RANGELAND DEGRADATION IN MONGOLIA: CHANGES IN VEGETATION COMPOSITION AND BIOMASS, AND POTENTIAL EFFECT ON SOIL CARBON

Burmaa Dashbal
Mongolian Society for Range Management
Microdistrict 12, Bayanzurkh District, Big Ring 49, Ulaanbaatar, Mongolia
d_burmaa_1@yahoo.com, burmaa@greengold.mn

Supervisor
Dr. Johann Thorsson
Soil Conservation Service of Iceland
johann.thorsson@land.is

ABSTRACT

Mongolian rangelands are degrading due to changes in land management and climate change. Grazing-induced disturbances will further exacerbate the problem and potentially increase the soil organic carbon (SOC) rate of loss. We lack understanding on what ecosystem processes are involved and how they interact and how they are expressed in different ecological zones of Mongolia in order to be able to mitigate the problems. To address these challenges, a series of experiments was designed, comparing open pastures and enclosures in different ecological zones of Mongolia, focusing on vegetation and soil properties. In addition, an effort was made to analyze Icelandic soil data to compare vegetation cover and SOC accumulation.

The results suggest that grazing reduces vegetation cover by 9.1%, biomass by 23.1%. Species diversity decreased and species composition changed with grazing. Species cover, biomass, species diversity, and species numbers differed significantly between ecological zones, suggesting an influential site effect, here interpreted as climatic effect. SOC differed significantly between land reclamation treatments and soil depths. The highest values were found in the grass treatment and the topsoils in all treatments.

Continuous grazing affects biodiversity, vegetation composition, biomass and cover. However, the effects differ between climatic zones. Vegetation cover and SOC appear to be positively correlated, suggesting that overgrazing will reduce soil fertility and hence the grazing resources.

Keywords: land degradation, soil carbon, plant composition, land management, grazing.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 Mongolia rangelands

Mongolia is one of the largest landlocked countries in the world. It is located between the latitudes 41°35'N and 52°09'N, and longitudes 87°44'E and 119°56'E, respectively, covering a total of 1,564,000 sq. km. Mongolia is divided into 21 provinces and the provinces are in turn divided into districts. Districts, or *soums*, are the smallest political units of Mongolia.

Mongolian rangelands have degraded due both to human activities and natural processes. Uncontrolled grazing and water use, both leading to unsustainable resource use, and climate change, are examples. Additionally, livestock is private property while land use is unrestricted in Mongolia. It has been estimated that about 70% of the pasture lands are degraded to some extent and widespread over-grazing has been documented (MSRM, 2010).

The Green Gold report by the Swiss Agency for Development and Co-Operation in the Mongolia-Ecosystem Management Program (MSRM, 2010) points out that degradation has accelerated sharply in the past two decades following unrestricted herding access after the period of socialism. Unrestricted grazing has also led to decreased pasture productivity and hence increasing grazing pressure, thus negatively affecting the herder's livelihood. The report also points out that the current land degradation trend is in part due to intense accumulation of livestock around watering points and lack of seasonal grazing rotation, the latter because herders with small flocks around don't adopt a rotation grazing system. Degradation of pastureland has accelerated sharply in the past two decades.

A further reason for pasture degradation is that land use is changing nowadays in Mongolia. Pastoralists have largely abandoned the traditional rotation grazing system whereby they moved their herds to different areas based on the season. The change is exacerbated by the problem that many people who do not belong to the group of traditional herders are herding livestock today as this is their only way to make a living.

The climate in Mongolia has already changed significantly, according to the report of Assessment of Impact and Adaptations to Climate Change (AIACC) (Batima et al., 2005). Annual mean temperatures have risen by 1.8°C between 1940 and 2003. This affects pastures and pastoralists' livelihood. AIACC predicts that the rate of future winter warming in Mongolia will vary from 0.9ºC to 8.7ºC, while the predicted summer temperature increase will vary from 1.3°C to 8.6°C. More than 80 percent of the county's territory has been defined as highly vulnerable to climate extremes (Batima et al., 2005).

Mongolia has six different ecological zones in terms of landscape features, including altitude, and climate (Ulziikhutag, 1985). The Forest Steppe, Steppe, Desert, and Desert Steppe zones range from north to south. The Alpine and High Mountain zones are found in western Mongolia.

High Mountain zone

The High Mountain zone ranges from 2000 to 2900 m a.s.l. on average with several peaks extending above 2900 m a.s.l. It is dominated by grass and humificate soils (Ulziikhutag, 1985). The vegetative communities differ from the other zones, as the vegetation is adapted to grow in cold areas, both dry and wet. Forbs are uncommon, but grasses and sedges dominate and bryophytes are common. Typical species found in the High Mountain zone include *Kobresia bellardii*, *K. filifolia*, *Carex melanantha*, *Thalictrum alpinum*, *Ptilagrostis mongholica*, *Poa altaica*, *P. sibirica*, *Festuca rubra*, *Saxifraga hirculus*, and *S. sibirica*.

Forest Steppe zone

The Forest Steppe zone is found in West, East and North Mongolia (Fig. 1). The elevation ranges from 850 m to 2000 m, with peaks up to 2000 m. The annual average precipitation ranges from 200–300 mm in the spring and fall seasons (Ulziikhutag, 1985). Typical forbs and grasses include *Koeleria* spp., *Festuca* spp., *Artemisia* spp. and *Potentilla* spp. The Forest Steppe zone has more species than the other ecological zones, an estimated 854 species (Ulziikhutag, 1985).

Steppe zone

The Steppe zone (Fig. 1) is the driest of all the Mongolian ecological zones with the average annual precipitation ranging between 125–250 mm. Typical vegetation species include *Caragana* spp., and *Artemisia frigida*, both uncommonly found in other ecological zones. The soil is nutrient rich, sandy without carbonate, and a few areas suffer from high soil salinity. *Stipa* spp., *Potentilla* spp. and *Elymus* spp. dominate the pastures of the Steppe zones (Ulziikhutag, 1985).

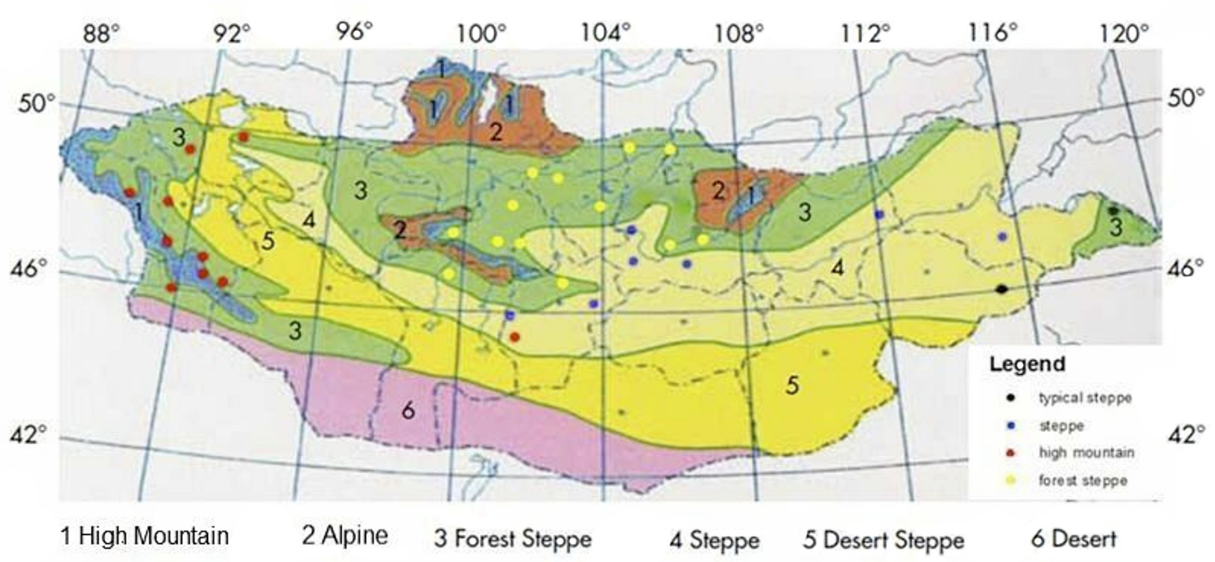


Fig. 1. *The ecological zones of Mongolia, which include research cases. Red points demonstrate High Mountain zones and include 10 cases, yellow points demonstrate the Forest Steppe zone, that includes 13 cases, the blue points mark the Steppe zone, which includes 7 cases, and the black points show Typical Steppe and include 2 case areas (Source: adapted from MSRM 2010).*

As seen in the climate diagram in Figure 2, the High Mountain and Steppe zones were drier than other ecological zones during the 2009 vegetation period.

Part of the data discussed in this paper was obtained using old fences around meteorological stations. This allowed for testing the impact of grazing (areas outside the fences) and resting (areas inside the fences). Having access to meteorological data for these sites as well allows us further to investigate the impact of climate on the vegetation (i.e. ecological zones). The effect of grazing and climate pose some of the most critical questions facing land managers in Mongolia today; how can land degradation be prevented and how can degraded pastures be restored.

1.2 Carbon content change

With increasing atmospheric concentration of carbon dioxide, the global climate will change. It is predicted, and has been observed, that temperatures will rise globally, but localized cooling trends are also expected. Extremes in climate events are also predicted to occur globally (Sundermeier et al., 2005).

Parton et al. (1995) made an attempt to assess the impact of increased atmospheric CO_2 on 31 temperate and tropical grasslands using the CENTURY model (Parton et al., 1995). They concluded that the climate change associated with increased atmospheric CO_2 concentration generally increased net primary production, except in cold desert steppe regions, and CO_2 increased vegetation production at all sites. Their results also showed that the climate change has caused an overall global soil carbon decrease, resulting in a loss of 4 Pg from global grasslands in 50 years. The modeled results also indicated that combined climate change and elevated CO_2

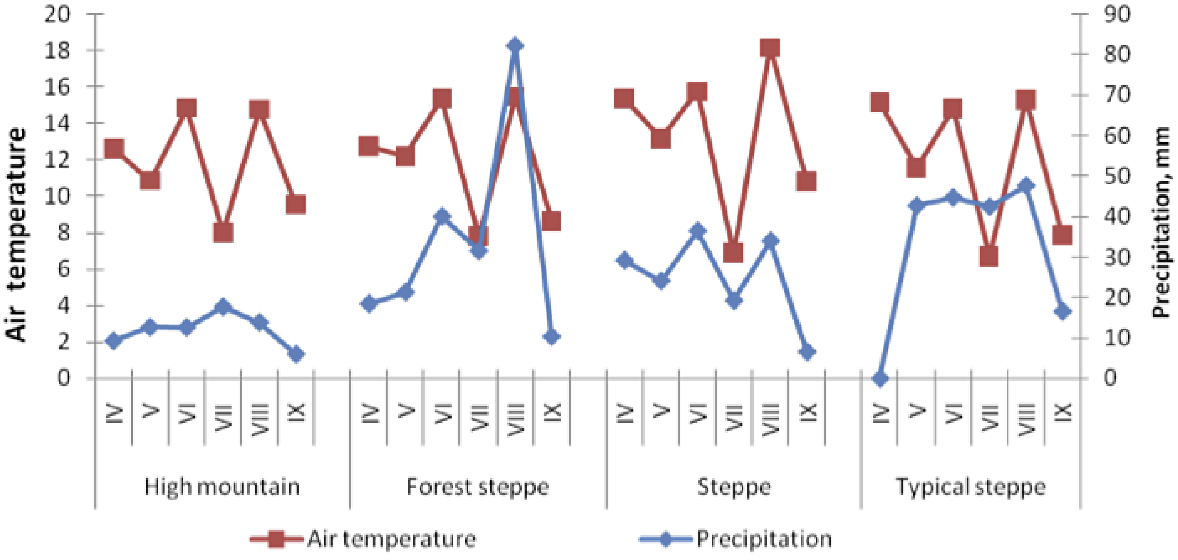


Fig. 2. *The figure shows air temperature and precipitation based on different ecological zones during the summer of 2009. The roman numerals indicate the month: for example IV is April, V is May, VI is June. (data from the Mongolian National Agency of Meteorology and Environmental Monitoring).*

would increase vegetation production and reduce global grassland C losses to 2 Pg due to tropical savannas becoming a small sink for soil C. Most of the predicted changes in plant production are less than 10%, but detection of statistically significant changes in plant production would require a 16% change in measured plant production because of high year-to-year variability in plant production (Parton et al., 1995).

