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Epiphytic lichens as indicators of grazing pressure in the Mongolian forest-steppe

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ABSTRACT

The ecological impact of the traditional land use by pastoral nomads on forest ecosystems is little studied. We analyzed the influence of livestock density on epiphytic lichen diversity in larch forests of the Mongolian forest-steppe, which we selected as a case example because pastoral nomadism is here most widespread within Central Asia. Canonical correspondence analysis showed that the epiphytic lichen vegetation was strongly influenced by the livestock density within a radius of 1 km around the sampled forests. Goats together with horses were most significant at shaping lichen vegetation in the forest edges as were horses alone in the forest interiors. This result matches with the results of interviews with 169 herder families and own field observations, which substantiate that goats preferably graze at the edges, whereas horses often browse the interiors. The livestock impact is thought to be primarily exerted through fertilization by the animals and mechanical abrasion. Based on an indicator species analyses, we propose to use epiphytic lichens as indicators of the grazing impact at different livestock densities in the Mongolian forest-steppe. The proposed indication system can be used as a tool for the rapid assessment of the livestock grazing impact. It has the advantage that it is thought to average the livestock impact of several years, which is important with regard to the nomadic style of livestock husbandry. The use of lichens as indicator species can at least partly substitute the time-consuming interviewing of the herder families to assess livestock densities and their impact on forest biodiversity. The proposed indicator system could thus be used as a planning tool for purposes of nature conservation.

1. Introduction

Epiphytic lichens are well-established indicators of acidic air pollution (Hawksworth and Rose, 1970). They can also be used to indicate different levels of nitrogen pollution (Hauck, 2010; van Herk, 1999) and as indicators of forest continuity (Rose, 1976; Tibell, 1992). In Central Asia, extensive mobile livestock keeping is an important branch of the local economies, which serves the subsistence of significant parts of the population (Griffin, 1995; Johnson et al., 2006; van Leeuwen et al., 1994). The pastures in Central Asia are often ecologically vulnerable because of unreliable rainfall and are subjected to overgrazing, degradation and soil erosion at many places (Sternberg et al., 2011; Ykhanbai et al., 2004). While effects of livestock grazing on the diversity and productivity of the ground vegetation have been studied repeatedly in grasslands (Wesche et al., 2010; Wu et al., 2009; Yoshihara et al., 2008), there are not many studies dealing with the responses of forest vegetation to mobile livestock keeping in Central Asia (Blaser et al., 1998). Since livestock in the forest-steppes of Central Asia is often little herded (Fernández-Giménez, 2000; Lkhagvadorj et al., 2013) and forests and grasslands usually form an aspect-dependent spatial small-scale pattern (Hilbig, 1995), livestock grazing is not restricted to the steppe, but regularly also extends to the forests, especially at the edges. The herders also intentionally drive their livestock into the forest to exploit its herbage in addition to that in the steppe (Lkhagvadorj et al., 2013).

While most attempts for forest conservation in Central Asia rely on the exclusion of land use from strictly protected areas (Reading et al., 2006), this concept is not applicable to forest-steppe regions populated by herders and their livestock. This is especially true in areas with high livestock densities and low income of the population. Therefore, it is necessary to develop measures for ecosystem conservation which include the protection of biodiversity in managed forest-steppes. A central issue in this context is to assess the ecological impact of traditional livestock keeping on individual forests. Since Hauck et al. (2012) found that the species richness and cover of epiphytic lichens were negatively correlated with the density of nomad summer camps in the forest-steppe of the Mongolian Altai, we became interested in the question whether lichens could be used as indicators of the severity of the livestock grazing impact

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in the Mongolian forest-steppe. Epiphytic lichens are not eaten by livestock, but are influenced by nutrient enrichment and mechanical abrasion. In their study from the Mongolian Altai, Hauck et al. (2012) could show that the bark of larch trees contained significantly more total N at the forest edge to the steppe than in the less intensely grazed forest interior. On nutrient-enriched bark, more nitrophytic lichen species were found than on nutrient-poor bark.

