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ANALYSIS OF VEGETATION AND SELECTED SOIL PROPERTIES IN FOUR DIFFERENT HABITATS AT THE HEKLA FOREST PROJECT AREA IN ICELAND

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ABSTRACT

Due to the long history of land degradation caused by land use activities coupled with natural factors, Iceland has embarked on efforts to fight land degradation by reclaiming and restoring degraded areas mainly through revegetation. The aim of this study was to analyse the relationship between the vegetation and some selected soil properties in four different habitats in the Hekla Forest Project area near Mt Hekla in South Iceland. Vegetation cover and aboveground biomass were studied at three sites in each habitat, selected by stratified random sampling. Soil samples were taken at the same sites and soil profiles were examined. The results show that the forest habitat had greater vegetation cover and aboveground biomass than all other habitats. Vegetated habitats, such as the grassland habitats in the study, which hadn't been eroded in the past, had thicker soils, higher soil C and N content, lower soil bulk density and lower pH than habitats affected by erosion. The results also reveal the potential increase in biomass, vegetation diversity and soil carbon and nitrogen content over decades following reclamation of eroded and barren areas.

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1. INTRODUCTION

Iceland is an island located in the North Atlantic Ocean between 63.2°N and 66.3°N, with a total area of about 103,000 km^2 and a population of 320,000 people. According to ancient records it is believed that the island was first settled in the year 874. The settlers used timber as a building material and as a source of energy. They also cleared some forested areas and turned them into grazing lands (Crofts 2011). During the time of settlement 60% of the country was fully vegetated of which 25-40% was covered with native birch woodland (Wöll 2008). Today the vegetation covers around 43% of which only 1% is covered with birch woodland (Crofts 2011).

Iceland today experiences major degradation of land, and soil erosion (Arnalds & Barkarson 2003). The anthropogenic activities such as overgrazing and forest clearing have been the major causes of soil erosion and vegetation degradation in Iceland. Natural factors such as low temperature and volcanic activities have also contributed to the situation (Oddsdóttir et al. 2010). A study done on the national soil erosion in the country indicates that 40 percent of the land is severely eroded (Arnalds et al. 2001). Icelandic soils are classified as young Andosols (Arnalds 2004). Andosols commonly are formed from volcanic ash deposition. They are fertile and rich in organic matter and therefore usually appear to be black in colour (Brady & Weil, 1996). Although Icelandic Andosols are rich in organic matter the soil gets buried in deeper horizons as the eolian and tephra materials keep being deposited at the soil surface (Arnalds 2008). This deposition therefore contributes to the formation of Icelandic soils (Arnalds 2010).

Namibia also suffers from soil erosion caused by natural factors and human land use activities and these result in desertification (Klintenberg & Seely 2004). Mining, especially for uranium, has played a big role in the Namibian economy since the late 1970s (MME 2010). Mining decreases the topsoil organic matter and causes soil compaction, making it difficult for natural seed germination and plant establishment (Burke 2003). It also contributes to the loss of vegetation, exposing the soil to wind- and water erosion. We therefore need the capacity to tackle degradation, especially through successful land restoration, keeping in mind that soil is important for the growth of vegetation and to withstand forces such as wind erosion.

The removal of vegetation has an effect on the chemical and physical properties of the soil and its overall health. Soil organic matter composition and breakdown rates affect the soil structure and porosity. They also affect the water infiltration rate and moisture holding capacity of soils, the diversity and biological activity of soil organisms and plant nutrient availability (Bot & Benites 2005). Reforestation of degraded land is therefore required to protect the soil from erosion (Hudson 1971) and increase the biomass as well as soil carbon sequestration (Lal 2004). To ensure successful restoration of ecological structure and function it is therefore important to understand the factors that influence soil properties and vegetation biomass.

Forests are not only important as a soil cover but also help the soil to conserve water and encourage hydrological functions such as infiltration and reduce run-off. Therefore there is a relationship between vegetation cover and soil properties. Plant aboveground biomass is used to assess the ecosystem productivity (FAO 2010). With increased vegetation, the amount of organic matter also increases, causing an increase in the water holding capacity in the soil (Olatunji 2009).

Vegetation restoration through planting of trees has been going on globally for millennia (Jordan et al. 1990). Iceland started planting trees in the early 20th century and in the year 2000 about 84 million native and exotic trees have been planted (Sigurdsson & Snorrason 2000). Tree planting is currently an important tool for fighting land degradation in Iceland (Ritter 2007). It can also be used as a tool to sequester carbon (Arnalds 2000) and reduce carbon dioxide from the air (Lal 2004). Through the decomposition of organic matter, the pH of alkaline soils is reduced (Brady & Weil 1996). Revegetation therefore plays a role in desalination of the soil (FAO 2010). The forest project has a potential to improve ecosystem functioning, increase biodiversity and restore wetlands (Pétursdóttir & Aradóttir 2008). The forest can also be a good environment for recreational purpose (Crofts 2011) and can be a good opportunity for ecotourism ventures (Nelson et al. 2004). Apart from the ecological benefits, reclamation has many other benefits, including economic and social (Pétursdóttir & Aradóttir 2008).

Reclamation and reforestation at the Hekla Forest Project (HFP) area started after 1970 by distributing fertilizers as well as grass seed by airplane and fencing off sensitive areas. The present project (Hekla Forest Project) was initiated after 2005. Historical and anthropological evidence shows that the area near Mt Hekla was previously rich in vegetation. As a result of intense soil erosion and loss of vegetation in past centuries, large parts of the area are now poor in nitrogen and dry. Unstable surfaces are common in the area due to erosion by wind and water. This led to the idea of reclaiming the land by sowing grass and applying fertilizers to stabilize the soil and create suitable growth conditions before planting trees. The aim of the HFP is to reclaim the native birch and willow forest to reduce erosion as well as to stabilize volcanic ash from the active Mt Hekla volcano. Other objectives include restoration of the ecosystem function, carbon sequestration and improving future biodiversity (Hekla Forest Project 2012).

The aim of this study was to compare some vegetation characteristics and soil properties in four different habitats in the Hekla Forest Project area.

1.1 Objectives

This study aimed at analysing the relationship between the vegetation and some selected soil properties in four different habitats in the Hekla Forest Project area near Mt Hekla in South Iceland. The study was carried out with the following objectives:

- To compare vegetation cover and aboveground biomass in the four selected study habitats.
- To determine the relationship between vegetation cover and selected soil properties.
- To compare soil formation in different habitats.

