Ecological Indicators 72 (2017) 667–674

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Response of moths (Lepidoptera: Heterocera) to livestock grazing in Mongolian rangelands

Khishigdelger Enkhtur[a], Martin Pfeiffer[a,b,*], Ariuntsetseg Lkhagva[a], Bazartseren Boldgiv[a,*]

[a] National University of Mongolia, School of Arts and Sciences, Department of Biology, Graduate Group in Ecology, Baga toiruu 47, P.O. Box 377, Ulaanbaatar 14201, Mongolia

[b] University of Bayreuth, Department of Biogeography, Universitätsstrasse 30, D-95440 Bayreuth, Germany

ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form 9 August 2016
Accepted 29 August 2016

Keywords:
Indicator species
Grazing effect
Rangeland
Herbivory
Mongolian steppe

ABSTRACT

Overgrazing has become an ecological problem in the wide steppes of Mongolia due to rapid livestock growth in the last two decades. Species diversity and productivity of biological communities, along with information on the presence and absence of certain species, can be indicators of environmental health to assess the state of pasture. Moths have been used as indicator species in various studies as they are abundant in many different habitats and sensitive to environmental changes. We used moths as indicators for pasture degradation in the Mongolian steppe for the first time. In this study, we investigated how overgrazing affected moth species diversity, identified indicator species for degraded pasture and collected baseline data to study distribution and migration of moths under future climate change. To accomplish these objectives, we compared moth diversity in plots with different grazing intensity in two locations in central Mongolia. Species diversity of moths was two times higher in lightly grazed plots than in medium-grazed and heavily grazed plots. Thus we conclude that pasture degradation affected moth diversity negatively. As a result of indicator species analysis we identified four indicator species for heavily grazed plots (*Leucoma salicis, Autographa buraetica, Mythimna impura* and *Pelochrista arabescana*) and seven indicator species for lightly grazed plots (*Panchrysia dives, Gastropacha quercifolia, Selagia argyrella, Lymantria dispar, Mythimna conigera, Stigmatophora micans* and *Perconia strigillaria*). The meadow moth *Loxostege sticticalis* was most abundant in all plots. In this study we collected a total of 115 species from Ikhtamir and Undurshireet as baseline data in order to study distribution and migration of moths under future climate change.

1. Introduction

Although Mongolia's wide steppe area is one of the largest pasture resources existing in the Asian temperate region, overgrazing has become a major ecological problem (Hilker et al., 2014), since herding is a major economic support of this country. Pasture degradation is intensifying due to recent years' rapid growth of livestock and loss of traditional methods of pasture use (Green Gold Project, 2015). As a result of transition from the centralized socialist system to a market economy in the 1990s, livestock were privatized and herd sizes increased, especially goats for production of cashmere, which is one of Mongolia's major agricultural products. Cashmere goats, which are more detrimental to the vegetation than other species of livestock, have tripled in numbers since 1990 (Lkhagvadorj et al., 2013). In 2005 the overall number of animals exceeded the carrying capacity of pastureland by 32.5% or 16 million sheep units at a national level (Jigjidsuren, 2005). Latest figures from November 2015 show that the number of livestock in Mongolia has reached almost 56 million head with an increase of 7.6% from 2014 (Monthly Bulletin of Statistics, 2015). Especially concerning is overgrazing in forest steppe and steppe zones where the number of livestock is 2–3 times higher than the estimated carrying capacity of those areas (Mongolian Society for Range Management, 2009). Pasture degradation is not only negatively affecting soil and vegetation (Wang and Wesche, 2016) and thus animal breeding, but also impacting other living organisms and their environment. Thus there is a need for sustainable pasture

Abbreviations: HG, heavily grazed; MG, medium grazed; LG, lightly grazed; IKH, Ikhtamir; UN, Undurshireet; NMDS, Non Metric Multidimensional Scaling.

* Corresponding authors.
E-mail addresses: khishigdelger@num.edu.mn (K. Enkhtur), martin.pfeiffer@uni-bayreuth.de (M. Pfeiffer), ariuntsetseg@num.edu.mn (A. Lkhagva), boldgiv@num.edu.mn (B. Boldgiv).

http://dx.doi.org/10.1016/j.ecolind.2016.08.053
1470-160X/

management and objective evaluation of pasture conditions (Pöyry et al., 2005).

Species diversity and productivity of biological communities are important indicators of environmental health (Rapport et al., 1998; Gerlach et al., 2013) that can be used to assess the state of pasture (Lawton and Gaston, 2001). For example, epiphytic lichens have been successfully used as indicators of overgrazing in Mongolian forest steppes (Hauck and Lkhagvadorj, 2013). Dayflying Lepidoptera (butterflies and moths) are indicators of the state of semi-natural grasslands for conservation in Europe (Lawton and Gaston, 2001; Rákosy and Schmitt, 2011), while ants (Hoffmann, 2010; Williams et al., 2012), dung beetles (Verdú et al., 2007), carabid beetles (Kaltsas et al., 2013) and plants (Best and Bork, 2003) have been successfully used as indicators of grazing pressure in Mediteranean and arid ecosystems. Compared to lichens (Walser et al., 2005), arthropod life span and generation times are short. As demonstrated by Niemelä et al. (1993), species with shorter generation times will respond to disturbance events faster than those with longer generation times and are therefore better indicator species. The higher mobility of invertebrates compared to plants and lichens allows for rapid adaptation to habitat changes, even at the community level. However, this goes hand in hand with a high variability in abundance due to weather conditions, a clear drawback of animal-bioindicators compared with stationary taxa like plants and lichens.

How grazing pressure affects plant diversity, cover and production has been widely studied in Mongolian steppes (e.g., Lkhagva et al., 2013), northern China (Wang and Wesche, 2016) and elsewhere (e.g. Manier and Hobbs, 2006), but there is not enough information about how pasture degradation affects herbivores other than pasture livestock (Pöyry et al., 2005) and what kind of organisms can be used as indicators for it. In the vast true steppes of central Mongolia trees are extremely rare so epiphytic lichens can not serve as indicators for overgrazing as they have further northern distribution and thus other bioindicators are needed.

