Land Restoration Training Programme
Keldnaholt, 112 Reykjavik, Iceland

Final project 2018

BIODIVERSITY OF GROUND CRAWLING ARTHROPODS UNDER DIFFERENT LAND RECLAMATION TREATMENTS IN SOUTH ICELAND

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ABSTRACT

Land reclamation success is often evaluated based on plant community development with little emphasis on arthropod communities. This experiment was conducted to examine arthropod association with reclamation treatments applied to restore degraded rangelands in South Iceland. Ground crawling arthropods were sampled under three reclamation treatments (untreated eroded land; site seeded with grass and fertilized; and site seeded with grass, birch and willow) with three replicate plots per each treatment. Three birch ecosystems were also selected as reference sites for studying arthropod community diversity under birch succession. Arthropods were sampled weekly with pitfall traps for a period of four weeks. Collected specimens were identified to order or species level by comparing with specimens in the collection at the Soil Conservation Service of Iceland. Land reclamation treatment had a significant effect (PERMANOVA, $p = 0.002$, F = 2.45) on arthropod community richness with some species associating exclusively with specific reclamation treatment(s). However, the abundance of arthropods did not differ significantly between treatments ($p = 0.26$, F = 2.85). Grass, birch and spruce treatment recorded the highest (35.3) mean catch/trap/week whilst the lowest (9.6) was recorded in the restored birch forest. Each reclamation treatment provides environmental conditions suitable for some arthropod group(s), which suggests that every treatment has a unique effect on arthropod biodiversity.

Key words: reclamation, diversity, abundance, arthropod

This paper should be cited as:
Nasare IL (2018) Biodiversity of ground crawling arthropods under different land reclamation treatments in South Iceland. United Nations University Land Restoration Training Programme [final project]
http://www.unulrt.is/static/fellows/document/nasare2018.pdf

TABLE OF CONTESTS

1. INTRODUCTION

Arthropods are known to be the most dominant phylum of the animal kingdom, which thrives in diverse ecological niches (Chakravarthy et al. 2016). This essential group of organisms plays vital roles in shaping ecological processes in terrestrial ecosystems (Gullan & Cranston 2010; Bagyaraj et al. 2016). Organic matter decomposition, nutrient cycling, pollination, seed dispersal and predation are among major ecological services provided by arthropods (Losey & Vaughan 2006; Klein et al. 2007; van der Heijden et al. 2008; Ollerton et al. 2011; Clay et al. 2013). For instance, without insect pollination, many interconnected processes within an ecosystem would collapse (Klein et al. 2007). Similarly, pest damage to plants would have been much higher if there were no predatory insects to keep pest below economic thresholds (Losey & Vaughan 2006). Arthropods are often described as ecosystem engineers (Bagyaraj et al. 2016) which contribute significantly to the improvement of bio-physical conditions of the soil through aeration and nutrient cycling (Costanza et al. 1997).

These ecological processes (seed dispersal, pollination, nutrient cycling and decomposition) form the basis of major biological interactions and are therefore essential to ecosystem recovery. Studies in restoration ecology have established positive relationships between invertebrate species richness and soil properties in reclamation sites (Oddsdottir et al. 2008; Hendrychová et al. 2012) which highlights the significance of arthropods in ecosystem recovery. Again, arthropods are known to be susceptible to ecosystem changes (Kremen et al. 1993; Davis et al. 2001; Arun & Vijayan 2004) and their abundance in an area provide a good bio-indicator for measuring ecosystem health and terrestrial ecological processes (Gullan & Cranston 2010). Insect species abundance could therefore be explored as a proxy for monitoring ecosystem recovery in reclamation sites.

Despite the enormous contribution of insects to ecosystem recovery, land reclamation success in many parts of the world has often been measured based on vegetation development with little emphasis on the extent to which these sites support local fauna. In Ghana, there are many efforts towards land reclamation mainly through the establishment of exotic tree plantations. However, the ability of these reclaimed sites to support local fauna, especially insects, have rarely been investigated. This is a case study project in Iceland to examine the ability of different reclamation treatments to support local fauna, especially insects, in degraded rangelands.