The global soil organic carbon (SOC) stock outweighs the C percent in the vegetation and the atmosphere combined, and has the potential to mitigate or promote future climate change depending on whether the amount of SOC increases with successive organic matter inputs or decreases due to SOC losses (Hopkins et al., 2009).

Countries have different possibilities in terms of carbon sequestration. Iceland has high possibilities of sequestering soil carbon based on sandy soils and volcanic soils. In fact, they have been doing carbon research on different kinds of soils to gain knowledge on carbon sequestration (Arnalds et al., 2002).

Iceland is located in the North Atlantic Ocean between 63° and 66° N, with a total area of 103,000 sq. km. The climate is maritime, driven by the Gulf Stream. Annual rainfall ranges from 500 mm in the north to 2000 mm in the south (Lal, 2009).

The volcanic soils of Iceland developed under high-latitude climates and are highly sensitive to land degradation processes and to climate change (Arnalds et al., 2000). The degraded and de-certified soils of Iceland are severely depleted of their SOC pool and there is a strong interest in restoring degraded soils and ecosystems (Lal, 2009).

Carbon sequestration in Icelandic soils ranges from 0 kg m^{-2} in Leptosols to 197.5 kg m^{-2} in Histosols (Lal, 2009). The highest potential for SOC sequestration exists in the eroded soil of Iceland. The potential annual rate of carbon sequestration in the biomass is estimated to be 0.01 to 1.7 Mg C ha^{-1} y^{-1}, but after restoring vegetation cover, it is estimated to reach 1.0 Tg C ha^{-1} y^{-1}.

Land degradation and soil erosion are serious environmental problems in Iceland. The Soil Conservation Service of Iceland and nongovernmental organizations have established long term erosion control and soil restoration programs through revegetation and a reforestation effort in order to recreate vegetative cover on the degraded lands (Lal, 2009).

Iceland provides a good example of the multiple role of carbon sequestration in meeting its national commitment to the United Nations Framework Convention on Climate Change (UNFCCC). In accordance with the agreements at the meeting goals include conserving and reclaiming biological diversity, combating soil erosion, revegetation and seeding eroded land, and restoration. Efforts to carry out such goals have led to carbon sequestration and have resulted in increased funds for conservation and restoration of degraded land in Iceland (Arnalds, 2004)

The second part of this paper is based on data acquired from the SCSI on soil carbon sequestration. Iceland has extensive deserts and barren patches. The desert areas include Andisols, that have very limited sources of macro-nutrients and low water capacity (Arnalds et al., 2000).

2. LITERATURE REVIEW

Multiple studies have been published on the topic of land use and SOC. Han and others (2008) examined the effect of grazing on grassland ecosystems at a meadow steppe site (Inner Mongolia, Northern China). Their results showed a reduction in root biomass with increased grazing intensity, as did SOC and soil N, hence concluding that intensive grazing would lead to a decrease in soil quality and fertility.

Steffens et al. (2008), studied how long term grazing in a semiarid steppe affected soil chemical and physical properties. Heavy grazing led to deterioration of soil physical and chemical parameters, and no ameliorating effect was detected five years after the grazing was stopped. Only after 25 years of exclusion were statistically significant changes detected, e.g. in SOC and total soil N. A similar resilience was detected in a study by Li et al. (2008) which looked at the effect of historic long term sheep grazing on vegetation cover and species composition and the soil properties of the Desert Steppe of Inner Mongolia in China. Their results suggested that the grazing had little effect on the vegetation total N and total P. The grazing did increase soil bulk density but had no effect on soil total N and soil total P. They concluded that grazing effects were generally not detected. However, the combination of sandy soils and general reduction of litter and plant cover with increased grazing pressure suggested that the Desert Steppe might be vulnerable to soil erosion. Ensuring appropriate grazing pressure and animal distribution with judicious herding may reduce this risk.

A Canadian study by Carter (2002) also revealed the important relationship between sustainable land use and soil structure. His studies on soil quality were initiated in the early 1980s and showed that loss of SOM and soil aggregate stability were standard features of non-sustainable land use.

It is not only that grazing managers must be aware of poor soil physical structure, as revealed by Li et al. (2008) and Carter (2002), but that the invisible nutrient status of the land is also important. Peter et al. (2008) looked into recent change in the floristic composition and nature conservation value of nutrient-poor, semi-natural grassland in the Swiss Alps. They discovered a clear shift in the composition of the vegetation community, with a higher proportion of nutrient-demanding species and a lower proportion per plot of nutrient poor grassland (NPG) species, or 3.6% to 11.6%. They observed that changes were greatest in pastures, and in meadows converted to sheep pastures, while the NPG-species were maintained in unfertilized meadows that were managed as ecological compensation areas. To prevent continuing decline in the conservation value of these grasslands, it is therefore important to support low-intensity management, especially mowing.

A study performed by Pei et al. (2008) focused on the effect of grazing on the soil properties and vegetation changes. It revealed a correlation between those factors and land management. Based on three sheep management regimes; with year-long grazing, livestock excluded for 2 years, and livestock excluded for 6 years, their results showed that, soil organic carbon and total N in the top 20 cm of the soil profile increased significantly with the prolonged exclusion period, with 22% higher SOC, and 14% higher N and in the 6 year exclusion treatment compared to continuous year-long livestock grazing. Plant biomass and vegetation diversity also increased with the increased number of exclusion years. They concluded, based on their results, that while continuous overgrazing in the erosion desert steppe was detrimental to soil and vegetation, this negative trend could be reversed, and that a significant increase in soil fertility, vegetation diversity, vegetation cover and biomass can be achieved with the implementation of protecting practices.

Similar results were published by Yong-Zhong et al. (2005). They compared vegetation and soil properties under both continuous grazing and exclusion of livestock for 5 and 10 years in a degraded sandy grassland in the Horqin region of Inner Mongolia, Northern China. Continuous grazing resulted in a considerable decrease in ground cover, leading to accelerated soil wind erosion, loss of SOC and soil N, and a decrease in soil biological properties, such as species and soil microorganisms. The grasslands that was subject to continuous grazing showed clear signs of land degradation. Excluding livestock grazing enhanced vegetation recovery, litter accumulation, and development of annual and perennial grasses. SOC and total soil N concentrations, soil biological properties, such as enzyme activity and basal soil respiration increased in the 10-year exclusion treatment, suggesting an improvement over time in the absence of livestock grazing. These results suggest that excluding grazing livestock on the desertified sandy grassland in the erosion-prone Horqin region offers a great potential to restore soil fertility, sequester soil organic carbon and improve biological activity.

Soil carbon sequestration has become a focal point in many countries, both because it is a potential atmospheric carbon sink, but also because increased SOC improves soils in terms of nutrient availability and structure. Icelandic soils, being of volcanic origin, have a high sequestration rate potential. It has been estimated that the total amount of eroded organic matter from Icelandic soils since settlement is 120–500 x 10^6 t C. The potential for sequestration is thus considerable (Oskarsson et al., 2004)

Batjes (1996) worked on developing methods to determine soil carbon sequestration rates in Icelandic land reclamation areas. He reported an average soil carbon sequestration rate across 33 nationwide sites of 0.6 t C ha^{-1} yr^{-1}, which was maintained for at least 50 yrs. However, as this number does not include sequestration in above- or belowground biomass, it is an underestimation of the system-wide sequestration at a given point in time.

Glenn et al. (1993) looked at carbon accumulation in arid areas. They suggested that changes in land use, by using plants better adapted to the dry environment, could result in net soil C sequestration of 0.5–1.0 Gt (Giga ton) yr^{-1} at a cost of \$10–18 per ton of C, based on a 100 year scenario. Investment in anti-desertification measures in the world's drylands appears to be an economical method to mitigate CO_2 buildup in the atmosphere while accomplishing a major international objective of restoring dryland productivity (Glenn et al. 1993).

The relationship between vegetation and SOC is often overlooked, but the vegetation is generally the factory responsible for the majority of SOC sequestration (Jobbágy & Jackson, 2000), and hence the reduction of vegetation will have negative effects on the sequestration process. Plants are thus the main source of the soil organic carbon, either from the decomposition of aerial plant parts or underground plant parts, e.g. roots in the form of root death, root exudates and root respiration (Kumar et al., 2006). Derner et al. (1997) looked at soil carbon and nitrogen accumulation beneath C_4, perennial grasses, comparing long term grazing (more than 25 years) on soil organic carbon and total nitrogen accumulation beneath individual plants. According to their results grazing appears to indirectly mediate nutrient accumulation beneath cespitose grasses along the environmental gradient by modifying the size class distribution of plants. Populations with a greater proportion of large plants have a greater potential for biomass incorporation into soils and may more effectively capture redistributed organic matter from between plant locations.

Similar results were also reported by Jackson et al. (2000), but they found that soil C and N are distributed deeper in arid shrublands than in arid grasslands, and subhumid forests have shallower nutrient distributions than do subhumid grasslands. Consequently, changes in vegetation may influence the distribution of soil carbon and nutrients over time (Jackson et al., 2000).

The relationship between vegetative cover and SOC became evident when birds started colonizing the island of Surtsey south of the Icelandic mainland. The island was formed in an eruption, starting in 1963. Vegetation cover was strongly related to the density of gull nests, due to the nutrients they brought in, and soil respiration measurements indicated significant increases in soil carbon (Sigurdsson & Magnusson, 2010).

Other studies have been published emphasizing on the relationship between vegetation and SOC. McLauchlan et al. (2006) showed that soil organic matter usually increased when fields used for agriculture were converted to perennial vegetation.

Ringrose et al. (1998) published data showing positive correlations between SOC and woody vegetation cover and negative relationships between SOC and bare soil. They suggested that SOC is mainly formed under woody vegetation cover, but less likely to be derived from dead herbaceous cover and litter components.

The aim and objective of this study

Mongolian pastures are rapidly degrading due to changes in land use practices and global climate change (MSRM, 2010). Intensive livestock grazing is resulting in general overgrazing on common lands, affecting both vegetation species diversity and cover and thus affecting SOC. Grazing-induced disturbances will further exacerbate the problem and potentially increase the SOC rate of loss. If this land use trend continues, pastures will lose vegetative cover, biodiversity will be reduced and SOC will decrease. Restoration of such degraded lands is difficult. We lack understanding of what ecosystem processes are involved and how they interact and how they are expressed in the different ecological zones in Mongolia.

To address this question a series of experiments was designed comparing open pastures and enclosures in different ecological zones of Mongolia, focusing on vegetation and soil properties. In addition, an effort was made to analyze Icelandic data, provided by the Soil Conservation Service of Iceland, for correlation between vegetation and soil properties:

1. What are the observed effects of grazing on Mongolian vegetation, by
    a. Comparing grazed areas and areas excluded from grazing in terms of vegetation cover
    b. Comparing species diversity for grazed areas and areas excluded from grazing
    c. Comparing occurrence of species for grazed areas and areas excluded from grazing
2. Identify the relationship between vegetative cover and type and SOC in Icelandic reclamation areas, by
    a. Comparing vegetative cover and SOC
    b. Comparing soil carbon content by reclamation methods, i.e. species

Hypothesis

The following three testable hypotheses were constructed:

1. Grazing will reduce biodiversity and vegetative cover.
2. A positive relationship exists between SOC and vegetative cover.
3. A positive relationship exists between aboveground biomass and SOC.

3. MATERIAL AND METHODS

3.1 Vegetation methodology

The field research for this study was done in Mongolia. It was based on areas fenced in by the Mongolian Meteorology and Hydrology Institute (MHI) in 26 *soums* in High Mountain (n=8), Forest Steppe (n=12), Dry Steppe (n=4) and Typical Steppe (n=2) ecological zones. The sites were selected as being a typical pasture type of each particular zone. Data was collected from July to August 2009.

