 2014). *Bars* represent mean values; *whiskers* show one standard deviation (SD)

allowance than for the pastures of small ruminants. Across both species, stocking density was slightly negatively correlated with herbage allowance in Mongolia ($r_s = -0.74$, $P < 0.001$), but not in China.

Herbage quality varied between countries, seasons and utilized pasture areas of different livestock species. Concentrations of CP and P were low on autumn and winter pastures, whereas high concentrations were measured on spring pastures. Comparing the quality parameters of pastures between livestock species, difference were largest for the CP concentration in herbage from the autumn/winter pastures; the Chinese cattle/small ruminant pastures showed −10 %/−21 % less CP than in Mongolia. The lowest NDF and ADF concentrations were measured for the summer pasture in China and for the winter pasture in Mongolia, whereby overall concentrations were lower for the Chinese than for the Mongolian pastures (Table 2). Comparing herbage NDF concentrations for livestock species and countries, maxima on cattle pastures were determined in spring (China) and autumn/winter (Mongolia), whereas maxima on small ruminant pastures were measured during autumn/winter (China) and summer (Mongolia). On both sides of the border, Ca concentrations were highest for the winter pastures in the desert areas. Given the relatively low P concentrations, Ca:P ratios varied between 4:1 (Chinese spring pasture) and 28:1 (Mongolian autumn/winter pasture). On all seasonal cattle pastures, lower Ca:P ratio were measured than on small ruminant pastures, particularly for the Chinese (−68 %) and Mongolian (−150 %) autumn/winter pasture (Figure 3).

The herbage offer of a respective pasture was positively related to herbage quality, as pasture sites with higher herbage offers showed also higher CP concentrations ($r_s = 0.35$, $P = 0.044$) with a particularly high correlation determined for the Chinese pasture areas utilized by cattle ($r_s > 0.52$, $P = 0.033$).

Discussion

Mobility pattern

Pastoralists in semi-arid and arid environments strongly depend on herd mobility to optimize forage availability for their animals and utilize pastures sustainably (Humphrey and Sneath 1999; Fernández-Giménez and Le Febre 2006; Behnke et al. 2011). This implies seasonally and annually flexible adaptation of long-distance transhumance routes, frequency of pasture changes and daily grazing itineraries (Saizen et al. 2010; Kakinuma et al. 2014). As in other transhumant systems of the world, livestock mobility in the Altay-Dzungarian region is mainly influenced by the seasonal variability of herbage quantity, quality and palatability, access to water, weather conditions (precipitation, snow depth, temperature and wind) and prevalence of pests and predators (such as mosquitos, horseflies and wolfs), topographic features, traditions, infrastructure and political and social framework but also by individual human decisions (Angerer et al. 2008; Tsui 2012; Kakinuma et al. 2014; Kerven et al. 2016a, 2016b).

We observed that as decisions were taken, pastoralists were assessing the benefits of specific herding strategies against potential risks. Yet, the two cooperating herders largely managed their animals and pastures according to regional practices which comprised in the Chinese Altay the use of transhumance routes of up to 640 km per year including 33 changes of pastures (Morrison 1999; Squires

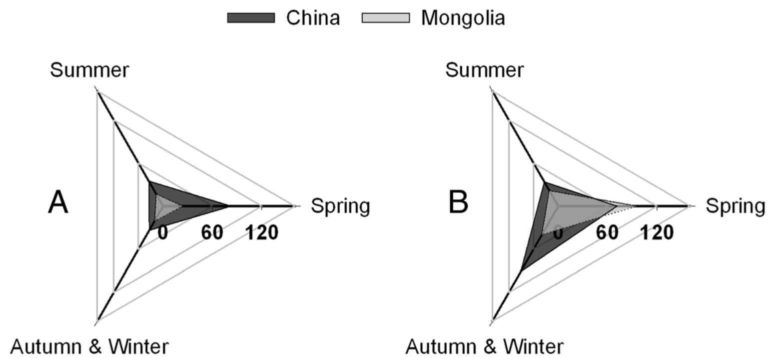

Figure 3 Average herbage allowances at the main seasonal pastures of cattle (**a**) and small ruminants (**b**) in China and Mongolia between 2012 and 2014. Values given are mean values