1.1 Goal

To assess the diversity and abundance of arthropods in rangelands under different reclamation treatments, with specific focus on restoration of birch ecosystems. Specifically, the study examined the diversity and abundance of arthropod communities and of specific groups of arthropods in order to assess the effect of reclamation practices.

1.2 Objectives

1. To examine the diversity and abundance of arthropods in degraded rangelands under different reclamation treatments.
2. To assess the effect of restoration of birch ecosystems on the succession of arthropod communities.

1.3 Effect of land restoration on arthropod diversity and abundance

The ecosystem successional trajectory in temperate Europe has been described as a sequence of several stages that starts with barren lands covered with sparse annual or biennial plant species that often persist for about 10 years and are later replaced by perennial forbs and followed by shrub land expansion for an estimated period of 15 years, and finally replaced by deciduous tree species after some decades (Prach & Pyšek 2001; Wiegleb & Felinks 2001). However, the diversity of insects at each successional stage is dependent on the spatial and structural conditions of the habitat (Walker & del Moral 2003). Recent studies have shown higher insect biodiversity in spontaneously recovered natural sites than human induced reclamation treatment sites (Tropek et al. 2010; Hendrychová et al. 2012). For instance, in the Czech Republic, natural succession sites had the largest abundance of individuals among all invertebrate groups (true bugs, molluscs, carrion beetles, centipedes, millipedes and isopods) as compared to reclamation treatment sites. A similar pattern was observed among vertebrates when Salek (2012) compared bird communities in a spontaneously developed site with reclaimed sites across all stages of succession.

Studies on the application of restoration treatments in Iceland (Elmarsdottir et al. 2003; Gretarsdottir et al. 2004; Aradottir et al. 2008; Arnalds et al. 2013) have shown that restoration treatments produce different outcomes in terms of ecosystem succession and function. For instance, Aradottir et al. (2008) recorded higher biological crust formation and colonization of native species in fertilizer treatments with seedings as compared to seeded treatments without fertilizer. This observation points out poor soil fertility as the major threshold to ecosystem recovery.

Arthropod communities have shown similar patterns. Oddsdottir et al. (2008) reported a significant effect of land reclamation treatment on soil arthropod composition when soil animals were studied under birch, lupine and grass reclamation treatments in Iceland. However, soil arthropod density responded differently to reclamation methods, with birch and lupine treatments recording significantly higher soil arthropod density than grass seeded treatments. Longcore (2003) observed an inverse relationship between the biodiversity of arthropod species and vegetation height but, on the other hand, a positive relationship was recorded for structural complexity of vegetation at intermediate heights. Therefore, the insect diversity and abundance of an area could be an outcome of the physical and biological complexities of the niche. Again, Longcore (2003) revealed that scavengers were more abundant in restored sites as compared to undisturbed and disturbed sites.

1.4 Gender effect

The role of insects in rangelands is of immense benefits to both men and women. The adoption of reclamation strategies to restore local fauna will therefore benefit both genders because ecosystem services provided by insects (pollination, seed dispersal and the food value of insects) are directly or indirectly beneficial to both men and women in Ghana. Edible insects such as C*irina forda* and some species of termites are often collected by women. These insects are food delicacies that are sold in local markets, providing income for rural women who collect Non-Timber Forest Products. Therefore, the restoration of insect biodiversity will boost the livelihoods of rural women.

Again, the collection of wild fruits of economic importance is an activity normally undertaken by women in northern Ghana. The restoration of insect species in reclaimed sites will enhance the availability of pollinators for wild trees such as shea (*Vitellaria paradoxa*). This will increase fruit yield and in the long run increase the income women derive from the collection of shea nuts. This will also help empower women economically. Some field crops require pollination services from insects for a good yield. The restoration of insect biodiversity in reclamation sites will also provide pollination services for crops often cultivated by men. This would increase crop yield and contribute to the economic empowerment of men as well.