To study the effects of pasture degradation on herbivores and to assess different pasture patterns, we chose to use moth species occurrence and diversity. As moths are abundant, mobile, and widespread in many different habitats and sensitive to environmental changes, they are particularly useful as indicator species (Maleque et al., 2009). Monitoring their numbers and ranges can give us vital clues to changes in our own environment, such as the effects of new farming practices, pesticides, air pollution, pasture degradation, ecosystem condition and climate change (Bachand et al., 2014; Folcher et al., 2012; Summerville et al., 2004; Kitching et al., 2000; Kroupa et al., 1990). Moths also can be indicators of diversity for other animal species (Lund and Rahbek, 2002). They live in close interaction with vegetation, as caterpillars and adult moths of many species depend on plants as food and nectar source, while moths in return act as important pollinators (Choi and Chun, 2009; Axmacher et al., 2011). As grasses and herbs are the prevailing vegetation in Mongolian steppe zone, herbivore caterpillars are directly competing with livestock for food and should be especially suited as indicator species, while bioindicators from other trophic groups are only in indirect competition. Compared with beetles and ants, moth offspring are less protected, as caterpillars are much more exposed to other direct effects of overgrazing, e.g. trampling, destruction of shelter and loss of individuals by (unintended) predation of livestock, and thus in some aspects similar to plants. Moreover, information on abundance, distribution and species diversity of moths are useful baseline data to study effects of climate change in the future (Itämies et al., 2011).

In this study we (1) investigated how pasture degradation affects moth diversity; (2) revealed indicator species of intensively grazed and less grazed pasture, and (3) collected baseline data of species richness and distribution of moths in the face of climate change.

We investigated the following detailed hypotheses: (1) Pasture degradation impacts moth diversity negatively, so species richness and diversity measures will be higher in less grazed areas; (2) Grazing pressure by large herbivores changes habitat conditions for insect herbivores, so indicator species of moths in lightly grazed and heavily grazed plots will be different; (3) Mongolian steppe is a diverse habitat, so moth and vegetation communities will be different at different sample sites.

2. Materials and methods

2.1. Study area

Mongolia is a landlocked country situated in Central Asia between Russia and China. It has a vast territory of 1.56 million square km. Mongolia is located in the transition zone between the deserts of Central Asia and the boreal taiga of southern Siberia and belongs to the temperate region (Tsegmid, 1969). About 72% of the territory (112.8 million hectares) is categorized as rangeland, which supports about 170,000 herder families. The rangeland is divided into six ecological zones: high mountain, taiga, forest steppe, steppe, desert steppe and desert. These ecological zones differ from each other by topography, climate, flora and fauna (Yunatov, 1976).

Our study sites were selected in the area around Undurshireet soum (subdistrict) (N 47°27′11.82″ E 105°03′19.11″) in Tuv Aimag (district) and in the Ikhtamir soum (N 47°25′01.86″ E 100°44′45.54″) of Arkhangai Aimag, which are located 180 km and 570 km from Ulaanbaatar, respectively (Fig. 1). Both areas have been monitored during recent years with help of the Green Gold Project funded and implemented by Swiss Development Agency at Mongolia, which also gave financial support to our study. In terms of vegetation and responses to livestock grazing, the sites were different (Fernandez-Gimenez and Allen-Diaz, 1999). Plots at Ikhtamir were placed in mountain steppe, while the plots at Undurshireet lay in dry steppe (Appendix Fig. A1 in Supplementary material). Annual precipitation at Undurshireet is 200–250 mm, with flat to undulating topography at altitude of up to 1700 m a.s.l. Annual precipitation at Ikhtamir is 300–400 mm, also with undulating topography at elevations up to 1700 m a.s.l. (Tsegmid, 1969).

In each study site we chose two plots for characterization of vegetation for grazing regime based on vegetation cover and structure. Pasture degradation was broken into the following categories according to Chognii (1978):

Lightly grazed pasture: The main vegetation community of steppe dominates (*Poa attenuata*, *Koeleria cristata*, *Agropyron cristatum, Stipa* spp.), forbs are less dominant and plants which tolerate grazing such as *Artemisia frigida, Potentilla acaulis, Convolvulus ammanii, Leymus chinensis, Cleistogenes squarrosa* are slightly increased in abundance. Plant species richness is decreased due to grazing pressure.

Medium grazed pasture: The plants of the main steppe vegetation community are decreased in abundance and grazing resistant plants such as *Artemisia frigida, A. adamsii, Potentilla acaulis, Convolvulus ammanii*, and *Leymus chinensis* dominate.

Heavily grazed pasture: Plant species from the main steppe vegetation community become very scarce and plants that tolerate grazing are dominant. For example, *A. frigida, A. adamsii, P. acaulis, Carex duriuscula*, and *L. chinensis*.

We sampled moths and plants from “Lightly grazed” (LG), “Medium grazed” (MG) and “Heavily grazed” (HG) plots depending on local situation. Completely ungrazed plots did not occur in either site, as fencing was damaged during the investigation period at the

Fig. 1. Locations of Ikhtamir and Undurshireet. Both places have similar latitudes and altitudes (1700 m). Shading marks protected areas of Mongolia.

(few) fenced plots that were available for study. These partially fenced plots were included with the LG plots. The LG plots of both Undurshireet and Ikhtamir matched the first category described by Chognii (1978), the MG plot at Ikhtamir matched the second category, and the HG plot at Undurshireet matched the third category. In the LG plot grasses and forbs dominated, while in MG and HG areas sage (*Salvia* sp.) and *Artemisia* were mostly dominant and sedges (*Carex* sp.) were subdominant. The two latter plots were situated near pens where nomadic herders protect their livestock in winter. In our plots in Undurshireet, the main grazers were usually horses and cows, while in Ikhtamir horses, cows, sheep and goats were all grazing. The total number of livestock in 2015 in Undurshireet was 211,742 and 283,580 in Ikhtamir (National Statistical Office of Mongolia, 2015). There was no precollected information on grazing intensity available.

We chose the experimental plots by making observations of vegetation and asking the local herders. Some of the plots were permanent observation plots for the Green Gold Project that have been used for years in other experiments and were partially fenced.

Grazed and lightly grazed plots were separated by 1 km in Undurshireet; that separation distance included a small hill that worked as an optical barrier preventing attraction of moth specimens from one plot to the other during light trapping. In Ikhtamir plots were evenly separated by 2 km; as light trapping usually attracts moths from a radius of about 25 m (Wirooks, 2006), this distance was considered sufficient to again avoid attracting moths across plots. Species richness and abundance of moths sampled depended on the surrounding environment (within ca. 2000 m^2 area), although negative effects, e.g. pasture degradation, may impact a larger area (Fuentes-Montemayor et al., 2011).

Table 1
Dominant plant species in both plots of our study sites.

