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Feed Intake of Small Ruminants on Spring and Summer Pastures in the Mongolian Altai Mountains

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Abstract: Climate variability, rising livestock numbers, decreasing herd mobility, and clustered grazing patterns have incited concern about the sustainable use of Mongolia's natural pastures as the nutritional backbone of the country's livestock sector. In 2013 and 2014 we studied daily itineraries, grazing behaviour, and feed and nutrient intake of small ruminants on spring and summer pastures in the southern Mongolian Altai, a remote livestock-dependent region. Offer of herbage dry matter (DM, kg ha^{-1}) along the daily itinerary was higher in 2014 than in 2013 (837 versus 711; $p > 0.05$) but was comparable to previously reported values. Concentration of cell wall constituents in herbage increased from June to August in both years, whereas crude protein and phosphorus concentrations declined ($p < 0.05$). Animals grazed most actively at noon and in the afternoon; their daily DM intake amounted to 1151 ± 300.8 g per head, with 60–72% of the ingested feed being digested. Feed intake enabled the animals to cover their nutritional requirements for maintenance, locomotion, and sizeable growth, rebutting the notion of unsustainable use of the regional spring and summer pastures. However, crude protein and phosphorus intake were deficient, pointing to a decline in vegetation quality that has to be counteracted with appropriate herd and pasture management strategies.

Keywords: alpine meadows; climate variability; feed intake; GPS tracking; herbage offer; small ruminants

1. Introduction

Mongolia has the largest area of common pasture land in the world [1], which over a year provides up to 95% of the fodder needs [2] of the country's 66 Mio domestic herbivores [3]. Given its importance, the aboveground net primary production of Mongolian pasture land has been extensively studied since the 1940s, and values strongly vary between pasture types, seasons, and geographical locations [4]. However, as a general pattern in a normal year, herbaceous biomass yield reaches its maximum during summer (June to August) and afterwards declines by 27–35% in autumn (September to November) and a further 60–63% in winter (December to February). In spring the vegetation starts to regrow to 65–70% of the annual peak [3,5]. Long-term data point to declining yields of herbaceous pasture biomass, especially during the last three decades (Figure 1): whereas high yields were obtained during the period 1981–1990, herbaceous forage availability on Mongolia's natural pastures has since then decreased by 1.9–3.1% annually [4]. Pasture yields are strongly affected by spatio-temporal variation in annual precipitation [6,7], which in some areas of Mongolia has increased and in others decreased by 2–5% during the past 40 years, while at the same time average annual air temperature increased by 1.7 °C [8]. According to Dagvadorj et al. [9], climate scenarios forecast increased air temperatures across Mongolia and increased precipitation amounts in some areas. However, potential evapotranspiration will increase more than precipitation amounts. Therefore, "future climate changes are expected to negatively impact mostly the agricultural and livestock sectors, which in turn will affect the society and economy of Mongolia" [9; p.8]. On the other hand, tree ring studies point to a recent increase of photosynthetic rates and soil moisture levels due to increased snowmelt in Mongolia and particularly in the southern Altai Mountains [10]—conditions that favour primary productivity of pastures.

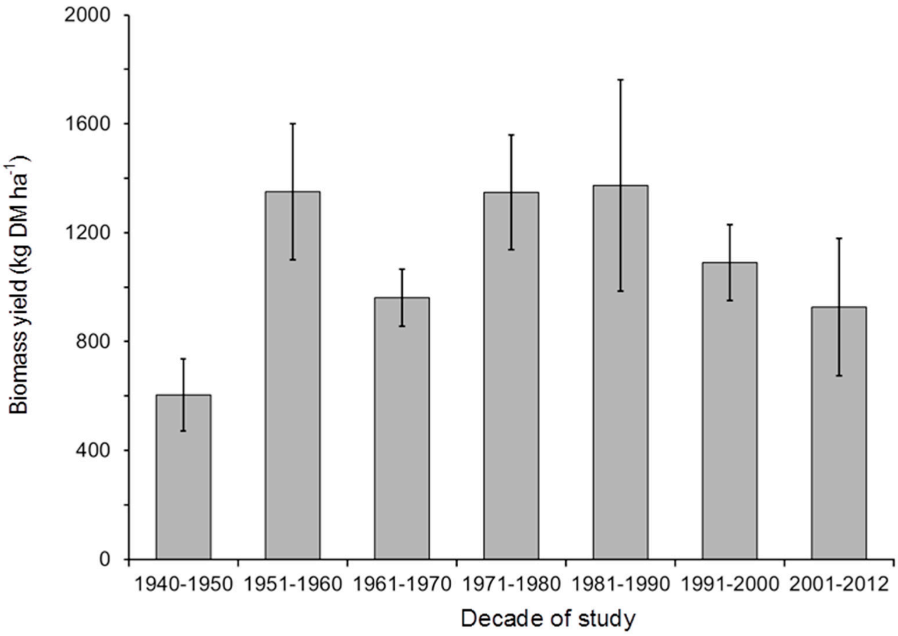
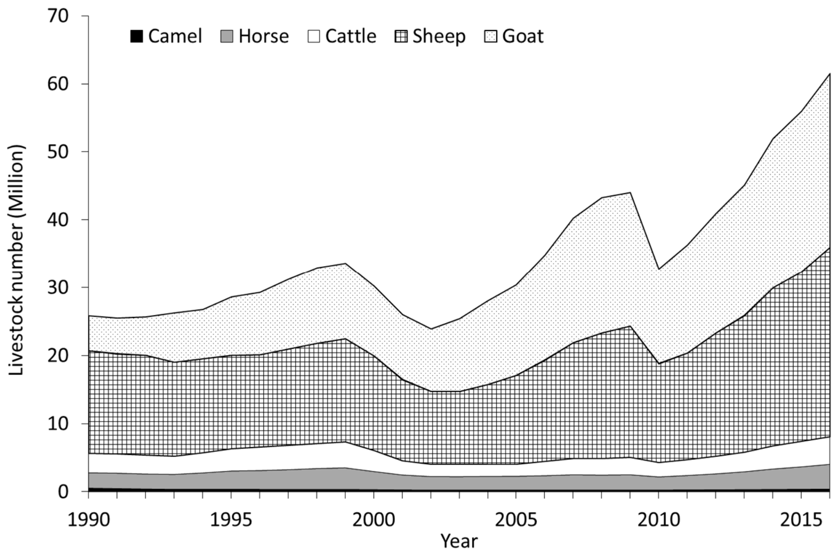


Figure 1. Vegetation availability on Mongolian natural pastures in 1940–2012 as reported in literature; means (bars) and standard errors (whiskers). Data source: [4]. DM = herbage dry matter.

Apart from climate, altitude, soil condition, and particularly grazing utilization also affect pasture productivity [11]. Across the country, livestock owners or (hired) herders move their herds between four main seasonal pastures (spring, summer, autumn, and winter), a key strategy to cope with highly unpredictable environmental variables and forage supply [12]. The winter and early spring seasons are most difficult in terms of feed supply [13], to which an increased feed requirement of females in the spring lambing/calving season is added. Late spring and summer, on the other hand, are the prime seasons that enable live weight gain of yearlings and new-borns, the replenishment of body fat and mineral reserves of mature animals, and securement of herder families' supply of milk and derived storable products [14].