1.5 Policy effects

There are many efforts towards land reclamation in Ghana, mainly targeted at enhancing the vegetation. Different plant species have been used in reclamation works over the years. The relevance of this project is to factor in faunal biodiversity to recommend reclamation treatments that will not only improve the flora of the degraded rangelands but also support local fauna. The study could be a guide for rangeland managers, foresters, pastoralists and other land users in identifying reclamation treatments for maximum fauna and flora.

Ecosystem function will be incomplete without essential services such as decomposition, seed dispersal, pollination and other services provided by insects. For instance, ground dwelling insects such as beetles play important roles in nutrient cycling which enhances the bio-physical conditions of the soil for faster recovery processes. There is therefore the need to identify reclamation treatments that support insects since soil pre-conditioning is essential to restoration success. Hence this study will be important in guiding restoration ecologists on the most efficient reclamation treatments that enhance insect activities to foster faster ecosystem recovery without having to spend much on altering soil conditions. This would therefore guide policy decisions on future restoration works.

2. METHODS

2.1 Experimental site

The experiment was conducted near Gunnarsholt, South Iceland, with three experimental sites (Fig. 1). The main experimental site was in Geitasandur, whilst Gunnlaugsskogur and Naefurholt were used as positive control sites for studying insect communities under birch succession. Geitasandur is an estimated 300 ha experimental field located at 63°49′ N, 20°13′ W where different land restoration treatments are being studied. The site was stratified into upper and lower plains where the lower plain is characterised by sandy surface soils and high incidence of wind erosion which causes rapid deposition of sand in barren areas. The upper plain, on the other hand, was a sandy-lag-gravel surface with an average elevation of 80 – 85 m (Arnalds et al. 2013). According to Aradottir & Halldorsson (2017), the experimental site has since been protected from livestock grazing from the 1990s to date. Restoration treatments were applied to the eroded bare soil in 1999 and have been protected from grazing and anthropogenic disturbances.

The site at Gunnlaugsskogur is a restored birch forest that was established in the 1930s. The area was originally an eroded land that was fenced from livestock grazing and later seeded with lyme grass (*Leymus arenarius*) and finally planted with birch (*Betula pubescens*) in 1939 and 1945 (Magnusson & Magnusson cited in Oddsdóttir et al. 2008). The site is currently characterised by a mature birch forest with semi-closed canopy cover. The surrounding areas of this forest are characterised by sparse vegetation (Oddsdottir et al. 2008)