Undurshireet	Ikhtamir
Lightly grazed plot	Lightly grazed plot
Agropyron cristatum	*Agropyron cristatum*
Allium odorum	*Amblynotus rupestris*
Allium anisopodium	*Arenaria capillaris*
Arenaria capillaris	*Artemisia commutata*
Artemisia frigida	*Artemisia pectinata*
Carex duriuscula	*Bupleurum bicaule*
Carex sp.	*Carex duriuscula*
Cleistogenes squarrosa	*Dontostemon integrifolius*
Convolvulus ammanii	*Festuca lenensis*
Dianthus versicolor	*Koeleria macrantha*
Galium verum	*Potentilla acaulis*
Haplophyllum dauricum	*Polygonum angustifolium*
Heteropappus hispidus	*Poa attenuata*
Potentilla bifurca	*Peucedanum hystrix*
Potentilla sericea	*Potentilla acaulis*
Sedum aizoon	*Scabiosa comosa*
Stipa krylovii	*Serratula centauroides*
Youngia tenuicaulis	*Stipa krylovii*
Heavily grazed plot	Medium grazed plot
Achnatherum splendens	*Agropyron cristatum*
Artemisia sp.	*Allium bidentatum*
Artemisia frigida	*Arenaria capillaris*
Carex duriuscula	*Artemisia commutata*
Cleistogenes squarrosa	*Artemisia mongolica*
Chenopodium album	*Artemisia pectinata*
Salvia sp.	*Carex duriuscula*
Urtica sp.	*Galium verum*
	Potentilla acaulis
	Potentilla bifurca
	Stipa krylovii

2.2. Sampling

Plant and insect data for the different sites were collected at the same plots in order to compare diversity of the taxa. Vegetation samples were taken from a 1 m^2 area with 10 replications both in Undurshireet and Ikhtamir. We chose the sample locations randomly by throwing the sample frame. Space between the samples within an area was on average ten meter. Plant species of each plot are listed in Table 1.

In both study areas our research was conducted between 1 st August 2013 and 20th August 2013, when we sampled LG and MG/HG plots alternately. In the first seven days we sampled from the LG plot of Undurshireet and Ikhtamir, and in the next seven days we sampled from MG/HG plots. In the remaining six days we sampled alternately. We sampled again in Undurshireet in 2015, but technical problems allowed only for a shorter sampling period from 27th to 30th July. We caught moths from 21:00 h to 24:00 h by using an ultraviolet light trap (small semitransparent fabric light tower with a 12 V ultra violet light produced by Bioform, Germany), and killed them in bottles with cyanide. We followed the "Method of Collecting, Treating and Preserving of Insects" (Namkhaidorj, 1981). We identified morphospecies in the field and from each morphospecies we mounted at least 1–2 individuals in the field (Appendix Fig. 1 in Supplementary material), brought them to a laboratory and identified them using the identification keys in "Noctuidae Sibirica" (Kononenko, 2010), "Identification Key of Insects of Mongolia", volume II, part 2 (Namkhaidorj et al., 2008), volume V of the "Identification Key of Insects of Far East, Russia" (Lera, 2005), and local taxonomic websites (www.catocala.narod.ru (Berlov and Berlov, 1999–2014) and www.omflies.narod.ru (Svyatoslav, 2000)). All other insect material was also brought to the lab and later reexamined to confirm identification.

2.3. Data analysis

Shannon-Wiener diversity (exp *H*), Simpson diversity (*D*) and Shannon Evenness (*E*) were used to calculate species diversity and species evenness of moths of each plot. Shannon-Wiener diversity was calculated as the exponent of the Shannon-Wiener diversity index (*H*). Results of different plots could be compared directly as all of these measures are linear (Jost, 2006). Sorensen's index was used to calculate the similarity of moth communities among plots. We used EstimateS Win 8.20 to calculate these indices and read out the combined results for the whole community of the respective treatments. We ran indicator species analyses using the method of Dufrêne and Legendre (1997) with the PC-ORD 5.17 program (McCune and Mefford, 2011). To test the indicator species we used the indicator value method of Dufrêne and Legendre (1997). The indicator value of each *i* species of *j* group was calculated as

$$INDVALij = A_{ij} \times B_{ij} \times 100$$

where A_{ij} is the relative abundance of species *i* in group *j* and B_{ij} is the relative frequency of species *i* in group *j*.

The higher the indicator value of a species, the higher is the possibility of being an indicator species. To test the statistical siginificance of the indicator value for each species, we used Monte Carlo tests with 4999 randomized runs. When the observed indicator value exceeds the randomized indicator value, it is statistically significant.

Non-metric Multidimensional Scaling (NMDS) was performed in R with the function metaMDS of *vegan* package using the Bray-Curtis Index on Wisconsin square root standardized data. MetaMDS uses random starts and iteratively tries to find the best possible solution for community structure. Species points were added to the ordination plot using the *wascores* function of R-package vegan (Oksanen et al., 2013).

3. Results

3.1. Species diversity of moths

We caught almost identical numbers of specimens at Ikhtamir and Undurshireet, 7896 and 7782, respectively. As indicated by the rarefaction plot (Fig. 2) species richness was almost saturated in both areas, thus sampling was nearly exhaustive. In both locations, species richness and diversity of moths were 1.3–2 times higher in the LG plots compared to the HG or MG plots (Table 2, Appendix Table 1 in Supplementary material). In Ikhtamir 50 species from 10 families of Lepidoptera were caught in the LG plot, while in Undurshireet we caught 62 species of nine families of moth from the LG plot. In HG and MG plots, on the other hand, 40 species of 10 families of moth were collected in Ikhtamir and 44 species of nine families in Undurshireet.

As demonstrated by the rank abundance curves a few species dominated the moth communities and many other species were relatively evenly distributed (Fig. 3). In Ikhtamir Soum, *Loxostege sticticalis* (*n* = 1516), *Selagia argyrella* (*n* = 117) and *Pyla fusca*

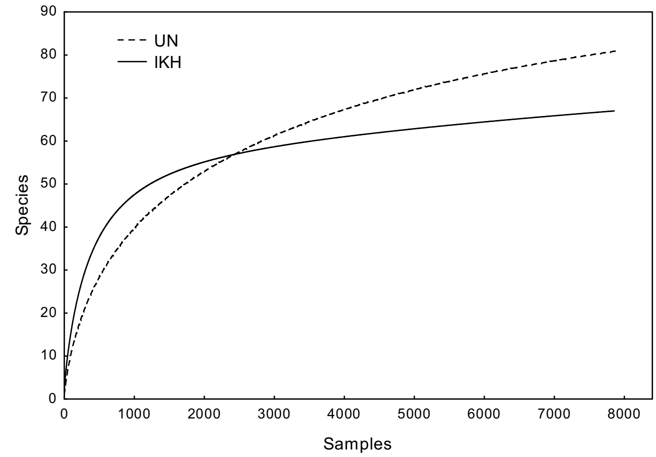

Fig. 2. Rarefaction curve for moth species of Undurshireet and Ikhtamir. In both places samples are almost saturated for species number.