The field areas consisted of enclosure and control plot pairs (Fig. 3). The fenced plots measured 25 m x 25 m. Three transects were established outside the enclosures and six transects in the enclosures. Samples were collected from a 1 m^2 plot. The enclosures used here were established by the MHI at different periods of time. The main purpose of the enclosures is to monitor long-term land quality and vegetation changes. The selection of study sites for this project was based on the following criteria:

1. The area should have been excluded from grazing since at least the year 2000
2. The area should represent the typical pasture type of the particular ecological zone
3. The fenced area should be totally protected from grazing during the vegetation growth period
4. The control area outside the enclosures should be grazed in a traditional manner during the vegetation growth period
5. The area should be undisturbed in relation to road construction, off-road driving or mining activities

The following data was collected:

Numbers of species at each site in three 10x10 m plot pairs inside and outside the enclosure fence, and located at the center of the transect.

1. Biomass by 5 replicates 1 m^2 by 0 cm (at the beginning of the transect) inside and outside of the field. We distinguished biomass by litter and weighed the air-dried mass in an electron balance, 0.000 g.
2. Vegetative cover was measured in six replicates from 1 m^2 each inside and outside of field.
3. Species diversity was calculated using Shannon's diversity index (SHDI). The SHDI is one of several diversity indices suitable for assessing species diversity based on categorical data.

The data was tested for homogeneity and normality of the residuals prior to analysis. The data was then compared using one-way ANOVA and Non-Metric Multidimensional Scaling (NMS) ordination. NMS differs in design and interpretation from other ordination techniques. The method relies on randomized data as a null model for comparison and has performed very well with simulated gradients, even when beta diversity is high or ecosystem gradient strengths unequal. Dimensionality of each ordination was checked by constructing stress plots (McCune, 2002).

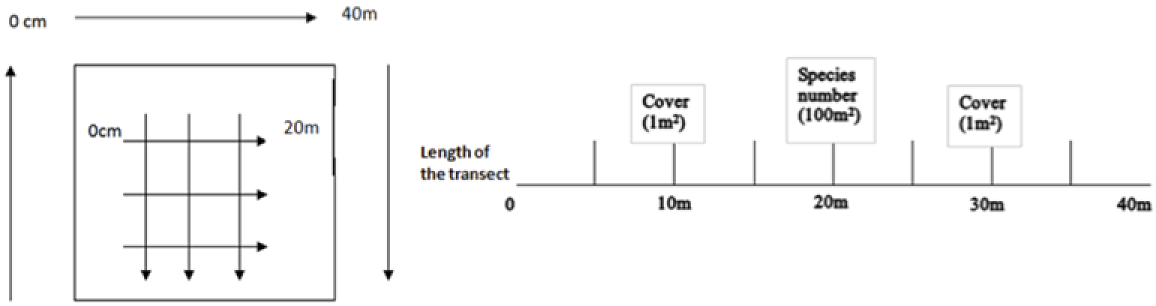


Fig. 3. *Sampling plots arrangement and their location on the transect. The control consisted of three transects 0–40 m in length with a 0–20 m transect on the inside with 6 replications; the enclosure transects were this shorter than the control transects because the whole fenced area was not large enough to accommodate 0–40 m transects. Data was collected from each transect. Note: The diagram is not to scale. The transect was 20 m in length if inside, but otherwise 40 m.*

3.2 Carbon methodology

The second objective of this study was to compare vegetation properties with SOC. The SCSI is currently undertaking a nationwide survey of land reclamation areas, collecting data on vegetation and soil properties. Preliminary data for 2007 was kindly provided by the SCSI for the purpose of this study. The dataset is based on extensive field sampling at randomly selected sampling sites intersecting SCSI project areas active since 1990. Each sampling site consists of a 10x10 m plot with five randomly selected 0.5 x 0.5 m subplots (Fig. 4). Species found within the main plot were counted but cover analysis (vegetation, gravel) and soil sampling was performed in each of the five subplots. The soil samples consisted of three composite samples from all subplots, i.e. 0–10 cm from the mineral surface, 10–20 cm from the mineral surface and 20–30 cm from the mineral surface.

The vegetative cover was estimated using a modified Braun-Blanquet scale (Pandeya, 1968). Soil samples were sieved with a 2 mm mesh to remove large roots and rocks. The volume of the larger particles was determined to correct for active soil volume. Soil bulk density was obtained from the field samples. The samples were analyzed at the Agricultural University of Iceland for carbon using the total combustion method, in a vario Max CN combustor analyzer (Elementar Analysensysteme GmbH, Hanau, Germany).

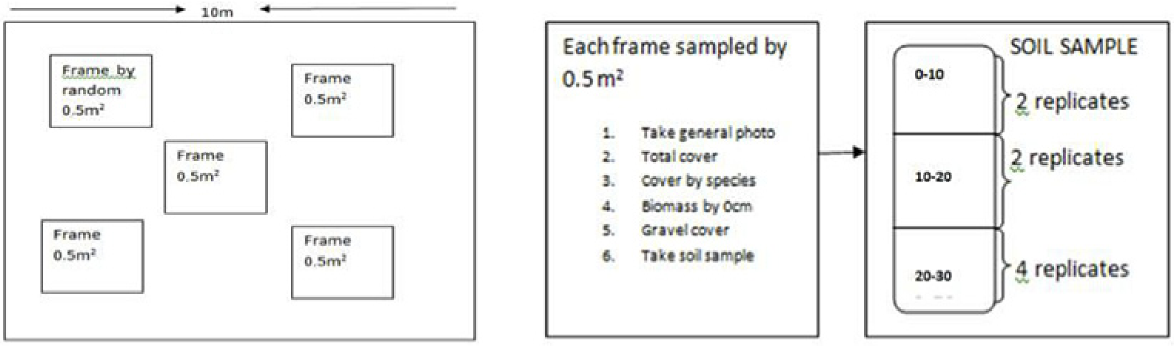


Fig. 4. *Vegetation and soil sampling at SCSI sites in Iceland, showing replicate of sample, depth of soil and list of sampling.*

4. RESULTS

4.1 The effect of grazing and climatic zone on vegetation

4.1.1 The effect of the grazing on vegetation

According to the data vegetative cover had decreased by 9.1% ($p<0.001$) and biomass by 23.1% ($p<0.001$). Species diversity and species numbers did not differ between enclosures and controls, with no difference between rested and grazing areas (Table 1, Fig. 5). Figure 5 illustrates the effect of enclosures on total vegetative cover, total vegetation biomass and the average number of species. Total cover and total biomass increased significantly in the enclosures (Table 1), but the total species number remained unaffected.

Figure 6 shows the grazing effect on the functional group. Cover of grasses, legumes and forbs increased when grazing was excluded. Under grazing grass cover decreased by 28% ($p<0.005$), legumes were absent in the grazed areas, and the forbs cover decreased by 31% ($p<0.002$). The more palatable species, e.g. legumes, were absent under the grazing regime, indicating the potential of greater harm from grazing for this group. Grazing also caused the area of bare ground to increase on all sites ($p<0.05$, Table 1).

Table 1. *The effect of the grazing on total cover, biomass, species diversity, species number and functional groups.*

Treatment	**Total cover, (%)**	**Total biomass, (g m^{-2})**	**Species diversity, H'**	**Species number, (#/100 m^2)**	**Grass cover, (%)**	**Sedge cover, (%)**	**Legume cover, (%)**	**Forb cover, (%)**	**Bare ground, (%)**
Rested	34.6	57.9	1.401	18	10.7	6.8	1.5	16.0	22.9
Grazed	25.9	41.2	1.286	16	8.0	6.6	0.4	10.7	29.9
p	0.002	0.001	0.231	0.105	0.005	0.914	0.002	0.002	0.033

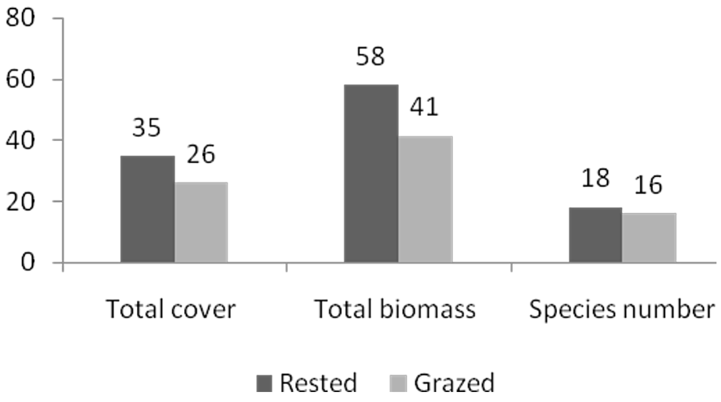


Fig. 5. *Grazing effect on total cover (%), biomass (g m^{-2}), and species number (average). Dark gray represents enclosures and light gray grazed areas (outside fences). Numbers above columns represent treatment averages. Note that the y axis represents multiple units.*

The average species numbers are shown in Figure 7, indicating a higher species diversity inside the enclosures than on the outside. The species composition decreased by 78% with grazing, as shown in Figure 7. The ordination in Figures 8 and 9 shows this further.

The proportional effect of grazing on species number can be seen by comparing the size of the third bar (inside and outside) to the other two (outside, inside). Here, about ¼ of the species are affected, or 50 out of 192 (Fig. 7 and 8).

The results for ordination of the grazing data are shown in Figure 8. The NMS ordination suggested a three dimensional solution after iterations. Clear trends were not obvious in the data, but the 41 species that occurred only inside the enclosures and the nine species occurring only on the outside can be identified, demonstrating the grazing effect (see Appendix for species codes).

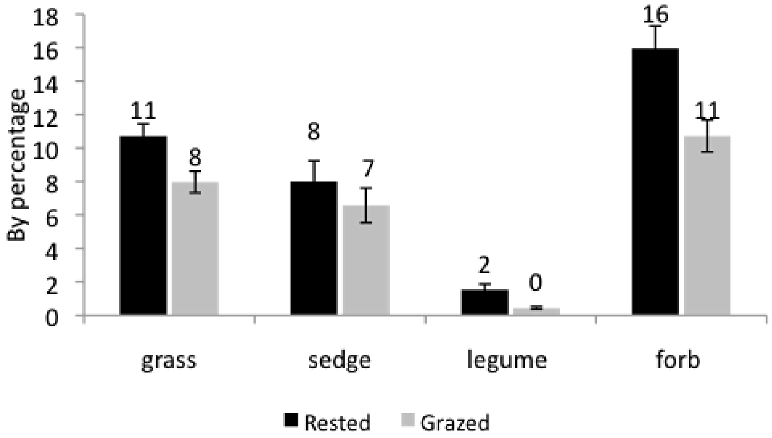


Fig. 6. *Grazing effect on cover (%) by functional group. Dark gray represents rested areas (inside fenced grazing enclosures) and light gray grazed areas (outside fences). Numbers above columns represent treatment averages and the I - bars indicate standard error of the mean.*

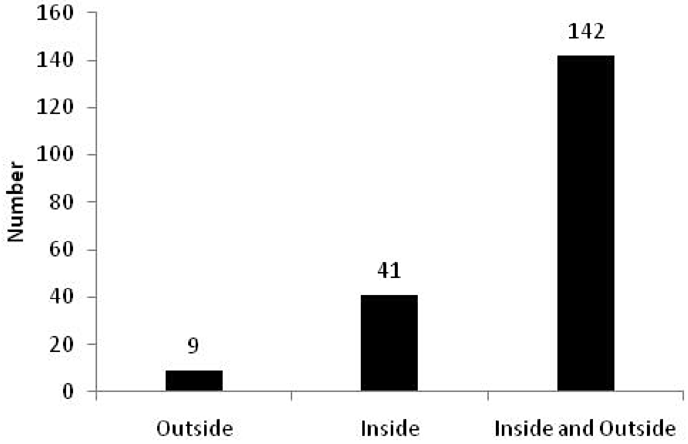


Fig. 7. *Average species numbers that occurred only inside, only outside, and both inside and outside the fenced areas.*

