The influence of land reclamation and afforestation on soil arthropods in Iceland

EDDA SIGURDÍS ODDSDÓTTIR[1]
KRISTÍN SVAVARSDÓTTIR[2]
AND
GUÐMUNDUR HALLDÓRSSON[1†]

[1] Icelandic Forest Research, Mógilsá, 116 Reykjavík, Iceland
E-mail: edda@skogur.is (corresponding author)
E-mail: gudmundur.halldorsson@land.is

[2] Soil Conservation Service of Iceland, Keldnaholt, 112 Reykjavík, Iceland
E-mail: kristin.svavarsdottir@land.is

[†]Current address: Soil Conservation Service of Iceland, Gunnarsholti, 851 Hella, Iceland

ABSTRACT
The paper reports the effects of land reclamation and afforestation on soil arthropods in Iceland. Density and group composition of soil arthropods in eroded areas and areas revegetated with birch, lupin and grass species were studied. Results showed that reclamation changed soil animal group composition and significantly increased the density of soil arthropods, regardless of the method used. Soil arthropod density was significantly higher in birch and lupin reclamations than in grass reclamation. Furthermore, soil arthropod community composition differed by reclamation methods; mites were dominant in birch while springtails were dominant in lupin plots. Neither group was dominant in grass plots. Soil arthropod density was found to be positively correlated with vascular plant species cover, the percentage of organic carbon, nitrogen, phosphorus and potassium, but negatively correlated with pH. The importance of soil arthropod restoration in reclamation and natural succession of eroded areas in Iceland is discussed.

Keywords: density, group composition, mites, ordination, reclamation methods, springtails

YFIRLIT
Áhrif skógræktar og landgræðslu á hryggleysingja í jarðvegi
Í þessari grein er skýrt frá niðurstöðum rannsókna á áhrifum skógræktar og landgræðslu á jarðvegsdýr. Borinn var saman þéttleiki og hópasamsetning jarðvegsdýra á óuppgræddum svæðum og á svæðum sem höfðu verið grædd upp með birki, lúpínu eða grastegundum. Rannsóknin leiddi í ljós að uppgræðsla breytti hópasamsetningu jarðvegsdýra og þéttleiki þeirra á uppblásnum svæðum var marktækt minni en á uppgræddum svæðum, sama hvaða aðgerð var notuð, enda frumframleiðni meiri á uppgræddum svæðum. Þéttleiki jarðvegsdýra var mismikill eftir aðgerðum og var marktækt hærri í uppgræðslum með birki og lúpínu heldur en í

grasuppgræðslu. Uppgræðsluaðgerðir höfðu jafnframt áhrif á hópasamsetningu jarðvegsdýra, mítlar voru ríkjandi í birkiuppgræðslu en mordýr í lúpínu. Í grasuppgræðslu var ekki munur á mítlum og mordýrum. Marktæk jákvæð fylgni var milli þéttleika jarðvegsdýra og þekju háplnatna, hlutfalls lífræns kolefnis, niturs, fosfórs og kalíums en neikvæð fylgni milli þéttleika og sýrustigs. Ályktað er að uppbygging jarðvegsdýrasamfélaga á uppblásnum svæðum geti verið mikilvægur þáttur í uppgræðslu og frumframvindu á lítt grónum svæðum.

INTRODUCTION

Assessment of soil erosion in the early 1990s showed that 40% of Iceland was classified as severe or extremely severely eroded land (Arnalds et al. 2001). Organized measures to halt soil erosion and to reclaim eroded land started in the early 20th century (Runólfsson 1987). Commonly used methods are sowing of grass species, such as *Festuca richardsonii* Hook, *Phleum pratense* L, *Deschampsia beringensis* Hultén and *Lolium muliflorum* Lam, the native sand dune species *Leymus arenarius* (L.) Hochst., or the introduced legume *Lupinus nootkatensis* Donn ex Sims. Other reclamation activities, such as planting or seeding of native *Betula pubescens* Ehr. and *Salix* shrubs, have been used to a lesser extent (Aradóttir & Eysteinsson 2005). Research on effects of reclamation in Iceland has focused on vegetation and soil (Aradóttir et al. 2000, Arnalds et al. 2002, Elmarsdottir et al. 2003, Gretarsdottir et al. 2004), but much less attention has been paid to other factors of the ecosystem, such as the soil biota. It is known that complex interactions occur between higher plant communities and the soil biota, including soil arthropod communities (e.g. Usher 1993, Van der Putten et al. 2001, Wardle 2006). Kaufmann et al. (2001) investigated the development of soil macrofauna and mesofauna in the successional chronosequence of an alpine glacier foreland. In Iceland insights into the impact of land reclamation and afforestation on soil fauna are very limited. Sigurðardóttir (1991) studied the effects of land reclamation on soil arthropods in the highlands of north Iceland and some studies have been done on the effects of afforestation on soil arthropods (Óskarsson 1984, Halldórsson & Oddsdóttir 2007, Oddsdóttir et al. 2008).