From 1990 to 2009, the number of herding households in Mongolia almost tripled and the total number of livestock increased by a factor of 1.7 [15]. The highest increase occurred in goats (factor 3.8) followed by sheep (factor 1.3), primarily due to the economic importance of small ruminants for household cash income [15]. Camel numbers, on the other hand, were and remained rather low, declining from a maximum of 540,000 head in 1991 to about 370,000 head in 2015 (Figure 2). Recurrent drought and harsh winters (*dzud*), such as those of 2002 and 2009/2010 [16], led to major sudden drops in livestock numbers, but headcounts always recovered rapidly thereafter. Even though current average herd sizes in Mongolia do not fully sustain their owners' need for income and food security provision [13,17], the steadily increasing livestock numbers have resulted in concerns about grazing-induced pasture degradation [18] and a debate on its extent [19,20]. The annual cost of unsustainable pasture utilisation, as derived from the net price of additional fodder required to feed those animals that are exceeding the maximum carrying capacity of the pastures, was in the year 2000 estimated at 9.5 billion Mongolian tugrik (1000 Mongolian Tugrik equalled 0.38 US-Dollars on 15 July 2019; OANDA currency converter, https://www.oanda.com/) [21]. The increasing number of small ruminants has further implications for pasture utilisation:since more animals are grazing the same plant species, the overall utilisation of vegetation becomes patchier [22] and the presence of grasses may decrease while the presence of forbs and weedy annuals may increase [23,24]. Furthermore, a trend towards reduced walking distances and frequencies of herd movements between and on seasonal pastures has been observed recently [25,26] which increases the grazing pressure on those sites where herding families camp during the spring, summer, and autumn [27].

(a)



(b)

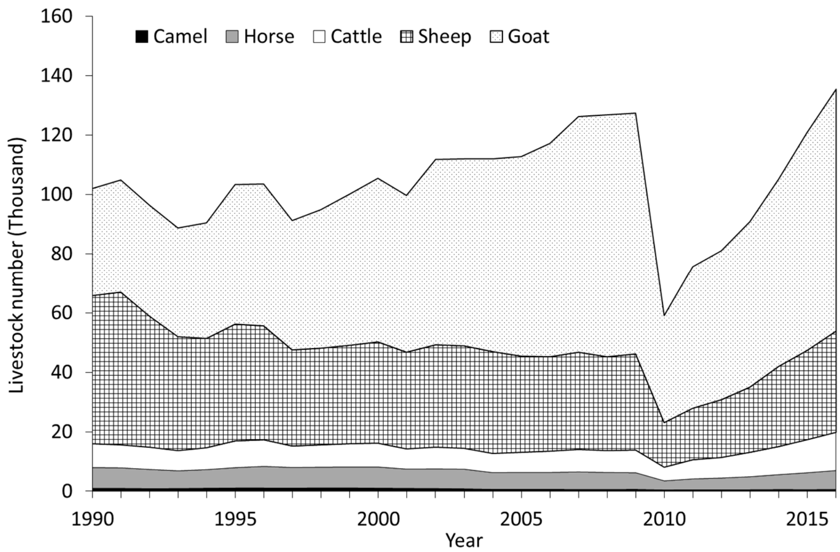


Figure 2. Development of livestock numbers in Mongolia (**a**) and in Bulgan *soum* of Khovd province (**b**) from 1990 to 2016 (Source: [28]). Please note that the two y-axes are scaled differently.

The westernmost region of Mongolia, situated at the southern fringe of the Mongolian Altai Mountains and the Dzungarian desert and bordering China, is one of the poorest regions in Mongolia [15,16] and to date is characterised by limited road and communication infrastructure. The ecological and geographical conditions of the Altai mountain steppes and alpine meadows are particularly suited for spring and summer grazing of small ruminants [29,30]. Currently the mountain pastures in this border area supply feed to approximately 370,000 head of animals which constitute the backbone of livelihood of the local population [26]. Due to the importance of spring and summer pastures for animal nutrition within the yearly cycle, their primary and secondary productivity is of high relevance for the economic and social sustainability of rural people's livelihoods. We thereby understand primary productivity as the plant biomass produced per unit surface and unit time, and secondary productivity as the animal mass (weight) produced per unit surface (or unit plant biomass) and unit time. In view of (a) increasing climate variability and change [10], (b) increasing numbers of domestic herbivores and particularly goats [26], (c) decreasing herd mobility [25], and (d) very clustered grazing patterns [27] that were evidenced in companion studies for the southern Altai region of Mongolia, we aimed at evaluating (1) quantity and quality of herbaceous biomass offered along the daily grazing itineraries of sheep and goats and (2) grazing behaviour, feed and nutrient intake of small ruminants during spring and summer seasons in order to (3) determine if forage availability and quality sustain secondary pasture productivity in the southern Mongolian Altai despite ongoing agro-ecological change processes (a–d).

2. Materials and Methods

2.1. Study Site

The study was carried out in Bulgan *soum* (county) of Khovd province with its central settlement Burenkhairkhan, and the neighbouring Bulgan *soum* of Bayan Ulgii province. These two administrative units were delineated during Mongolia's socialist era, but earlier people in this region shared pasture and water resources along the Bulgan River watershed. Our research focused on the traditional small ruminant grazing system which utilizes, in a transhumant manner, alpine meadows in the southern Altai Mountains for spring and summer grazing and steppe ecosystems at the mountain foothills for autumn and winter grazing. The latter constitute the transition area from the Altai Mountains to the Dzungarian Desert in western Mongolia. Geographically the region extends from 91° to 92° Eastern longitude and 46° to 47° Northern latitude, and elevation ranges from 1100 to 3250 m a.s.l. The area is characterized by an extremely continental climate, with average annual minimum and maximum air temperatures of −32 °C to +26 °C and an average annual precipitation of 75 mm with a standard deviation of 34 mm and a coefficient of variation of 45% (Burenkhairkhan weather station records, 1963–2014). During the 2013 and 2014 study period, own measurements of annual air temperature and rainfall determined an average of 4 °C and 47.9 mm (2013) and 51.2 mm (2014) in Burenkhairkhan, the *soum* center (1189 m a.s.l.), whereas on the alpine meadows (2432 m a.s.l.) average minimum and maximum air temperatures were −40 °C and +23 °C and annual precipitation amounted to 305.4 mm (Figure 3).

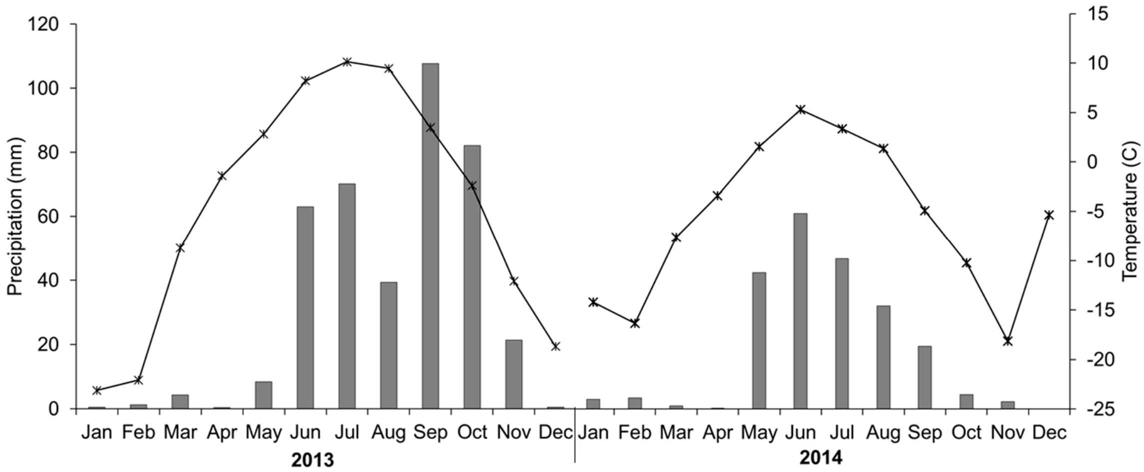


Figure 3. Monthly precipitation (bars) and average temperatures (lines) in 2013 and 2014 recorded by the research team at Tsunkhul Lake summer pasture (2432 m a.s.l.) in the Mongolian Altai Mountains.

The predominant land use and livelihood system is pasture-based transhumant animal husbandry [26]. Paralleling the nationwide trend, the total number of livestock in Bulgan *soum* of Khovd province as well as in Bulgan *soum* of Bayan Ulgii province increased from 1990 to 2009, mostly due to a sharp increase in the number of goats (Figure 2). Given the region's remoteness, its lack of infrastructure and in consequence difficult access to regional and national markets [26], storable cashmere fibre and, very recently, sheep wool, are at the moment the only commodities worth producing at a larger scale in this region [26]. Moreover, the regional ecological conditions are very suitable for keeping small ruminants and particularly goats. Yet, cattle, yak, horses, and camels are also part of the local herds.