Mongolia was chosen as a case example for our studies, because this country has kept the most intact culture of mobile livestock keeping in Central Asia (Fernández-Giménez, 1999; Janzen, 2005), with approximately one third of the total population depending on it economically (Dagvadorj et al., 2009). Our key objective was to study whether epiphytic lichens can be used as indicators of livestock density using the fact that many lichen species are sensitive to changes in nutrient availability, which is in turn a function of the density of livestock. We combined data on epiphytic lichen diversity with the results of interviews with the local herders on human population, livestock densities, seasonal migration behavior and grazing habits from two regions of the Mongolian forest-steppe. We tested the hypothesis that the occurrence and abundance of individual epiphytic lichen species is correlated with the densities of the total livestock and of individual species of livestock around the analyzed forest stands in the forest-steppe.

2. Materials and methods

2.1. Study areas

The study was carried out in two regions of the Mongolian forest-steppe, namely in the Mongolian Altai and the Khangai, western Mongolia (Fig. 1) in 2010 and 2011. In the Mongolian Altai, the study was conducted south and southeast of Lake Dayan (48°14′39″–48°16′3″ N, 88°50′17″–88°57′0″ E) in the Dayan administrative subunit ('bag') in the Altai Tavan Bogd National Park in the province ('aimag') of Bayan-Ulgii, western Mongolia, 110 km SW of the city of Ulgii. The study sites in the Khangai Mountains were located in the valley of the river Shireegiin Gol (47°29′11″–47°30′37″ N, 96°59′20″–97°13′59″ E), ca. 30 km SSE of the city of Uliastai and 40 SW of Mt. Otgontenger in the province of Zavkhan. The elevation of both study regions was >2000 m a.s.l. The climate is highly continental with low winter temperatures and a relatively narrow peak of precipitation in summer. Both study areas are typical forest-steppe landscapes with pure forests of Siberian larch (*Larix sibirica* Ledeb.) on north-facing mountain slopes and steppe in the footslopes and in the valleys; *L. sibirica* covers approximately 80% of the forested area in Mongolia (Tsogtbaatar, 2004). The south-facing slopes are covered with dry mountain steppe.

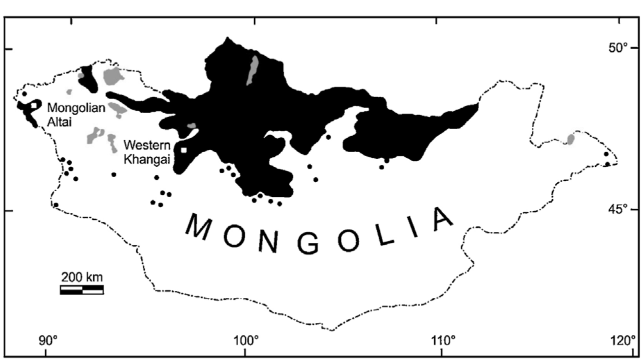

Fig. 1. Position of the study areas in the Mongolian Altai and the western Khangai in western Mongolia. Black areas are landscapes which are dominated by continuous conifer forest or forest-steppe; black dots mark isolated conifer forests; gray areas represent lakes.

The valleys serve for summer camps for pastoral nomads during summer; in the Altai some of the herders live there the whole year.

2.2. Assessment of epiphytic lichen diversity

Data of epiphytic lichen diversity were recorded from 480 trees of *L. sibirica* with a stem diameter at breast height of ≥15 cm. These trees were distributed over 24 sample plots with 20 trees each. In each study region, six plots were selected each at the forest edge to the steppe and at least 50 m within the forest interior. The lower boundary of the forest edge plot was identical with the forest line to the adjacent grassland. Plot size was 20 m × 20 m size. If more than 20 trees with a stem diameter ≥15 cm were available on these plots, the 20 trees growing most closely to the lower edge of the plot were selected in order to include those trees in the sampling which were most exposed to edge conditions. On plots with less than 20 trees, additional trees growing most closely to the sample plot were selected in addition to the trees on the plot. This sampling procedure was applied because the plots where also used for biodiversity surveys in other groups of organisms. Forest stands were selected on north-facing slopes by making use of the relatively even aspect-dependent spatial pattern of forest patches and steppe in the Mongolian forest-steppe. In both study regions, the investigated forest stands were aligned in a row at the southern rim of a valley, which was inhabited by several nomad families. The mean distance between neighboring study sites was 2.2 ± 0.5 km in the Mongolian Altai and 3.8 ± 0.5 km in the Khangai. Though site selection was not at random, it was little subjective because forest patches in near equidistance were chosen without bias by looking at the vegetation or stand density before. However, relatively moist depressions, which occur locally on the mountains slopes, were deliberately avoided to improve the comparability between the individual sites.