The aim of the current study was to determine the effects of land reclamation on the density and group composition of soil arthropods. Three different land reclamation areas were studied, i.e. eroded land reclaimed with: (1) birch (*Betula pubescens*), (2) lupin (*Lupinus nootkatensis*) and (3) a mixture of three grass species (*Festuca richardsonii, Phleum pratense* and *Lolium muliflorum*). Our hypotheses were that: (1) reclamation activities increase the density of soil arthropods, and (2) that different reclamation methods affect density and group composition of soil arthropods differently.

Site description

The study was carried out near Gunnarsholt, Rangárvallasýsla County in southern Iceland. This district has a long history of soil erosion and land reclamation activities. When reclamation work began in the district in the 1920s many farms were close to being or had been abandoned due to soil erosion and people had struggled for almost a century to keep the district inhabited (Olgeirsson 2007). Three areas were chosen, one for each of the three studied reclamation methods. These areas were chosen as they represent different land reclamation methods within a relatively short distance. However, the time since reclamation began varied between the three methods with the birch reclamation being the oldest (see below). Untreated sites near each of the reclamation sites were selected for controls. These sites were similar to the adjacent reclamation sites, except for the treatments.

The birch site is located in Gunnlaugsskógur (Figure 1), a forested area approximately 100-110 m a.s.l. The area was fenced and protected from grazing in the 1930s. The land was completely eroded at that time, but after fencing lyme grass (*Leymus arenarius*) was sown in part of the area which is sheltered by a nearby lava flow (Runólfsson pers. communication).

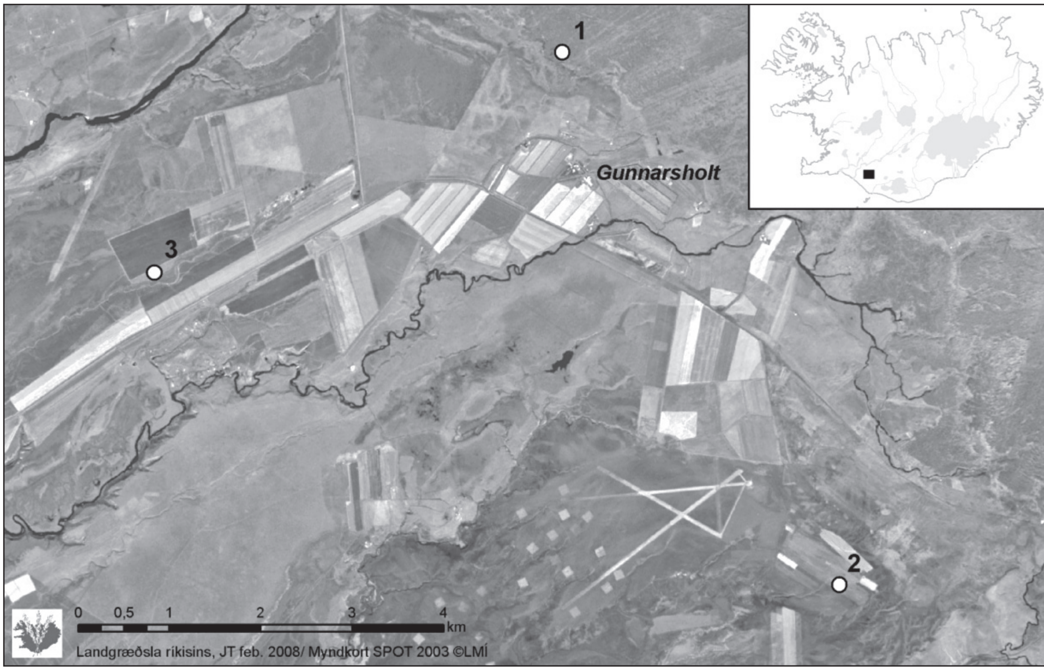

Figure 1. Aerial photo showing the three study areas near Gunnarsholt, southern Iceland. (1) Gunnlaugsskogur, birch area; (2) Geitasandur, lupin area; and (3) near Vakalág, grass area. Within each area there were 10 plots, five reclaimed (treated) and five eroded (control) plots.

Birch was established in that area by sowing on two occasions in 1939 and in 1945 (Magnússon & Magnússon 1989). Young birch plants were later replanted in several groves on top of the neighbouring lava field. These repositions began around 1945 and continued annually for a few years (Runólfsson pers. communication), resulting in 13-15 birch groves. Outside the birch groves the surface is rough and rocky with sparse vegetation. For further description of the area see Aradóttir (1991).