et al. 2010). However, increasing population density, rising economy and governmental interference with the transhumance system (such as regulation of mobility and animal numbers, state-sponsored fencing programmes, clearance of 'degraded' rangeland, expansion of irrigated agricultural land and mandatory forced resettlement of herders) has changed the traditional herding system in the Chinese Altay (Yeh 2005; Brown et al. 2008; Squires et al. 2009; Yeh 2009; Squires et al. 2010; Tsui 2012).

The transhumance system in the Mongolian Altay, in contrast, remained largely unregulated by the distant government, but is currently also changing due to a shift from camels to trucks for the transportation of families, mobile homes (yurts) and weak animals, and changes in people's way of living such as year-round grazing near the villages due to a rising demand for social and health services and generation of supplementary income. This was also described by other studies conducted in Mongolia (Lise et al. 2006; Okayasu et al. 2007; Kamimura 2013; Lkhagvadorj et al. 2013b; Bruegger et al. 2014).

Despite these altered social and political circumstances, the long-distance movements (particularly of small ruminants) in the Chinese and Mongolian Altay were longer compared with distances reported for other regions in China (Xinjiang Autonomous Region, Altay prefecture) and Mongolia (the Mongolian plateau and Ugtaal sum) ranging from 90 to 190 km (Morrison 1999; Lise et al. 2006; Zhen et al. 2010; Kreutzmann 2013b). The remoteness from markets and the high altitudinal gradient of the Altay-Dzungarian region may explain the relatively high degree of mobility (Lkhagvadorj et al. 2013a; Liao et al. 2014b).

Regardless of the different framework conditions across our study region long-distance movement patterns were similar. During the period of our on-site measurements, the transhumance routes of Chinese small ruminants changed from long-distance movement to the desert steppe in 2012 to pasture sites closer to the settlements (in 2013 and 2014), due to low herbage availability on the more remote pastures. The latter was triggered by an expansion of irrigated agricultural land and mining activities directly within the autumn and winter pasture areas during the last two years of this study. The frequency of changes of individual pasture areas within a seasonal pasture and the duration of long-distance movements in our study region were within the range of values reported in other studies of similar ecological context (Lise et al. 2006; Behnke et al. 2011; Liao et al. 2014a), in which the number of utilized pastures and duration of stay ('sojourn') varied between three and eight times and 1.5 and 3.5 months, respectively. The higher number of movements and consequently shorter duration of stays in China compared with Mongolia largely reflected governmental regulations.

A further integral component of herd mobility and use of pasture in accordance with the environmental conditions is the exploitation of seasonal pastures. Grazing itineraries and the resultant theoretical utilized pasture area are determined by a variety of factors such as meteorological conditions, topographic features, the spatial expansion of the pasture, herbage yield and quality, animals' dietary preferences, distance to water, land use rights and management strategies such as daily herding practices (Baumont et al. 2000; Lin et al. 2011; Askar et al. 2013). The average daily walked distance in the study area was slightly lower (particularly during autumn and winter) than reported by studies of transhumance systems in sub-Saharan Africa (Turner et al. 2005; Schlecht et al. 2006; Butt 2010; Raizman et al. 2013). Environmental conditions such as low temperature, snow cover and strong wind as well as the herd-release strategy (small ruminants) or absence of active herding (cattle) likely reduced the length of daily grazing itineraries (Vetter 2005; Schlecht et al. 2006; Squires et al. 2010). This assumption is substantiated by a comparison with daily itineraries tracked under similar management conditions in Inner Mongolia, Mongolia and the Tibetan plateau, which closely matched the data of the current study and ranged between 3 and 13 km per day (Kawamura et al. 2005; Joly et al. 2013; Ding et al. 2014).