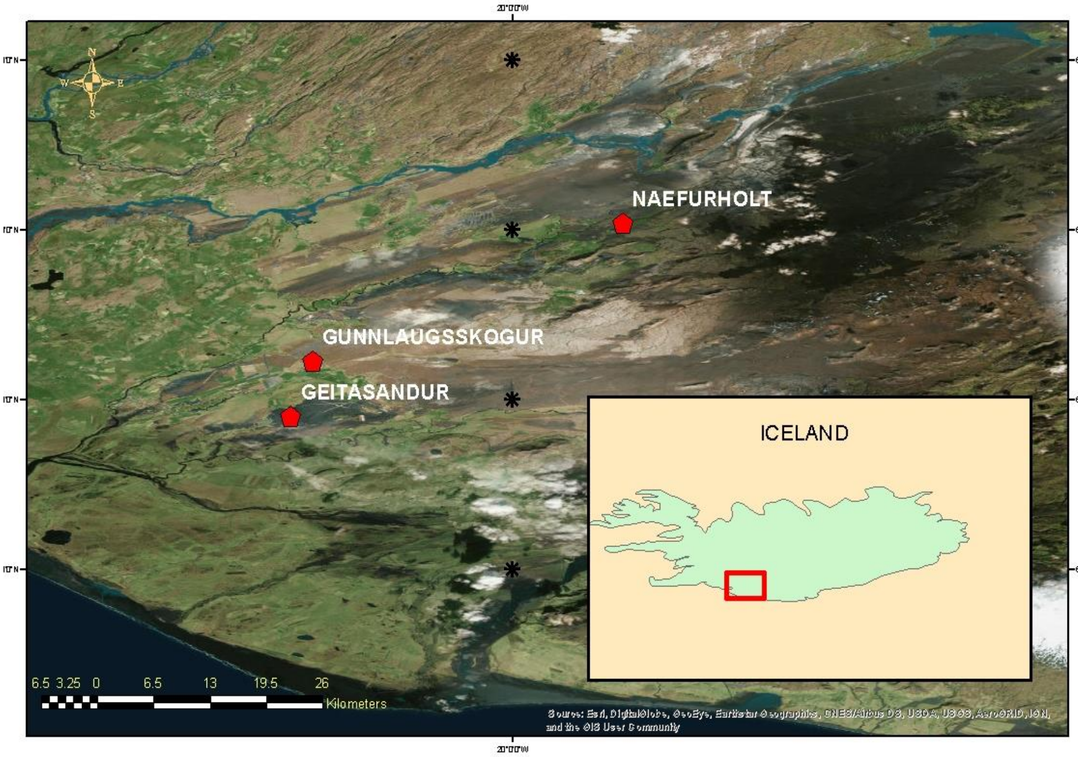

Figure 1. Map showing the three study sites with the inset showing the location of the study area within Iceland.

The site at Naefurholt is a native birch forest which represented a sample of the indigenous flora of the Icelandic landscape. The dominant tree species is birch with a dense herbaceous undergrowth protecting the soils from wind and water erosion. The site conditions are like those of Gunnlaugsskogur except that the native birch forest had a denser canopy cover.

The soils of Gunnarsholt and its surrounding areas have generally been classified as Vitric Andosols with sandy loam in the A and B horizons (Arnalds et al. 2013). Organic carbon content was estimated to be 0.2% in the top 10 cm of the soil and the surface is maintained by the frost heave of gravel during winter (Arnalds et al. 2013). The area is generally characterised by sparse vegetation which was attributed to desertification in medieval times (Hjartarson, cited in Aradottir & Halldorsson 2017). The limited organic cover on soil surface has made the soils prone to frost and wind actions.

The climate data from the Icelandic Meteorological Office for 1971-2000 shows an average annual precipitation of 1,260 mm based on climate data from the nearest weather station, Hella. The average monthly temperatures for July and January are 11°C and -2°C respectively. However, soil temperature in the summer is often above the average air temperatures due to the dark basalt parent materials (Arnalds et al. 2013).

2.2 Experimental design

The Geitasandur experimental site originally consisted of 4 blocks and 10 treatments organised in a randomized complete block design (Aradottir et al. 2008). However, heavy sand encroachment has destroyed many plots on the lower plain, where most of the plots of Block G and H were situated. In addition to this, several plots have been damaged by invasion of lupine (*Lupinus nootkatensis*). The present study included the following treatments with three replicate plots per treatment; 1) Control: untreated, eroded land; 2) Seeded with grasses (*Poa pratensis* and *Festuca rubra*) and fertilized; and 3) Seeded with grasses and planted with clusters of birch and willows (*Salix phylicifolia* and *S. lanata*). In addition to these, there were three reference sites; A) Seeded with grass and planted with birch and spruce; B) Restored birch forest; and C) Native birch forest (Fig. 2). Reference site A was originally part of the Geitasandur experimental setup. Now, most of the spruce has died and the plots are now dominated by 1-2 m high birch shrubs. However, all except one of these plots have either been invaded by lupine or destroyed by sand encroachment. Therefore, we decided to include this treatment only as a reference site.