On each sample tree, all individual lichen species were recorded on the trunks in a height of 0–1 m above the ground, including all aspects, i.e. the whole circumference of the trunk. The cover of each species was estimated in percent. Cover values of <1% were processed with the value of 0.5% in the data analyses. The recording of lichens was limited to the lowest 1 m of the tree trunks, because the stems were virtually devoid of lichens above this height; the few lichen thalli found above the trunk base were not specialized species but consistently species which also occurred (in higher quantity) at 0–1 m above the ground. Coarse roots located above the soil surface were included in the investigated bark surfaces. Nomenclature is based on Urbanavichus (2010), except for *Xanthoria* s.l. where we follow Fedorenko et al. (2012). Lichen data presentation in the scope of the present paper is limited to data which are related to the immediate context of grazing pressure responses. Species richness (α-diversity) is given as the total species numbers per plot or tree; values of tree-level species richness were averaged plot-wise, before included in further calculations.

2.3. Interviews with the local population

The nomad families living in the grasslands in front of the studied larch forests were interviewed during summer 2010 in the Mongolian Altai and summer 2011 in the Khangai. This included 82 households with 442 members in the Altai and 87 households with 347 members in the Khangai. Interviews were held with at least one member of each household at their homes in the Mongolian language. In the Mongolian Altai, where most nomads belong to the Kazakh minority and usually do not speak Mongolian, a translator with socioeconomy background acted as a translator. The position of each household at the time of the interview was recorded using GPS. A fixed questionnaire was used to obtain data on the number

Table 1
Epiphytic lichen species richness and cover on the lower trunk (0–1 m above the ground) of *Larix sibirica* in the forest interior (FI) and the forest edge (FE).[a]

	Altai		Khangai	
	FI	FE	FI	FE
Species richness				
Species tree^{-1}	12.0 ± 2.3 (9–13) a	5.6 ± 2.5 (2–13) b	10.9 ± 1.5 (7–17) ab	12.2 ± 0.7 (11–16) a
Species plot^{-1}	29.0 ± 0.7 (26–31) ab	21.8 ± 4.7 (10–36) a	31.5 ± 2.1 (23–39) b	36.2 ± 2.5 (27–44) b
Total cover (%)	12.0 ± 2.3 (6–21) ab	5.6 ± 2.0 (1–17) a	14.3 ± 4.1 (8–28) b	14.8 ± 1.5 (10–19) b

[a] Arithmetic means ± SE, ranges in brackets. Within a row, means sharing a common letter do not differ significantly (Duncan's multiple range test, $P \leq 0.05$, $df = 3, 20$).

of household members, livestock numbers, the seasonal migration behavior of the families, and grazing and herding habits.

2.4. Data analysis

Household densities were calculated from the geographical coordinates of the nomad summer camps ('gers') and the sample plots for the biodiversity surveys; sample plot coordinates always refer to the forest edge plot. The calculation of distances (D) was done using the formula $D = \arccos(\sin \text{lat}_1 \sin \text{lat}_2 + \cos \text{lat}_1 \cos \text{lat}_2 \cos(\text{long}_1 - \text{long}_2)$ r_{earth}, with lat_1, lat_2 being the radians for latitude and long_1, long_2 being the radians for longitude of the positions 1 and 2; r_{earth} is the earth's equatorial radius of 6378.137 km. The calculation of livestock densities around a given sample plot was based on the livestock numbers owned by the nomads living in a radius of 1 or 5 km around the plot; our field experience showed that most livestock was grazing within 1 km from the owner's household.

The influence of livestock, household and human population densities on epiphytic lichen diversity was analyzed with canonical correspondence analysis (CCA). These analyses were calculated separately for the forest edge and the less land-use affected forest interior. The CCA was combined with a Monte Carlo permutation test with 999 iterations. Species indicating different levels of livestock densities (summarized in classes for low, moderate and high grazing impact) were calculated with the indicator species analysis after Dufrêne and Legendre (1997). The indicator value yielded in this analysis specifies the percent of perfect indication, which is 100% when a species is found in all plots of a group and is not found in any plot of the other group(s). The indicator species analysis was followed by a Monte Carlo permutation test with 4999 iterations; species with $P \leq 0.05$ were selected as indicators. In the next step after this mathematical procedure, the indicator species were evaluated for species, which are well suited for indication for practical reasons with regard to easy identification, based on the senior author's assessment. The dissimilarities of the epiphytic lichen vegetation of the trees from the two study regions (Altai and Khangai) and the two habitas (edge and interior) were analyzed with non-metric multidimensional scaling (NMDS) using Euclidean distances. The goodness of the fit was assessed by calculating Kruskal's stress 1, which should be <20. A Monte Carlo test with 250 permutations was run to test the significance of the model. Eighteen trees without epiphytes had to be excluded from the NMDS, CCA and indicator species analysis.