The cross-country comparison of daily grazing itineraries revealed larger distances covered by cattle in Mongolia than in China, likely caused by lower herbage offers in Mongolia on the one hand and the Chinese regulation of animal numbers per pasture on the other hand. However, differences in daily distances and thus in sizes of theoretical utilized pasture areas between species may be explained by their different foraging preferences and accessibility of pastures. As various authors have reasoned, in particular, topographic features such as steep slopes and high stone cover at the pastures may limit the grazing radius of cattle (Zemmrich et al. 2010; Fujita et al. 2013; Turner et al. 2014) as was also observed in the Altay-Dzungarian region. The relatively short distances covered by of Chinese cattle during the winter are a result of restricted pasture grounds (pastures near the village and partly fenced pastures) and additional fodder supply in the form of hay.

The stocking density and stocking rate differed between the two countries due to the above-discussed differences in livestock mobility patterns, such as the number of movements and duration of stay, but also livestock numbers and daily herding strategies. In particular during spring and summer, the observed stocking rates were relatively high in both countries compared with similar regions in Inner Mongolia and Mongolia (Kawamura et al. 2005; Lise et al. 2006; Chen et al. 2007; Sugita et al. 2007; Glindemann et al. 2009; Lkhagvadorj et al. 2013a; Bösing et al. 2014; Liao et al. 2014a). Governmental regulation of animal numbers and duration of stay on pastures seemed to lower the stocking densities particularly in the Chinese Altay. However, the non-compliance with administratively prescribed arrival and departure dates for pasture sites by most of the herders (own data, unpublished) disclosed the limited reach of strict regulation in a highly fragile environment (Banks et al. 2003; Campbell et al. 2006; Lee et al. 2015). Mongolian pastures, in contrast, are currently subjected to rising grazing pressure due to increasing livestock numbers (especially before the 2009/2010 *dzud*) and particularly increasing numbers of cashmere goats, as well as possibly reduced livestock mobility (Saizen et al. 2010; Saizen 2013; Hilker et al. 2014). These phenomena were also observed in Bulgan county (personal communication, Bulgan *sum* governor), where from 1999 to 2014 the goat and sheep population in the Mongolian study region increased by 51 % and 9 %, with peaks of 114 % and 14 %, respectively, reached in the pre-*dzud* year 2008 (Appendix). Furthermore, our three-year data of long-distance movements and complementary information from the baseline survey indicate a decline of long-distance movements to the desert steppes (winter) and alpine belts (summer) in favour of year-round grazing of pastures near settlements. The localized high grazing pressure resulting from these developments is exacerbated by a declining number of active herders and a concurrent increase of herd sizes, which is partly the result of an increased number of herders who are in charge of additional livestock of other herders in return for payment, which has also been observed elsewhere (Humphrey and Sneath 1999; Saizen 2013).

In addition, active daily herding was often lacking, which reflects labour scarcity, loss of traditional knowledge and absence of an effective coordinating authority at the pastures which intensified the grazing pressure in both countries' study areas (Brown et al. 2008; Yamamura et al. 2013).

Quantity and quality of herbage

The harsh continental climate with its high inter-annual rainfall variability and short growing period limits the rangeland productivity in the Chinese-Mongolian Altay (Chen et al. 2007; Saizen et al. 2010). These circumstances may be aggravated according to climate change predictions for the Altay-Dzungarian region that foresee an increase in the average annual temperature, more frequent and prolonged summer droughts and temporal shifts of precipitation from summer to winter (Angerer et al. 2008; Lkhagvadorj et al. 2013a; Hilker et al. 2014; Liao et al. 2014a). Moreover, herd management such as daily herding practices and grazing duration, livestock numbers and herd composition are known to affect the occurrence, frequency, distribution and growth of grassland species and thus herbage yield and its nutritive value (Briske et al. 2003; Schönbach et al. 2012; Kreutzmann 2013a; Lkhagvadorj et al. 2013b; Hilker et al. 2014).