Table 2
Species richness and species diversity of moths in Ikhtamir and Undurshireet at maximum sample size for each plot. Given are the results of the randomization software with bootstrap SDs, based on variation in sample order among randomizations. Species richness and diversity of moth were higher in both of the lightly grazed plots.

Ikhtamir	Medium grazed plot	Lightly grazed plot
Total captured individuals	3824	4072
Species richness	40 ± 0.1	50 ± 0.5
Shannon Diversity	4.28 ± 0.05	7.2 ± 0.05
Simpson Diversity	2.53 ± 0.01	4 ± 0.02
Undurshireet	Heavily grazed plot	Lightly grazed plot
Total captured individuals	4682	3101
Species richness	44 ± 4.08	62 ± 3.89
Shannon Diversity	1.54 ± 0.2	3.02 ± 0.01
Simpson Diversity	1.1 4 ± 0.01	1.57 ± 0.01

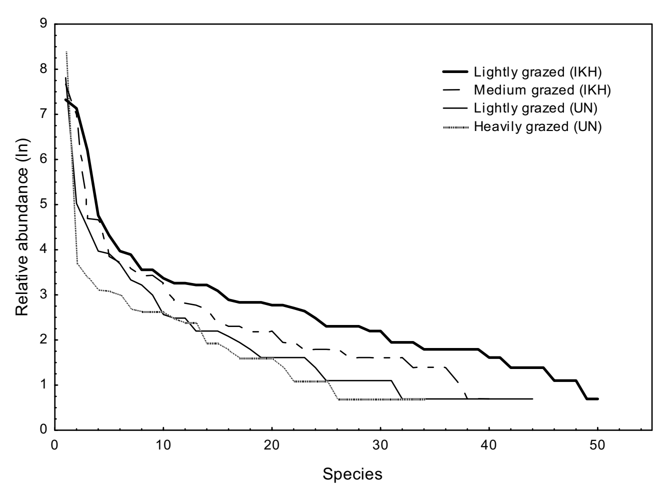

Fig. 3. Rank abundance curves of moth species in Ikhtamir Soum (IKH) of Arkhangai Aimag and Undurshireet Soum (UN) of Tuv Aimag. Heavily/medium grazed and lightly grazed plots showed a similar distribution of species.

Table 3
Species richness and species diversity of vegetation. Given are the results of the randomization software at 10 samples with bootstrap SDs, based on variation in sample order among randomizations.

Ikhtamir	Medium grazed plot	Lightly grazed plot
Species richness	5.6 ± 1.2	13.5 ± 0.47
Shannon Diversity	2.26 ± 0.12	11.76 ± 0.21
Simpson Diversity	1.46 ± 0.05	7.58 ± 0.2
Undurshireet	Heavily grazed plot	Lightly grazed plot
Species richness	3.7 ± 2.6	6.1 ± 1.3
Shannon Diversity	4.44 ± 0.37	6.20 ± 0.2
Simpson Diversity	3.07 ± 0.23	4.69 ± 0.18

(n = 1253) were dominant in the LG plot, while in the HG plot relative abundances of *Loxostege sticticalis* (n = 2145), *Lampropteryx suffumata* (n = 106) and *Pelochrista arabescana* (n = 107) were highest. In Undurshireet Soum, in the LG plot *Loxostege sticticalis* (n = 2468), *Gastropacha quercifolia* (n = 152), *Anarta trifolii* (n = 90) and *Lygephila ludicra* (n = 53) dominated, while the HG plot was dominated by *Loxostege sticticalis* (n = 4387) and *Anarta trifolii* (n = 41). *Loxostege sticticalis* was the most abundant species of moth in all plots and was caught in large numbers.

3.2. Species diversity of vegetation

Plant diversity and plant cover was higher in both LG plots (Table 3). Vegetation cover of the LG plot in Undurshireet was 40 ± 4% on average, and species number per 1 m^2 was 6.1 ± 1.3, while in the HG plot of Undurshireet vegetation cover was 32 ± 9.3% on average, and mean species number in 1 m^2 was 3.7 ± 2.6. Vegetation cover was 84.55 ± 6.13% at the LG plot of Ikhtamir and species number/m^2 was 13.5 ± 0.47, while at the MG plot of Ikhtamir vegetation cover was 74 ± 7.63% and species number/m^2 was 5.6 ± 1.2.

3.3. Similarity of moth communities

Moth communities in the two different treatments (LG and HG plots) of Ikhtamir differed by about 1/3, as measured with the Sorensen's index (0.674), while plots of Undurshireet differed to approximately 50% (Table 4). However, when grouped in terms of grazing pressure, the plots of similar type in Undurshireet and Ikhtamir had even less similarities with each other than with nearby sites under different grazing pressure (LG vs. LG 0.252 similarity and HG vs. MG 0.154 similarity), thus pointing to highly diverse moth communities in both sites.

In NMDS analysis moth communities in two treatment plots (LG and MG) of Ikhtamir Soum were grouped together and differed in NMDS significantly among each other (Mann-Whitney U-test, U = 5, Z = 3.4, n = 20, p < 0.001), while those of Undurshireet Soum were overlapping with no significant differences (Fig. 4). Communities of the different localities were widely separated, indicating high species turnover between sites (NMDS1, Mann-Whitney U-test, U = 0, Z = −5.76, n = 46, p < 0.001).

3.4. Similarity of plant communities

Plots of Undurshireet LG and HG were most similar to each other by vegetation (0.643) as measured with a Sorensen's index, while plots of Ikhtamir differed by approximately 1/4 (Table 5). When grouped in terms of grazing pressure, the plots of similar type in Undurshireet and Ikhtamir had very low similarity (LG with LG

Table 4
Similarity of study plots by moth species as calculated by shared species (above diagonal) and Sorensen's index (below diagonal).

	Ikhtamir lightly grazed plot	Ikhtamir medium grazed plot	Undurshireet lightly grazed plot	Undurshireet heavily grazed plot
Ikhtamir lightly grazed plot	–	30	14	8
Ikhtamir medium grazed plot	0.674	–	12	7
Undurshireet lightly grazed plot	0.252	0.237	–	32
Undurshireet heavily grazed plot	0.158	0.154	0.561	–

Table 5
Similarity of study plots by vegetation as calculated by shared species (above diagonal) and Sorensen's index (below diagonal).

	Ikhtamir lightly grazed plot	Ikhtamir medium grazed plot	Undurshireet lightly grazed plot	Undurshireet heavily grazed plot
Ikhtamir lightly grazed plot	–	11	3	3
Ikhtamir medium grazed plot	0.275	–	2	2
Undurshireet lightly grazed plot	0.14	0.118	–	9
Undurshireet heavily grazed plot	0.133	0.111	0.643	–

Table 6
Indicator species analysis. Given are species names, indicator groups (1 = ungrazed plot, 2 = grazed plot), indicator values,standard deviation, as well p-values of the Randomization Test.