Data were tested for normal distribution with the Shapiro–Wilk test; Duncan's multiple range test was used to test means for significant difference between more than two groups; degrees of freedom are specified as $df = df_{\text{model}}$, df_{error}. Mean values are followed by standard errors throughout the paper. These statistical analyses were conducted with SAS 9.13 software (SAS Institute Inc., Cary, NC, USA). The CCA, the NMDS and the indicator species analysis were calculated with the program PC-Ord 5.14 (MjM Software, Gleneden Beach, OR, USA).

3. Results

3.1. Epiphytic lichen diversity

The epiphytic lichen vegetation on most trees was restricted to the lowest decimeters of the tree trunks, whereas the middle and upper parts of the stems were usually devoid of epiphytes. The lichen vegetation was particularly sparse at the forest edges of the Mongolian Altai, where the total cover of all lichens and the species richness were lower than otherwise (Table 1) and 11% of the trees where devoid of epiphytic lichens. The plot-level species richness was generally lower in the Altai than the Khangai. Forty-three percent of the total species were found in both the Altai and the Khangai, whereas 29% and 28% were found only in the Altai or the Khangai, respectively. The results of the NMDS ordination (Appendix S1) showed that trees from the two study regions formed different, but overlapping clusters. There was even higher overlap between trees the forest interior and the forest edge.

3.2. Households and livestock

The nomad families in the valley in front of the studied forests kept a total of 9115 pieces of livestock in the Altai and 13,421 animals in the Khangai. Like elsewhere in Mongolia livestock of different species was kept in mixed flocks on common pastures. The herders in the Mongolian Altai owned sheep, goats, yaks, horses and a few camels; the livestock in the Khangai included sheep, goats, yaks, cattle and horses (Table 2). The shares of the different livestock species were similar in the two study region, with sheep and goats constituting 88% (Altai) and 95% (Khangai) of the total livestock. Goats had a higher, but yaks and horses had a lower share in the total livestock in the Khangai than the Altai.

The population and livestock densities were lower in the Khangai than the Altai (Table 3). In the Altai, total livestock densities in 1 km radius around the sample plots used for the lichen surveys ranged from 178 to 1551 animals (or from 57 to 494 animals km^{-2}; Table 4). In the Khangai, these values varied between 0 and 753 animals within 1 km from the plots or 0–240 animals km^{-2}. The nomad families in the Altai said that they moved only up to four times a year; one-third of them stayed in the studied valley without moving throughout the year. In the Khangai, most herders moved with their livestock ten times a year. Based on the interviews and own observations in the field, the joint flocks of sheep and goats

Table 2
Total livestock kept by pastoral nomads in the study areas in the Mongolian Altai and the Khangai.

	Altai		Khangai	
	Total	% of total	Total	% of total
Sheep	4869	53.4	6760	50.2
Goats	3150	34.6	6013	44.6
Yaks and cattle	599	6.6	351	2.6
Horses	486	5.3	346	2.6
Camels	11	0.1	0	0.0

Table 3
Household and livestock numbers within a radius of 1 and 5 km from the study sites in the Mongolian Altai and the Khangai.[a]

	Altai		Khangai	
	1 km	5 km	1 km	5 km
Households	7 ± 2 (1–15)	62 ± 10 (23–79)	2 ± 1 (0–3)	22 ± 6 (7–41)
Household members	43 ± 14 (7–90)	333 ± 52 (133–425)	10 ± 3 (0–21)	78 ± 16 (29–122)
Total livestock	811 ± 213 (178–1551)	6632 ± 1163 (2257–8712)	371 ± 118 (0–763)	2699 ± 561 (1098–4349)
Sheep	424 ± 123 (100–838)	3562 ± 657 (1100–4738)	182 ± 55 (0–366)	1462 ± 305 (616–2406)
Goats	298 ± 70 (62–514)	2283 ± 373 (867–2945)	177 ± 63 (0–373)	1092 ± 224 (433–1705)
Yaks and cattle	51 ± 16 (62–514)	438 ± 71 (169–571)	4 ± 2 (0–7)	56 ± 19 (12–122)
Horses	36 ± 11 (8–86)	342 ± 64 (113–452)	8 ± 3 (1–17)	89 ± 18 (37–143)
Camels	2 ± 1 (0–8)	7 ± 1 (3–11)	–	–