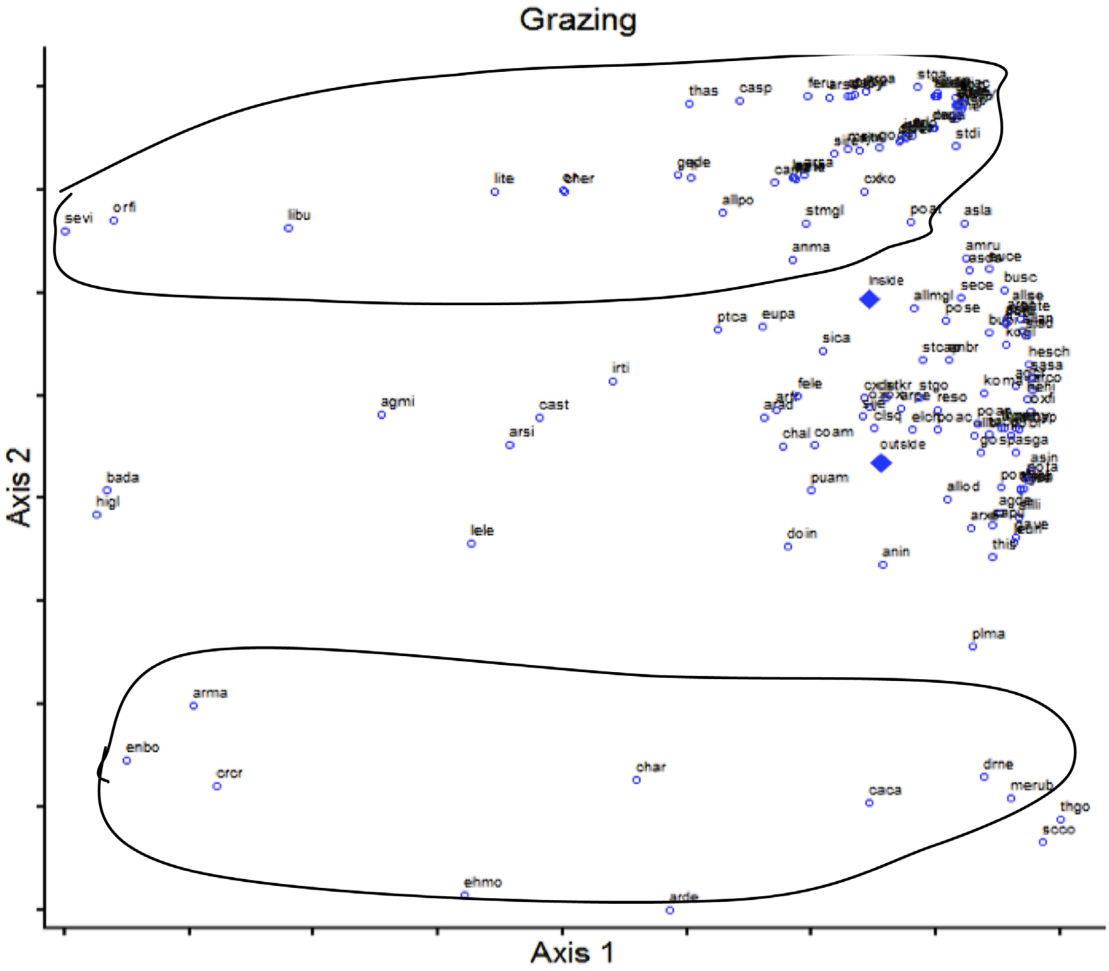


Fig. 8. *An ordination diagram showing species location as either inside or outside the enclosures. The inside domain is above and the outside domain is below as indicated by the diamond labels. The circles group the most common species for each domain. Species codes and clarification of species abbreviations are given in the Appendix.*

4.1.2 The effect of climatic zones

Table 2 lists the total cover, biomass, species diversity, species number, functional groups and bare ground in the four ecological zones. All tested variables were significantly different between zones, suggesting an influential site effect, here interpreted as climate effect.

According to the results, the High Mountain and Steppe zones were more vulnerable to grazing and climate changes. This can be seen by looking at cover, biomass, species diversity and species numbers. In addition, in the High Mountain zone the total cover of 9.8 percent was 32.2 units smaller than that of the Forest Steppe, 16.8 units smaller than the Steppe, and 30.7 units less than for the Typical Steppe. The species diversity (0.715) and species numbers (11) are correlated with the total cover result. Second, we focused on the Steppe zone, which has less precipitation and is drier than the Forest Steppe and Typical Steppe. The total biomass in the Steppe zone is smaller than for the Forest Steppe and Typical Steppe. The SHDI value was 1.308 and there

Table 2. *The climate effect on total cover, biomass, species diversity, species number, functional groups and bare ground.*

Zones	Total cover, (%)	Species diversity (H')	Species number (# / 100 m^2)	Total biomass (g m^{-2})	Grass cover (%)	Sedge cover (%)	Legume cover (%)	Forb cover (%)	Bare ground (%)
High Mountain	9.8	0.715	11	15.2	4.8	0.2	0.3	4.8	48.0
Forest Steppe	42.2	1.632	22	55.7	13.9	12.8	1.8	14.8	18.1
Steppe	26.7	1.308	13	48.4	3.4	4.8	0.3	16.9	16.4
Typical Steppe	40.6	1.854	22	147.2	10.3	0.2	0.6	29.5	10.5
p	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001

were 13 species. No difference was seen between the Forest Steppe and the Typical Steppe in species diversity and number. Both of these zones may be more tolerant than the Steppe and High Mountain zones to climate change and grazing (Fig. 9). As can be seen in Figure 2, drought was prevailed in the High Mountain zone. It is thus to be expected that the pasture quality will be affected in these two zones. The High Mountain zone had more bare ground cover than the other zones, which can contribute to increased vulnerability to grazing.

The data on total cover, total biomass and species numbers presented in Table 2 are further compared in Figure 9.

Figure 10 shows the cover of functional groups by zones. Forb cover is typically highest especially in the Typical Steppe. Sedges and legumes were absent or almost absent in both the High Mountain and Typical Steppe zones (Fig. 10).

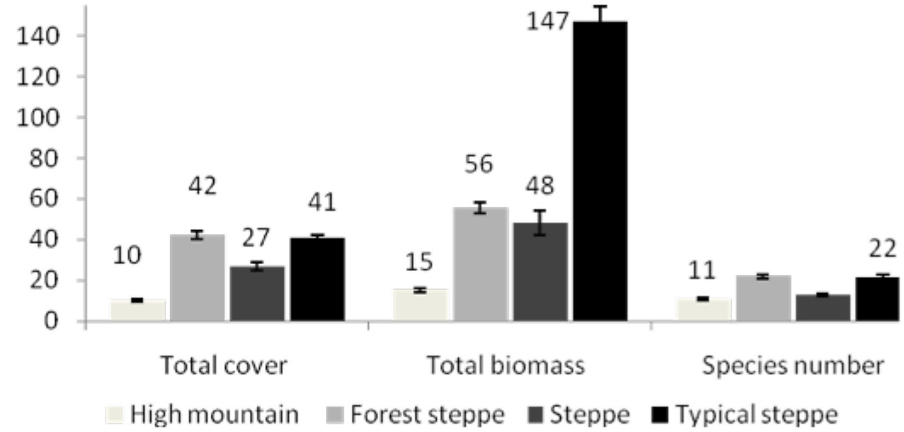


Fig. 9. *The climatic effect on total cover (%), biomass (g m^{-2}) and species number (average). The error bar shows standard errors and numbers demonstrate the value of each zone for each parameter. All tested variables were significantly different between zones, suggesting a climate effect.*

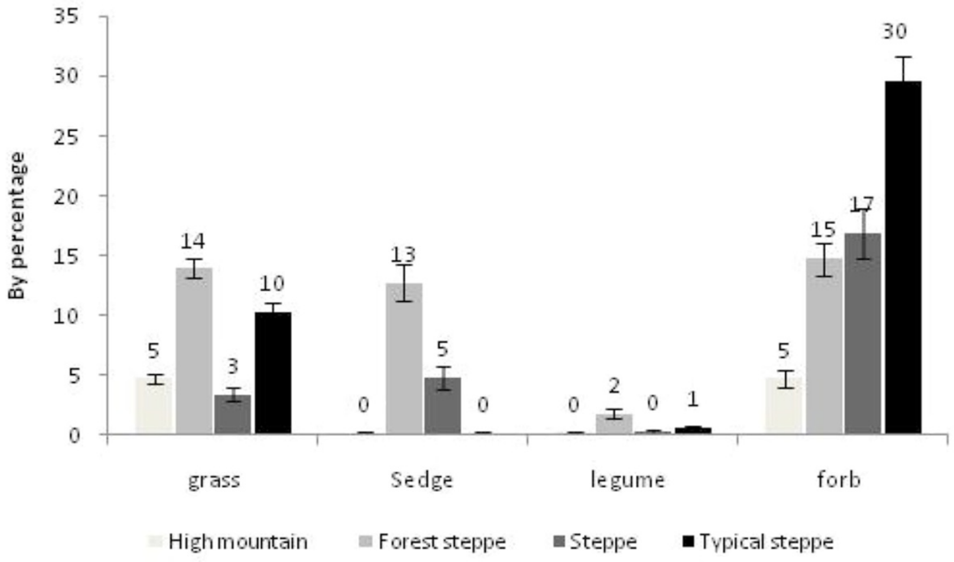


Fig. 10. *The climatic effect on the cover (%) of functional groups. Light gray shows High Mountain, gray is Forest Steppe, dark gray is Steppe and black is Typical Steppe.*

Furthermore, the ordination analysis, which showed how the climatic zones differed from each other, showed that 73 species occurred in only one climatic zone, 22 species occurred in 2 climatic zones, 13 species occurred in three climatic zones, and only 4 species occurred in all four climatic zones (Fig. 11 and 12). This indicates that 73 species seem to be specialized and occurred in only one climatic zone. In contrast there was only a small number of species that can occur in very different climatic zones (13 in three zones and only 4 species in all four climatic zones) The results showed that, in terms of total cover, biomass and functional groups, the High Mountain zone was

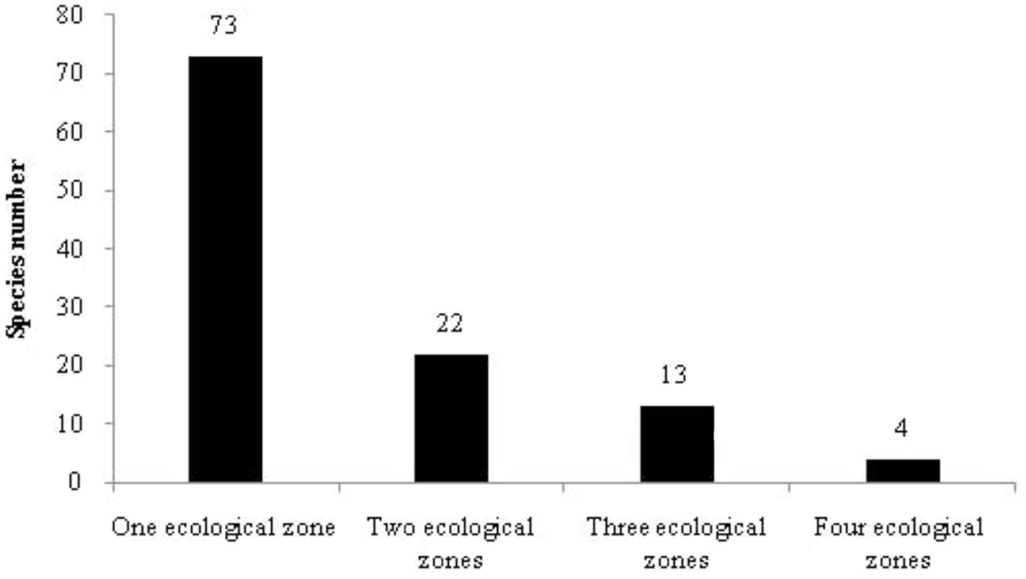


Fig. 11. *Number of species that occurred in one or more different ecological zones.*

more vulnerable than the others with a very low cover and biomass, but species composition is relatively higher than in the other zones. This may demonstrate that this area really was different from the others and therefore contained different species. The Steppe, Forest Steppe and Typical Steppe zones are relatively high in species composition compared to the High Mountain zone. This may reflect differences in precipitation hence the difference in species composition (Fig. 10 and 12).

The NMS ordination on cover by zones is shown in Figure 12.