Treatments 1, 2, and 3 were located at Geitasandur, as well as Reference site A, whilst Reference sites B and C were established in Gunnlaugsskogur and Naefurholt respectively. In Geitasandur, seeding of grasses and fertilization was first done in the autumn of 1999 and repeated in 2001, 2003, 2005, 2008 and 2012 for treatment 2. Seeding was done with *Festuca rubra* and (red fescue) and *Poa pratensis* (smooth meadow) grasses at rates of 8.7 and 17.3 kg/ha, respectively (Aradottir & Halldorsson 2017). Fertilizer was also applied at a rate of 50 kg N/ha and 27 kg P_2O_5/ha each time.

Treatment 3 had four clusters of birch and two clusters of willow per plot with each birch cluster having an estimated 80 birch seedlings planted in three contours. The willow clusters on the other hand were about 8 × 25 m with 80 cuttings planted into evenly spaced contour strips (Aradottir & Halldorsson 2017). The woody species (birch and willow) were planted in May 2002 and refilled in 2003 to replace dead seedlings. Four species of native legumes (*Vicia cracca, Vicia sepium, Lathyrus japonicus, and Lathyrus pratensis)* were also planted within the willow and birch clusters in 2002. However, Aradottir et al. (2008) reported that the native legumes did not have any significant influence on the vegetation cover of the treatment because of poor survival rates.