The lupin site is at Geitasandur (Figure 1), 50-60 m a.s.l., SE of Gunnarsholt. The land is flat and its surface classified as cambic vitrisols (melur) following Arnalds' (2004) classification. The soil was sandy with signs of frost heaving. In 1996 a strip of approximately 1100x200 m near a recent grass field was sown with lupin (1 kg of Rhizobioum inoculated seeds ha^{-1}) (Runólfsson pers. communication).

The grass site is located near Vakalág (Figure 1), 50-60 m a.s.l. The surface at the study site is covered by aeolian sediments and classified as cambic vitrisols (Arnalds 2004). Reclamation started in 1978 with fertilization and aerially sown grasses, *Festuca richarsonii, Phleum pratense* and *Lolium muliflorum*. The field was harvested for six subsequent years but has not been harvested since 1983 (Gretarsdottir 2002).

MATERIALS AND METHODS

Within each study area five reclaimed (treated) plots and five eroded (control) plots were selected. The plots were circular with a radius of 2 m (12.6 m^2).

In Gunnlaugsskógur, the reclaimed plots were placed in five randomly selected birch groves on the top of the lava field. Plots were randomly located within each of the birch groves. To avoid any edge effect, all plots were at least 2 m from the margin of the grove. The control plots were placed randomly in the lava field between the birch groves. In the other two reclamation areas, 250 m long transects were laid in the centre of the treated site and five plots randomly located along them. Plots were located in a similar manner within adjacent control sites. The assumption was made that the vegetative cover and soil types were similar at untreated and treated sites within each area when reclamation started.

Soil arthropods were sampled three times during the summer of 2000 (7 June, 20 July and 22 September) by forcing a cylinder (5 cm diameter and 5 cm height) into the topsoil. At each sampling time, two samples were taken within each plot and sampling spots were randomly selected at each time. Soil samples were immediately sealed, placed into plastic bags and transported to the laboratory for extracting soil arthropods. Animals were extracted by the dry funnel method (Macfadyen 1962) into 0.6% benzoic acid. Springtails and mites were sorted out from the soil particles and identified as to family (springtails) and suborder (mites) level under a light stereoscope, following Maynard (1951), Fjellberg (1980, 1997) and Hopkin (1997) for springtails, and Baloch (1972), Gilyarov (1975, 1977, 1978), Huges (1976), Gjelstrup (1983) and Gjelstrup & Petersen (1987) for mites.

In September 2000, four subplots (50x50 cm) were randomly selected within each plot. The percentage cover of bryophytes, litter, total plant cover and bare ground was visually estimated. Vascular plant species were identified following Kristinsson (1987) and their cover visually estimated.

Soil samples for chemical analysis were taken from all plots in 2002, one sample from each plot, resulting in five samples/treatments. To reduce cost, only three out of these five samples were analysed. The three samples to be analysed were randomly selected from each lot of five. Samples were analysed for pH, the percentage of C and N, total P and total K.

Since the soil animal density data were not normally distributed, the Kruskal-Wallis test was performed on the average density to test for differences between reclamation methods. ANOVA was used to test for differences in vegetation cover and soil variables. Ordination (ter Braak & Smilauer 2002) was carried out to examine the overall soil arthropod patterns and to detect any relationships between these patterns, vegetation cover and soil conditions. Ordination was carried out on soil arthropod density in study plots for the three sampling dates, a total of 90 samples. Detrended Correspondence Analysis (DCA) revealed a short gradient length in the soil arthropod data (2 SD), thus Principal Component Analysis (PCA) was selected. Vegetation and soil analysis data were viewed as environmental variables and their correlations with the ordination axes explored for relationships. These variables were correlated with PCA scores from the analysis of the average density of arthropods on the three sampling dates. SPSS statistical software version 15.0 (SPSS Inc., Chicago, Illinois) was used for all statistical analyses except for ordination, then Canoco for Windows version 4.5 (ter Braak & Smilauer 2002) was used.

RESULTS

Vegetation and soil

Average vegetation cover in all reclaimed areas was over 99%, while the highest vegetation cover in controls was approximately 50% (Table 1). Vegetation cover differed significantly between reclaimed and adjacent control sites for all reclamation methods (birch: $F=29.9$, $p=0.001$; lupin: $F=1929.6$, $p<0.001$; and grass: $F=133.0$, $p<0.001$).

In total, 25 vascular plant species were recorded in the study. The highest number of species (19) was recorded in the birch plots, whereas only 8 species were found in the control plots for grass and lupin (Table 1).

Soil values varied between reclamation areas and within them, but %C and %N were highest in the birch area (Table 2).

Soil arthropods

Total soil arthropod density was higher in reclaimed plots than controls, and the difference was significant for all areas and all sampling times, except for the September sampling in the birch and grass areas (Table 3).

The highest soil arthropod density occurred in the reclaimed lupin (7862 individuals m^{-2}) and reclaimed birch (7030 individuals m^{-2}) plots. The density in the reclaimed grass plots (2581 individuals m^{-2}) was significantly lower than in the birch ($p=0.001$) and lupin ($p=0.008$) plots.