Our study focused on spring (46°23′ N, 91°05′ E, 1820 m a.s.l.) and summer (46°37′ N, 91°35′ E, 2430 m a.s.l.) pastures in the Altai Mountains that are grazed in a sequential manner, with an average duration of herds' stay per spring and summer pasture of 42 and 32 days [25]. The surface of spring pastures is covered with gravel and erosion debris consisting predominantly of granite and slate rock [31], while the summer pastures surround the small and slightly salty *Tsunkhul* Lake (also known as *Sonkhel* Lake [26] or *Tsunhal Nur* [27]) that provides drinking water for animals. Spring and summer pastures are typical foothill and mountain steppes, respectively. Spring pastures are dominated by the grasses *Agropyron cristatum* (L) Gaertn., *Stipa krylovii* Roshev. and *S. tianschanica* subsp. *gobica* (Roshev.) D.F.Cui, along with the herbaceous dicotyledonous species *Allium mongolicum* Regel, *Taraxacum leucanthum* (Ledeb.) Ledeb. and *Ajania fruticulosa* (Ledeb.) Poljakov. Major summer pasture grasses are *Agropyron cristatum* (L.) Gaertn., *Festuca altaica* Trin. ex Ledeb., *F. tristis* Krylov & Ivanitzk. and *Hordeum brevisubulatum* (Trin.) Link; major dicotyledonous plants are *Leontopodium ochroleucum* Beauverd and *Trifolium eximium* DC. (O. Chuluunkhuyag, pers. comm.). Except for laurel-leaf poplar (*Populus laurifolia* Ledeb.) along rivers and streams on spring pasture, only dwarf shrubs such as *Artemisia* but no larger shrub and tree species are present on the studied sites.

2.2. Data Collection

Grazing itineraries, grazing behaviour, feed intake and live weight (LW) changes of Mongolian native breeds of sheep and goats were studied in seven castrated male animals of each species. Following their owner's suggestion, study animals were selected anew each spring but always occupied a middle social rank within the herd. All animals were approximately two years old and in 2013 had an average LW of 38 ± 4.2 kg (goats) and 44 ± 0.9 kg (sheep); in 2014 their initial LWs were 35 ± 2.1 kg (goats) and 34 ± 2.7 (sheep). All animals were grazing in one large mixed flock that consisted of about 500 small ruminants (59.3% goats, 40.7% sheep). During daytime the herd grazed on its own, whereby the herder guided the animals towards the intended grazing direction each morning (herd-release mode; [25]). To avoid wolf predation, animals did not graze at night but camped near the family's temporary residence (the yurt; further referred to as camp site). At all times the animals had free access to drinking water and locally available natural minerals (mainly sodium chloride).

Data were collected in June, July, and August 2013 and 2014, respectively; these months represent the late spring, early summer, and late summer seasons. Each data collection period comprised 6 days for goats and for sheep, respectively, whereby the two species were monitored subsequently. While grazing itineraries and animal behaviour were recorded on days 1 to 3, faecal excretion was quantified on days 1 to 5 and herbaceous biomass on offer along the animals' grazing itinerary was determined on day 6. During two consecutive days that preceded each data collection period, all animals were weighed in the morning by using locally fabricated weigh slings and a digital electronic hanging scale (range 5–300 kg, accuracy 0.5 kg). All animal handling in this study's experiments and monitoring was authorized by Order №A/142 of the ethics commission of the Mongolian University of Life Sciences at Ulaanbaatar.

2.2.1. Determination of Grazing Itineraries

To determine the direction and length of the animals' daily grazing itineraries, geographical data was collected using GPS collars (GPS PLUS Globalstar, Vectronic Aerospace GmbH, Berlin, Germany).

During each data collection period, three of the seven goats, randomly chosen at the start of the study, were fitted with a GPS collar during three consecutive days. Subsequently, for another three days the collars were mounted onto three sheep that also had been chosen randomly when the study was initiated. Per animal, the geographical position (latitude, longitude, and altitude) along with time were recorded at one-minute intervals for 72 h continuously. When changing the collars from the goats to the sheep, the recorded goat data were downloaded and saved on a laptop PC. The same was done when the collars were detached from the sheep.

2.2.2. Determination of Herbage Yield and Quality along Grazing Itineraries

Being acquainted with the animals' daily routes from the GPS tracking, the herbaceous biomass on offer along the itinerary was determined on day 6 of the data collection period. Starting at the animals' night resting place, a 50 cm × 50 cm sampling frame was positioned on the ground at each 500 m along the itinerary. At each spot, the geographical position and environmental variables (altitude, aspect) were recorded and stone cover, vegetation cover and mean vegetation height were determined within the frame. Subsequently, all herbaceous plants within the frame were cut with scissors at 1 cm height above ground, whereby non-forage plants and litter were ignored. The total fresh mass of the clipped material was determined on a portable electronic scale (range 0–3000 g, accuracy 0.1 g). After air-drying the individual samples in cotton bags in the shade, they were weighed again and then ground to 1-mm particle size using a FOSS sample mill (Cyclotec TM 1093, Haan, Germany). For individual samples, the concentrations of dry matter (DM) and crude ash (CA) were determined applying VDLUFA [32] methods MB3-3.1 and MB3-8.1. The concentration of organic matter (OM) was derived by subtracting crude ash concentration (g 100 g^{-1} DM) from 100. To determine the nitrogen (N) concentration, a CN analyser (Vario MAX CN; Elementar Analysensysteme, Hanau, Germany) was used (MB3-4.1.2 [32]); the N-concentration was multiplied with factor 6.25 to calculate the crude protein (CP) content. Phosphorus (P) and calcium (Ca) concentrations were determined with a Hitachi U-2000 (Tokyo, Japan) spectrophotometer following methods MB3-10.6.1 and MB3-10.3.1 [32]. The cell wall fractions, that is neutral detergent fibre (NDF; hemicellulose, cellulose and lignin) and acid detergent fibre (ADF; cellulose and lignin) were determined according to van Soest et al. [33], thereby applying the protocol of Schiborra et al. [34]; both fractions included residual ash. As only a fraction of the collected samples was analysed wet-chemically, near infrared spectroscopy (NIRS; XDS-Rapid Content Analyzer, FOSS NIRsystems, Hillerod, Denmark) was used to predict the concentrations of OM, N, NDF and ADF in the remaining biomass samples [35], using the calibration equations described by Jordan et al. [25].

2.2.3. Determination of Grazing Behaviour and Feed Intake

In 2013 the grazing behaviour of the three goats and three sheep equipped with the GPS collars was monitored during three consecutive days per animal. Animals were observed during daylight (from 07:00 to 21:00 h) whereby morning (07:00–10:00 h), noon (11:00–15:00 h), afternoon (15:00–19:00 h) and evening (19:00 h onwards) were distinguished when analysing the data. To record the behaviour, an observer followed the animals at a distance of about 100 m and, in 5-minute intervals, identified the animals' activity at that specific moment (instantaneous observation; [36]) by using binoculars if needed. Activities were classified as 'grazing', 'resting', 'walking' and 'other activities' [37]. Biting/harvesting grass, chewing and walking between feeding stations were referred to as 'grazing', while walking in search of forage and walking faster without grazing were classified as a 'walking'. Interaction with peers as well as drinking water and ingesting soil or rubbish were classified as 'other activities'. At the moment of observation, the observer recorded the number of animals that were expressing a specified activity. The observed number of animals per activity was multiplied with the length of the observation interval (usually 5 min), and the sum of all animal-intervals per activity and day (or daytime-period) was divided by the total number of animals observed (i.e., three per day) times the total daily (or periodical) observation time, to obtain the proportion (%) of each activity in a day or daytime-period, respectively.