Species	Indicator group	Indicator value (observed)	Indicator value (randomized)	S.dev	p-Value
Panchrysia dives	1	33.3	15.4	5.52	0.0092
Gastropacha quercifolia	1	36.8	21.5	6.49	0.0282
Lymantria dispar	1	54.8	31.8	6.6	0.0044
Mythimna conigera	1	33.3	15.4	5.44	0.0082
Stigmatophora micans	1	32.4	17.1	5.93	0.0244
Autographa buraetica	2	31.6	13.3	4.87	0.0078
Selagia argyrella	1	49.6	26.1	7.13	0.007
Leucoma sulicis	2	37	20	4.93	0.0464
Pelochrista arabescana	2	40.5	24.1	7.3	0.0236
Perconai strigillaria	1	38	19	4.54	0.0044
Mythimna impura	2	31.6	13.5	4.97	0.0082

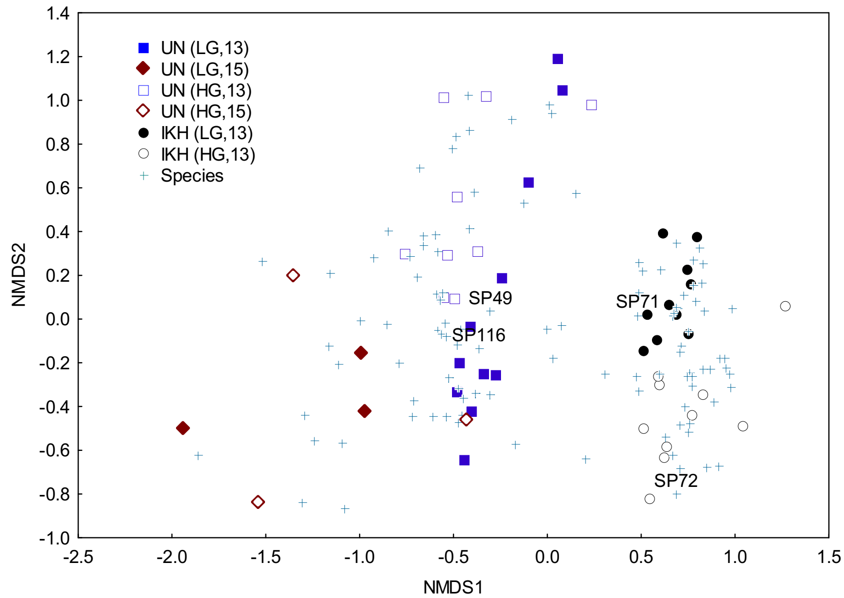

Fig. 4. Results of the Nonmetric Multidimensional Scaling analysis. We took samples from each plot of Undurshireet and Ikhtamir during 10 nights in 2013 and additional samples in Undurshireet in 2015. Sampling nights of medium grazed (MG) and lightly grazed (LG) plots of Ikhtamir clustered together and showed distinct groupings, while sampling nights of heavily grazed (HG) and lightly grazed (LG) plots of Undurshireet Soum were overlapping in range. In this figure indicator species are coinciding with the plot where they have been caught: sp. 49 – *Gastropacha quercifolia*, sp. 71 – *Mythimna conigera*, sp. 116 – *Stigmatophora micans*, sp. 72 – *Mythimna impura*. UN – Undurshireet and IKH – Ikhtamir.

0.140 and HG with MG 0.111), thus corroborating the expected differences in habitat type (see methods).

3.5. Indicator species

As a result of the indicator species analysis *Panchrysia dives, Gastropacha quercifolia, Selagia argyrella, Lymantria dispar, Mythimna conigera, Stigmatophora micans* and *Perconia strigillaria* were identified as indicator species for LG plots, while *Leucoma salicis, Autographa buraetica, Mythimna impura* and *Pelochrista arabescana* were identified as indicator species of HG and MG plots (Table 6, Appendix Fig. A2 in Supplementary material). The distribution of some indicator species in the multidimensional space is shown in Fig. 4.

4. Discussion

Our results demonstrate that moths are suitable indicators of grazing pressure in Mongolia. A large number of similar studies from other countries support our findings. Compared to HG plots, LG plots harbored a higher species diversity of moths in Scotland (Littlewood, 2008), Canada (Bachand et al., 2014) and in Finland (Pöyry et al., 2005). In Germany micromoths had higher diversity in ungrazed plots and lower diversity in grazed plots (Rickert et al., 2012). In Canada plants and moths provide complementary bio-indication of ecosystem condition under various herbivore densities in a study of ecosystem recovery after reduction of large herbivores (deer) (Bachand et al., 2014). Large herbivores influence the composition and diversity of steppe habitats (Manier and Hobbs, 2006), with direct impact on moths.

In abandoned or lightly grazed pastures arthropod species richness was higher than in moderately and highly stocked plots (Rickert et al., 2012; Klink et al., 2013; Yadamsuren et al., 2015). But after long abandonment of meadows some arthropod and vegetation species disappear (Klink et al., 2013). Thus rotational grazing can be a useful tool to restore butterfly and moth communities of abandoned pastures (Pöyry et al., 2004). Livestock grazing alters composition and structure of vegetation (Lkhagva et al., 2013) and thus impacts phytophagous species such as Lepidoptera. Livestock grazing disturbance influences moth species diversity and species richness more negatively than plant species richness and vegetation structure (Rickert et al., 2012). Grazing influences arthropods negatively in general, by affecting arthropods directly and indirectly by unintentional eating, trampling, reducing food sources and disturbing their living habitat (Klink et al., 2015). But, the effects of grazing were not the same for all moth species (Littlewood, 2008). For example, in our study some species were even more abundant in grazed plots, such as *Loxostege sticticalis, Anarta trifolii* and *Pelochrista arabescana.* The growing number of livestock has a negative impact on grasses (Monocotyledonae) that are their preferred food and the resulting expansion of dicotyledonous plants in the grassland and the arable lands might also contribute to the outbreaks of some moth species such as *Loxostege sticticalis*, which prefer herbs to grasses (Lizhi et al., 2009).

When we calculated species diversity of plants of both plots in Ikhtamir, plant species diversity of the LG plot was seven times higher than that of the HG plot. This result for plants matched our result on moths (Table 4).