Even though the total number of soil arthropods was similar in the birch and lupin plots, there was a shift between the arthropod groups of springtails and mites. In the birch plots, mites constituted the dominant group, whereas springtails dominated in lupin plots. In the grass plots and in the control plots for birch, lupin and grass the two groups were co-dominant (Figure 2).

Table 1. Summary of vegetation data sampled from the same plots as soil arthropods in three reclamation areas near Gunnarsholt, southern Iceland. Values are means of five plots. Note that only the most common vascular plant species are shown. Birch cover is not included. + = reclaimed sites, - = control sites.

	Birch area		Lupin area		Grass area	
	+	-	+	-	+	-
Total number of plant species	19	16	9	8	11	8
Vegetation cover (%)	99.3	49.5	99.8	13.1	100.0	35.7
Vascular plants cover (%)	72.6	22.1	79.0	9.5	31.2	10.1
Moss cover (%)	16.3	26.4	16.8	3.5	54.5	21.7
Fungi, lichens and litter cover (%)	10.4	1.0	4.0	0.1	14.3	3.9
Vascular plant species cover (%):						
Agrostis capillaris L.	11					
Deschampsia flexuosa L.	33					
Festuca richardsonii Hook		5		7	20	6
Festuca vivipara L.			27			2
Phleum pratense L.					6	
Poa pratensis L.			30			
Cerastium alpinum L.				0.5		
Empetrum nigrum L.		11			2	
Lupinus nootkatensis Donn ex Sims			56			
Luzula spicata (L.) Caud.						1
Thymus praecox Opiz				0.3		
Salix lanata L.		4				

Table 2. Mean values for soil variables measured. + = reclaimed sites, - = control sites.

	Birch		Lupine		Grass	
	+	-	+	-	+	-
%C	6.30	1.44	0.98	0.26	2.26	0.77
%N	0.39	0.10	0.07	0.02	0.16	0.06
C/N	16.04	14.22	14.78	16.78	14.39	13.5
pH	6.02	6.32	6.67	6.72	5.94	6.79
mg P/100 g	2.88	0.40	0.40	0.21	2.91	0.30
meq K^+/100 g	0.08	0.02	0.04	0.02	0.02	0.02

Arthropods group composition

The first two PCA ordination axes accounted for most of the variation in the data. The eigenvalues were 0.72 for axis 1 and 0.26 for axis 2 and they explained 98% of the variance. Lupin and birch reclamation had most impact on the PCA results as the lupin plots spread along axis 1 and the birch plots along axis 2. The grass plots were more clumped at the centre of the graph, together with control plots from all three areas (Figure 3a). The mean site scores for each treatment and sampling date also showed that species composition changed more during the season for the birch and lupin areas than for the grass area (Figure 3b). The analysis also showed negligible changes in the compositional data of the controls between sampling dates.

Table 3. Kruskal-Wallis tests comparing total soil arthropods density between reclaimed and control plots within each reclamation area. Significance levels are shown. NS=Not significant.

	June	July	Sept
Birch area	$p<0.01$	$p<0.01$	NS
Lupin area	$p=0.01$	$p<0.01$	$p<0.01$
Grass area	$p<0.01$	$p<0.01$	NS

The PCA analysis, in which soil arthropod density was averaged for the three sampling dates prior to analysis (n=30) gave eigenvalues of 0.65 and 0.34 for axis 1 and 2, respectively. The first axis, which explained most of the arthropod variation, was best explained by biological factors, i.e. the sum of vascular plant species cover (r_s=0.77, $p<0.001$), vegetated surface (r_s=0.76, $p<0.001$) and number of arthropod groups (r_s=0.64, $p<0.001$). These variables were positively correlated with the first PCA axis, reflecting an increase in those factors with a higher density of Isotomidae, Entomobryidae and Onychiuridae (Figure 3a). Of the measured environmental variables the second axis was best explained by soil chemistry. The percentage of organic carbon (r_s=0.77, $p<0.001$), nitrogen (r_s=0.77, $p<0.001$), phosphorus (r_s=0.72, $p<0.001$) and potassium (r_s=0.65, $p<0.001$) were all positively correlated with the PCA axis 2, while pH was negatively correlated with it (r_s=-0.65, $p<0.001$). Thus plots with the densest Cryptostigmata (birch area) had the highest values of soil C, N, P and K, and a low pH (Figure 3a).