The animals' daily feed intake was quantified using the total faecal collection method [38]. To this end, the four sheep and four goats not selected for GPS tracking in a particular period, plus one randomly selected sheep and goat, respectively, that carried a GPS collar, were fitted, for five days each, with a faecal collection bag connected to a harness [39]. The bags were emptied in the morning and in the evening, and the total amount of faeces was weighed fresh (portable electronic scale, range 0–3000 g, accuracy 0.1 g) and then air-dried in cotton bags in the shade. At the end of the collection period, when all samples were dry, they were weighed again and afterwards pooled by animal (n = 5 per species) and period (n = 3 per year). The pooled material was thoroughly homogenized, subsampled (200 g air dry material per pool), ground through a 1.5 mm screen and analysed wet-chemically for the concentrations of DM, OM, and N as described above. The organic matter digestibility (OMD) of the ingested diet was calculated from the faecal CP concentration (CP_f) using a regression equation (Equation (1)) built on 721 individual in vivo digestibility data of sheep [40]:

$$y = 0.899 - 0.644\left(\frac{-0.5774 * CP_f}{100}\right) \quad (1)$$

where y is the organic matter digestibility (%) of the ingested diet, 0.899, 6.44, and 0.5774 are the fixed-effect parameters, and CP_f is the faecal crude protein concentration (g kg^{-1} OM).

Subsequently, the organic matter intake (OMI) was calculated (Equation (2)) by dividing the total faecal OM excretion (FOM) by the indigestible fraction of the diet [38].

$$y = \frac{FOM}{(1 - OMD)/100} \quad (2)$$

where y is the organic matter intake (g OM d^{-1}), OMD (in %) is the organic matter digestibility of the ingested diet, and FOM is the faecal organic matter excretion (g OM d^{-1}).

Based on the quantitative intake of pasture vegetation and its concentration of CP, NDF, ADF, P and Ca, the intake of these constituents was calculated (Equation (3)).

$$y = x * OMI \quad (3)$$

where y is the intake of a certain component (g kg^{-1} OM) and OMI is the organic matter intake (g $animal^{-1}$ d^{-1} or g $kg^{-0.75}$ LW d^{-1}).

2.3. GPS Data Evaluation and Statistical Analyses

All GPS raw data obtained from the tracking of sheep and goats were corrected for outliers and failed GPS readings (GPS positions estimated from only three satellites and fewer than three satellites, respectively), and then converted to Universal Transverse Mercator (UTM) grid projection (WGS 1984, zone 46N). Afterwards, successively logged positions were merged per individual animal, month (June, July and August) and year (2013, 2014) using the software package ArcGIS 9.2 (ESRI Corp, Redlands, CA, USA). A buffer of 100 m width was plotted along each three-day itinerary and defined as the area grazed [25] by the entire flock of sheep and goats, respectively. This surface, as well as the total length of the three-day track, was then divided by the number of tracking days to calculate the area grazed per day and the length of the daily itinerary.

Simple linear regressions were computed in Microsoft Excel 2010, while all other statistical analyses were performed in SPSS version 20.0 for Windows (IBM Corp., 2011; IBM Armonk, NY, USA). First, the data residuals were checked for normal distribution using the Shapiro-Wilk test; then Levene's test was run to check for homogeneity of variance. In case of normal distribution of dependent variables, the generalized linear model (GLM) procedure was applied to determine effects of independent variables (animal species, month and year) and their interactions; where applicable, Tukey post-hoc test was used to determine differences between factor levels. For non-normal distributed variables, the Mann–Whitney-U and Kruskal–Wallis test were used. Significance was declared at $p < 0.05$; data are depicted as arithmetic mean and standard deviation (±) or standard error of the mean (SEM), respectively.

3. Results

3.1. Grazing Itineraries

Across the two years, the average daily distance walked by sheep and goats, respectively, was 13 ± 1.3 km and 14 ± 0.9 km ($p > 0.05$), and the areas grazed by the flocks of sheep ($n = 204$) and goats ($n = 297$) averaged 64 ± 11.7 ha and 71 ± 9.2 ha per day (Figure 4). Both variables slightly decreased from spring (June) to early and late summer (July and August) in each year. In both years, goats covered considerably longer distances than sheep in June ($p < 0.05$), whereas in July and August the daily itinerary lengths of sheep and goats were similar ($p > 0.05$). In sheep, length of the daily itinerary did not vary significantly between months within and across the two years, whereas in goats the average daily itinerary length was significantly higher in June than in July and August ($p < 0.05$). The individual maximum itinerary length for sheep and goats was 18.2 and 21.3 km day^{-1}, and the minimum was 9.3 and 9.5 km day^{-1}, respectively.

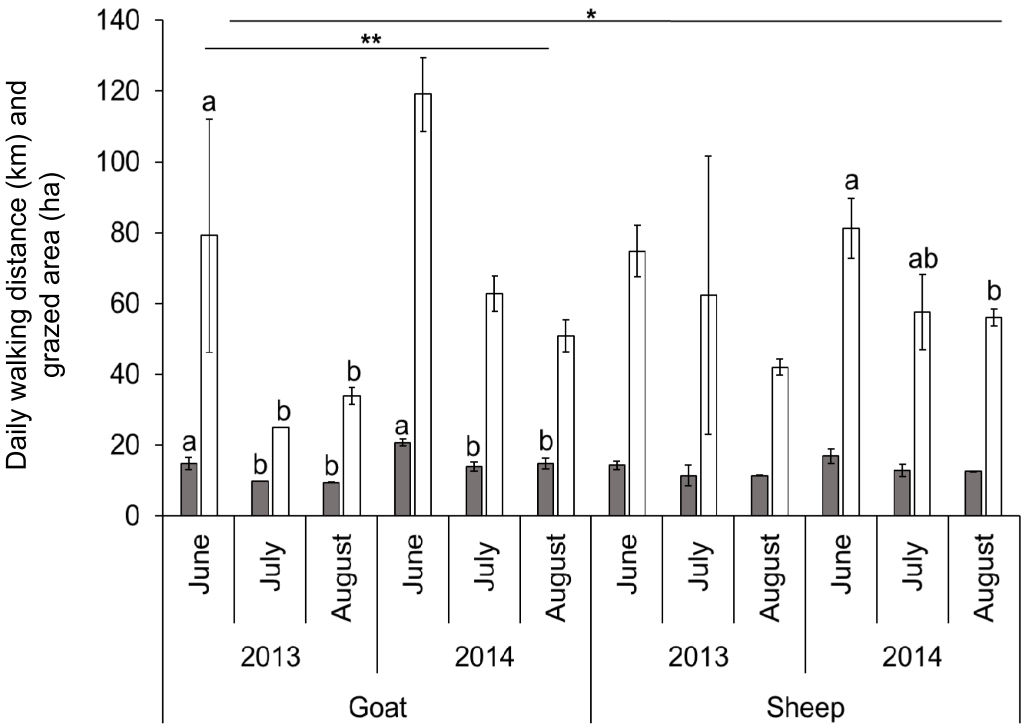


Figure 4. Average daily walking distances (km; grey bars) and grazed areas (ha; white bars) of goats and sheep on Mongolian Altai Mountain pastures during spring (June) and summer (July, August) 2013 and 2014. Whiskers on bars represent one standard deviation. Statistical difference between years among goats (**$p < 0.01$) and between goats and sheep (*$p < 0.05$) are shown. [a, b] Superscripts on bars indicate significant differences between months within a year according to the Kruskal–Wallis test. Bars without superscript are not significantly different.

Across both years, the average area grazed per day by the sheep (64.1 ha) and the goats (70.6 ha) was significantly different ($p < 0.05$). This difference was due to the fact that in June 2013 and in June 2014 the daily grazed area was larger for goats than for sheep ($p < 0.05$), whereas values were similar during the other months ($p > 0.05$). The minimum and maximum sizes of grazed areas by sheep and goats were 21 versus 100 ha day^{-1} and 20 versus 127 ha day^{-1}, respectively. As a result of the way of calculating the grazed areas, they were strongly and positively correlated to the length of the daily grazing itinerary ($R^2 = 0.99$, $p < 0.05$); therefore, seasonal differences in the size of grazed areas can be interpreted in the same way as variations in itinerary length.