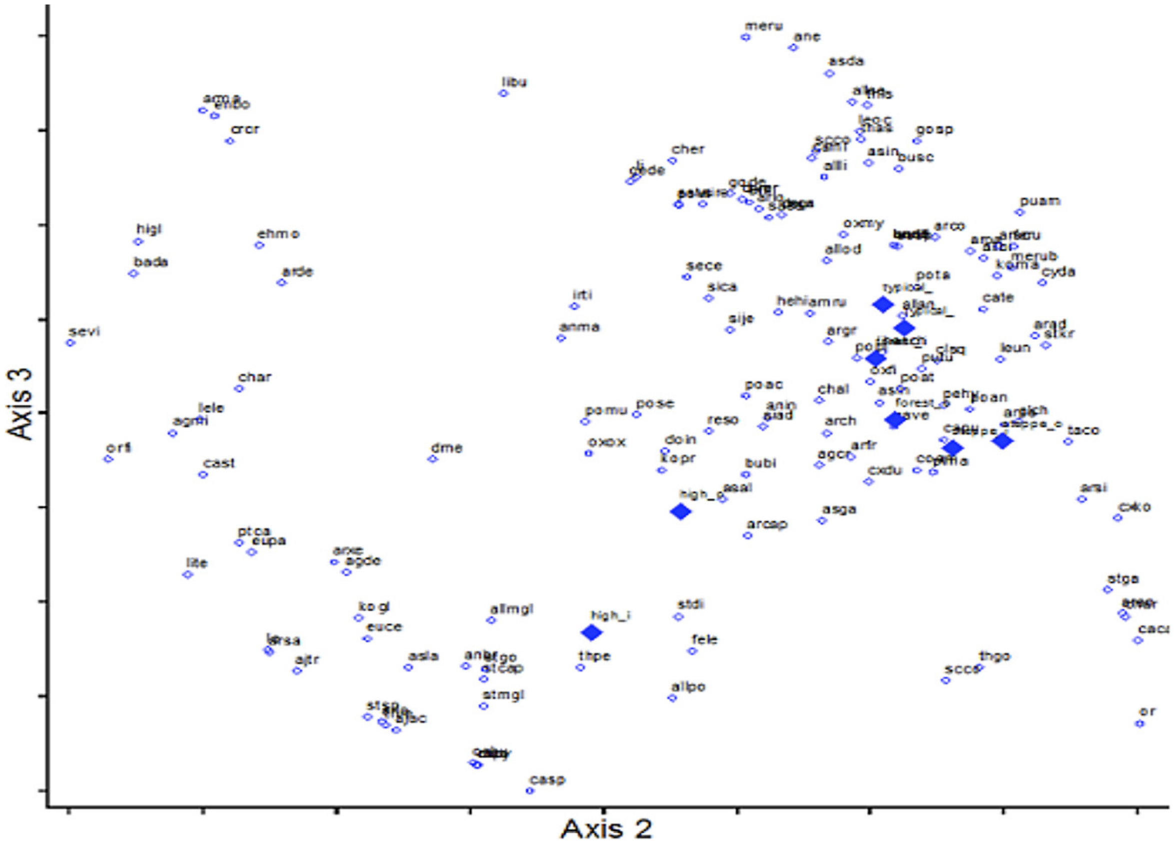


Fig. 12. Ordination between climatic zones. High-o indicates the mean for High Mountain outside, high-i the mean for High Mountain inside. Typical-i indicates the mean for Typical Steppe inside and typical-o the mean for Typical steppe outside. Steppe-o indicates the mean for Steppe outside and steppe-i the mean for Steppe inside. Forest-i indicates the mean for Forest Steppe inside and forest-o the mean for Forest Steppe outside.

4.2 Relation between vegetation and soil properties

Overall differences in soil carbon between land reclamation treatments were significant for all sampling depths (Fig. 13, Table 3). The highest carbon values were found in the topsoil, and the grass treatment yielded higher carbon than the other two.

The relationship between vegetative cover and SOC for the topmost 10 cm is shown in Figures 14–15. Both lupine and grass showed an increase in SOC trend with increased vegetative cover. The fertilized treatment stood out, however, possibly underlining a fundamental difference between the areas subject to these different land reclamation methods (Fig. 14–15). SOC decreased with depth as is evident from the 10–20 and 20–30 cm data (Table 4).

The results show that SOC is related to the vegetation cover. A high cover yields a high SOC and a low cover yields a low SOC (Table 4, Fig. 16).

Table 3. *Soil carbon in different land reclamation treatments in Iceland.*

Treatment	**Carbon content**		
	0–10 cm	**10–20 cm**	**20–30 cm**
Lupine	1.90	1.37	1.07
Grasses	16.36	12.56	12.02
Fertilizer	11.06	8.63	9.16
p	0.006	0.005	0.006

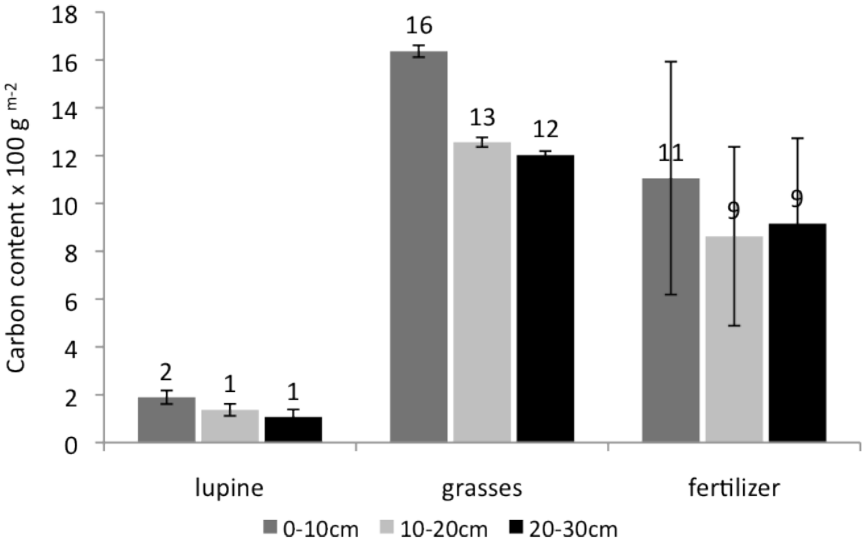
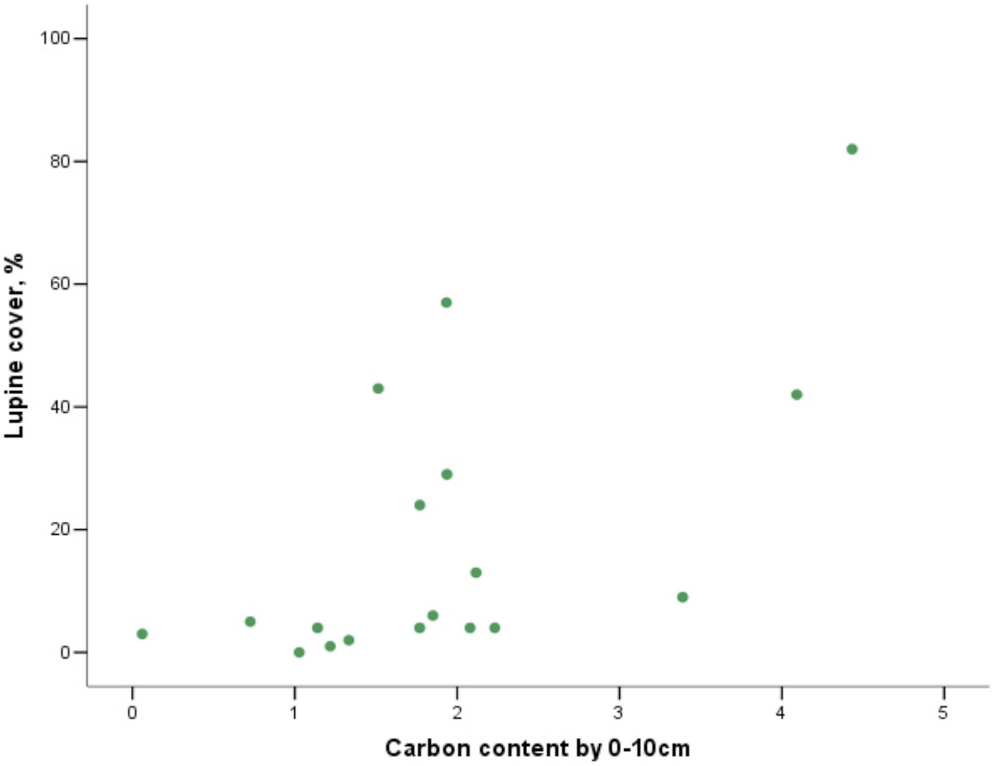


Fig. 13. *The soil carbon content comparison between treatments.*



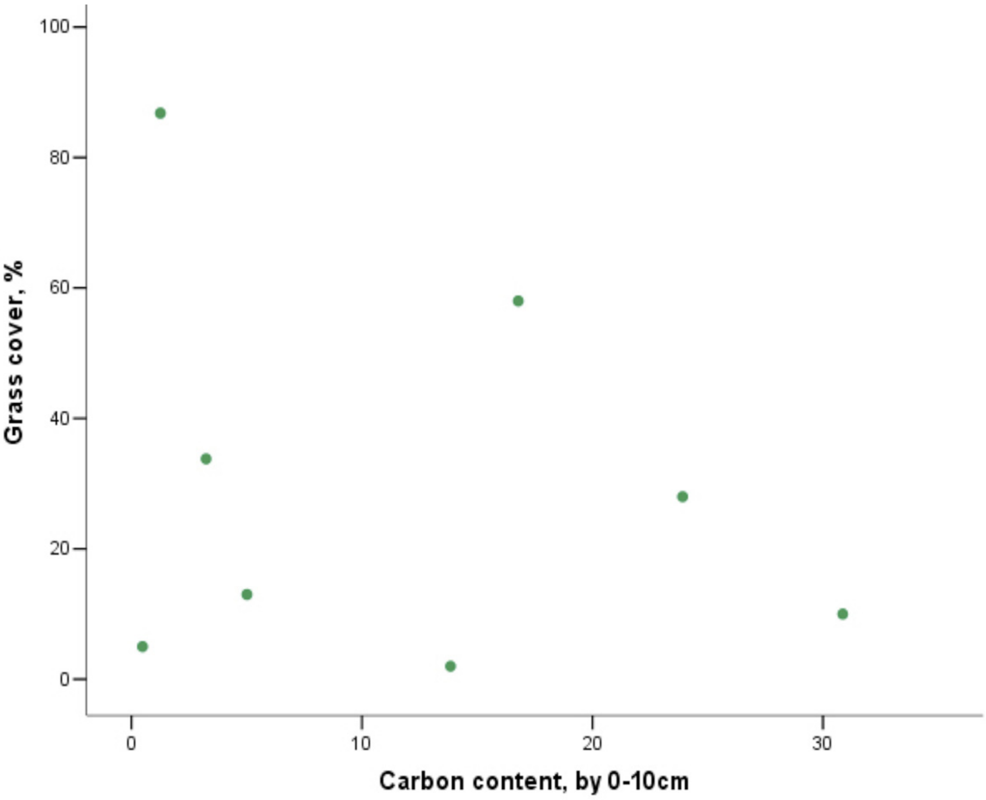


Fig. 14. *Relationship between vegetative cover and carbon content in 0–10 cm soil depth in the lupine and grass treatments.*