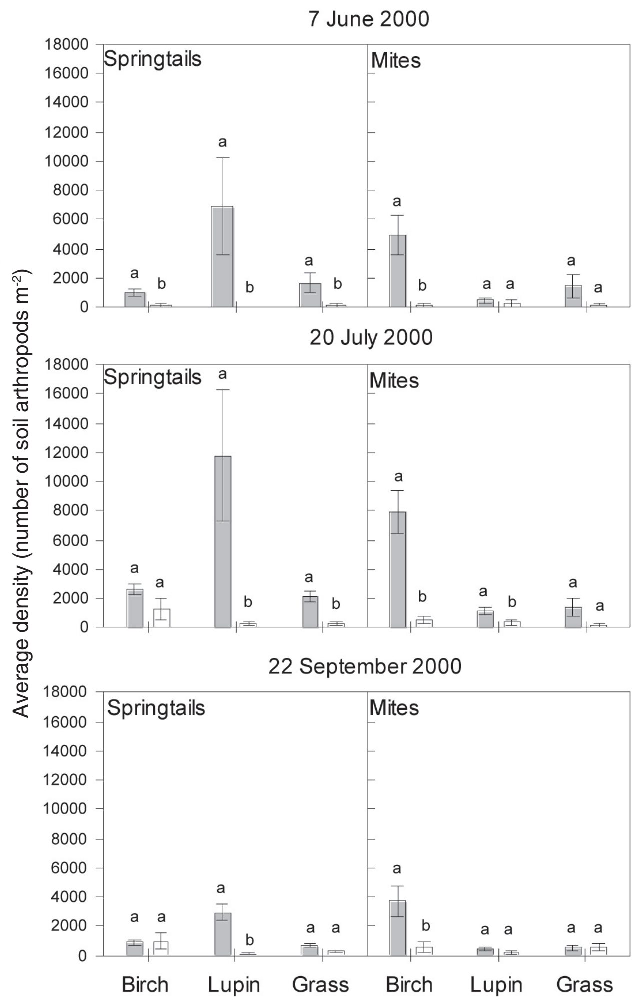

Figure 2. Average number of collembola (left) and mites (right) in soil samples from five subplots within reclamation (filled bars) and control (open bars) sites. Vertical lines show SE. Different letters above bars show the significant difference ($p<0.05$) between the paired reclaimed and control sites.

DISCUSSION

The current study compares soil arthropod density and group composition in reclaimed areas to that of nearby eroded land and demonstrates that land reclamation significantly increases the total density of soil arthropods and changes group composition. The differences between untreated and reclaimed sites obtained in this study reflect the differences found in the decomposition rates of cotton strips used in the same plots as in the present study (Oddsdóttir, 2002), as well as the difference in occurrence of mycorrhizal fungi in eroded areas vs. birch woodlands in Iceland (Oddsdottir et al. 2002). The density of soil arthropods found in reclaimed areas in this study was similar to that found in birch and heathland in eastern Iceland (Halldórsson & Oddsdóttir 2007), but low compared to birch and heathland in western Iceland (Oddsdóttir et al. 2008) and larch and heathland in eastern Iceland (Óskarsson 1984). The differences between these studies are difficult to explain. Óskarsson (1984) used sampling and extraction methods different from those used in the present study, whereas Halldórsson and Oddsdóttir (2007) and Oddsdóttir et al. (2008) used the same methods as in the present study. It is also possible that the differences were due to differences in soil arthropod population densities between years.

There are complex interactions between higher plant communities and soil biota (Usher 1993) but it is problematic to try to differentiate between correlation and causation. Below-ground communities affect nutrient availability and detritus buildup (Hooper et al. 2000) and higher primary production increases the density of soil biota (Wardle et al. 2003). Generally, vascular plant cover and primary production at eroded sites in Iceland are low (Gretarsdottir et al. 2004, Aradóttir et al. 2000) and thus do not support a high density of belowground fauna. No attempt was made to measure primary production in the present study, but soil fauna density was found to be significantly correlated with vascular plant cover. The density of soil arthropods from the grass reclamation area in the current study was lower than or comparable to the density of soil arthropods in grasslands in east and west Iceland (Halldórsson & Oddsdóttir 2007, Oddsdóttir et al. 2008).

There was a difference in the group composition of soil arthropods in the three sites with different reclamation methods, i.e. birch, lupin and grass sites. Mites, especially Cryptostigmata, were the dominant group in birch plots but springtails, mainly Isotomidae, dominated in lupin plots. In grass plots mites and springtails were codominant. It is known that Cryptostigmata are often the dominant soil arthropod group in mature forest soil (Wallwork 1983) so their dominance in the birch soil was not surprising.