Table 1. Proportion of bare and vegetated soil, average herbage height, herbage dry matter yield (DM, kg ha^{-1}), dry matter concentration (DM, g kg^{-1} fresh matter) and concentration of other major proximate constituents of herbaceous pasture vegetation sampled on spring (June) and summer (July, August) pasture in the Mongolian Altai Mountains in 2013 and 2014.

Year	Month	Bare Soil or Stones (%)	Vegetated Area (%)	Vegetation Height (cm)	Herbage Yield kg DM ha^{-1}	DM g kg^{-1} FM	OM g kg^{-1} DM	CP g kg^{-1} DM	NDF g kg^{-1} DM	ADF g kg^{-1} DM	Ca g kg^{-1} DM	P g kg^{-1} DM
2013	June	2.1 ^{b}	43.4 ^{b}	15 ^{A,a}	986 ^{A,a}	473 ^{B,c}	919 ^{a}	125 ^{A,a}	453 ^{B,c}	279 ^{b}	9.8 ^{A,a}	1.8 ^{A,a}
	July	6.9 ^{a}	67.8 ^{a}	6 ^{b}	821 ^{ab}	617 ^{b}	898 ^{B,b}	129 ^{a}	520 ^{b}	290 ^{A,b}	7.8 ^{A,b}	1.4 ^{b}
	August	7.2 ^{a}	44.3 ^{b}	9 ^{b}	601 ^{B,b}	767 ^{a}	902 ^{b}	82 ^{b}	617 ^{a}	332 ^{A,a}	4.9 ^{c}	1.1 ^{c}
	SEM	*0.84*	*2.91*	*0.6*	*47.3*	*16.8*	*2.3*	*3.0*	*9.8*	*5.0*	*0.4*	*0.04*
	Effect of month	***	**	***	**	***	***	***	***	***	***	***
2014	June	9.2	26.7 ^{b}	6 ^{B}	844 ^{B}	742 ^{A,a}	913 ^{a}	101 ^{B,b}	509 ^{A,b}	291 ^{a}	5.1 ^{B}	1.4 ^{B,a}
	July	12.7	76.3 ^{a}	8	904	592 ^{B,b}	923 ^{A,a}	127 ^{a}	523 ^{b}	248 ^{B,b}	5.5 ^{B}	1.3 ^{ab}
	August	8.2	58.1 ^{a}	9	777 ^{A}	749 ^{a}	898 ^{b}	79 ^{c}	579 ^{a}	298 ^{B,a}	4.1	1.1 ^{b}
	SEM	*2.34*	*3.89*	*0.4*	*66.5*	*18.3*	*2.5*	*3.8*	*9.2*	*6.3*	*0.3*	*0.04*
	Effect of month	*n.s.*	***	*n.s.*	*n.s.*	***	***	***	**	**	*n.s.*	**
Effect of year	*June*	*n.s.*	*n.s.*	*	**	**	*n.s.*	*	**	*n.s.*	**	*
	July	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*n.s.*	*n.s.*	*	*	*n.s.*
	August	*n.s.*	*n.s.*	*n.s.*	***	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	*n.s.*	*n.s.*

FM = fresh matter, DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fibre, ADF = acid detergent fibre, Ca = calcium, P = phosphorus. SEM = standard error of the mean. Effects for independent variable month (per year) are according to one way ANOVA and Kruskal–Wallis test; significant differences between means at $p < 0.05$ are indicated by different lower case letters ($^{a,\ b}$). Effects for independent variable year (per month) are according to *t*-test and Mann–Whitney U-test; significant differences between means at $p < 0.05$ are indicated by different capital letters ($^{A,\ B}$). Asterisks indicate probability values as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s. = non-significant.

3.2. Quantity and Quality of Pasture Vegetation

Since the summer pastures were located in the alpine meadow zone with partly shallow soil profiles, stone cover was higher on summer than on spring pasture in both years ($p < 0.05$). Overall, vegetation cover did not differ between years ($p > 0.05$) and ranged from 37% to 71% on spring and summer pastures, respectively (Table 1). Highest cover was recorded in July in both years while considerably lower values were determined on spring pasture (June). Average vegetation height was slightly higher in spring 2013 than in spring 2014 ($p < 0.05$), and higher in spring than in summer (July and August) 2013, while there were no differences between months and pastures in 2014.

Averaged for the year, offer of herbage dry matter (kg DM ha^{-1}) along spring and summer grazing itineraries of small ruminants (Table 1) was a bit higher in 2014 (837 kg DM ha^{-1}) than in 2013 (711 kg DM ha^{-1}; $p > 0.05$). However, at seasonal level, the highest amount of herbage was measured in June 2013 as compared to July and August 2013, as well as compared to June 2014 ($p < 0.05$). Herbage offer on summer pasture was highest in July 2014 and slightly decreased in August 2014 ($p > 0.05$). From a spatial point of view, the highest biomass values were recorded at a 3.0–4.5 km distance from the camp site in June and August and at 9–10 km distance in July (data not shown). The lowest amount of biomass offer in all three months was found nearby the camp site where the daily itineraries started and ended.

In both years, the average DM content of the collected herbaceous biomass significantly increased from June to August whereas the CP concentration considerably decreased, by 34.4% from spring to late summer 2013 and by 20.2% from spring to late summer 2014 (Table 1). The concentration of cell wall constituents increased from June to August in both years, reflecting the maturation of the herbaceous plants. The maximum NDF concentration (617 g NDF kg^{-1} DM) was found in August 2013, whereas the minimum (453 g NDF kg^{-1} DM) was determined in June 2013. In both years, Ca and P concentrations decreased from June to August, whereby the decrease was significant ($p < 0.05$) for P in both years and for Ca in 2013.

3.3. Grazing Behaviour and Forage Intake

During the three months of behaviour observation in 2013, sheep spent on average 54, 29, 16, and 2% of day time on grazing, resting, walking, and other activities, respectively (Table 2), and the values determined for goats were very similar (grazing 56%, resting 30%, walking 11%, other activities 2%). In both species, there were no significant differences between months (June, July, and August) in the proportion of time spent on the four activity classes. However, for both species the lowest proportion of time spent grazing was recorded in July, whereas the highest was found in June for sheep and in August for goats. In both species, the proportion of time spent resting and walking gradually decreased from June to August. Across all months, the shortest proportion of time spent grazing and the longest proportion of time spent resting was recorded in the morning in comparison to noon (Figure 5) when grazing lasted longest ($p < 0.001$) and resting shortest ($p < 0.01$). Likewise, both species spent a higher proportion of their time on grazing in the afternoon and evening than in the morning ($p < 0.05$), whereas the proportion of time both species devoted to walking and other activities did not vary during a day ($p > 0.05$).

With the exception of one goat that lost weight throughout the study period of 2013, the sheep and goats monitored for grazing behaviour and feed intake showed a substantial increase in live weight from June to August in both years. Average daily LW gains of sheep across the 2013 and 2014 spring/summer period were 96 and 130 g day^{-1}, and the respective values for goats (including the animal losing weight in 2013) were 146 and 118 g day^{-1} (Table 3). Numerically, the overall daily LW gain of sheep was higher in 2014 than in 2013, but in both species daily LW gain did not differ between years ($p > 0.05$).

Table 2. Proportion (%) of time allocated by sheep and goats to different activities on spring (June) and summer (July, August) pastures in the Mongolian Altai Mountains in 2013.