2. METHODS AND MATERIALS

2.1 Study area

The study was done at the Hekla Forest Project area which is located between 100 and 600 m a.s.l. west and north of Mt Hekla in South Iceland (Fig. 1).

Most of the land is partially vegetated, bare sand and areas with little vegetation. Thirty percent is well vegetated, mostly with willows but some with birch. In some areas Lyme grass was seeded first to stop wind erosion. After that trees have been planted or have seeded naturally from wooded land. Areas with less erosion have been seeded with other grass species (Hekla Forest Project 2012).

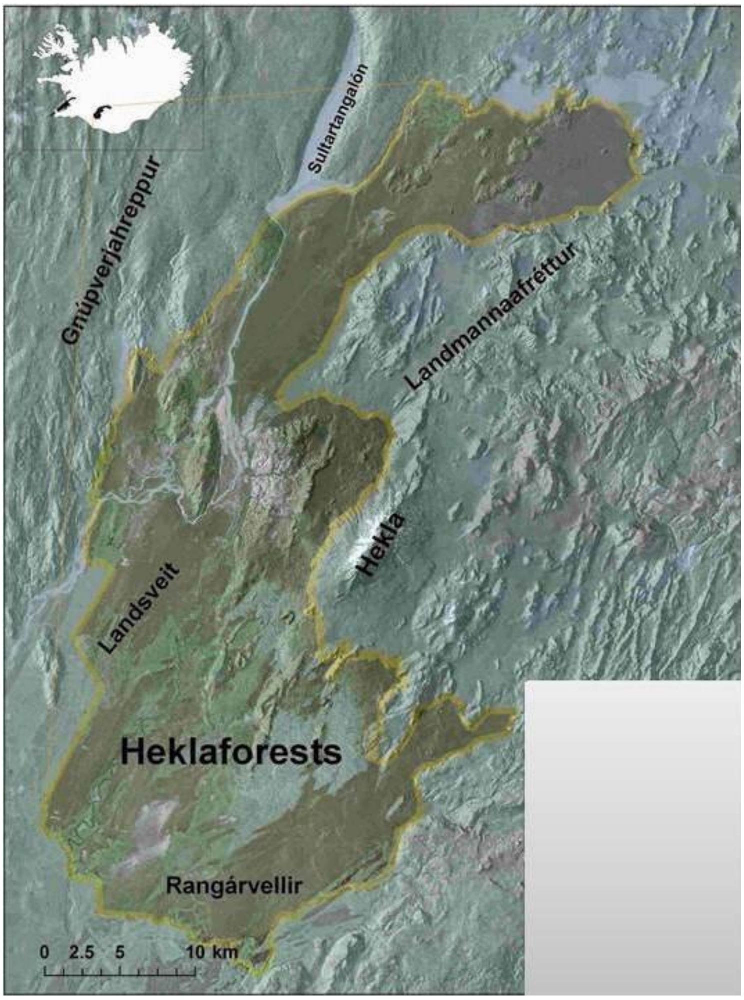

Fig. 1. *The location of Hekla Forest Project area in Iceland where the study was done. (Map: Arna Björk Þorsteinsdóttir, modified by Hreinn Óskarsson May 2008, Hekla Forest Project).*

Biomass and soil samples were taken randomly from four selected habitats. The four habitats were: desert, heathland, grassland, and forest. Some habitats were in an eroded state while some were vegetated. The study habitats were selected from an ongoing study in the area which is estimating the effects of the Hekla Forest Project on biodiversity as well as the immediate effects of volcanic eruptions on biodiversity. These habitats were selected using a stratified random sampling method due to the rarity of some habitats and also because some areas were not accessible due to lava formations. Sites close to road access were therefore chosen. For each selected habitat three sites were randomly selected from the whole area making three desert sites, three forest sites, three grassland sites and three heathland sites (Appendix 1). At each site, three sample replicates (a, b and c) were taken about 5 m apart.

2.2 Vegetation analysis

The composition of the vegetation cover was studied using three 50 × 50 cm quadrates per site. The vegetation cover was simplified by grouping species together into the following groups: (1) bushes and trees; (2) herbs; (3) grasses, sedges and rushes; (4) heath plants; (5)

mosses and lichens; and (6) litter (Fig. 2). A biomass study was done by cutting aboveground vegetation with electric clippers inside the quadrates described above. The vegetation was then dried at 30°C and weighed before it was milled. Three replicates of five grams each were taken from each sample and dried in the oven at 105°C for 24 hours to determine the dry matter content.