[a] Arithmetic means ± SE, ranges in brackets.

regularly grazed at forest edges, more rarely in the forest interior. Horses regularly grazed inside the forest especially during winter. Yaks and especially camels very much preferred the steppe over the forests.

3.3. Correlations between livestock densities and lichen diversity

In the Mongolian Altai, the CCA revealed strong relationships between pastoral livestock husbandry and epiphytic lichen diversity. In an analysis including the density of nomad households and the total livestock within a radius of 1 km around the individual sample plots, livestock density clearly had a stronger effect than household density (interset correlation with the first axis for forest-edge data was $r = 0.48$; data not shown). The effect of the total number of family members was even lower. Therefore, we relied on the livestock data for in-depth analysis. Tables 5 and 6 show CCA results for the correlation of epiphytic lichen species abundance and population densities of the five livestock species kept in the forest-steppe (sheep goats, yaks, horses, and camels) in 1 and 5 km radius from the sample plots at the forest edge (Table 5) or in the forest interior (Table 6). The models both for the forest edge and the interior explained a considerable proportion of the variance in the lichen species data. The variance explained with the first axis was 38% in the edge and 52% in the interior. The cumulative variance explained with the first to third axes was 80% or 85%, respectively. The species-environment correlations were $r = 1.0$ in all cases, but more highly significant in the edge ($P = 0.008$) than the interior data ($P = 0.03$) in the Monte Carlo permutation test. Interset correlations for livestock densities within 5 km radius were lower than those within 1 km radius in both habitats. The effect of the different livestock species on epiphytic lichen diversity was different between edge and interior. At the forest edge, goats had the strongest effect (axis 1: $r = 0.70$), followed by horses ($r = 0.68$). There was also a significant decrease of the total lichen species richness on both the tree and the plot levels with the number of goats within 1 km from the edge plots (Fig. 2). In the forest interior, the closest correlation between livestock densities and epiphytic lichen abundance was found for horses; the correlation with the first axis of the CCA was $r = 0.90$ (Table 6). The results of comparable CCA with the Khangai

Table 4
Total livestock densities within 1 km radius from the sample plots for epiphytic lichen sampling in the Mongolian Altai and the Khangai.

Site no.	Livestock within 1 km radius		Livestock density class
	Total (Heads)	Density (Heads km^{-2})	
Altai:			
A1	178	57	Low
A2	453	144	Moderate
A3	548	174	Moderate
A4	870	277	Moderate
A5	1266	403	High
A6	1551	494	High
Khangai:			
H1	0	0	Low
H2	227	72	Moderate
H3	228	73	Moderate
H4	348	111	Moderate
H5	657	209	Moderate
H6	753	240	Moderate

Table 5
Results of the CCA analyzing the effect of livestock densities within 1 km or 5 km radius from the sample plots on the epiphytic lichen vegetation (51 species) from six plots with 107 larch trees in the forest edge of the Mongolian Altai.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.290	0.193	0.136
Randomized data for eigenvalue[a]	0.267	0.181	0.128
Cumulative variance explained (%)	37.5	62.4	80.0
Species-environment correlations	1.000	1.000	1.000
Randomized data for correlations[b]	0.988	0.989	0.993
Interset correlations, 1 km			
Goats	0.702	0.109	−0.520
Sheep	0.514	0.329	0.738
Horses	0.680	0.298	−0.184
Yaks	0.527	0.280	−0.577
Camels	0.452	0.117	0.712
Interset correlations, 5 km			
Goats	0.509	−0.184	−0.762
Sheep	0.534	−0.162	−0.742
Horses	0.570	−0.167	−0.736
Yaks	0.518	−0.185	−0.743
Camels	−0.688	−0.046	0.117

[a] $P = 0.006$ (Monte Carlo permutation test).
[b] $P = 0.008$ (Monte Carlo permutation test).