In our study indicator species included members of the Noctuidae, Arctiidae, Lasiocampidae, Lymantriidae, Pyralidae, Tortricidae, and Geometridae. In LG plots *Stigmatophora micans* (Arctiidae), *Perconia strigillaria* (Geometridae), *Lymantria dispar* (Lymantriidae), *Gastropacha quercifolia*[3] (Lasiocampidae) and *Selagia argyrella (Pyralidae)* were abundant, while in HG plots *Autographa buraetica* (Noctuidae) and *Pelochrista arabescana* (Tortricidae) were present in abundant numbers. Noctuids *Panchrysia dives* and *Mythimna conigera* were found exclusively in LG plots at both sites, thus being the most important bioindicators for extensive grazing in our study, although they were recorded in lower total abundance than other species. In Europe *M. conigera* is known

[3] In Russia *Gastropacha quercifolia* is listed in the Red Book and considered a rare species (Antipova, 2013).

as widespread indicator of extensively used grasslands and is missing in slurry treated meadows; its larvae feed on grasses (Wagner, 2005). In Britain this moth is also evaluated as a decling species (Conrad et al., 2006). *Pelochrista arabescana*, on the other hand, may be the best indicator for overgrazed sites and was found in both study areas in higher abundances. The larvae of this species are known to feed on *Artemisia* species (Liu and Li, 2002), which are considered pasture weeds and overgrazing indicators (Bazha et al., 2012).

Because the impact of grazing on species' populations is different and little is known about the life history of most of the indicator species, we can only speculate why certain species act as indicators. In *Lymantria dispar* for example, females preferentially deposit their eggs in large cocoon-covered colonies on rock outcrops and shrubs within the steppe (Hauck et al., 2008). These nests may be directly impacted by trampling of livestock, so *L. dispar* is a bioindicator for LG plots, although it is an important defoliator of broad-leaved and coniferous trees and does not feed on grasses. In *Leucoma salicis*, an indicator for HG plots, on the other hand, larvae feed on *Salix* and *Populus* species (Seitz, 1912–1913); the use of those woody plants may help the larvae of *Leucoma salicis* to avoid negative direct impact of large herbivore grazing. *Mythimna* moth species feed on various grasses, while *Perconia strigillaria* prefers herbs (http://ukmoths.org.uk/).

Working in Gangotri Landscape, India, to study diversity and indicator species of moth assemblages in different vegetation zones, Sanyal et al. (2011) revealed six indicator species from six different vegetation zones, and indicator moths came from families of Arctiidae, Noctuidae, Lymantriidae, Pyralidae and Crambidae. This high diversity of indicator species is similar to our findings.

In all plots *Loxostege sticticalis* was the most abundant species and in the HG plots the number of individuals of this species was two times higher than in the LG plot. This may be due to the weed species *Chenopodium album*, the preferred food plant of *L. sticticalis* that was growing in high density in the HG plots and was used for oviposition (see Yin et al., 2005). In recent years the number and frequency of outbreaks of this species have been increasing with potential links to global warming through a decrease in the proportion of diapausing larvae because of the raise of temperature in July. *Loxostege sticticalis* is an important outbreak pest in Northern China, causing serious damage to crops and forage such as soybean, sugar beet, alfalfa and sunflower, and leading to severe harvest losses. The adults from this area make a long-range migration in two ways, within the border of China or outside (Mongolia) into Northeast China (Xiao et al., 2008).

The wide distribution of these Palaearctic species potentially allows an application of our findings to other regions. However, care should be taken to ensure that bio-indicators inhabit the same niche in different areas. Livestock species, local grazing schemes and pattern of grazing area vs. surroundings may greatly differ among countries and further impact the usage of the bioindicators we identified in Mongolia. However, we clearly demonstrated that herbivorous moths are an accurate indicator for overgrazed and less grazed plots, that may even lead to better indication results compared to arthropod groups from different trophic levels and with different life histories (ants, beetles) that are less exposed to direct competition and indirect side effects of grazing (trampling). Bioindicator plants (Best and Bork, 2003) and epiphytic lichens (Hauck and Lkhagvadorj, 2013), on the other hand, are difficult to monitor: sometimes it is hard to find them, and it is even more complicated to assure their absence in a given area. Moths are attracted over larger distances and can thus integrate information from a larger area. When good weather conditions allow for abundant sampling results, moths are a superior bioindicator taxa.

5. Conclusion

Our study suggests that pasture degradation affects species diversity of moths negatively. As evidenced by indicator species analysis and moth diversity, different treatments of the plots influenced the moth species community composition significantly. High grazing pressure negatively impacts certain moth species directly or indirectly and possibly endangers them. *Panchrysia dives* and *Mythimna conigera* were best indicators for lightly grazed plots, together with *Lymantria dispar* and *Selagia argyrella.* Other moth species showed a positive response to overgrazing*, Autographa buraetica* and *Pelochrista arabescana* could be identified as bioindicators for that. These results demonstrate that moths are valuable indicator species for pasture quality. In order to sustain maximum moth diversity pasture management should be rotational, if in one area pasture is being restored, grazing can proceed in an another area. More research is necessary to include more locations and better information on the life history of species if we want to formally establish this method as an agricultural practice in Mongolia. Improved monitoring methods can help to reduce the impact of overgrazing when this information is included in management plans that are accepted by local herders.

Acknowledgements

We thank the Phase IV of Green Gold Project funded by the Swiss Development Cooperation Agency for supporting our field work, and the German Society for International Cooperation (GIZ) for funding of equipment. We are very grateful to T. Enkhbayar for helping in identification and verification of moth species and thank M. Uuganbayar for taking samples from Ikhtamir Soum, Arkhangai Aimag. Moreover we are thankful to R. Tungalag for verifying our plant species. M.P. is grateful to the German Academic Exchange Service (DAAD) for supporting his stay in Mongolia (Grant No. 11000351). K.E. and B.B. thank the Taylor Family-Asia Foundation Endowed Chair in Ecology and Conservation Biology, which partly supported this study. We appreciate the English language correction by Eli Hornstein, NC State University, Raleigh, USA and the comments of Associate Editor Dr. Roland Achtziger and of an anonymous reviewer.

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.2016.08.053.

References

Antipova, L.F., 2013. Rare and protected species of butterflies (Insecta, Lepidoptera), found in Pskov region. Pskov Region J. 15, 102–122 [in Russian].

Axmacher, J.C., Liu, Y., Wang, C., Li, L., Yu, Z., 2011. Spatial α-diversity patterns of diverse insect taxa in Northern China: lessons for biodiversity conservation. Biol. Conserv. 144 (9), 2362–2368.

Bachand, M., Pellerin, S., Côté, S.D., Moretti, M., De Cáceres, M., Brousseau, P.-M., Cloutier, C., Hébert, C., Cardinal, É., Martin, J.-L., Poulin, M., 2014. Species indicators of ecosystem recovery after reducing large herbivore density: comparing taxa and testing species combinations. Ecol. Indic. 38, 12–19.