Animal Species and Month		Grazing	Resting	Walking	Other
Sheep	June	56	26	16	2
	July	51	27	20	2
	August	54	33	11	2
	SEM	*3.7*	*3.5*	*1.7*	*0.5*
	Effect of month	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Goats	June	56	29	13	2
	July	52	34	11	3
	August	61	28	10	1
	SEM	*3.7*	*3.5*	*1.7*	*0.5*
	Effect of month	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Fixed effects					
Species		*n.s.*	*n.s.*	*n.s.*	*n.s.*
Month		*	*n.s.*	*n.s.*	*n.s.*
*Species*Month*		*n.s.*	*n.s.*	*n.s.*	*n.s.*

SEM = standard error of the mean. Effects for independent variables and their interactions are according to the Mann–Whitney U-test; Asterisks indicate probability values as * $p < 0.05$. n.s. = non-significant.

(a)

(b)

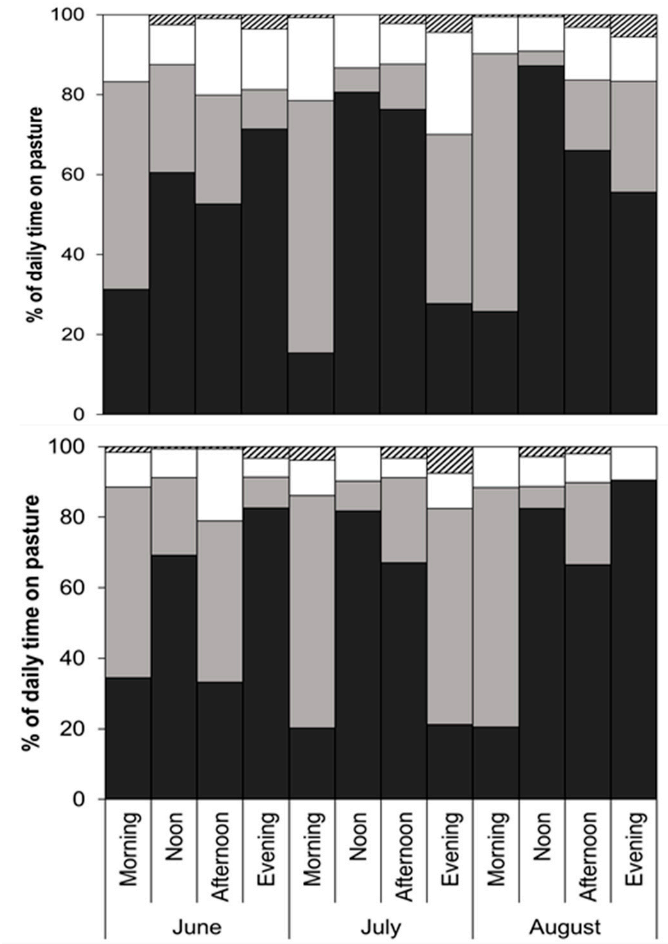


Figure 5. Proportion of time devoted to grazing (dark grey), resting (light grey), walking (white), and other activities (patterned) by sheep (**a**) and goats (**b**) on the Mongolian Altai Mountain pastures during spring (June), early (July) and late (August) summer 2013.

Table 3. Live weight (LW, kg) and average daily LW gain (ADG, g d^{-1}) of sheep and goats, digestible organic matter concentration (OMD, g kg^{-1} OM) of the diet, and daily intake (g $kg^{-0.75}$ LW) of dry matter and major diet constituents in spring (June) and summer (July, August) pastures in the Mongolian Altai Mountains in 2013 and 2014.

Species	Year	Month	LW[#]	ADG[##]	OMD	Daily Intake (g $kg^{-0.75}$ LW) DM	OM	CP	NDF	ADF	P	Ca
Sheep	2013	June	44 ^{A,b}		723 ^{A,a}	77 ^{b}	72 ^{b}	9 ^{b}	31 ^{b}	19 ^{b}	0.13 ^{a}	0.74 ^{A,a}
		July	48 ^{ab}	115	703 ^{A,b}	99 ^{A,b}	92 ^{A,b}	12 ^{A,a}	48 ^{A,a}	28 ^{A,a}	0.13 ^{A,a}	0.73 ^{A,a}
		August	51 ^{A,a}	68	622 ^{c}	63 ^{b}	58 ^{b}	4 ^{c}	36 ^{b}	20 ^{b}	0.06 ^{b}	0.30 ^{b}
		SEM	*1.2*	*19.5*	*11.9*	*4.9*	*4.5*	*0.9*	*2.4*	*1.3*	*0.010*	*0.060*
	Effect of month		*	*n.s.*	***	***	***	***	***	**	***	*
	2014	June	34 ^{B,b}		669 ^{B,a}	81	76	8	39	22 ^{a}	0.10 ^{a}	0.38 ^{B}
		July	40 ^{B,a}	158	678 ^{B,a}	57 ^{B}	53 ^{B}	7 ^{B}	28 ^{B}	13 ^{B,b}	0.07 ^{B,ab}	0.29 ^{B}
		August	42 ^{B,a}	107	623 ^{b}	64	60	5	35	18 ^{ab}	0.07 ^{b}	0.25
		SEM	*1.5*	*19.7*	*7.6*	*5.1*	*4.8*	*0.6*	*2.5*	*1.5*	*0.007*	*0.025*
	Effect of month		**	*n.s.*	***	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*	*	*n.s.*
	Effect of year	*June*	*		*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*
		July	**	*n.s.*	*	**	**	*	*	**	*	*
		August	*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Goats	2013	June	38 ^{b}		724 ^{a}	86	81	10 ^{ab}	38	23	0.14 ^{A,a}	0.73 ^{A,a}
		July	40 ^{b}	65	684 ^{b}	92 ^{A}	86 ^{A}	11 ^{A,a}	44 ^{A}	24 ^{A}	0.13 ^{A,a}	0.66 ^{A,a}
		August	46 ^{a}	218	599 ^{c}	64	59	5 ^{b}	36	19	0.07 ^{b}	0.28 ^{A,b}
		SEM	*1.5*	*53.8*	*14.2*	*6.6*	*6.2*	*1.0*	*2.9*	*1.6*	*0.011*	*0.068*
	Effect of month		**	*n.s.*	***	*n.s.*	*n.s.*	*	*n.s.*	*n.s.*	*	*
	2014	June	34 ^{b}		684 ^{a}	66 ^{a}	62 ^{a}	6 ^{a}	32 ^{a}	18 ^{a}	0.09 ^{B,a}	0.33 ^{B,a}
		July	37 ^{a}	100	656 ^{b}	47 ^{B,b}	44 ^{B,b}	6 ^{B,a}	23 ^{B,b}	11 ^{B,b}	0.06 ^{B,b}	0.25 ^{B,b}
		August	41 ^{a}	138	595 ^{c}	52 ^{ab}	49 ^{ab}	4 ^{b}	28 ^{ab}	14 ^{ab}	0.05 ^{b}	0.20 ^{B,b}
		SEM	*1.3*	*36.0*	*11.7*	*3.4*	*3.2*	*0.4*	*1.6*	*1.0*	*0.005*	*0.018*
	Effect of month		**	*n.s.*	***	*	*	**	*	**	*	**
	Effect of year	*June*	*n.s.*		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	**	*
		July	*n.s.*	*n.s.*	*n.s.*	**	*	*	*	**	*	*
		August	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*	*

[#] Weighing dates: **2013** Sheep: 31 May + 01 Jun.; 12+13 Jul.; 10+11 Aug.; Goats: 06+07 Jun.; 05+06 Jul.; 05+06 Aug.; **2014** Sheep 13+14 Jun.; 12+13 Jul.; 09+10 Aug.; Goats: 07+08 Jun.; 07+08 Jul.; 03+04 Aug.. [##] These values are reporting ADG from June to July and July to August weighing in each year. DM = dry matter, OM = organic matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fibre, Ca = calcium, P = phosphorus, SEM = standard error of the mean. Effects for independent variable month (per year) are according to one way ANOVA and Kruskal–Wallis test; significant differences between means at $p < 0.05$ are indicated by different lower case letters ($^{a, b}$). Effects for independent variable year (per month) are according to the *t*-test and the Mann–Whitney U-test; significant differences between means at $p < 0.05$ are indicated by different capital letters ($^{A, B}$). Asterisks indicate probability values as follows: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, n.s. = non-significant.