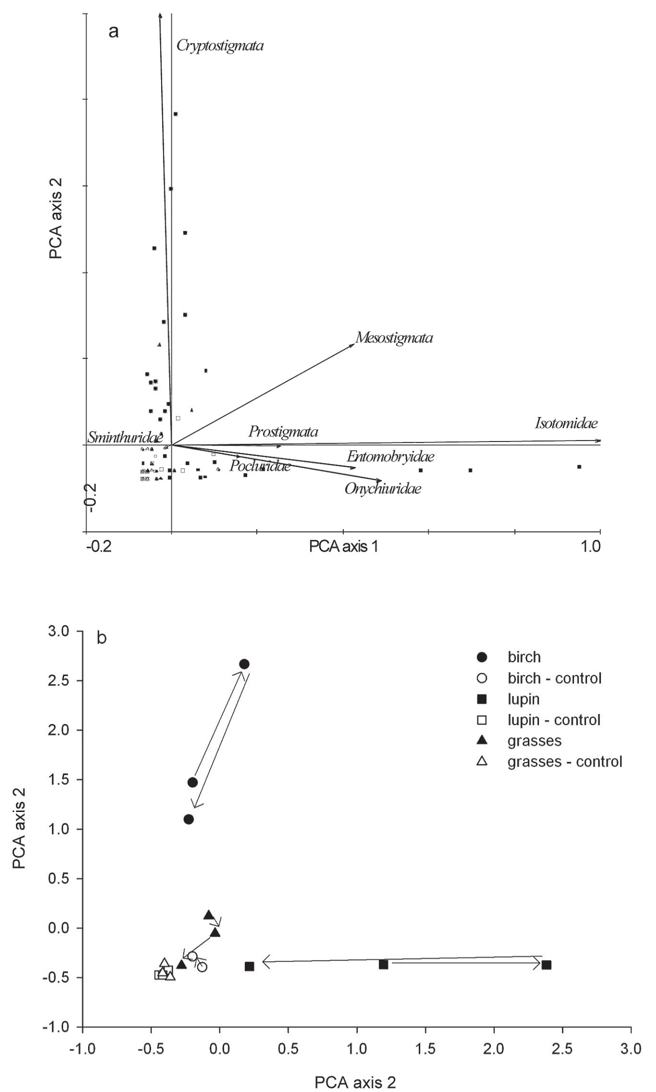

Figure 3. (a) PCA plot summarizing the results from the PCA analysis using all sampling dates (n=90). Samples are shown with symbols and arthropod groups with arrows. (b) Changes in the composition of the arthropod groups between sampling dates are shown with arrows between mean PCA sample scores (n=5) from each sampling date.

Springtails are known as fast-colonisers and often dominate the soil fauna during the first 10 years of colonisation (Kaczmarek et al. 1995, Koehler 1998, Irmler 2000), so that this may well partly explain their dominance in the young lupin plots. It often takes a long time for the soil fauna on reclaimed land to resemble the fauna on undisturbed land (Majer 1990). However, Kaufmann et al. (2002) found that in alpine glacier foreland soil fauna abundance increased rapidly during the first 50 years after deglaciation.

It must be noted that the current study was not set up to compare different reclamation methods. However, the DCA analysis showed that there was relatively small variation in group composition or soil arthropod density amongst the control sites. This suggests that before reclamation started all sites were similar. Therefore it can be concluded that the observed differences between different reclamation methods were either caused by the reclamation method used or the time since reclamation started.

Natural colonisation of degraded areas in Iceland is often very slow and can take decades. Various physical, chemical or biological factors influence the process of succession and ecosystem development (Bradshaw 1993, Walker & Moral 2003) and knowledge of these restricting factors is important for the success of restoration projects. Studies in Iceland show that available plant nutrients, primarily N and P, are the major limiting factors in plant survival and performance (Óskarsson et al. 2006). Bardgett and Chan (1999) showed that soil fauna enhanced nutrient mineralisation and nutrient uptake by grass species in mountain grassland ecosystems in the United Kingdom. This study was conducted at one site in south Iceland and further studies are needed to elucidate the effects of land reclamation and afforestation on soil biota in Iceland. However, the present study showed that the density of soil arthropods was low in untreated areas compared to reclaimed areas and other studies have shown that disturbed areas in Iceland are low in other soil biota (Oddsdottir et al. 2003). Therefore, the restoration of soil arthropod communities, as well as other soil biota, is likely to contribute to restoration of functional ecosystems on eroded land in Iceland.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Bjarni E. Gudleifsson, professor at the Agricultural University of Iceland, for assistance on soil arthropod identification and Jóhann Thorarensen at the Icelandic Soil Conservation for preparation of Figure 1. Financial support from the Icelandic Research Council and Landsvirkjun was greatly appreciated.

REFERENCES

Aradóttir ÁL 1991. *Population biology and stand development of birch (Betula pubescens Ehrh.) on disturbed sites in Iceland.* Dissertation. A&M University, Texas, 105 p.

Aradottir AL & Eysteinsson T 2005. Restoration of birch woodlands in Iceland. In: Stanturf J & Madsen P (eds.) *Restoration of Boreal and Temperate Forests.* CRC/Lewis Press, pp. 195-209.

Aradóttir ÁL, Svavarsdóttir K, Jónsson TH & Guðbergsson G 2000. Carbon accumulation in vegetation and soils by reclamation of degraded areas. Icelandic Agricultural Sciences 13, 99-113.