The spatio-temporal variability in herbage yield and quality challenges grazing management decisions as both parameters are the main determinants of animal performance in transhumant livestock systems (Behnke et al. 2011). Hence, long-distance moves (temporary relocation of herds) and selective feeding strategies of individual livestock species are of importance in the quest for the best possible forage exploitation for animal growth and production (Baumont et al. 2000; Vallentine 2001; Behnke et al. 2011; Yoshihara et al. 2013; Liao et al. 2014a). In accordance with literature (Ni 2004; Angerer et al. 2008) Chinese-Mongolian pastures feature a wide range of above-ground biomass yields (30 to 20,210 kg^{-1} DM ha), depending on the ecotype and season. At the same time, high standard deviations indicate a high variability within each pasture due to varying topography and variability of rainfall. Nonetheless, the observed herbage offers were relatively low compared with studies in similar climatic contexts elsewhere (Sankey et al. 2009; Behnke et al. 2011; Sasaki et al. 2012; Tao et al. 2013), whereas the nutritive values were relatively high and constant throughout the studied years. Especially the latter observation is surprising, as in Central Asia the nutritive value of natural vegetation varies strongly with season and has been reported to be particularly low during winter and early spring (Yoshihara et al. 2008; Glindemann et al. 2009; Olson et al. 2010; Sasaki et al. 2012; Schönbach et al. 2012; Bösing et al. 2014; Ding et al. 2014; Ma et al. 2014; Müller et al. 2014). It may therefore be concluded that the herd mobility patterns observed in the Altay-Dzungarian region is balanced for the seasonal variability in herbage quality (Yoshihara et al. 2013). With values of approximately 0.05 to 2.5 kg DM of above-ground herbaceous biomass per kilogramme live weight and day, the herbage allowance in the study region was at the lower end of values reported for pastures in Inner Mongolia (0.7 to 26.4 kg DM per kilogramme live weight; Schönbach et al. 2012; Bösing et al. 2014). According to Lin et al. (2011) who categorized herbage allowances (kg DM kg^{-1} live weight), the values obtained in our study correspond to the classes 'heavy grazing' and 'very heavy grazing' during all seasons.

In the present study, interactions between stocking density and stocking rate on the one hand and herbage yield on the other were observed, especially at the Mongolian sites. Other studies pointed to a reduction of above-ground biomass yield at stocking densities >0.4 sheep ha^{-1} in Mongolian grasslands (Chen et al. 2007; Sugita et al. 2007). Most stocking densities on the studied pastures exceeded 0.4 SU ha^{-1} and thus indicated a high grazing pressure. Additionally, grazing duration, which is a decisive factor for rangeland productivity (Glindemann et al. 2009; Ma et al. 2014) was negatively (China) and positively (Mongolia) correlated with herbage allowance. These contradictory tendencies may be explained by strict regulations in China that forced herders to stay at pastures with relatively low herbage allowance (Banks et al. 2003), whereas Mongolian herders could flexibly adapt the length of their stay depending on the circumstances (Fernández-Giménez and Le Febre 2006).

Although cattle and small ruminant herds mostly grazed on spatially different rangelands in the study region, no significant differences in herbage offer and quality were observed on the sites visited by the two livestock groups, with the exception of the winter pastures. Besides environmental characteristics of a pasture such as slope, exposition, stone cover and density of woody vegetation, factors such as land use rights are likely to prevail over species-specific diet preferences (Ganskopp and Bohnert 2009), together with high stocking rates and absence of active herding, leading to a broad dietary overlap (Vallentine 2001; Yoshihara et al. 2009). However, as herbage allowance was negatively correlated with the size of the area visited per day and the daily walked distance (in particular for cattle), it can be assumed that grazing cattle were hampered by topographical features (Ganskopp and Bohnert 2009) and animals therefore walked further distances per day, which inevitably increased their theoretical utilized pasture area, but not necessarily the herbage allowance. This relationship seemed to be more pronounced on the Mongolian side, which may be explained by an increased competition between livestock species for the same fodder resources (Vallentine 2001).