Table 6
Results of the CCA analyzing the effect of livestock densities within 1 km or 5 km radius from the sample plots on the epiphytic lichen vegetation (51 species) from six plots with 119 larch trees in the forest interior of the Mongolian Altai.

	Axis 1	Axis 2	Axis 3
Eigenvalue	0.219	0.077	0.059
Randomized data for eigenvalue[a]	0.212	0.077	0.059
Cumulative variance explained (%)	52.0	70.4	84.5
Species-environment correlations	1.000	1.000	1.000
Randomized data for correlations[b]	1.000	0.999	0.998
Interset correlations, 1 km			
Goats	0.491	−0.328	0.251
Sheep	0.483	−0.621	0.147
Horses	0.898	0.000	0.234
Yaks	0.553	−0.387	0.364
Camels	0.175	0.939	−0.114
Interset correlations, 5 km			
Goats	0.145	−0.840	−0.190
Sheep	0.145	−0.831	−0.216
Horses	0.194	−0.808	−0.200
Yaks	0.150	−0.836	−0.229
Camels	−0.694	0.164	0.530

[a] $P = 0.005$ (Monte Carlo permutation test).
[b] $P = 0.03$ (Monte Carlo permutation test).

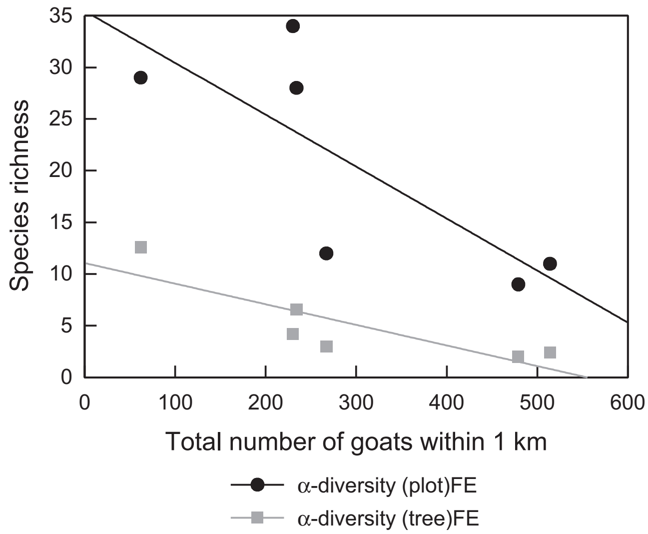

Fig. 2. Epiphytic lichen species richness on the forest edge plots in the Mongolian Altai on the plot ($r = -0.78$, $P = 0.04$, $y = -0.05x + 35.5$) and tree ($r = -0.84$, $P = 0.02$, $y = -0.02x + 11.1$) levels as a function of the total number of goats within 1 km radius.

data revealed similar trends as for the Altai, but the models for the Khangai were not significant in the Monte Carlo test.

The Appendices S2 and S3 show the results of indicator species analyses for low, moderate and high livestock densities (Table 4). In the forest edge (Appendix S2), there was only one species (*Arthonia apatetica*) indicating high livestock numbers, but larger groups of 28 and 13 species which indicate moderate or low livestock densities. In the forest interior (Appendix S3), also a small group of five species was found as indicators of high livestock impact, whereas larger group of 20 and 19 species indicated moderate and low livestock numbers. Indicators of moderate (*Lecanora albellula*) or even low (*Parmelia sulcata*, *Candelariella reflexa*) livestock densities at the forest edge, jointed *A. apatetica* in this group of indicator species in the forest interior.