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

Arnalds O, Aradottir AL & Gudbergsson G 2002. Organic carbon sequestration by restoration of severely degraded areas in Iceland. In: Kimble JM, Lal R & Follet RF (eds.) *Agricultural practices and policies for carbon sequestration in soil*. Lewis Publishers, London, pp. 267-280.

Arnalds O, Thorarinsdottir EF, Metusalemsson S, Jonsson A, Gretarsson E & Arnason A 2001. *Soil Erosion in Iceland.* The Soil Conservation Service and the Agricultural Research Institute, Reykjavik, 121 p.

Baloch J 1972. *The orbatid genera of the world.* Akademiai Kiado, Budapest, 188 p.

Bardgett RD & Chan KF 1999. Experimental evidence that soil fauna enhance nutrient mineralization and plant nutrient uptake in montane grassland ecosystems. *Soil Biology & Biochemistry 31*, 1007-1014.

Bradshaw A 1993. Introduction: Understanding the fundamentals of succession. In: Miles J & Walton DWH (eds.) *Primary Succession on Land.* Blackwell Scientific Publications, Oxford, pp. 1-3.

Elmarsdottir A, Aradottir AL & Trlica MJ 2003. Microsite availability and establishment of native species on degraded and reclaimed sites. *Journal of Applied Ecology* 40, 815-823.

Fjellberg A 1980. *Identification key to Norwegian Collembola.* Norsk entomologisk Forening, 158.

Fjellberg A 1997. *Nordic collembola: Identification keys to genera - Checklist of species.* Swedish University of Agricultural Sciences (Mimeograph), 30 p.

Gilyarov MS 1975. *A key to the soil-inhabiting mites (Sarcoptiformes)*. Nauka, Moscow, 740 p.

Gilyarov MS 1977. *A key to the soil-inhabiting mites.* Mesostigmata. Nauka, Moscow, 1029 p.

Gilyarov MS 1978. *A key to the soil-inhabiting mites* of the Tromvidiformes. Nauka, Moscow, 441 p.

Gjelstrup P 1983. *Mider i hus og haver*. [Mites in houses and gardens]. Naturhistorisk Museum, Århus, 31 p. [In Danish].

Gjelstrup P & Petersen H 1987. *Jordbundens mider og springhaler.* [Mites and collembola in soil]. Naturhistorisk Museum, Århus, 31 p. [In Danish].

Gretarsdottir J 2002. *Long term effects of reclamation treatments on plant succession on two localites in Iceland.* Cand. Scient. Thesis. University of Bergen, Norway, 82 p.

Gretarsdottir J, Aradottir AL, Vandvik V, Heegaard E & Birks HJB 2004. Long-term effects of reclamation treatments on plant succession in Iceland. *Restoration Ecology* 12, 268-278.

Halldórsson G & Oddsdóttir ES 2007. ICE-WOODS: The effects of afforestation on abundance of soil fauna in Iceland. In: Halldorsson G, Oddsdottir ES & Eggertsson O (eds.) *Effects of afforestation on ecosystems, landscape and rural development.* TemaNord 2007, 147-152.

Hooper DU, Bignell DE, Brown VK, Brussaard L, Dangerfield JM, Wall DH, Wardle DA, Coleman DC, Giller KE, Lavelle P, Van der Putten WH, De Ruiter PC, Rusek J, Silver WL, Tiedje JM & Wolters V 2000. Interactions between aboveground and belowground biodiversity in terrestrial ecosystems: Patterns, mechanisms, and feedbacks. *Bioscience* 50, 1049-1061.

Hopkin S 1997. *Biology of the Springtails: Insect - Collembola*. Oxford University Press, 330 p.

Huges AM 1976. *The mites of stored food and houses.* Ministery of Agriculture, Fisheries and Food. *Technical Bulletin*, 400 p.

Irmler U 2000. Changes in the fauna and its contribution to mass loss and N release during leaf litter decomposition in two deciduous forests. *Pedobiologia* 44, 105-118.

Kaczmarek M, Kajak A & Wasilewska L 1995. Interactions between diversity of grassland vegetation, soil fauna and decomposition processes. *Acta Zoologica Fennica* 196, 236-238.

Kaufmann R, Fuchs M & Gosterxeier N 2002. The soil fauna of an Alpine glacier foreland: Colonization and succession. *Arctic, Antarctic and Alpine Research* 34, 242-250

Koehler H 1998. Secondary succession of soil mesofauna: A thirteen year study. *Applied Soil Ecology* 9, 81-86.

Kristinsson H 1987. *Flowering plants and ferns of Iceland.* Mál og Menning, Reykjavík, 304 p.

Macfadyen A 1962. Soil Arthropod Sampling. *Advances in Ecological Research* 1, 1-34.