Climatic conditions vary with latitude and altitude and result in different ecological zones, that is desert and mountain steppe and alpine meadows, in the Altay-Dzungarian region. Increasing latitude and altitude usually correspond with an increased biomass production, but not necessarily with a higher nutritional quality of the pastures (Fernández-Giménez and Allen-Diaz 2001; Zemmrich et al. 2010).

The spring pastures at the fringes of desert and mountain steppes are of particular importance for the herds' reproduction (Kerven 2003). In accordance with literature (Fryxell 1991; Yoshihara et al. 2008; Fujita and Amartuvshin 2013), the highest CP and P concentrations were determined on the spring pastures in newly sprouting protein-rich forbs and shrubs of the genera *Stipa*, *Caragana* and *Achnatherum*.

At the summer pasture, high herbage yields and nutritive values allow the fattening of livestock and the maintenance of milk production (used for processing cheese and butter for the winter; Behnke et al. 2011). The summer pastures at the alpine belt are characterized by a delayed snow melt which retards vegetation growth and therefore prolongs the availability of young vegetation, similar in quality to the spring pastures (Bauer et al. 2011). In addition, the Umbrisols prevailing in the summer pastures in both countries are relatively rich in organic carbon and nutrients, favouring high herbage yields and high CP concentrations (Fernández-Giménez and Allen-Diaz 2001; Schönbach et al. 2012), which was particularly true for the Chinese summer pasture.

Marked herbage offer differences were observed between the Chinese and Mongolian summer pasture. Compared to the Mongolian summer pasture, higher water availability due to higher amounts of snow melt water and spring precipitation were likely to foster plant growth on the Chinese summer pasture during the late spring, the period immediately preceding summer pasture utilization. For 2013 and 2014, the average cumulated precipitation before summer pasture utilization amounted to 71 mm in China and 32 mm in Mongolia (Figure 1). These data imply that the Mongolian summer pasture suffered from low soil moisture contents in the late spring/early summer season; in addition, very low average daily air temperatures before the utilization period was of −11 °C in Mongolia as compared with only −2 °C in China (Figure 1) and was delaying vegetation growth (Yiruhan et al. 2014).

Additionally, strict regulations at the Chinese summer pasture (that is, limited animal numbers and restricted access to the pastures until the end of the main flowering period) may have favoured herbage production.

Despite the high herbage offers, herbage allowances were lowest on the summer pastures as a result of the relatively high density of herds during summer, leading to high stocking rates. The herbage quality on the summer pastures was relatively high primarily due to the occurrence of *Allium* sp. and *Polygonum alpinum* at the Chinese site and *Artemisia* sp. at the Mongolian site. At the Mongolian summer pasture, the high occurrence of grazing weeds (such as *Carex duriuscula*) indicated a strong anthropo-zoogenic influence as a result of intense pastoral utilization (Fernández-Giménez and Allen-Diaz 1999, 2001; Fujita and Amartuvshin 2013). The data from the Mongolian summer pasture revealed that both quality and quantity of herbage were not sufficient to adequately fatten livestock and help them recover from live weight losses experienced during winter. This highlights the importance of the Mongolian autumn pasture for livestock production and health.

During autumn, high-quality fodder is needed to boost the nutritional status of herds before breeding and to build up sufficient fat reserves for the winter (Behnke et al. 2011; Yoshihara et al. 2013). The herbage offer of the autumn pastures was relatively high, but the high concentration of structural carbohydrates and relatively low concentration of crude protein of the then-dry standing biomass (especially *Achnatherum splendens*) may have reduced herbage digestibility (Fryxell 1991; Yoshihara et al. 2008). Compared with the Mongolian autumn pasture, lower herbage offer and quality were observed on the Chinese mountain steppes grazed in autumn. In Mongolia, the autumn pasture was located in the flood plains of the Bulgan River which are characterized by favourable water availability allowing for high herbage yields and ensuring high herbage availability throughout the year (Zemmrich et al. 2010). In China, flood plain areas were mainly used for irrigated crop and hay production or were inaccessible to livestock due to urbanization and political regulation, also reported by Squires et al. (2009) and Dittrich et al. (2010). Consequently during autumn and winter, Chinese livestock had to shift to less productive pasture sites outside the fertile floodplains that are the mountain and desert steppes.