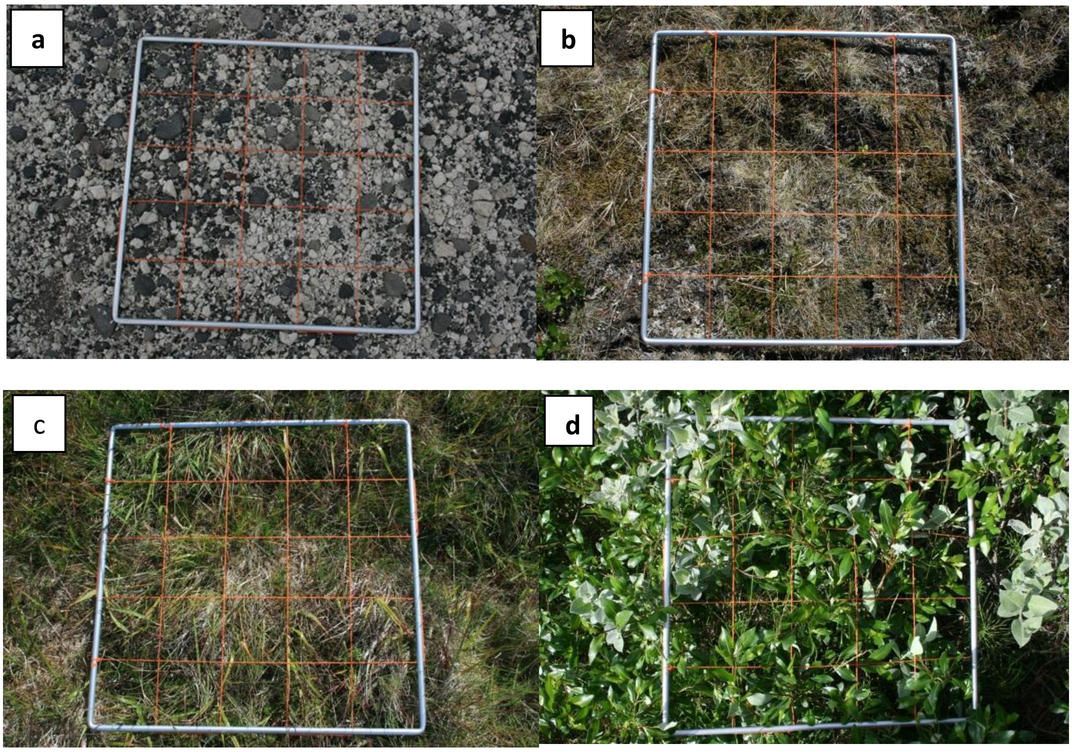

Fig. 2. *The 50 × 50 cm quadrats that were used for vegetation analysis in the four study habitats; a) Desert b) Heathland, c) Grassland and d) Forest. (Photos: H. Gehringer 2012).*

2.3 Soil analysis

Examination of soil profiles and collection of soil samples were done at the same sites as described previously for vegetation analysis.

2.3.1 Soil profile description

Before taking soil samples, profiles were dug 50 cm deep for soil examination. Munsell soil colour cards (Munsell Color Company 2000) were used to identify the colour of the top soil (0-8 cm) horizon at the different sites (Appendix 2). Three colour components were examined: (1) the hue which mostly represents the redness or yellowness; (2) the lightness or darkness; and (3) the chroma which indicates the intensity or brightness of the soil colour (Brady & Weil 2004). The structure of the different soil horizons was observed and described according to the visual appearance and feel of the soil.

2.3.2 Soil sampling

Soil samples were taken at the edges of the profiles from the top soil layer (0-8 cm). In each site, three samples were taken for bulk density and another three for grain size analysis. Samples for carbon and nitrogen (C/N) analysis were taken from the three profiles and mixed to make one composite sample per site. Parts of the soil samples for C/N analysis were also used for pH determination.

2.3.3 Soil carbon and nitrogen (C/N) analysis

The samples for C/N analysis were air dried at 30°C and ball milled in a rotator for 24 hours. Three replicates were taken from each soil sample to determine the dry weight of the soil to be used for correction of C and N results.

The C/N samples were sent to the Agricultural University of Iceland for analysis. A vario MAX CN analyser manufactured by the Elementar Analysensysteme GmbH was used for analysis (Elementar 2012). The analysis is based on the principle of catalytic tube combustion under oxygen supply and high temperatures (900°C). The combustion gases are freed from foreign gases. The desired measuring constituents are alienated from each other with the help of specific adsorption columns and determined with a thermal conductivity detector. Helium is used to serve as flushing and carrier gas. The C/N results were corrected with the dry weight results.

2.3.4 Soil particle size analysis

The grain size analysis was done using the U.S. Department of Agriculture (USDA) classification method (Gee & Or 2002). Different mesh sieves with different size dimensions were used to separate sand into different fractions. The sizes of the sieves used were: 2mm, 500µm, 250µm, 125µm and 63µm. A pan was placed below the finest sieve to collect the smallest grains. The samples were hand shaken and the soil on plant roots was carefully removed by firmly crushing it with the fingers.

2.3.5 Soil bulk density

For measuring soil bulk density, a cylinder with a height of 8 cm and a diameter of 8 cm (volume 402.3 cm^3) was used for taking the soil samples. The samples were air dried, weighed and oven dried at 105°C to remove soil moisture. Then the samples were weighed again to get the dry mass of the soil.

2.3.6 Soil pH

Soil pH in H_2O was measured in the laboratory, using a method modified from Blakemore et al. (1987), by adding 5 grams of soil to a plastic tube with 25ml of distilled water to make a ratio of 1:5. For the analysis, two soil replicates were taken from the soil sampled for C/N analysis after milling.

2.3.7 Data analysis

One way analysis of variance (ANOVA) was used for testing differences in vegetation and soil parameters between habitats, and Turkey's studentised range test was used to find significant differences between means. Statistical analysis was done with SAS 9.2 (SAS 2002-2010).

3. RESULTS

3.1 Aboveground biomass and vegetation cover

There was a significant difference (P=0.003) in the mean aboveground biomass between different habitats (Fig. 3). The aboveground biomass in the forest habitat was significantly higher than for other habitats. The desert habitat had much lower biomass than the other habitats.

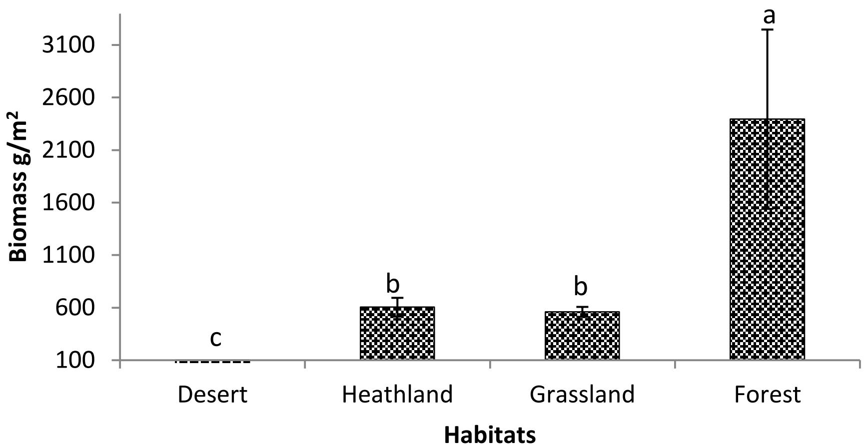

Fig. 3. *Plant aboveground biomass in different habitats (desert, heathland, grassland and forest). The columns represent the means (n=9), the error bars represent the standard error (±SE,) while the letters above indicate the significance of difference; means with the same letter are not significantly different from each other.*

There was a difference in the cover of different vegetation components between different habitats (Fig. 4) for bushes and trees (P=0.003), herbs (P=0.016), grasses, sedges and rushes (P=0.001), heath plants (P=0.001), mosses and lichens (P=0.001) and litter (P=0.003).