In both species, organic matter intake (OMI) across the spring and summer season (Table 3) was higher in 2013 (sheep and goats: 75 g OM kg$^{-0.75}$ LW) than in 2014 (sheep: 63 g OM kg$^{-0.75}$ LW; goats: 52 g OM kg$^{-0.75}$ LW) even though slightly more herbage was on offer along daily itineraries in 2014 as compared to 2013 (Section 3.2). In both years, however, OMI of sheep and goats was similar for the months of June and August. Likewise, the intake of the various diet components (CP, NDF, ADF, P, and Ca) was not significantly different between animal species, even though sheep consumed 3.0–6.5% more nutrients per day than did goats. In sheep, intake of OM and all other diet components was significantly different between the three months in 2013, while only ADF and P intake varied markedly between months in 2014 (Table 3). In goats, the intake of all diet components in 2014, and of CP, Ca, and P in 2013, were different between the three months ($p < 0.05$), whereby in both species the highest intake of all diet components was determined in July 2013 and the lowest in July 2014. Interactions between species, month, and year did not affect the intake of herbaceous vegetation ($p > 0.05$). The digestibility (OMD) of the diet selected by the grazing animals (Table 3), as derived from their faecal crude protein concentration (goats: 106–194 g CP_f kg^{-1} DM; sheep: 113–181 g CP_f kg^{-1} DM), was not different between sheep and goats, but was higher in 2013 than in 2014 ($p < 0.001$). In both years and species OMD decreased significantly from June to August, whereby the decrease was more pronounced in 2013 (sheep: −14%, goats: −17%) than in 2014 (sheep: −7%, goats: −13%).

4. Discussion

The number of animals (seven per species, three for behaviour recording and five for intake determination, with one being involved in both) as well as the length of the observation and sampling period (three to five days per month) are typical for on-farm monitoring studies [37,39], but since our data was obtained from castrated yet still growing male animals only, this might limit its direct transferability to the entire herd.

4.1. Grazing Itineraries

Following the reasoning of Lin et al. [37] we assume that our GPS recordings were accurate even though not differentially corrected. The open landscape of the studied pastures as well as the mostly cloudless sky conditions during spring and summer time provided good conditions for position logging. The lengths of daily grazing itineraries of the Mongolian small ruminant breeds showed trends similar to those previously reported for goats on high mountain pasture in semi-arid Oman as well as in (flat) West Africa, decreasing from spring to autumn season [41,42]. However, the present sheep itineraries of 14.3 km day^{-1} were substantially longer than the 4.7–6.4 km day^{-1} reported for sheep grazing Inner Mongolian steppes [37]. These marked differences might be explained by herd management, topography, biomass availability and pasture size, since much smaller areas (4 and 2 ha paddocks) were grazed in the latter study. At an overall average of 13.5 km day^{-1}, the present small ruminant itineraries were also longer than the 9–10 km day^{-1} reported by Jordan et al. [25] but closely match the 11–13 km day^{-1} reported by Kawamura et al. [43] for small ruminants in Inner Mongolia. The longest itineraries were recorded in June in both years—June often marks the beginning of the growing season in Mongolia, especially in high mountain areas [2,44]. At this time fresh herbaceous vegetation grows first in depressions (normally characterized by higher winter snow cover thus higher soil moisture than slopes and elevated spots). Newly emerging grasses and forbs are preferred over dwarf shrubs (also mostly found in depressions), but as depressions are scattered across the landscape the animals must cover considerable distances. The relatively high stocking rates of 2.5 to 7 sheep units (SU) per hectare on areas surrounding *Tsunkhul* Lake, and of >13 SU ha^{-1} near the campsites [25,27] might have influenced itinerary length in July and August: Animut et al. [45] showed that itineraries prolong when grazing intensity increases in comparable climatic contexts. Similar to the findings of the latter authors, sheep and goats had to walk for several kilometers to reach a valuable grazing area in the morning given the lower herbage availability near their camp site as compared to areas further away [27]. This was also reflected in the activity patterns of both species, with a larger proportion of time (15–19%) spent on walking in the morning than later in the day. Joly et al. [46] found that small ruminants graze at an average 5.1 km distance from the camp site in the Mongolian Gobi region during summer season, which agrees with the radius of 6.75 km day^{-1} grazed around the camp site in our study and the 3.5–6.5 km radius reported for summer herding of sheep and goats from different regions in Mongolia [47]. The decreasing monthly differences in itinerary length of sheep and goats might be explained by increasing herbage availability on the pastures from spring to early summer [48]. Due to different methodological approaches, the determined surfaces of the daily grazed areas cannot be directly compared to the 25 ha [25] and 197 ha [27] reported for the *Tsunkhul* Lake summer pasture, but they are well within the range provided by these companion studies.

4.2. Amount and Quality of Herbage Offer on Spring and Summer Pastures

In arid and semiarid areas, herbaceous biomass production strongly depends on annual precipitation and its intra-annual distribution [6], which has been confirmed for the Mongolian context [49,50]. Despite the lower summer rainfall in 2014, the amount of herbage offered along the animals' grazing itineraries on the summer pasture was higher in 2014 than in 2013, because higher autumn and winter precipitation (mostly snowfall) had occurred from September 2013 to March 2014. An important reserve of soil moisture was therefore available for vegetation development at the beginning and in the course of spring and maybe even later in the vegetation period [44,51]. Snow melt in April (spring pasture) and May (summer pasture) was followed by a sufficiently high amount of rainfall and warmer temperatures during May and June 2014, providing favourable conditions for herbage regrowth after a first utilization by small ruminants. In 2014, the highest amount of herbage DM on offer was determined in July, in agreement with reports of a higher correlation between precipitation and herbage yield in July than in June and August [7,52]. Likewise, Tserendash [53] proclaimed highest biomass yield in July and a gradual decrease thereafter as a general rule for Mongolian pasture vegetation, a pattern also observed here.

Across the two study years, herbage offer along the animals' itineraries at the start of summer pasture grazing in July (821 and 904 kg DM ha^{-1} in 2013 and 2014) was higher than the average value measured shortly before the start of grazing on the same pastures and in the same years (2013: 495 ± 413.6 kg DM ha^{-1}, 2014: 655 ± 415.6 kg DM ha^{-1} [25]). This can be explained by regrowth of pasture vegetation during the grazing season [2]. By relating herbage on offer (kg DM ha^{-1}; Section 3.2) to the area grazed (ha^{-1}; Section 3.1) and the number of animals in the flock (Section 2.2), an average daily herbage allowance per animal of 33 to 40 kg DM was calculated for June 2013 and 2014, which declined to about 18 kg DM in July of both years and to 9 to 15 kg DM in August 2013 and 2014. These values compare well to the herbage allowance of 20 to 50 kg DM per sheep unit and day reported for similar Altai pastures [25]. In all cases, daily herbage allowance largely exceeded the animals' daily feed intake in the beginning of the spring and summer season. Yet, possibilities for fodder selection deceased with dwindling herbage allowance as the season progressed [54].