The late winter and early spring pastures are known as bottlenecks to animal nutrition since livestock then has to rely on the mature standing biomass which may be partly snow-covered (Fryxell 1991; von Wehrden and Wesche 2007; Yoshihara et al. 2008). During the winter months, small ruminants accessed low-altitude areas in the desert steppe (ranging from 1,194 to 1,366 m in China and 1,528 to 1,938 m in Mongolia) which are normally less subjected to dense snow cover. The relatively high nutritional quality of herbage at the winter pasture may be attributed to the occurrence of nutritious plants (especially *Anabasis brevifolia*), particularly in Mongolia (Vetter 2005). However, due to infrastructure limitations, herbage was sampled already in September in the present study, and a decline of herbage quality until the arrival of the herds in December cannot be ruled out (Olson et al. 2010; Ding et al. 2014). In addition, the observed wide Ca:P ratios in winter pasture herbage may lead to P deficiency and in the longer term can lead to infertility, non-infectious abortions, anaemia and bone abnormalities (van Soest 1994; Olson et al. 2010; Yoshihara et al. 2013).

In contrast to small ruminants, cattle remained in the vicinity of villages (China) and on the autumn pastures (Mongolia) during the winter. During this period, the herders provided supplementary feed such as hay, cereals and crop residues, mainly to cattle, which is also reported from Central Asia and north-eastern Asia (Kerven et al. 2004; Kreutzmann 2013a, b). Moreover, on the Chinese side, cattle were partly fenced on agricultural land that in summer was irrigated and on which only a few crop residues, if any, remained. This may explain the relatively low herbage allowance and lower nutritive value of herbage compared with Mongolia. Furthermore, it can be assumed that cattle herds staying in the vicinity of villages locally foster rangeland degradation due to high stocking rates on both sides of the border (Lise et al. 2006; Addison et al. 2012; Bruegger et al. 2014).

To address our initial hypothesis, it can be stated that for cattle, differences in the Chinese and Mongolian transhumance system were observed, whereas for small ruminants the results from both sides of the border were similar, despite the different socio-political and socio-economic framework conditions. Whereas for herbage quality no substantial divergence was observed between both countries, herbage offers clearly differed on the summer pastures. Since the number of utilized pastures was higher and theoretical utilized pasture area was larger in China, herds in general spent less time on a specific pasture. In consequence, the herbage allowance on all seasonal pastures was higher in China compared with Mongolia, except for the spring pasture of small ruminants.

Conclusions

In the Altay-Dzungarian region, a highly mobile and flexible transhumance strategy is of major importance for pastoral herds to cope with the seasonal and spatial variability in the quality and quantity of pasture vegetation. The regulation of animal numbers, a larger number of utilized pastures and the control of prescribed dates of transhumance movements (especially of small ruminants) to the summer and autumn pasture seem to maintain herbage yield and quality in China. Nevertheless, changes of the transhumance routes of small ruminants (triggered by expansion of irrigated agricultural land and mining activities) may hamper these positive regulation effects. On the other hand, these restrictions are likely to prevent the flexible reaction of herders to the high inter- and intra-annual variation of precipitation and sudden adverse weather conditions. In Mongolia, however, high stocking densities (particularly due to a high number of goats), a diminished frequency of pasture changes (especially at the spring and winter pastures characterized by low precipitation) and grazing of the summer pasture before flowering of herbaceous plants seem to decrease the herbage offer. The introduction of access dates and the reduction of stocking densities and/or the duration of the herds' sojourn in particular areas may help to improve herbage offer and to sustain animal production.

On both sides of the border, the introduction of active daily herding strategies may be promising to optimize the exploitation of the entire rangeland and consequently reduce high stocking rates. Nevertheless, to maintain large-scale mobility as a core feature of the transhumance system in the Altay-Dzungarian region, amenities should be provided to herders even at remote pasture locations; these include mobile shops and medical services, public transport between the pastures, and regular visits of traders in livestock, dairy products and wool as it is partly done in China.