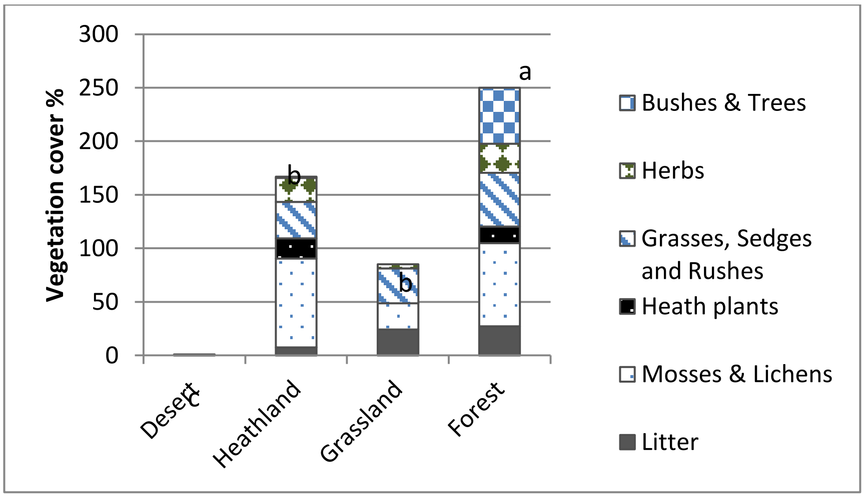

***Fig. 4**. Stratified columns showing different components of the vegetation cover in the four habitats. The columns represent the means (n=9) and the letters above indicate the significant difference in total vegetation cover between the four habitats; means with the same letter are not significantly different from each other.*

As for biomass, the total vegetation cover in the forest habitat was higher (250%) than in other habitats and the desert had very low vegetation cover where only grass was found with 0.9% cover. The cover of bushes and trees was significantly higher in the forest than in other habitats, except for heathland. The cover of grasses, sedges and rushes was also significantly higher in the forest habitat than in grassland and the desert was significantly lower than all other habitats. There was no significant difference in herb cover between habitats, except for the desert. The same applied for the cover of mosses and lichens. Heath plants had significantly more cover in the forest habitat than all other habitats. And finally, litter cover was significantly higher in the forest and the grassland than in the desert.

3.2 Soil properties

There was a significant difference ($P<0.001$) in pH between the four habitats (Fig. 5). The pH in the desert area was higher than in other habitats while the pH in the grassland was the lowest. There was a significant difference ($P<0.001$) in the relative amount of soil grains larger than 2.0 mm in diameter between habitats (Fig. 6). There was also a significant difference ($P<0.001$) in the relative amounts of grains between the 2.0 - 0.5 mm size range and in the 0.5 – 0.25 mm range ($P=0.005$). Smaller sand fractions showed no significant difference between habitats.

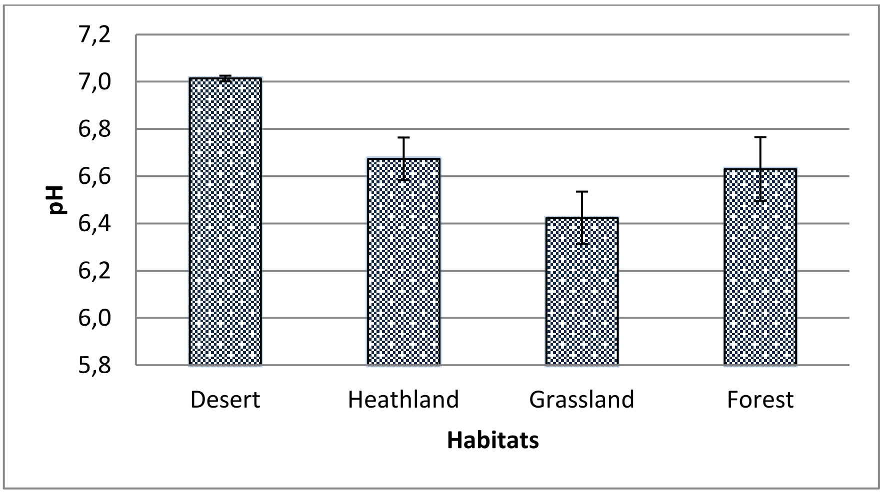

***Fig.5**. Soil pH values for different habitats. The vertical bars represent the ±SE and means with the same letter are not significantly different from each other. The columns represent the mean (n=3), the error bars represent the ±SE and the letters above indicate the significance of difference; means with the same letter are not significantly different from each other.*

The soil bulk density was significantly different ($P=0.001$) between habitats (Fig. 7). The bulk density in the desert soil was significantly higher than in other habitats. Furthermore, the bulk density of the soil in grassland was significantly lower than in the forest.

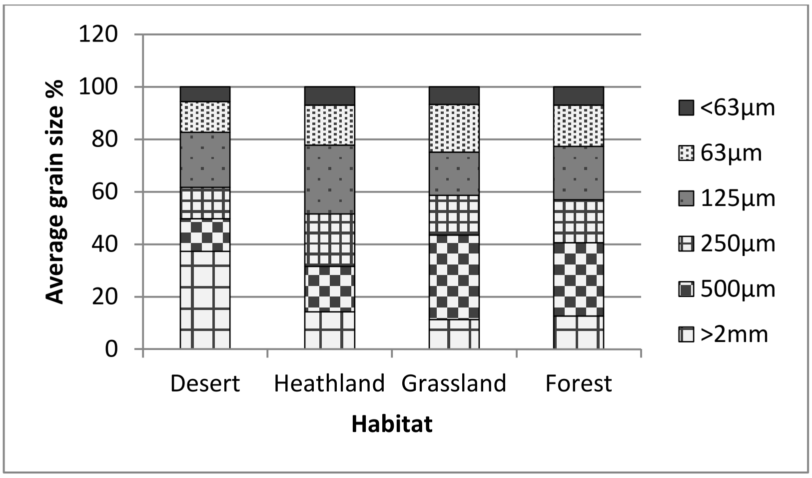

Fig.6. *Relative sand fractions in soils from different habitats. The columns represent mean (n=9) grain size distributions obtained with different mesh sizes: 2mm, 500µm, 250µm, 125µm and 63µm.*