Bazha, S.N., Gunin, P.D., Danzhalova, E.V., Drobyshev, Y.I., Prishcepa, A.V., 2012. Pastoral degradation of steppe ecosystems in central Mongolia. In: Werger, M.J.A., van Staalduinen, M.A. (Eds.), Eurasian Steppes. Ecological Problems and Livelihoods in a Changing World. Springer, pp. 289–320.

Berlov, E., Berlov, O., 1999–2014. 1000 Siberian Butterflies and Moths, Retrieved from http://www.catocala.narod.ru, (accessed on 10.06.15).

Best, J.N., Bork, E.W., 2003. Using transplanted plains rough fescue (*Festuca hallii* (Vasey) Piper) as an indicator of grazing in Elk Island National Park, Canada. Nat. Areas J. 23, 202–209.

Chognii, O., 1978. The main principle of alter and rehabilitation of pasture of Dornod Khangai. In: Second Volume of Flora and Vegetation Study of Mongolian People's Republic. Ulaanbaatar khot. Academy of Science, Ulaanbaatar (in Mongolian), pp. 191.

Choi, S.W., Chun, J.H., 2009. Combined effect of environmental factors on distribution of Geometridae (Lepidoptera) in South Korea. Eur. J. Entomol. 106 (1), 69–76.

Conrad, K.F., Warren, M.S., Fox, R., Parsons, M.S., Woiwod, I.P., 2006. Rapid declines of common: widespread British moths provide evidence of an insect biodiversity crisis. Biol. Conserv. 132, 279–291.

Dufrêne, M., Legendre, P., 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecol. Monogr. 67 (3), 345–366.

Fernandez-Gimenez, M.E., Allen-Diaz, B., 1999. Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. J. Appl. Ecol. 36, 871–885, http://dx.doi.org/10.1046/j.1365-2664.1999.00447.x.

Folcher, L., Weissenberger, A., Delos, M., 2012. Quantitative relationships between *Ostrinia nubilalis* activity and deoxynivalenol contamination in French maize. Int. J. Pest Manage. 58 (4), 302–309.

Fuentes-Montemayor, E., Goulson, D., Park, K.J., 2011. The effectiveness of agri-environment schemes for the conservation of farmland moths: assessing the importance of a landscape-scale management approach. J. Appl. Ecol. 48, 532–542.

Gerlach, J., Samways, M., Pryke, J., 2013. Terrestrial invertebrates as bioindicators: an overview of available taxonomic groups. J. Insect Conserv. 17, 831–850.

Green Gold Project, 2015. National report on rangeland health of Mongolia. In: Guide to the Moths of Great Britain and Ireland, Retrieved from http://www.ukmoths.org.uk, (accessed on 12.07.15).

Hauck, M., Lkhagvadorj, D., 2013. Epiphytic lichens as indicators of grazing pressure in the Mongolian forest-steppe. Ecol. Indic. 32, 82–88.

Hauck, M., Dulamsuren, C., Heimes, C., 2008. Effects of insect herbivory on the performance of *Larix sibirica* in a forest-steppe ecotone. Environ. Exp. Bot. 62, 351–356.

Hilker, T., Natsagdorj, E., Waring, R.H., Lyapustin, A., Wang, Y., 2014. Satellite observed widespread decline in Mongolian grasslands largely due to overgrazing. Global Change Biol. 20, 418–428.

Hoffmann, B.D., 2010. Using ants for rangeland monitoring: global patterns in the responses of ant communities to grazing. Ecol. Indic. 10, 105–111.

Itämies, J.H., Leinonen, R., Meyer-Rochow, V.B., 2011. Climate Change and Shifts in the Distribution of Moth Species in Finland, with a Focus on the Province of Kainuu. InTech Open Access Publisher.

Jigjidsuren, S., 2005. Pasture Management. Admon Publishing, Ulaanbaatar Mongolia.

Jost, L., 2006. Entropy and diversity. Oikos 113, 363–375.

Kaltsas, D., Trichas, A., Kougioumoutzis, K., Chatzaki, M., 2013. Ground beetles respond to grazing at assemblage level, rather than species-specifically: the case of Cretan shrublands. J. Insect Conserv. 17, 681–697.

Kitching, R.L., Orr, A.G., Thalib, L., Mitchell, H., Hopkins, M.S., Graham, A.W., 2000. Moth assemblages as indicators of environmental quality in remnants of upland Australian rain forest. J. Appl. Ecol. 37 (2), 284–297.

Klink, R.V., Rickert, C., Vermeulen, R., Vorst, O., Wallis De Vries, M.F., Bakker, J.P., 2013. Grazed vegetation mosaics do not maximize arthropod diversity: evidence from salt marshes. Biol. Conserv. 164, 150–157.

Klink, R.V., van der Plas, F., van Noordwijk, C.G.E., Wallis DeVries, M.F., Olff, H., 2015. Effects of large herbivores on grassland arthropod diversity. Biol. Rev. 90 (2), 347–366.

Kononenko, V., 2010. Noctuidae Sibirica, 2. Entomological Press.

Kroupa, M., Spitzer, K., Novak, I., 1990. The heavy metals content in melanic and typical forms of *Biston betularia* (Lepidoptera, Geometridae) and its bioindicator significance. Acta Entomol. Bohemoslov. 87 (4), 249–252.

Lawton, J.H., Gaston, K.J., 2001. Indicator species. Encycl. Biodivers. 3, 437–450.

Lera, P.A., 2005. Identification key of Insects of Far East, Russia. T. V. Trichoptera and Lepidoptera.Volume 5. Владивосток: «Дальнаука».

Littlewood, N.A., 2008. Grazing impacts on moth diversity and abundance on a Scottish upland estate. Insect Conserv. Diver. 1 (3), 151–160.

Liu, Y.Q., Li, G.W., 2002. Fauna Sinica Insecta. Lepidoptera, Tortricidae, 27. Chinese Science Press, pp. 463.

Lizhi, L., Shaozhe, H., Xingfu, J., Lei, Z., 2009. Characteristics and causes for the outbreaks of beet webworm, *Loxostege sticticalis* in northern China during 2008. J. Plant Prot. 1, 009.

Lkhagva, A., Boldgiv, B., Goulden, C.E., Yadamsuren, O., Lauenroth, W.K., 2013. Effects of grazing on plant community structure and aboveground net primary production of semiarid boreal steppe of northern Mongolia. Grassland Sci. 59, 135–145.

Lkhagvadorj, D., Hauck, M., Dulamsuren, C., Tsogtbaatar, J., 2013. Twenty years after decollectivization: mobile livestock husbandry and its ecological impact in the Mongolian forest-steppe. Hum. Ecol. 41 (5), 725–735.