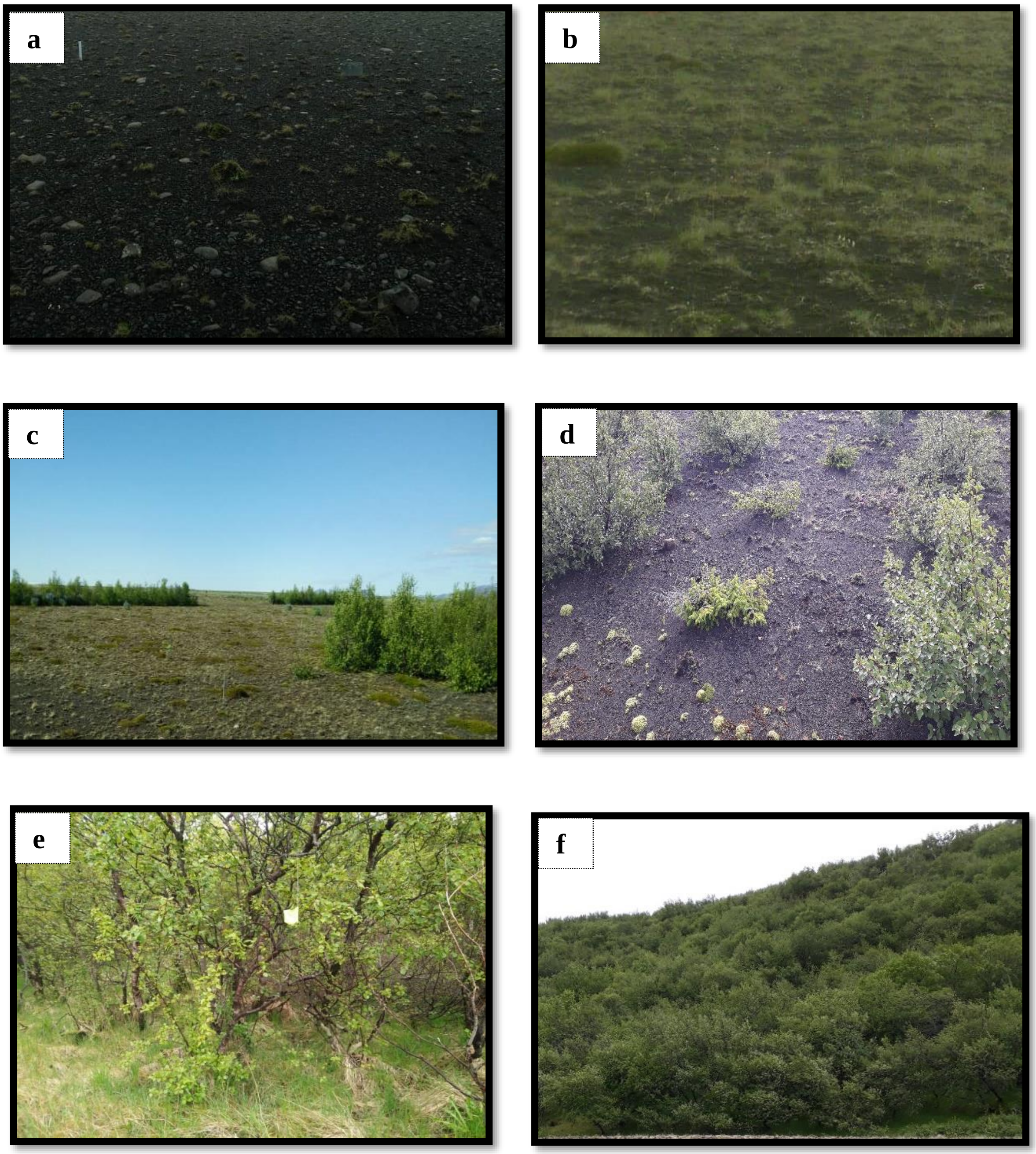

Figure 2**.** Experimental treatments (a – Control, b – Grass and fertilizer, c – Grass, birch and willow) and reference sites (d – Grass, birch and spruce, e – Restored birch forest and f – Native birch forest)

2.3 Arthropod sampling

The study focused on ground crawling insects in all reclamation treatment sites (Longcore 2003). Pitfall traps were used for sampling arthropods since this method has been widely used in catching ground surface-active invertebrates (Hendrychová et al. 2012). Traps were made of two plastic containers of about 7 cm wide and 8 cm deep buried to the ground such that the rim of the inner container was levelled with the ground surface (Fig. 3). The inner container was emptied weekly with minimal disturbance to site conditions (Ward et al. 2001). Containers were half-filled with antifreeze (ethylene glycol) to preserve invertebrates. Two drops of liquid soap were added to the ethylene glycol to reduce surface tension. A plastic plate, about 20 cm in diameter, supported with two pieces of iron rods, was used in casting a water-proof cover over the trap to prevent the container from collecting water during down pours (Fig. 3). The plastic plate was placed 2 cm above the soil surface to allow space for creeping insects to crawl into the trap.