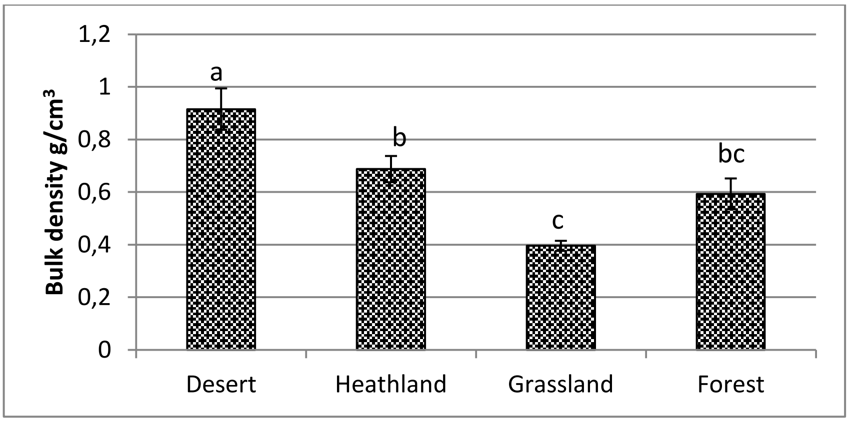

Fig.7. *Soil bulk density in different habitats. The columns represent the mean (n=9), the error bars represent the standard error (±SE), and the letters above indicate the significance of difference; means with the same letter are not significantly different from each other.*

There was a significant difference ($P<0.001$) in soil nitrogen content as well as carbon content between habitats. The carbon and nitrogen contents in desert soil were significantly lower than in other habitats. Significantly higher soil carbon and nitrogen content was observed in the grassland (Fig. 8 and Fig. 9). The C/N ratio was in the range of 14.7 and 17.2 and there was no significant difference between habitats. There was a weak negative correlation ($R^2=0.051$) between soil %N and pH in the study area and an even weaker ($R^2=0.049$) negative correlation between soil %C and pH.

3.3 Soil colour and soil formation

Examination of the soil colour in different habitats showed that in the desert, the soil ranged from black to a mixture of black and white pumice from the eruptions. The colour of the topsoil (0-8 cm) in heathlands and grasslands was more variable within habitats but mostly dark reddish brown while some were black, very dark grey and dark olive brown. The forest habitat soils were all black in colour. Soil profiles in desert habitats were all less than 50 cm deep compared to the other habitats (Fig.10), where it was easy to dig to 50 cm depth (Appendix 3). Coarse sand layers were observed in heathland, grassland and forest habitats but not in the desert (Appendix 3). The desert pits also had no distinctive soil layers and in some pits the soil was loose and collapsed easily.

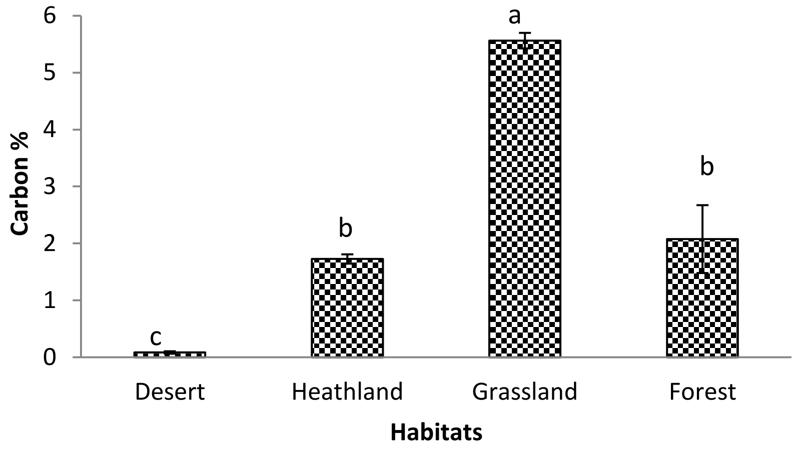

Fig.8. *Soil carbon content in different habitats. The columns represent the means (n=3) the error bars represent the ±SE. The letters above indicate the significance of difference; means with the same letter are not significantly different from each other.*

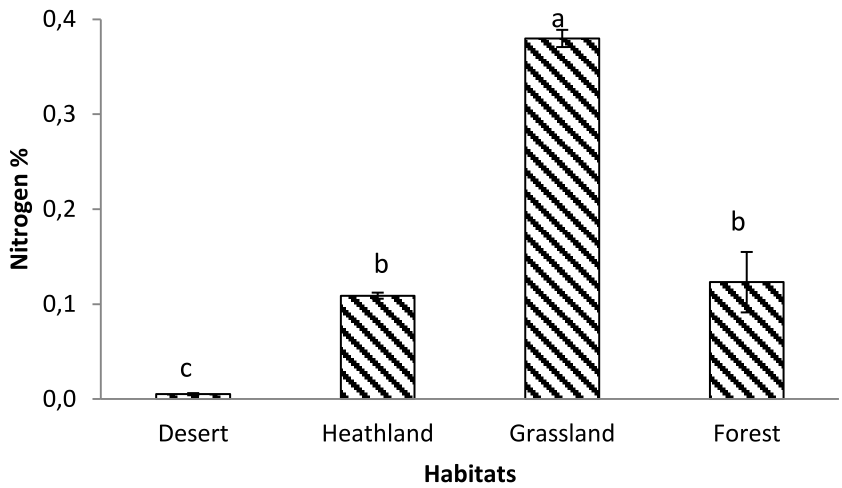

Fig.9. *Soil nitrogen content in different habitats. The columns represent the means (n=3) and the error bars represent the ±SE. The letters above indicate the significance of difference; means with the same letter are not significantly different from each other.*