Lund, M.P., Rahbek, C., 2002. Cross-taxon congruence in complementarity and conservation of temperate biodiversity. Anim. Conserv. 5, 163–171.

Maleque, M.A., Maeto, K., Ishii, H.T., 2009. Arthropods as bioindicators of sustainable forest management, with a focus on plantation forests. Appl. Entomol. Zool. 44 (1), 1–11.

Manier, D.J., Hobbs, N.T., 2006. Large herbivores influence the composition and diversity of shrub-steppe communities in the Rocky Mountains, USA. Oecologia 146 (4), 641–651.

McCune, B., Mefford, M.J., 2011. PC-ORD. Multivariate Analysis of Ecological Data. Version 5. MjM Software, Gleneden Beach, Oregon, U.S.A. Mongolian.

Mongolian Society for Range Management, 2009. Livelihood Studies of Herders in Mongolia: Draft study report. Unpublished internal report. Ulaanbaatar. Mongolia.

Namkhaidorj, B., Puntsagdulam, J. and Mygmarsuren, D., 2008. Identification key of Insects of Mongolia, Volume II, second part.

Namkhaidorj, B., 1981. Method of Collecting, Treating and Preserving of Insects. National Publishing.

National Registration and Statistical Office of Mongolia, 2015, Monthly Bulletin of Statistics, Ulaanbaatar.

Niemelä, J., Langor, D., Spence, J.R., 1993. Effects of clearäcut harvesting on boreal groundäbeetle assemblages (Coleoptera: Carabidae) in Western Canada. Conserv. Biol. 7 (3), 551–561.

Oksanen, J., Blanchet, G.F., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, B.R., Simpson, G.L., Solymos, P., Stevens, M.H.H., Wagner, H., 2013. *Vegan*: Community Ecology Package. R package version 2. 0–10.

Pöyry, J., Lindgren, S., Salminen, J., Kuussaari, M., 2004. Restoration of butterfly and moth communities in semi-natural grasslands by cattle grazing. Ecol. Appl. 14, 1656–1670.

Pöyry, J., Lindgren, S., Salminen, J., Kuussaari, M., 2005. Responses of butterfly and moth species to restored cattle grazing in semi-natural grasslands. Biol. Conserv. 122 (3), 465–478.

Rákosy, L., Schmitt, T., 2011. Are butterflies and moths suitable ecological indicator systems for restoration measures of semi-natural calcareous grassland habitats? Ecol. Indic. 11, 1040–1045.

Rapport, D.J., Costanza, R., McMichael, A.J., 1998. Assessing ecosystem health. Trends Ecol. Evol. 13 (10), 397–402.

Rickert, C., Fichtner, A., van Klink, R., Bakker, J.P., 2012. α- and β-diversity in moth communities in salt marshes is driven by grazing management. Biol. Conserv. 146, 24–31.

Sanyal, A.K., Uniyal, V.P., Chandra, K., Bhardwaj, M., 2011. Diversity and indicator species of moth (Lepidoptera: Heterocera) assemblages in different vegetation zones in Gangotri landscape, Western Himalaya, India, Envis Bulletin: Arthropods and their Conservation in India (Insects & Spiders) pp. 114–129.

Seitz, A. Ed.,1912-1913. Die Großschmetterlinge der Erde, Verlag Alfred Kernen, Stuttgart Band 2: Abt. 1, Die Großschmetterlinge des palaearktischen Faunengebietes: Die palaearktischen Spinner und Schwärmer.

Summerville, K.S., Ritter, L.M., Crist, T.O., 2004. Forest moth taxa as indicators of lepidopteran richness and habitat disturbance: a preliminary assessment. Biol. Conserv. 116 (1), 9–18.

Svyatoslav, K.A., 2000. Electronic Atlas of Lepidoptera of Omsk Field, Retrieved from http://www.omflies.narod.ru, (accessed on 14.06.15).

Tsegmid, Sh., Institute of Geography – Cryopedology, MAS, 1969. Physical geography of Mongolia. Ulaanbaatar, Republic of Mongolia (In Mongolian).

Verdú, J.R., Moreno, C.E., Sánchez-Rojas, G., Numa, C., Galante, E., Halffter, G., 2007. Grazing promotes dung beetle diversity in the xeric landscape of a Mexican Biosphere Reserve. Biol. Conserv. 140, 308–317.

Wagner, W. 2005–2016. Europäische Schmetterlinge und ihre Ökologie –Mythimna conigera. Donwloaded at 02.07.2016 from http://www.pyrgus.de/Mythimna_conigera.html.

Walser, J.-C., Holderegger, R., Gugerli, F., Hoebee, S.E., Scheidegger, C., 2005. Microsatellites reveal regional population differentiation and isolation in *Lobaria Pulmonaria*, an epiphytic lichen. Mol. Ecol. 14 (2), 457–467.

Wang, Y., Wesche, K., 2016. Vegetation and soil responses to livestock grazing in Central Asian grasslands: a review of Chinese literature. Biodivers. Conserv., 1–20, http://dx.doi.org/10.1007/s10531-015-1034-1.

Williams, E.R., Mulligan, D.R., Erskine, P.D., Plowman, K.P., 2012. Using insect diversity for determining land restoration development: examining the influence of grazing history on ant assemblages in rehabilitated pasture. Agric. Ecosyst. Environ. 163, 54–60.

Wirooks, L., 2006. Zum Flächenbezug von Lichtfangartenspektren (Lepidoptera, Macroheterocera). Mitt. Dtsch. Ges. Allg. Angew. Ent. 15, 403–408.

Xiao, C., Baoping, Z., Ruijie, G., Minghao, Y., You, Z., Kuijun, Z., 2008. Source area of spring population of meadow moth, *Loxostege sticticalis* L. (Lepidoptera: Pyralidae), in Northeast China. Acta Ecol. Sin. 28 (4), 1521–1535.

Yadamsuren, O., Hayford, B., Gelhaus, J., Ariuntsetseg, L., Goulden, C., Podenas, S., Podeniene, V., 2015. Declines in diversity of crane flies (Diptera: Tipuloidea) indicate impact from grazing by livestock in the Hövsgöl region of Mongolia. J. Insect Conserv. 19 (3), 465–477.

Yin, J., Cao, Y.Z., Luo, L.Z., Hu, Y., 2005. Oviposition preference of the meadow moth, *Loxostege sticticalis* L., on different host plants and its chemical mechanism. Acta Ecol. Sin. 25 (8), 1844–1852.

Yunatov, A.A., 1976. Main Features of Vegetation Cover of the Mongolian People Republic. Ulaanbaatar, Mongolia.