4. Discussion

The present results clearly show that the epiphytic lichen diversity in the Mongolian forest-steppe is influenced by the density of livestock kept by pastoral nomads in the nearby grasslands. The CCA even allowed attributing the livestock impact on the epiphytic lichen vegetation to individual animal species which occur in the herders' mixed and free-roaming flocks of livestock. The key effects were exerted by goats, followed by horses, at the forest edge, but horses alone in the forest interior. This pattern matches remarkably well with the information on livestock grazing patterns, which was derived from our interviews as well as own observations (Lkhagvadorj et al., 2013). The key influence of goats, rather than the more frequent sheep, is explainable by the different food preferences, as goats, but not sheep like to consume woody plants (Baraza et al., 2009). We often observed in the field that larch needles and even bark were a preferred diet of goat, even though plenty of grasses and herbs were available around the trees (Appendix S4). Most herders try to keep their smaller animals (goats and sheep) away from the forest interiors to avoid that they are killed by wolves and bears, which are widespread in the Mongolian forest-steppe and (especially in the case of wolves) regularly kill livestock. By contrast, horses are not herded and therefore regularly stay in the forest for grazing. Yaks (and even more camels) rarely graze in the forests by themselves. The lower livestock densities and the herders' more frequent seasonal migrations in the Khangai explain the much weaker influence of livestock on the epiphytic lichen vegetation in the Khangai than in the Mongolian Altai. The herders' different behaviors for seasonal migrations are caused by differences in the herders' income due to better market access in the Khangai (Lkhagvadorj et al., 2013 and unpublished data). The higher income facilitates the herder families in the Khangai to the pay the transportation costs for moving. In this way, the herders' market access for their dairy and meet products is one out of several factors influencing the epiphytic lichen diversity in the Mongolian forest-steppe.

The results of the indicator species analysis have to be interpreted more carefully than the results of the CCA. This is because environmental parameters other than grazing animals are more likely to interfere with the livestock effect on the species level than on the lichen–livestock relationship itself. Important factors which influence the distribution of epiphytic lichens in the Mongolian forest-steppe in addition to livestock include the abundance of large-diameter trees and deadwood as well as climate on both the stand and the landscape levels (Hauck et al., 2007, 2012). Many species with preference for moderate livestock densities at the forest edge or moderate to high densities in the forest interior are known to benefit from elevated nitrogen levels (Hauck, 2010; Wirth, 2010). These lichens include species of *Caloplaca*, *Candelariella* and *Physcia* as well as *Amandinea punctata*, *Lecanora hagenii*, *Massjukiella candelaria* (Appendix S5), *Oxneria ulophyllodes*, *Phaeophyscia orbicularis*, *Physconia hokkaidensis*, and *Rusavskia elegans*. However, many of these species (e.g. *Caloplaca cerina*, *P. hokkaidensis*) do not stand heavy eutrophication, like in areas of intense pig and poultry farming in Western Europe (van Herk, 1999). This shows that the livestock impact on the forests of the Mongolian forest-steppe is moderate, at least in many cases. Another indicator for this moderate level of disturbance by the nomads' livestock is the co-occurrence of anitrophytic species with nitrophytic ones in the forest interiors. Examples of species of acidic, nutrient-poor substrata include *Bryoria*, *Calicium*, *Flavopunctelia soredica*, *Hypocenomyce scalaris*, *Lecanora cadubriae*, *Lecanora varia*, and *Parmeliopsis ambigua*.

The lists of indicator species in Appendices S1 and S2 as deriving from our surveys are probably not suited to be used one-to-one as an indicator scale for assessing the livestock impact on the forests of the Mongolian forest-steppe. The unbiased procedure of the indicator species analysis implies that some species might be included into a certain group by coincidence due to the covariation of unregarded 'hidden' factors. Species which were suspected that such error might have occurred are suggested to be excluded from the list of indicator species. Other species are difficult to identify or are connected with taxonomic difficulties and are therefore excluded from the indicator species for practical reasons. The procedure of the indicator species analysis also implies that an important characteristic of heavily grazed stand, the scarcity of epiphytic lichens and the complete lack of epiphytic lichens on many trees is disregarded; the rareness of lichens in heavily grazed forests is probably primarily due to mechanical abrasion. Therefore, we propose an interpreted revised scale of indicator species of different levels of grazing impact in Table 7, which is thought to be suited better for application. Compared with Appendices S1 and S2, species were only omitted from, but not added to this list. Species printed in bold are thought to be especially well suited as target species for practical reasons, as they might be more easily identified by non-lichenologists after short training than other species. *A. apatetica*, *L. albellula* and *Lecanora subintricata* are important diagnostic species of high livestock density, but easily overlooked with limited experience. Heavily grazed forest edges are generally very poor in lichens, whereas forest interiors at high livestock densities show a shift in the epiphytic lichen vegetation from anitrophytic acidophytes to nitrophytic species, since the grazing pressure at the edge strongly exceeds that in the interior at a given livestock density.