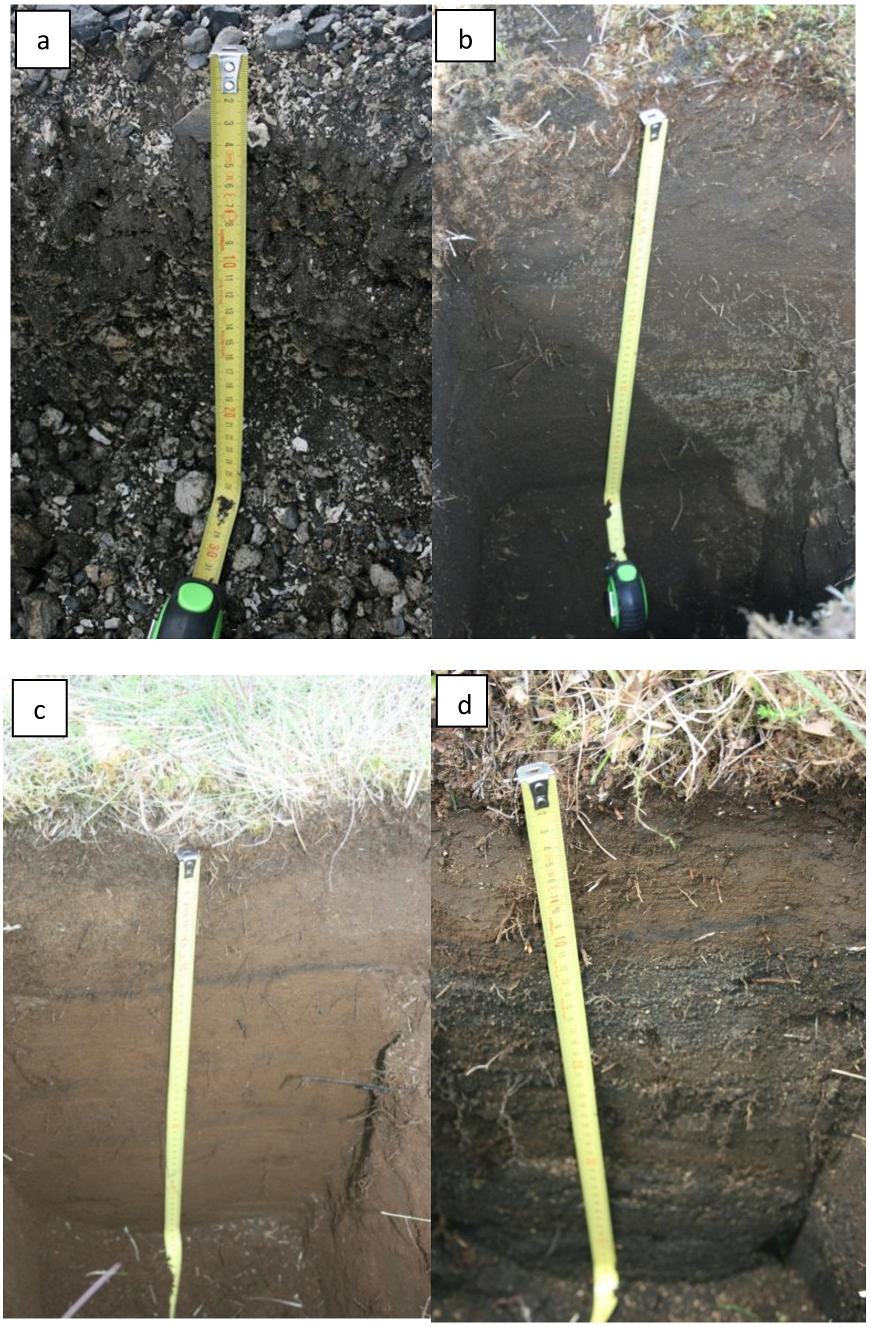

Fig.10. *Typical soil profiles in different study habitats; a) desert, b) heathland, c) grassland and d) forest. (Photos: H. Gehringer 2012).*

4. DISCUSSION

4.1 Comparisons of biomass and vegetation cover

The study habitats were originally selected based on their vegetation cover and this is clearly reflected in the vegetation data. The forest habitat had higher biomass mainly because of trees and bushes, as indicated by the vegetation cover analysis. The desert habitat had very little biomass and vegetation cover to protect the already eroded bare soil. The current reclamation and afforestation efforts are aiming at changing desert areas directly into birch woodlands (Hekla Forest Project 2012). Other eroded areas may change into heathlands similar to the ones in the current study. These may in turn later develop into forests or grasslands. The study therefore shows the potential of eroded or reclaimed areas to increase their vegetation biomass and cover and vegetation species diversity with time.

4.2 Soil properties

The results show the effect of soil organic matter on the soil pH. In the desert habitat, where soil carbon and nitrogen were low, the pH was high, while with high carbon and nitrogen in grassland the pH was low. This indicates that when the soil organic carbon increases, the pH of that soil decreases (Arnalds 2004).
The soil bulk density in the desert was significantly higher compared to the other habitats. This was explained by the desert soil having a higher proportion of large grain size particles (>2 mm) and this contributed to the higher bulk density. The heathland, grassland and forest had low soil bulk density that can be explained by more vegetation and therefore more soil organic matter which results in low soil bulk density (Brady & Weil 2004).

A higher nitrogen and carbon percentage was observed in the grassland habitat and this might be because these sites have not been eroded in the past. Although these sites have accumulated a lot of aeolian material in past centuries (Arnalds 2010) they still maintain high levels of C and N in the topsoil. This indicates the potential increase in soil C and N following reclamation of eroded areas.

Although Icelandic Andosols accumulate a lot of organic matter, it gets buried to deeper horizons when aeolian and tephra materials keep being added to the soil (Arnalds 2008). The forest sites in the study were either at, or near, inactive or active erosion fronts. Therefore it is likely that much of the accumulated C and N is buried under fresh aeolian material or had been eroded away in past centuries.

4.3 Soil formation

The soil profile studies showed a clear indication of different horizons in the forest and grassland habitat area and in some of the heathland sites. The surface horizons indicated the accumulation of organic matter from vegetation as well as the deposition of soil by erosion (Brady & Weil 2004). Furthermore, deeper horizons indicated ash deposition during past volcanic eruptions. No apparent horizon separations were seen in the desert profiles and this could be attributed to the loss of soil layers by erosion.

5. CONCLUSIONS

In conclusion, the study showed the potential increase in the plant aboveground biomass and nitrogen and carbon following reclamation. It also showed the potential increase in vegetation diversity over decades after reclamation.
The study also highlighted the role of vegetation on soil development. Vegetation accumulates aeolian materials such as volcanic ash and sand carried by wind and these materials influence soil development.

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REFERENCES

Arnalds, A. 2000. Evolution of rangeland conservation strategies. Pages 153-163 in O. Arnalds and S. Archer, editors. Rangeland desertification. Advances in Vegetation Sciences Series, Kluwer, Dordrecht, the Netherlands.