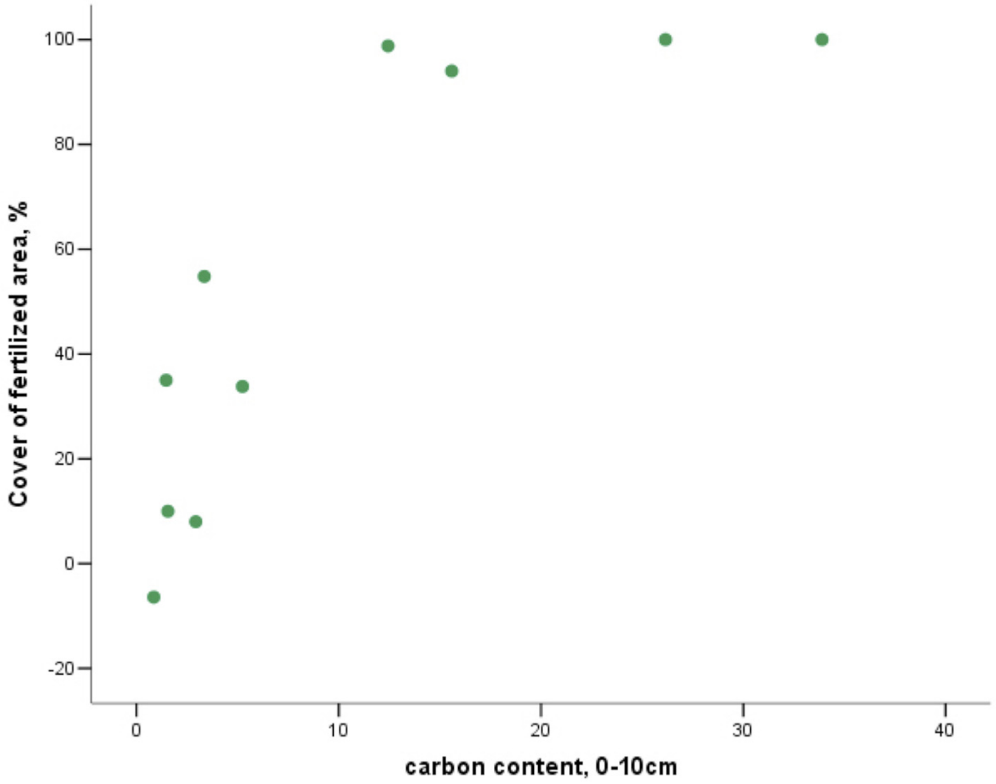


Fig. 15. *Relationship between vegetative cover and carbon content in 0–10 cm soil depth in the fertilized treatment.*

Table 4. *The carbon content comparison between covers.*

Treatment by vegetative cover	**Carbon content**		
	0–10 cm	**10–20 cm**	**20–30 cm**
low (0–9%)	2.3	1.7	1.7
medium (10–45%)	7.0	6.5	5.9
high (>45%)	14.6	10.4	10.3
p<	0.010	0.020	0.027

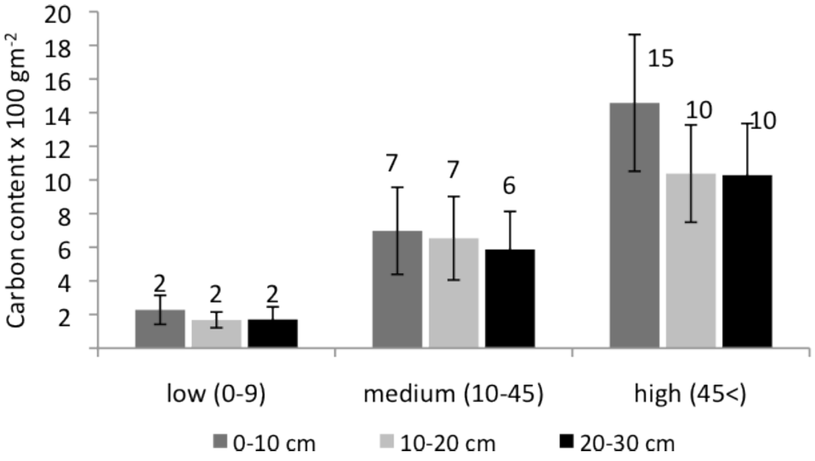


Fig. 16. *Soil carbon versus vegetation cover classes.*

5. DISCUSSION

5.1 The effect of grazing and climatic zone on vegetation

5.1.1 Grazing effect on the vegetation

Briske and Heitschmidt (1991) described how grazing animals can affect plants both directly and indirectly through grazing. Direct effects include alterations in plant physiology and morphology due to defoliation and trampling. Indirect effects include factors such as altering the microclimate, changing soil properties and plant competitive interactions. It can be challenging to distinguish between those two categories of predominantly influencing factors or their interactions.

The names of the species that occurred only inside the enclosures were *Setaria viridis*, *Oxytropis filiformis*, *Linaria buriatica*, *Bassia dasyphylla*, *Hierochloe glabra*, *Agropyron Michnoi*, *Leontopodium Leontopodioides*, *Artemisia siversiana*, *Caragana stenophylla*, *Limonium tenellum*, *Chamaerhodos erecta*, *Iris tigridia*, *Goniolimon speciosum*, *Alium polyrrhizum*, and *Ptilotrichum canescens.* As to the results for the outside area, the table shows 10 species found outside the enclosures but ordination figures showed 11 species occurred on the outside, namely *Artemisia macrantha, Enneapogon borealis, Crepis crocea*, *Ehedran mono*, *Chenopodium arist, Carum carvi, Artemisia desertorum, Draba nemorosa, Medicago rubra, Thymus gobicus,* and *Scabiosa comosa*. These species seem to be very tolerant of grazing, able to withstanding even continuous grazing.

Continuous grazing has clear effects on the vegetation. The vegetation cover decreased by 9.1% and biomass decreased by 23.1%. If we look at species diversity and species numbers, there were no differences between the rested and grazing areas. However, clear trends appeared to be present in the data, indicating an ecological difference between those areas but which has not established itself yet statistically. For example, the SHDI was 1.401 in the rested area but 1.286 in the grazing area. In addition, species numbers were lower, by two species, in the grazed areas compared to the enclosures. This indicates that grazing pressure affects species diversity and number. In this research, the total biomass and total cover appeared to be more vulnerable to grazing and therefore showed an intensive response. Furthermore, species diversity and species numbers may be long-term issues under grazing pressure (Belsky 1992; Cingolani et al., 2005).

Han et al. (2008) published similar findings to those presented here. According to their results, the amount of ground vegetation cover decreased and bare soil increased in the grazed areas. Furthermore, total biomass decreased with grazing intensity after four years. Also my results corresponded to those of Li et al. (2008), who found that litter cover, plant cover, aboveground and primary production decreased with increasing grazing pressure.

Grazing research has been conducted in Inner Mongolia for a long time. One study focused on the influences of continuous grazing and livestock exclusion on soil properties in degraded sandy grassland (Yong-Zhong et al., 2005). According to their results, live vegetation and litter were highest in areas that had had no grazing for 10 years, intermediate in areas where grazing had been excluded for 5 years, and lowest in the areas with continuous grazing. After 10 years of exclusion of livestock, bare ground decreased by 3.4 times compared to the grazed site. The total biomass increased 1.6 times after 5 years of exclusion and 2.9 times after 10 years of exclusion. In fact, biomass could increase up to 16 times in ungrazed compared to grazed areas (Yong-Zhong et al. 2005). Similarly, Ringrose et al. (1998) found an 1.5 fold biomass increase after six years of exclusion, and a 56% ground cover increase.

The results presented in this paper indicate that total cover and total biomass in Mongolia have decreased significantly due to overgrazing. It appears however, that livestock exclusion is sufficient to reverse the negative degrading trend, indicating that the ecosystem has not yet passed a non-reversible ecological threshold.

5.1.2 The effect on climatic zones

Climate change is causing problems all over the world and many countries are developing mitigating programs. Mongolia is no exception, as it has experienced unusual climate trends in recent years. The impact of climate change and increasing atmospheric CO_2 may increase net primary production in Mongolia, with the exception of the cold desert Steppe regions. It is estimated that the combined climate change and elevated CO_2 will increase production and reduce global grassland C losses to 2 Pg (Parton et al., 1995). The potential for SOC sequestration is thus present.

By simulating the dynamic response of vegetation distribution, carbon, and fire and comparing it to historical climate data, it has been possible to construct two contrasting scenarios of climate change in California (Lenihan et al., 2003). The validation of the results was complicated due to the lack of land use effects in the model, but the data showed that the changes in precipitation were complex, affecting not only soil moisture and its availability for vegetation productivity, but also changes in tree–grass competition mediated by fire. The summer months were warmer and persistently dry under both scenarios, so the trends in a simulated fire area under both scenarios were primarily a response to changes in vegetation biomass.

As the results presented in this paper validate, the ecological zones in Mongolia are very different from each other, especially the High Mountain zone. The climate diagram shows that the air temperature line is above the precipitation line, indicating severe drought. This is also true of the Steppe zone. It can therefore be stated that both of these zones are drier than the Forest Steppe and Typical Steppe. The High Mountain and Steppe zones have less vegetative cover and biodiversity than the others. This may be due to the harsher climate, but other environmental factors, such as altitude or soil properties cannot be excluded.

5.2 Carbon sequestration

Reclamation of eroded area is the primary strategy of C sequestration in an ecosystem. In Iceland the impact of fertilizer and re-vegetation have been extensively studied. These studies indicate that the terrestrial C pool in the soil and biota can be enhanced. Lupine is an exotic plant in Iceland which has been widely used for land reclamation purposes. The use of Nootka lupine for reclamation started in the mid-1980s. It is used in addition to other species such as Lyme grass, fertilizer and manures to improve rangeland (Lal, 2009). The results presented here indicate that carbon sequestration is present in these treatments. Guo and Gifford (2002) published similar results; after lupine was planted the soil carbon stock increased.

Vegetative cover in the lupine treatment appears to have a higher linear correlation with SOC than covers in the other treatments (Figures 14–15). Ringrose et al. (1998) conducted regression analysis between soil organic carbon on the one hand and woody vegetation cover and dead herbaceous cover on the other, and they found a positive relationship between those, but a negative relationship between soil organic carbon and bare soils. Comparable relationship was found between vegetative cover in lupine treatment and soil organic matter. They suggested, based on their results, that the soil organic carbon was derived from vegetation cover, so we can say that my results further validated their conclusion.

The grass treatment appears to accumulate more carbon compared to the other treatments. Jobbagy et al. (2008) stated that the highest soil organic carbon levels were always found at the lowest sampling depths in shrublands, compared to intermediate carbon levels in grassland, and lowest in forests. This appears to be in agreement with what was observed in the grass treatment published here. However, Hopkins et al. (2009) found that soil organic carbon levels took a long time to increase in grasslands. By comparing data from 1982 and 2006, they discovered no significant change in the concentration of soil organic carbon at any depth and the same was true for fertilized areas. My results, on the other hand, showed a, strong treatment effect, here possibly due to differences in study areas, as the results published here represent reclamation areas, whereas they studied grasslands.

6. CONCLUSIONS

Continuous grazing of the Mongolian rangelands over recent decades has resulted in decreased total vegetation cover, biomass, and declining species diversity. The biomass and vegetative cover are especially vulnerable to continuous and intensive grazing. Functional vegetation groups such as legumes and forbs decrease in cover with grazing, but groups better adapted to grazing, such as grasses, decrease less. The area of bare ground also increased with grazing, and species composition changed toward more unpalatable species where grazing was present.

According to the climatic zones, the High Mountain zone showed signs of being sensitive to climate and grazing disturbances. The High Mountain zone total cover was less than the total cover of the Forest Steppe, Steppe and Typical Steppe zones. The forb functional group was common in all ecological zones, especially in the Typical Forest Steppe zone. Grasses were also common in all zones, but sedges and legumes were almost or totally absent in the High Mountain zone. The High Mountain zone has more bare ground compared to the other zones. A total of 73 species occurred in only one climatic zone, 22 species occurred in two climatic zones, 13 species occurred in three climatic zones and only 4 species occurred in four climatic zones. The four ecological zones compared here, the High Mountain, Forest Steppe, Steppe and Typical steppe zones, appear to have very different vegetation patterns.

Vegetation cover and carbon content appear to be positively correlated with each other. If vegetation cover increases, the SOC content immediately increases. Grasses seem to accumulate more SOC than the other treatments compared here, but lupine the least.

ACKNOWLEDGEMENTS

I would like to express my gratitude to the UNU-LRT programme and especially to Acting Programme Director Berglind Orradóttir, Acting Deputy Programme Director Jona Bjork Jonsdottir, Office Manager Thorbjorg Valdis Kristjansdottir and Professor Ingibjorg S. Jonsdottir at the Institute of Biology, University of Iceland. Thank you very much, all of you, for affording me the opportunity to study in the UNU-LRT programme. Furthermore, my gratitude also goes to the Mongolian Society for Rangeland Ecosystem Management Program.