Magnússon B & Magnússon S 1989. Þættir um vistfræði birkis og not þess í landgræðslu. [The ecology of birch and its use in land reclamation]. In: Arnalds A & Þórhallsdóttir AG (eds.) *Græðum Ísland, Landgræðslan 1988. Árbók II.* Landgræðsla ríkisins, Gunnarsholt, pp. 97-109. [In Icelandic].

Majer JD 1990. Rehabilitation of disturbed land: Long-term prospects for the recolonization of fauna. *The Proceedings of the Ecological society of Australia* 16, 509-519.

Maynard EA 1951. *A Monograph of the Collembola or Springtail insects of New York State.* Comstock Publishing Company Inc., 339 p.

Oddsdóttir, ES 2002. *Áhrif skógræktar og landgræðslu á jarðvegslíf.* [The effects of afforestation and land reclamation on soil biota]. MSc thesis. University of Iceland, 50 p. [In Icelandic].

Oddsdottir ES, Halldorsson G, Nielsen C, Eilenberg J, Harding S, Leivsson T & Sen R 2003. Identification of ectomycorrhiza forming fungi and impact on birch and pine seedling growth in Icelandic soil. *The Fourth International Conference on Mycorrhizae, ICOM4 August 10-15 2003*. Montreal, Canada, 343 p.

Oddsdóttir E, Fjellberg A, Elmarsdóttir Á & Halldórsson G 2008. Áhrif skógræktar með mismunandi trjátegundum á tíðni og fjölbreytileika mordýra (Collembola). [The effects of afforestation with different tree species on density and diversity of Collembola]. *Fræðaþing landbúnaðarins 2008, pp.* 103-110. [In Icelandic].

Oddsdottir ES, Halldorsson G & Sen R 2002. Identification of ecthomycorrhiza forming fungi and impacts on birch seedling growth in Icelandic soil. In: Saari J & Sen R (eds.) 8th *New Phytologist Symposium, Impacts of Soil Microbes on Plant Populations Dynamics and Productivity, June 9-14 2002.* Viikki InfoCentre, Helsinki, Finland, P5 043.

Olgeirsson FG 2007. *Sáðmenn sandanna: saga landgræðslu á Íslandi 1907-2007*. [The cultivation of the sands: The history of soil reclamation in Iceland 1907-2007]. Landgræðsla ríkisins, Reykjavík, 250 p. [In Icelandic].

Óskarsson H, Sigurgeirsson A & Raulund-Rasmussen K 2006. Survival, growth, and nutrition of tree seedlings fertilized at planting on Andisol soils in Iceland: Six-year results. *Forest Ecology and Management* 229, 88-97.

Óskarsson Ú 1984. Framvinda gróðurs, jarðvegs og jarðvegsdýra í ungum lerkiskógi í nágrenni Hallormsstaðar. [The succession of vegetation, soil and soil arthropods in young larch forest]. *Ársrit Skógræktarfélags Íslands 1984, pp*. 32-44. (In Icelandic).

Runólfsson S 1987. Land Reclamation in Iceland. *Arctic and Alpine Research* 19, 514-517.

Sigurðardóttir H 1991. Athuganir á stökkmor (Collembola) í uppgræðslusvæðum á virkjunarsvæði Blöndu á Auðkúluheiði. [Observations of collembola in reclamation sites at Audkuluheidi]. In: Þorsteinsson I (ed.) *Uppgræðsla á Auðkúluheiði og Eyvindarstaðaheiði 1981-1989*. Rannsóknastofnun landbún-aðarins, Reykjavík, pp. 77-87. [In Icelandic].

ter Braak CJF & Smilauer P 2002. *CANOCO reference manual and CanoDraw for Windows user's guide: Software for Canonical community ordination (version 4.5).* Micro-computer Power, Ithaca, NY, USA, 500 p.

Usher MB 1993. Primary succession on land: Community development and wildlife conservation. In: Miles J & Walton DWH (eds.) *Primary Succession*. Blackwell Scientific Publications, Oxford, pp. 283-293.

Van der Putten WH, Vet LEM, Harvey JA & Wackers FL 2001. Linking above- and belowground multitrophic interactions of plants, herbivores, pathogens, and their antagonists. *Trends in Ecology & Evolution* 16, 547-554.

Walker LR & Moral R 2003. *Primary succession and ecosystem rehabilitation.* Cambridge University Press, 348 p.

Wallwork JA 1983. Oribatids in Forest Ecosystems. *Annual Review Entomology* 28, 109-130.

Wardle DA 2006. The influence of biotic interactions on soil biodiversity. *Ecology Letters* 9, 870-886.

Wardle DA, Yeates GW, Williamson W & Bonner KI 2003. The response of a three trophic level soil food web to the identity and diversity of plant species and functional groups. *Oikos* 102, 45-56.

Manuscript received 3 March 2008
Accepted 5 June 2008