Table 7
Scale for the indication of different levels of livestock density within 1 km radius in forest interiors and at forest edges of the Mongolian forest-steppe with epiphytic lichens. Species which are considered to be particularly suited for indication due to comparatively easy identification are printed in bold.

Livestock density	Indicator species
Forest edge:	
High (>1000 animals)	*Arthonia apatetica* Trunk bases of many trees (>5%) without epiphytic lichens. Most trees with few small lichen thalli.
Moderate (450–900 animals)	*Amandinea punctata*, *Bacidina* spec., *Buellia disciformis*, ***Caloplaca cerina***, ***C. chlorina***, ***C. pyracea***, ***Candelariella aurella***, ***Evernia mesomorpha***, *Lecanora albellula*, ***L. dispersa***, ***L. hagenii***, ***Lecidella euphorea***, ***Leptogium saturninum***, ***Oxneria ulophyllodes***, ***Phaeophyscia orbicularis***, ***Physcia adscendens***, ***P. caesia***, ***P. dubia***, ***P. stellaris***, ***Physconia hokkaidensis***, ***Rusavskia elegans***, *Trapeliopsis flexuosa*, ***Xanthoparmelia camtschadalis***
Low (<200 animals)	***Bryoria fuscescens***, ***Calicium viride***, *Cyphelium karelicum*, ***Hypocenomyce scalaris***, *Lecanora cadubriae*, ***L. varia***, ***Melanohalea elegantula***, ***M. exasperatula***, *Ochrolechia turneri*, ***Parmelia sulcata***, ***Parmeliopsis ambigua***
Forest interior:	
High (>1000 animals)	*Arthonia apatetica*, ***Candelariella reflexa***, *Lecanora albellula*, ***Parmelia sulcata***
Moderate (450–900 animals)	*Amandinea punctata*, *Buellia disciformis*, ***Caloplaca chlorina***, ***C. pyracea***, ***Candelariella aurella***, *Cyphelium karelicum*, ***Evernia mesomorpha***, *Lecanora subintricata*, ***Massjukiella candelaria***, ***Melanohalea exasperatula***, ***Oxneria ulophyllodes***, ***Physcia caesia***, ***Physconia hokkaidensis***, *Trapeliopsis flexuosa*
Low (<200 animals)	*Biatora chrysantha*, ***Bryoria fuscescens***, ***Calicium viride***, ***Cladonia coniocraea***, ***Flavopunctelia soredica***, ***Hypocenomyce scalaris***, ***Hypogymnia bitteri***, *Lecanora cadubriae*, ***L. varia***, *Lepraria* spec., ***Melanohalea elegantula***, *Ochrolechia turneri*, ***Parmeliopsis ambigua***

5. Conclusions

The epiphytic lichen vegetation in the Mongolian forest-steppe is strongly influenced by the density of livestock within a radius of 1 km. In comparison with other animal species, the ordination of epiphytic lichen abundances with livestock density data even allowed tracking the higher grazing pressure of goats at the forest edge and horses in the forest interior. The present study is the first proof that components of the vegetation are impacted by grazing which are neither consumed as forage nor indirectly promoted because they are unpalatable.

In addition to the scientific progress our results can be applied for the rapid assessment of livestock impact in forest of the Mongolian forest-steppe. Since 80% of the Mongolian forests are *L. sibirica* forests (Tsogtbaatar, 2004), our concept is suited for broad application. The advantage of the indication of livestock density with lichens is that they sum up the livestock effect over several years. This is important, since the spatial-temporal patterns of the dispersal of nomad camps and the herder's livestock underlie periodic cycles indeed, but consume much time of researchers for analysis. The indication of the mean grazing impact of resulting from different livestock densities can be used as a tool to improve the efficacy of the assessment of the pastoral nomads' impact on the forest-steppe. The ability to average levels of environmental stresses over a longer period is also a principal reason for the use of lichens as indicators of sulfur dioxide (Conti and Cecchetti, 2001) and as biomonitors of heavy metal pollution (Garty, 2001).

The clear dependency of the impact of livestock density on the forests on the distance of the herders' household also suggests that increasing the distance of the nomads' gers to at least 1 km from the nearest forest should be an important target for conservation in the forest-steppe. If enough land is available, such rule is likely to be enforced more easily than the reduction of total livestock numbers, which reduces the nomads' income (Lkhagvadorj et al., 2013), or the exclusion of herders and their livestock from strictly protected areas.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ecolind.2013.03.002.

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