Arnalds, O., and B. Barkarson. 2003. Soil erosion and land use policy in Iceland in relation to sheep grazing and government subsidies. Environmental Science & Policy **6:**105-113.

Arnalds, O. 2004. Volcanic soils of Iceland. Catena **56:**3-20.

Arnalds, O., E. F. Thorarinsdottir, S. Metusalemsson, S. Jónsson, E. Gretarsson, and A. Arnason. 2001. Soil erosion in Iceland. Agricultural Research Institute, Soil Conservation Service, Iceland.

Arnalds, O. 2008. Soils of Iceland. Jökull **58**:409-421.

Arnalds, O. 2010. Dust sources and deposition of aeolian materials in Iceland. Icelandic Agricultural Sciences **23**:3-21.

Bashour, I. I., and A. H. Sayegh. 2007. Methods of analysis for soils of arid and semi-arid regions. FAO, Rome, Italy.

Blakemore, L., P. Searle and B. K. Daly. 1987. Methods for chemical analysis of soils. NZ Soil Bureau scientific report 80. NZ Soil Bureau, Lower Hutt, New Zealand.

Bot, A., and J. Benites. 2005. The importance of soil organic matter: Key to drought-resistant soil and sustained food production. FAO soil bulletine 80. Food and Agriculture Organization of the United Nations, Rome, Italy.

Brady, N. C., and R. R. Weil. 1996. The nature and properties of soils. Prentice-Hall, Upper Saddle River, NJ, USA.

Brady, N. C., and R. R. Weil. 2004. Elements of the nature and properties of soils. Prentice Hall, Upper Saddle River, NJ, USA .

Burke, A. 2003. Practical measures in arid land restoration after mining: A review for the southern Namib. South African Journal of Science **99:**413-417.

Crofts, R. 2011. Healing the land. Soil Conservation Service of Iceland, Gunnarsholt, Iceland.

Elementar. 2012. Elementar Analysensysteme GmbH, http://www.elementar.de/cms/en/products/elementar-products/vario-max/ (accessed on 14 September 2012).

FAO (Food and Agriculture Organization of the United Nations). 2010. Global forest resources assessment 2010. FAO forestry paper 163. FAO, http://www.fao.org/docrep/013/i1757e/i1757e.pdf (accessed on 9 August 2012).

Gee, G. W., and D. Or. 2002. Particle-size analysis. Pages 255-293 in J. H. Dane and G. C. Topp, editors. Methods of soil analysis. Part 4. Soil Science Society of America, Madison, WI, USA.

Hekla Forest Project. 2012. http://www.hekluskogar.is/ (accessed on 6 September 2012).

Jordan, W. R., M. E. Gilpin, and J. D. Aber. 1990. Restoration ecology: A synthetic approach to ecological research. Cambridge University Press, Cambridge, UK.

Klintenberg, P., and M. Seely. 2004. Land degradation monitoring in Namibia: A first approximation. Environmental Monitoring and Assessment **99:**5-21.

Lal, R. 2004. Soil carbon sequestration to mitigate climate change. Geoderma **123:**1-22.

MME (Ministry of Mines and Energy). 2010. Strategic environmental assessment for the central Namib uranium rush. Ministry of Mines and Energy, Windhoek, Republic of Namibia.

Munsell Color Company. 2000. Munsell soil color charts. Munsell Color Company, USA.

Nelson, F. 2004. The evolution and impacts of community-based ecotourism in northern Tanzania. Issue paper 131. International Institute for Environment and Development, London, UK.

Oddsdottir, E. S., C. Nielsen, R. Sen, S. Harding, and G. Halldorsson. 2010. Distribution patterns of soil entomopathogenic and birch symbiotic ectomycorrhizal fungi across native woodland and degraded habitats in Iceland. Icelandic Agricultural Sciences **23:**37-49.

Olatunji, K. 2009. Organic matter and nutrients depletion in soil of Itakpe iron ore deposit area of Kogi State, Nigeria. Research Journal of Applied Sciences **4:**17-19.

Pétursdóttir, T., and A. Aradóttir. 2008. Multiple benefits of land reclamation: The imporantance of public acceptance in successful reclamation.

Ritter, E. 2007. Carbon, nitrogen and phosphorus in volcanic soils following afforestation with native birch (*Betula pubescens*) and introduced larch (*Larix sibirica*) in Iceland. Plant and Soil **295:**239-251.

SAS software. 2009. Version 9.2. SAS Institute Inc., Cary, NC, USA.

Sigurdsson, B. D., and A. Snorrason. 2000. Carbon sequestration by afforestation and revegetation as a means of limiting net-CO~ 2 emissions in Iceland. Biotechnologie Agronomie Societe et Environnement **4:**303-307.

Wöll, C. 2008. Treeline on mountain birch (*Betula pubescens* Ehrh.) in Iceland and its relationship to temperature. Diploma thesis. Department of Forestry, Technical University Dresden, Dresden, Germany.

APPENDIX 1

The four habitats where the study was done. In each habitat three sites were randomly selected.

The 4 habitats	Sites random numbers	Coordinates	Site description
Desert	17	64°04.980'N 19°45.413'W	Eroded pumice field; the area is still grazed.
	7	64°05.458'N 19°43.957'W	Eroded pumice field; the area is still grazed.
	4	64°03.245'N 19°52.017'W	Eroded lava field with volcanic ash and sand at the soil surface; now protected against grazing.
Forest	9	64°00.493'N 19°53.336'W	Old natural birch forest near an eroded area; the forest is still grazed.
	24	64°05.327'N 19°56.443'W	Young, self seeded birch forest in an inactive erosion front; the area was many years ago seeded with Nootka lupine and protected from grazing.
	21	64°01.182'N 19°58.718'W	Young birch forest in an afforestation area; protected from grazing.
Grassland	23	63°52.362'N 20°09.378'W	Old grassland, not eroded; now protected from grazing.
	12	63°53.906'N 20°03.673'W	Old grassland, not eroded; now protected from grazing.
	29	63°53.855'N 20°14.476'W	Old grassland, not eroded, unprotected from grazing.
Heath	20	63° 50,355'N 20°08.666'W	Previously eroded area, reclaimed many decades ago with aerial fertilization and protection against grazing.
	13	63°51.223'N 20°07.316'W	Previously eroded area, reclaimed many decades ago with aerial fertilization and protection against grazing.
	6	63°52.194'N 20°14.908'W	Previously eroded area, reclaimed using fertilization and protection against grazing; recently seeded with Nootka lupine.