In years with average-to-good precipitation, active herding and fine-tuned pasture management can sustain herbage yield and quality and thus enhance animal performance at a longer term. To justify the increased work load and economic cost of active herding, the development of niche markets for clean, green and maybe even organic products in urban demand centres of China and Mongolia is an important prerequisite.

Abbreviations
ADF, acid detergent fibre; AU, autumn; C, carbon; Ca, calcium; CP, crude protein; DM, dry matter; M, Mongolia; N, nitrogen; NDF, neutral detergent fibre; OM, organic matter; P, phosphorus; SD, standard deviation; SECV, standard error of cross-validation; SU, sheep units; SP, spring; WI, winter

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

Authors' contributions
GJ carried out the fieldwork with the assistance of SG, TM and AS and GJ compiled the manuscript under the supervision and guidance of ES, SG and AB. All authors contributed with comments and suggestions during the writing. ES checked that data processing and interpretation. All authors have read and approved the final draft of this manuscript.

Authors' information
GJ is a PhD student at the Section Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics at the University of Kassel and Animal Husbandry in the Tropics and Subtropics at the University of Kassel and the University of Göttingen, TM and AS are PhD students at the Section Animal Husbandry in the Tropics and Subtropics at the University of Kassel and the University of Göttingen and SG is a postdoctoral fellow at the Section Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics at the University of Kassel. AB is a professor of Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics and head of the above-mentioned section at the University of Kassel. ES is a professor of Animal Husbandry in the Tropics and Subtropics, and head of the above-mentioned section at the University of Kassel and the University of Göttingen.

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Appendix

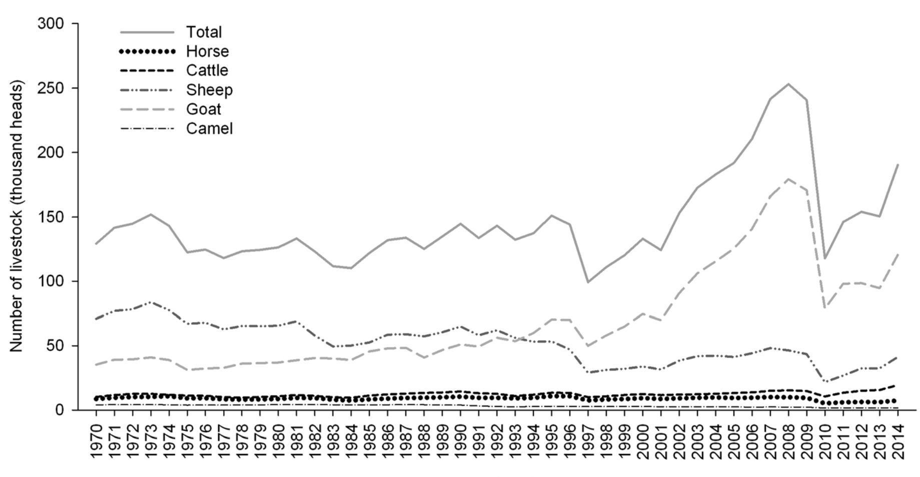

Figure 4 Changes in the number of total livestock, horses, cattle, sheep, goats and camels (thousand heads) in Bulgan *sum*, Mongolia, from 1970 to 2014 (data source: Livestock account, National Statistical Office of Mongolia)

Author details
[1]Animal Husbandry in the Tropics and Subtropics, University of Kassel and Georg-August-Universität Göttingen, Steinstr. 19, 37123 Witzenhausen, Germany. [2]Organic Plant Production and Agroecosystems Research in the Tropics and Subtropics, University of Kassel, Steinstr. 19, 37123 Witzenhausen, Germany. [3]Research Institute of Animal Husbandry, Mongolian University of Life Sciences, Ulaanbaatar, Mongolia. [4]Rangeland Research Institute, Xinjiang Academy of Animal Science, Urumqi, China.

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