I am extremely grateful to my supervisor, Dr. Johann Thorsson, Project Manager of the Soil Conservation Service of Iceland for his outstanding continual guidance and support throughout the entire period of research, analysis and writing. I would say he has contributed time and ideas to the whole of my writing process.

My warm thanks go to all of the lecturers and people who shared their knowledge and experiences and helped me during this program and who helped me as well on field trips and with the ideas that are the background for this report.

My project included one study of the effects of fencing, which belongs to the MSRM, supported by the Swiss Agency for Development and Co-operation in Mongolia, and the carbon data came from SCSI. I would like to thank all of my colleagues who collected these data and our international consultant Dr. Andreas Lüscher, and again Johann Thorsson, for their contribution and helpful advice.

To any whom I have not mentioned, I also say thank you.

REFERENCES

Arnalds, A. (2004). Carbon sequestration and the restoration of land health. *Climatic change*, *65*, 333–346.

Arnalds, O., Aradottir, A.L. & Gudbergsson G. (2002). Organic carbon sequestration by restoration of severely degraded areas in Iceland. In J.M. Kimble, R. Lal & R. Follett, (Eds.), *Agricultural Practices and Policies for Carbon Sequestration in Soil* (pp. 267–280). Boca Raton: CRC Press LLC.

Arnalds, O., Gudbergsson, G. & Gudmundsson, J. (2000). Carbon sequestration and reclamation of severely degraded soils in Iceland. *Icelandic Agricultural Sciences*, *13*, 87–97.

Batima, P., Natsagdorj, L., Gombluudev, P. & Erdenetsetseg, B. (2005). Observed climate change in Mongolia. AIACC Working Paper No.12. Retrieved from http://aiaccproject.org/working_papers/Working%20Papers/AIACC_WP_No013.pdf

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, *47*, 151–163.

Belsky, J.A. (1992). Effects of Grazing, Competition, Disturbance and Fire on Species Composition and Diversity in Grassland Communities. *Journal of Vegetation Science*, *3*, 187–200.

Briske, D.D. & Heitschmidt, R.K. (1991). An ecological perspective. In R.K. Heitschmidt & J.W. Stuth (Eds.) *Grazing management: An ecological perspective* (pp. 11–26). Portland: Timber Press.

Carter, M.R. (2002). Soil Quality for Sustainable Land Management: Organic Matter and Aggregation Interactions that Maintain Soil Functions. *Agronomy Journal*, *94*, 38–47.

Cingolani, A.M., Noy-Meir, I. & Diaz, S. (2005). Grazing effects on rangeland diversity: A synthesis of contemporary models. *Ecological Applications*, *15*, 757–773.

Derner, J., Briske, D. & Boutton, T. (1997). Does grazing mediate soil carbon and nitrogen accumulation beneath C_4, perennial grasses along an environmental gradient? *Plant and Soil*, *191*, 147–156.

Glenn, E., Squires, V., Olsen, M. & Frye, R. (1993). Potential for carbon sequestration in the drylands. *Water*, *Air and Soil Pollution*, *70*, 341–355.

Guo, L.B. & Gifford, R.M. (2002). Soil carbon stocks and land use change: A meta analysis. *Global Change Biology*, *8*, 345–360.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B.H., Willms, W. & Wang, M. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture*, *Ecosystems & Environment*, *125*, 21–32.

Hopkins, D.W., Waite, I.S., McNicol, J.W., Poulton, P.R., Macdonald, A.J. & O'Donnell, A.G. (2009). Soil organic carbon contents in long-term experimental grassland plots in the UK (Palace Leas and Park Grass) have not changed consistently in recent decades. *Global Change Biology*, *15*, 1739–1754.

Jackson, R.B., Schenk, H.J., Jobbagy, E.G., Canadell, J., Colello, G.D., Dickinson, R.E., Field, C.B., Friedlingstein, P., Heimann, M., Hibbard, K., Kicklighter, D.W., Kleidon, A., Neilson, R.P., Parton, W.J., Sala, O.E. & Sykes, M.T. (2000). Belowground consequences of vegetation change and their treatment in models [Review]. *Ecological Applications*, *10*, 470–483.

Jobbágy, E.G. & Jackson, R.B. (2000). The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications*, *10*, 423–436.

Kumar, R., Pandey, S. & Pandey, A. (2006). Plant roots and carbon sequestration. *Current Science*, *91*, 885–890.

Lal, R. (2009). Potential and Challenges of Soil Carbon Sequestration in Iceland. *Journal of Sustainable Agriculture*, *33*, 255–271.

Lenihan, J., Drapek, R., Bachelet, D. & Neilson, R. (2003). Climate change effects on vegetation distribution, carbon, and fire in California. *Ecological Applications*, *13*, 1667–1681.

Li, C., Hao, X., Zhao, M., Han, G. & Willms, W.D. (2008). Influence of historic sheep grazing on vegetation and soil properties of a Desert Steppe in Inner Mongolia. *Agriculture*, *Ecosystems & Environment*, *128*, 109–116.

McCune, B., Grace, J.B. & Urban, D.L. (2002). *Analysis of ecological communities*. Gleneden Beach, Oregon: MjM Software Design.

McLauchlan, K.K., Hobbie, S.E. & Post, W.M. (2006). Conversion from agriculture to grassland builds soil organic matter on decadal timescales. *Ecological Applications*, *16*, 143–153.

MSRM (Mongolian Society for Range Management) (2010). *Livelihood Study of Herders in Mongolia*. Ulaanbaatar: MSRM and Swiss Agency for Development and Cooperation SDC.

Oskarsson, H., Arnalds, O., Gudmundsson, J. & Gudbergsson, G. (2004). Organic carbon in Icelandic Andosols: Geographical variation and impact of erosion. *Catena*, *56*, 225–238.

Pandeya, S.C., Puri, G.S. & Singh, J.S. (1968). *Research Methods in Plant Ecology*. London: Asia Publishing House.

Parton, W., Scurlock, J., Ojima, D., Schimel, D. & Hall, D. (1995). Impact of climate change on grassland production and soil carbon worldwide. *Global Change Biology*, *1*, 13–22.

Pei, S., Fu, H. & Wan, C. (2008). Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China. *Agriculture*, *Ecosystems & Environment*, *124*, 33–39.

Peter, M., Gigon, A., Edwards, P.J. & Lüscher, A. (2008). Changes over three decades in the floristic composition of nutrient-poor grasslands in the Swiss Alps. *Biodiversity & Conservation*, *18*, 547–567.

Ringrose, S., Matheson, W. & Vanderpost, C. (1998). Analysis of soil organic carbon and vegetation cover trends along the Botswana Kalahari Transect. *Journal of Arid Environments*, *38*, 379–396.

Sigurdsson, B.D. & Magnusson, B. (2010). Effects of seagulls on ecosystem respiration, soil nitrogen and vegetation cover on a pristine volcanic island, Surtsey, Iceland. *Biogeosciences*, 7, 883–891.

Steffens, M., Kölbl, A., Totsche, K.U. & Kögel-Knabner, I. (2008). Grazing effects on soil chemical and physical properties in a semiarid steppe of Inner Mongolia (PR China). *Geoderma*, *143*, 63–72.

Sundermeier, A., Reeder, R. & Lal, R. (2005). *Soil Carbon Sequestration — Fundamentals*. The Ohio State University Extension Fact Sheet, AEX 510-05, Columbus, OH. Retrieved from. http://ohioline.osu.edu/aex-fact/ 0510.html

Ulziikhutag, N. (1985). *Key to forage plants of the pasture and hayfields of the MPR*. Ulaanbaatar: Ulsiin Khevleliin Gazar. (in Mongolian).

Yong-Zhong, S., Yu-Lin, L., Jian-Yuan, C. & Wen-Zhi, Z. (2005). Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena*, *59*, 267–278.

APPENDIX

Species that occurred exclusively inside the fence (rested area) and species that occurred exclusively outside the fence (grazed area)

No.	Exclusively Inside	Code	Exclusively Outside	Code	Inside and Outside	Code
1	*Ajana achileoides*	ajac	*Thymus gobicus*	thgo	*Agropyron cristatum*	agcr
2	*Ajania trifida*	ajtr	*Artemisia macrantha*	arma	*Agropyron desertorum*	agde
3	*Artemisia annue*	aran	*Artemisia desertorum*	arde	*Agropyron Michnoi*	agmi
4	*Artemisia long*	arlo	*Crepis crocea*	crcr	*Ajana achileoides*	ajac
5	*Artemisia palustris*	arpa	*Ehedran mono*	ehmo	*Ajania trifida*	ajtr
6	*Artemisia santolinifolia*	arsa	*Enneapogon borealis*	enbo	*Alium Mongolicum*	allmgl
7	*Artemisia scoparia*	arsc	*Carum carvi*	caca	*Alium polyrrhizum*	allpo
8	*Artemisisa longifolia*	arlo	*Medicago rubra*	merub	*Allium anisopodium*	allan
9	*Astargalus tenitsifolia*	aste	*Scabiosa comosa*	scco	*Allium bidentatum*	allbi
10	*Astragalus absurgens*	asab	–	–	*Allium limeare*	allli
11	*Caragana Bungei*	cabu	–	–	*Allium odorum*	allod
12	*Caragana microphylla*	cami	–	–	*Allium senescens*	allse
13	*Caragana pygmaea*	capy	–	–	*Amblynotus rupestris*	amru
14	*Caragana Sp*	casp	–	–	*Anabasis brevifolia*	anbr
15	*Carex carjinskii*	cxca	–	–	*Androsace incana*	anin
16	*Chamaerhodos erecta*	cher	–	–	*Androsace maxima*	anma
17	*Chenopodium arist*	char	–	–	*Anemone*	ane
18	*Cleistogenes songarica*	clso	–	–	*Arctogeron graminium*	argr
19	*Delphinium grandiflorum L.*	degr	–	–	*Arenaria capillaris*	arcap
20	*Dianthus versicolor Fisch.*	diver	–	–	*Artemisia adamsi*	arad
21	*Erysimum flavum*	erfl	–	–	*Artemisia annue*	aran
22	*Festuca rubra*	feru	–	–	*Artemisia changaica*	arch
23	*Gentiana decumbens*	gede	–	–	*Artemisia commutata*	arco
24	*Goniolimon speciosum*	gode	–	–	*Artemisia frigida*	arfr
25	*Helictotrichon schellianum*	hada	–	–	*Artemisia long*	arlo
26	*Iris flabissima*	irfl	–	–	*Artemisia palustris*	arpa
27	*Leontopodium ochroleucum*	leoc	–	–	*Artemisia pectinata*	arpe
28	*Limonium tenellum*	lite	–	–	*Artemisia santolinifolia*	arsa
29	*Linaria buriatica*	libu	–	–	*Artemisia scoparia*	arsc
30	*Medicago ruthenica*	meru	–	–	*Artemisia siversiana*	arsi
31	*Orostachys*	or	–	–	*Artemisia xerophytica*	arxe
32	*Orostachys fimbriata*	orfi	–	–	*Artemisisa longifolia*	arlo
33	*Oxytropis myriophylla*	oxmy	–	–	*Astargalus inopinatus*	asin
34	*Polygonum viviparum*	povi	–	–	*Astargalus tenitsifolia*	aste
35	*Sangiosorba oficinalis*	saof	–	–	*Aster alpinus*	asal
36	*Scabiosa comosa*	scco	–	–	*Astragalus absurgens*	asab
37	*Setaria viridis*	sevi	–	–	*Astragalus dahuricus*	asda
38	*Silene repens*	sire	–	–	*Astragalus galacitites*	asga