APPENDIX 2
Topsoil (0-8 cm) colour identification at different sites according to the Munsell Color System.

Habitat	Site no	Hue	Value/Chroma	Colour
Desert	4a	10	2/1	Black
Desert	4b	10	2/1	Black
Desert	4c	10	2/1	Black
Desert	17a	10	2/1	Black
Desert	17b	10	2/1	Black
Desert	17c	10	2/1	Black
Desert	7a	Mixed colours with pumice		
Desert	7b	Mixed colours with pumice		
Desert	7c	Mixed colours with pumice		
Forest	9a	5	3/1	Very dark grey
Forest	9b	5	3/1	Very dark grey
Forest	9c	5	3/1	Very dark grey
Forest	24a	7.5	3/1	Very dark grey
Forest	24b	7.5	3/1	Very dark grey
Forest	24c	7.5	3/1	Very dark grey
Forest	21a	7.5	3/1	Very dark grey
Forest	21b	7.5	3/1	Very dark grey
Forest	21c	7.5	3/1	Very dark grey
Grassland	23a	2.5	3/3	Dark olive brown
Grassland	23b	2.5	3/3	Dark olive brown
Grassland	23c	2.5	3/2	Very dark greyish brown
Grassland	12a	2.5	2,5/1	Black
Grassland	12b	2.5	2,5/1	Black
Grassland	12c	2.5	2,5/1	Black
Grassland	29a	5	3/3	Dark reddish brown
Grassland	29b	5	3/2	Dark reddish brown
Grassland	29c	5	3/2	Dark reddish brown
Heathland	20a	5	2.5/2	Dark reddish brown
Heathland	20b	5	3/1	Very dark grey
Heathland	20c	5	3/1	Very dark grey
Heathland	13a	7.5	2.5/1	Black
Heathland	13b	7.5	2.5/2	Very dark brown
Heathland	13c	10	2/1	Black
Heathland	6a	5	2.5/2	Dark reddish brown
Heathland	6b	5	2.5/2	Dark reddish brown
Heathland	6c	5	2.5/2	Dark reddish brown

APPENDIX 3

Soil profile layers at different sites with the description of the soil at different depths.

Habitat	Site no	Soil description	Profile layers and depth(cm)
Desert	4a	Pebbles	0-1
		Sand	1-46
		Tephra	46-50
Desert	4b	Pebbles	0-1
		Sand	1-47
		Tephra	47-50
Desert	4c	Pebbles	0-1
		Sand	1-32
		Tephra	32-50
Desert	17a	Stone and pumice	0-20
Desert	17b	Stone and pumice	0-27
Desert	17c	Stone and pumice	0-27
Desert	7a	Soil mixed with pumice and not stable	0-25
Desert	7b	Soil mixed with pumice and not stable	0-30
Desert	7c	Soil mixed with pumice and not stable	0-40
Heathland	20a	Organic	0-4
		Coarse sand	4-10
		Fine material	10-24
		Black sand intercepted with ash layer	24-49
Heathland	20b	Organic	0-5
		Sand	5-15
		Fine material	18-27
		White ash	27-29
		Cemented	29-38
Heathland	20c	Organic	0-4
		Coarse sand	4-10
		Very coarse sand	10-20
		Thin layer of ash	20-22
		Cemented	22-26
Heathland	13a	Organic	0-5
		Mixed fine sand with coarse	9-50
Heathland	13b	Organic	0-5
		Mixed fine sand with coarse	9-50
Heathland	13c	Organic	0-9
		Dark sand	9-24
		Darker sandy	24-50
Heathland	6a	Organic	0-4
		Fine material with stones	4-15
		Coarse sand	15-32
		Cemented	32
Heathland	6b	Organic	0-4
		Fine material with big stones	4-16
		Coarse sand	16-29
		Cemented	29
Heathland	6c	Organic	0-3
		Fine material	3-17
		Coarse sand	17-29
		Cemented	29
Grassland	23a	Organic	0-9
		Fine sand	9-50
Grassland	23b	Organic	0-10
		Fine material	10-50
Grassland	23c	Organic	0-7
		Fine material	7-50
Grassland	12a	Organic	0-6
		Fine material	6-23

		Fine sand with coarse tephra	23-27
		Coarse sand	27+
Grassland	12b	Organic	0-6
		Fine material	6-21
		Darker layer	21-38
		Fine sand	38+
Grassland	12c	Organic	0-6
		Sand	6-26
		Coarse sand	26-36
		Fine material	35-50
Grassland	29a	Organic	0-5
		Fine material intercepted with ash	5-50
Grassland	29b	Organic	0-4
		Finer layer	4-12.5
		Dark and fine layer	12,5-13.5
		Fine layer	13,5-50
Grassland	29c	Organic	0-5
		Finer layer	5-17
		Dark and fine layer	17-18
		Fine layer	18-50
Forest	9a	Organic	0-3
		Coarse sand	3-12,5
		Finer ash layer	12.5-16
		Coarse sand	16-50
Forest	9b	Organic	0-3
		Coarse sand	3-14
		Ash layer	14-17
		Fine layer	17-35.5
		Ash layer	35,5-37.5
		Fine layer	37,5
Forest	9c	Organic	0-2
		Coarse sand	2-16
		Ash layer	16-19.5
		Coarse sand	19.5-33
		Ash layer	33-35
		Coarse sand	35-50
Forest	24a	Organic	0-4
		Coarse and sandy	4-29
		Finer material	29-50
Forest	24b	Organic	0-5
		Coarse	5-20
		Fine intercepted with black line	20-27
		Coarse pumice	27-38
		Finer material	38-50
Forest	24c	Organic	0-2
		Coarse	2-22
		Fine intercepted with black line	22-33
		Coarse pumice	33-40
		Fine material	40-50
Forest	21a	Organic	0-3
		Fine intercepted with black line	3-12
		Coarse and fine mixed	12-50
Forest	21b	Organic	0-5
		Fine material	5-15
		Coarse and fine mixed	15-50
Forest	21c	Organic	0-6
		Fine intercepted with black line	6-13
		Coarse and fine mixed	13-33
		Fine material	33-36
		Coarse and fine mixed	36-50