Furthermore, in both years the overall herbage offer (kg DM ha^{-1}) was lower than values previously reported for the Mongolian Altai (1050–1500 kg DM ha^{-1} [53]); this may in part be explained by the high grazing pressure (demand/supply ratio between dry matter requirements of livestock and quantity of forage available in a pasture at a specific time) of 0.5 to >6 on the studied pastures as determined in simultaneous investigations [25,27]. Even though this did not substantially affect the amount of herbaceous mass on offer [48], the fact that the studied pastures are grazed with a high number of animals every spring and summer since the 1970s appears to have introduced qualitative degradation, as indicated by the high occurrence of so-called grazing weeds such as *Carex duriuscula* C.A.Mey., *Plantago major* L., *Agropyron cristatum* (L.) Gaertn., and *Artemisia frigida* Willd. (B. Oyuntsetseg, personal communication). Nevertheless, in terms of its concentration of OM, CP, cell wall constituents (NDF, ADF), Ca, and P, the quality of the herbaceous vegetation encountered along the animals' itineraries was within the range of values reported for pastures across Mongolia [5]. Vegetation quality was best in July, with high concentrations of CP and low concentrations of NDF and ADF. This is in accordance with the results of Tserendash et al. [55], who stated that maturity of vegetation on Mongolian alpine pastures occurs in August when herbaceous plants set seeds. At that moment, the concentration of OM and CP declined whereas NDF and ADF concentrations increased, due to a declining leaf to stem ratio and an increasing stem diameter [56].

For pasture vegetation across Mongolia, Nergui et al. [2] reported an OMD of 61–67%; for the Altai mountain pastures an OMD of 71% was determined. In the present study, OMD of vegetation ingested by sheep and goats also ranged from 60% to 73%, with the highest values determined in June and July. Since the development of plants on the alpine meadows is retarded (peak quality in July) as compared to those growing on the lower-lying spring pastures (peak quality in May/June), the similarity of digestibility values obtained in June and July may be explained by a similar developmental stage of plants at the time of measurement, but may also be due to differences in the botanical composition of the pastures [25] and the plant species selected at each site. The lower digestibility values in August reflect the maturation of the alpine pasture plants. The slightly lower OMD determined for goats as compared to sheep, particularly in 2013, may reflect the somewhat lower ability of goats than of sheep to digest fibrous feeds [57].

For Altai summer pastures similar to the ones studied here, Tserendulam [58] reported a concentration (per kg of DM) of 110 to 120 g digestible crude protein in August, and a concentration of 108 g CP kg^{-1} DM was found by Murray et al. [5]. In comparison to these values, the present CP concentrations were 1–5% lower than values reported for Mongolia's mountain forest steppe [4], steppe [59] and desert steppe [5], but similar to values found in the country's central mountainous zone [60]. Whereas the present NDF and ADF concentrations were substantially higher than values reported in the mentioned studies, the concentrations of Ca and P were in agreement with previously reported values [53,59]. The only modest quality of herbaceous vegetation in our study may on the one hand be explained by spatio-temporal differences in precipitation and temperatures as compared to previous studies [7,8], but on the other hand also be a consequence of the mentioned high grazing pressure [25,27] and thus intense selection for high quality forage by the animals (note: vegetation samples were taken on grazed pastures) and the expansion of grazing weeds. Therefore, the comparatively low concentrations of CP and DOM and high concentrations of NDF and ADF might point to a gradual but widespread decline of pasture quality in the southern Altai Mountains, paralleling the trend observed in Mongolia's forest steppe [53].

4.3. Grazing Behaviour and Feed Intake

In the present study, the grazing time of sheep (57%) was higher than the 41% reported from central Mongolia [61] but matches findings from Inner Mongolia [37] where longest grazing phases also occurred in the afternoon and shortest ones in the morning. Likewise, the latter authors observed an increasing proportion of time spent grazing and a decreasing proportion of time spent resting and walking as summer progressed. The lower share of time spent grazing and higher share of time spent resting at noon and in the early afternoon, which was observed for both species in June as compared to July and August, might be explained by the distance between pasture and water source as well as by weather conditions [62]: In June the animals could only drink from a small tree-lined stream at some distance from the camp site—they went there at noon to drink and rest for 1.5–2 h in the shade, and only restarted grazing when temperatures decreased and a bit of wind came up, a condition especially suiting sheep (herder G. Dashdavaa, pers. comm.). In both species, resting time during July and August was reduced by 16–20% compared to June, due to cooler weather at the higher altitude of the summer pasture and immediate access to drinking water near the camp site. Furthermore, day length decreases from June to August, to which small ruminants adjust their grazing time [37].

Given the almost exclusive dependency of Mongolia's livestock sector on pasture-based feeding, various studies quantified the feed intake of grazing animals since the 1960s, but data is mostly published in reports and theses written in Mongolian language [62]. According to these authors, daily feed DM intake of a Mongolian sheep ranges from 0.7 to 1.5 kg in spring and 1.4 to 1.9 kg in summer;

the respective figures for goats are 0.7 to 1.1 kg (spring) and 1.1 to 1.2 kg (summer). These values compare well to the average daily DM intake of 0.7 to 1.5 kg per goat and 0.9 to 1.8 kg per sheep determined in the present study. In 2013, the feed and nutrient intake of sheep and goats decreased from June to August, which is in agreement with findings from Inner Mongolia [63] where similar environmental conditions exist. ADF intake of sheep and DM, OM, NDF, and ADF intake of goats slightly increased from July to August 2014, which might be explained by the already mentioned better regrowth of grazed plants on the summer pasture in this year.

Following the approach of Lin et al. [37], we used the OMD concentration of the ingested diet to derive its metabolizable energy (ME) content (ME (MJ kg^{-1} OM) = 17 × (OMD/100) − 0.9, where OMD is in %). Across the two spring and summer seasons, the thus estimated concentration of ME in the ingested diet ranged from 9.2 to 11.4 MJ ME kg^{-1} DM for the two species; based on these values, an average daily intake of 8.7 to 18.8 MJ ME per sheep and of 6.9 to 14.6 MJ ME per goat was calculated. Thereof, between 1.0 and 1.8 MJ ME were necessary to cover an animal's daily energy requirement for locomotion across the pastures [64], leaving between 5.6 and 17.4 MJ ME to meet daily energy requirements for maintenance and growth [65]. Average daily LW gains in the range of 46 to 223 g indicate that the sheep were seemingly efficient in converting the ingested feed and nutrients. For goats the situation was more heterogeneous, with each year one of the study animals losing weight and the others gaining up to 280 g d^{-1} across the spring/summer period. Divergence between calculated energy intake and energy requirements on the one hand and measured live weight changes on the other hand might be due to the multiple calculation steps underlying our ME consumption estimates as well as differences in energy use efficiency of the Mongolian sheep and goats as compared to standard (western) breeds in which requirements are normally determined [64,65].

Nevertheless, CP and Ca intakes of goats were below their tabulated requirements [65] in August 2013 and throughout spring and summer 2014; for sheep a deficient CP intake was only observed in August 2014. Furthermore, in all animals and at all times, P intake did at best supply 50% of the respective requirements [65]. According to Underwood and Suttle [66] the ideal dietary ratio of Ca to P is 1:1 to 2:1 if both elements cover the animals' requirements, but if dietary P concentrations are low an increased Ca intake can intensify the symptoms of a P deficiency—a scenario that is rather unlikely in the studied region.

5. Conclusions

The present results on the lengths of daily grazing itineraries, amounts and quality of herbage offer along these pathways, and on nutrient intake as well as live weight changes of sheep and goats on southern Altai pastures indicate sufficient feed supply during spring and summer. The comparison of present amounts of herbage offer with earlier Mongolian data does not point to a decline of available forage mass on spring and summer pastures in the study region; this is supported by recent results of increased photosynthetic rates in the southern Altai Mountains. The current situation therefore sustains sizeable daily live weight gains of small ruminants. However, a trend towards qualitative degradation of the pasture vegetation can be deduced from the generally modest nutritional value of the grazed herbage and the suboptimal supply of animals with crude protein in the second half of summer, and with phosphorus throughout the season. Companion studies suggest that this trend is brought about by the relatively stationary and intense grazing around seasonal camp sites which reduces the animals' forage selection possibilities and challenges longer-term sustainability of pasture use and productivity. Therefore, adjustments of herd management seem to be indicated, such as the provision of mineral-rich licking blocks and a more frequent change of camp sites within a seasonal pasture to enhance animals' forage selection possibilities and nutrient intake. Conversely, further lengthening the daily grazing itineraries around fixed camp sites is no option as this would increase energy expenditure for locomotion and decrease the animals' weight gain.

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