No.	Exclusively Inside	Code	Exclusively Outside	Code	Inside and Outside	Code
39	*Stipa garndis*	stga	–	–	*Astragalus inopinatus*	asin
40	*Thesium repens Ldb.*	thre	–	–	*Astragalus lasiopetalus*	asla
41	*Thymus asiaticus*	thas	–	–	*Astragalus sp*	assp
42	–	–	–	–	*Bassia dasyphylla*	bada
43	–	–	–	–	*Bupleurum bicaule*	bubi
44	–	–	–	–	*Bupleurum scorzonerifolium*	busc
45	–	–	–	–	*Calamagrostis purpurea*	capu
46	–	–	–	–	*Caragana Bungei*	cabu
47	–	–	–	–	*Caragana microphylla*	cami
48	–	–	–	–	*Caragana pygmaea*	capy
49	–	–	–	–	*Caragana Sp*	casp
50	–	–	–	–	*Caragana stenophylla*	cast
51	–	–	–	–	*Caragana teniufolia*	cate
52	–	–	–	–	*Carex carjinskii*	cxca
53	–	–	–	–	*Carex duruscula*	cxdu
54	–	–	–	–	*carex korjinskii*	cxko
55	–	–	–	–	*Chamaerhodos erecta*	cher
56	–	–	–	–	*Chenopodium album*	chal
57	–	–	–	–	*Chenopodium arist*	char
58	–	–	–	–	*Chloris virgata*	char
59	–	–	–	–	*Cleistogenes songarica*	clso
60	–	–	–	–	*Cleistogenes squarrosa*	clsq
61	–	–	–	–	*Convolvulus ammanii*	coam
62	–	–	–	–	*Cybaria dahurica*	cyda
63	–	–	–	–	*Delphinium grandiflorum*	degr
64	–	–	–	–	*Dianthus versicolor*	diver
65	–	–	–	–	*Dontostemon integrifolius*	doin
66	–	–	–	–	*Draba nemorosa*	drne
67	–	–	–	–	*Elymus chinensis*	elch
68	–	–	–	–	*Erysimum flavum.*	erfl
69	–	–	–	–	*Euphorbia Pallasii*	eupa
70	–	–	–	–	*Eurotia ceratoides*	euce
71	–	–	–	–	*Festuca lenensis*	fele
72	–	–	–	–	*Festuca rubra*	feru
73	–	–	–	–	*Galium verum*	gave
74	–	–	–	–	*Gentiana decumbens*	gede
75	–	–	–	–	*Goniolimon speciosum*	gode
76	–	–	–	–	*Halophylon dahuricus*	gosp
77	–	–	–	–	*Helictotrichon schellianum*	hada
78	–	–	–	–	*Heteropappus altaicus*	heal
79	–	–	–	–	*Heteropappus hispidus*	hehi
80	–	–	–	–	*Hierochloe glabra*	higl

No.	Exclusively Inside	Code	Exclusively Outside	Code	Inside and Outside	Code
81	–	–	–	–	*Iris flabissima*	irfl
82	–	–	–	–	*Iris tigridia*	irti
83	–	–	–	–	*Kochia prostrata*	kopr
84	–	–	–	–	*Koeleria glauca*	kogl
85	–	–	–	–	*Koeleria macranthà*	koma
86	–	–	–	–	*lemoneum*	le
87	–	–	–	–	*Leontopodium Leontopodioides*	lele
88	–	–	–	–	*Leontopodium ochroleucum*	leoc
89	–	–	–	–	*Leuzea uniflora*	leun
90	–	–	–	–	*limoneum*	li
91	–	–	–	–	*Limonium tenellum*	lite
92	–	–	–	–	*Linaria buriatica*	libu
93	–	–	–	–	*Medicago ruthenica*	meru
94	–	–	–	–	*Orostachys*	or
95	–	–	–	–	*Orostachys fimbriata*	orfi
96	–	–	–	–	*Oxytropis filiformis*	oxfi
97	–	–	–	–	*Oxytropis myriophylla*	oxmy
98	–	–	–	–	*Oxytropis oxyphilla*	oxox
99	–	–	–	–	*Peucedanum hystrix*	pehy
100	–	–	–	–	*Plantago major*	plma
101	–	–	–	–	*Poa attenuate*	poat
102	–	–	–	–	*Polygonum angustifolium*	poan
103	–	–	–	–	*Polygonum viviparum*	povi
104	–	–	–	–	*Potentilla acaulis*	poac
105	–	–	–	–	*Potentilla bifurca*	pobi
106	–	–	–	–	*potentilla multifida*	pomu
107	–	–	–	–	*Potentilla sericea*	pose
108	–	–	–	–	*Potentilla tanacetifolia*	pota
109	–	–	–	–	*Ptilotrichum canescens*	ptca
110	–	–	–	–	*Pulsatilla ambigua*	puam
111	–	–	–	–	*Pulsatilla Turczaninovii*	putu
112	–	–	–	–	*Reaumuria soongorica*	reso
113	–	–	–	–	*Sangiosorba oficinalis*	saof
114	–	–	–	–	*Sausurea salicifolia*	sasa
115	–	–	–	–	*Scabiosa comosa*	scco
116	–	–	–	–	*Serratula centauroides*	sece
117	–	–	–	–	*Setaria viridis*	sevi
118	–	–	–	–	*Sibbaldianthe adpressa*	siad
119	–	–	–	–	*Silene jenisseensis*	sije
120	–	–	–	–	*Silene repens*	sire
121	–	–	–	–	*Sinecio campester*	sica
122	–	–	–	–	*Stelaria dichotoma*	stdi

No.	Exclusively Inside	Code	Exclusively Outside	Code	Inside and Outside	Code
123	–	–	–	–	*Stipa capillata*	stcap
124	–	–	–	–	*Stipa garndis*	stga
125	–	–	–	–	*Stipa gobica*	stgo
126	–	–	–	–	*Stipa krylovii*	stkr
127	–	–	–	–	*Stipa Mongolica*	stmgl
128	–	–	–	–	*Stipa sp*	stsp
129	–	–	–	–	*Taraxacum collinum*	taco
130	–	–	–	–	*Thalictrum påtaloidåum*	thpe
131	–	–	–	–	*Thalictrum simplex*	this
132	–	–	–	–	*Thesium repens*	thre
133	–	–	–	–	*Thymus asiaticus*	thas
134	–	–	–	–	*Thymus gobicus*	thgo
135	–	–	–	–	*Artemisia macrantha*	arma
136	–	–	–	–	*Artemisia desertorum*	arde
137	–	–	–	–	*Crepis crocea*	crcr
138	–	–	–	–	*Ehedran mono*	ehmo
139	–	–	–	–	*Enneapogon borealis*	enbo
140	–	–	–	–	*Carum carvi*	caca
141	–	–	–	–	*Medicago rubra*	merub
142	–	–	–	–	*Scabiosa comosa*	scco

Species that occurred exclusively in one specific ecological zone

	Species name	Code	Species name	Code	Species name	Code	Species name	Code	Species name	Code	Number of species in ecologi-cal zones
No.	**Exclusively in High Mountain zone**		**Exclusively in Forest Steppe zone**		**Exclusively in Steppe zone**		**Exclusively in Typical Steppe zone**		**Number of species that occur in ecological zones**		
1	*Hierochloe glabra*	higl	*Linaria buriatica*	libu	*Orostachys*	or	*Medicago ruthenica*	meru	*Agropyron cristatum*	agcr	4
2	*Setaria viridis*	sevi	*Gentiana decumbens*	gede	*Chenopodium arist*	char	*Astragalus dahuricus*	asda	*Alium lineare*	allli	2
3	*Artemisia macrantha*	arma	*Sinecio campester*	sica	*Artemisia annue*	aran	*Thalictrum simplex*	this	*Allium anisopodium*	allan	3
4	*Enneapogon borealis*	enbo	*Silene jenisseensis*	sije	*Stipa garndis*	stga	*Anemone*	ane	*Allium bidentatum*	allbi	2
5	*Bassia dasyphylla*	bada	*Androsace incana*	anin	*Artemisia siversiana*	arsi	*Halophylon dahuricus*	gosp	*Arenaria capillaris*	arcap	3
6	*Crepis crocea*	crcr	*Astargalus tenitsifolia*	aste	–	–	*Thymus asiaticus*	thas	*Artemisia adamsi*	arad	2
7	*Orostachys fimbriata*	orfi	*Polygonum viviparum*	povi	–	–	–	–	*Artemisia commutata*	arco	2
8	*Agropyron Michnoi*	agmi	*Goniolimon speciosum*	gode	–	–	–	–	*Artemisia frigida*	arfr	3
9	*Ehedran mono*	ehmo	*Amblynotus rupestris*	amru	–	–	–	–	*Astragalus galacitites*	asga	2
10	*Leontopodium Leontopodioides*	lele	*Dianthus versicolor*	diver	–	–	–	–	*Astragalus inopinotus*	asin	2
11	*Caragana stenophylla*	cast	*Erysimum flavum*	erfl	–	–	–	–	*Bupleurum bicaule*	bubi	2
12	*Chloris virgata*	char	*Iris flabissima*	irfl	–	–	–	–	*Bupleurum scorzonerifolium*	busc	2
13	*Limonium tenellum*	lite	*Artemisisa longifolia*	arlo	–	–	–	–	*Caragana teniufolia*	cate	3
14	*Artemisia desertorum*	arde	*Scabiosa comosa*	scco	–	–	–	–	*Carex duruscula*	cxdu	4
15	*Ptilotrichum canescens*	ptca	*Carex carjinskii*	cxca	–	–	–	–	*Chenopodium album*	chal	3
16	*Euphorbia Pallasii*	eupa	*Delphinium grandiflorum*	degr	–	–	–	–	*Cleistogenes squarrosa*	clso	2
17	*Artemisia santolinifolia*	arsa	*Oxytropis filiformis*	oxfi	–	–	–	–	*Convolvulus ammanii*	coam	3
18	*Ajania trifida*	ajtr	*Astargalus inopinatus*	asin	–	–	–	–	*Cybaria dahurica*	cyda	2
19	*Artemisia xerophytica*	arxe	*Galium verum*	gave	–	–	–	–	*Dontostemon integrifolius*	doin	2
20	*Koeleria glauca*	kogl	*Oxytropis myriophylla*	oxmy	–	–	–	–	*Elymus chinensis*	elch	3
21	*Eurotia ceratoides*	euce	*Thymus gobicus*	thgo	–	–	–	–	*Festuca lenensis*	fele	2
22	*Astragalus lasiopetalus*	asla	*Pulsatilla Turczaninovii*	putu	–	–	–	–	*Heteropappus altaicus*	heal	3
23	*Draba nemorosa*	drne	*Plantago major*	plma	–	–	–	–	*Heteropappus hispidus*	hehi	3
24	*Thesium repens*	thre	*Astragalus absurgens*	asab	–	–	–	–	*Iris tigridia*	irti	2
25	*Ajana achileoides*	ajac	*Helictotrichon schellianum*	hada	–	–	–	–	*Koeleria macranthà*	koma	2
26	*Anabasis brevifolia*	anbr	*Sangiosorba oficinalis*	saof	–	–	–	–	*Leuzea uniflora*	leun	2
27	*Stipa Mongolica*	stmgl	*Peucedanum hystrix*	pehy	–	–	–	–	*Oxytropis oxyphilla*	oxox	2
28	*Stipa capillata*	stcap	*Calamagrostis purpurea*	capu	–	–	–	–	*Poa attenuate*	poat	2
29	*Stipa gobica*	stgo	*Polygonum angustifolium*	poan	–	–	–	–	*Potentilla acaulis*	poac	3
30	*Caragana Bungei*	cabu	*Festuca rubra*	feru	–	–	–	–	*Potentilla bifurca*	pobi	4
31	*Caragana pygmaea*	capy	–	–	–	–	–	–	*Potentilla sericea*	pose	2
32	*Cleistogenes songarica*	clso	–	–	–	–	–	–	*Potentilla tanacetifolia*	pota	3
–	–	–	–	–	–	–	–	–	*Pulsatilla ambigua*	puam	2
–	–	–	–	–	–	–	–	–	*Salsola collina*	saco	3
–	–	–	–	–	–	–	–	–	*Saussurea saichanensis*	sasa	2
–	–	–	–	–	–	–	–	–	*Sibbaldianthe adpressa*	siad	4
–	–	–	–	–	–	–	–	–	*Stipa krylovii*	stkr	3
–	–	–	–	–	–	–	–	–	*Taraxacum collinum*	taco	2
–	–	–	–	–	–	–	–	–	*Serratula centauroides*	sece	2