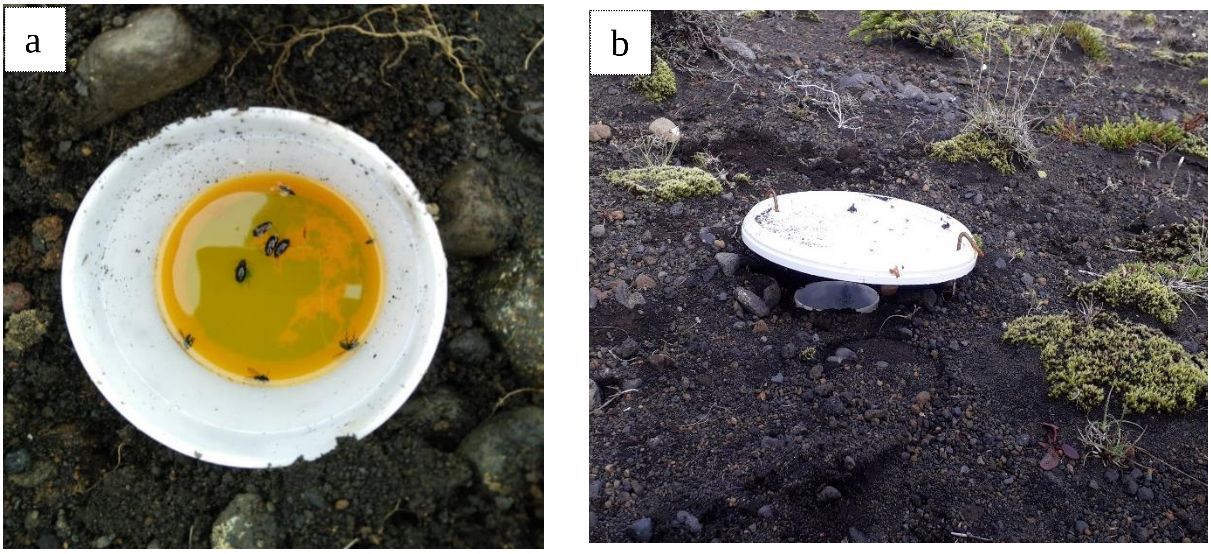

Figure 3. (a) Ground crawling arthropods were captured using pitfall traps. (b) Traps were protected from collecting water during downpours with a plastic plate cover.

Two traps were set in each plot with traps located randomly in the middle of the plot to minimize edge effect from adjacent site conditions (Taboada et al. 2004). Traps were, however, spaced at a minimum distance of 5 m apart to avoid sampling bias associated with closely spaced pitfall traps (Ward et al. 2001). Traps were established on June 25th and emptied weekly from 25th of June to 23rd of July 2018. Collected specimens were retrieved from the trap by pouring out specimens drowned in ethylene glycol into plastic containers (Fig. 4) and transported to the laboratory of the Soil Conservation Centre of Iceland for processing and identification.

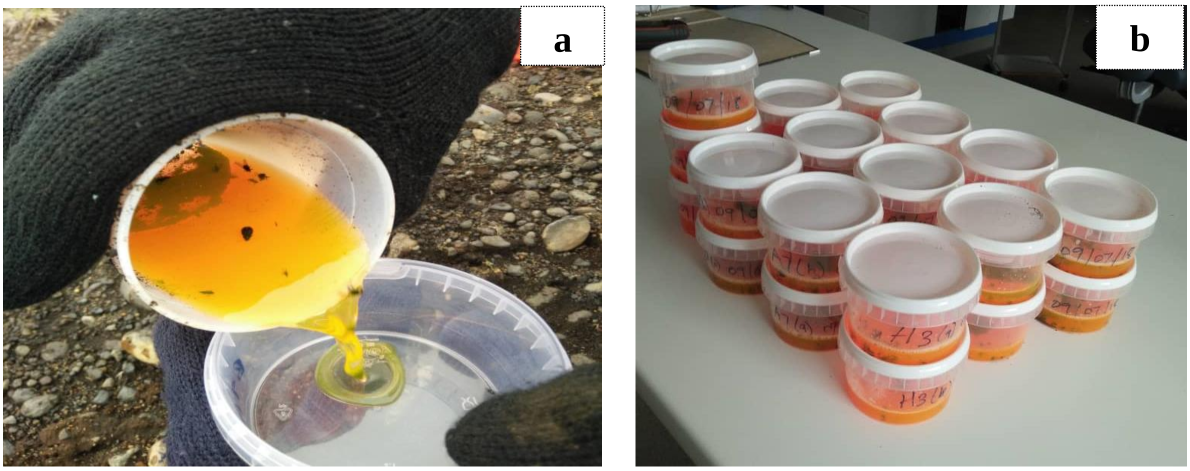

Figure 4. (a) Collecting specimens from the traps involved pouring them into containers. (b) Specimens were stored in containers until identification.

2.4 Specimen identification

Samples were processed in the laboratory by sieving out insect specimens from the ethylene glycol into petri dishes and observed under the microscope (Fig. 5). However, bigger insects that could be seen clearly were observed with the naked eye. Identification was done to genus or species levels by comparing specimens with identified insects in collection, pictures and taxonomic descriptions in books (Chinery 1977; Richards & Davies 1977). Expert identification was sought from Gudmundur Halldorsson and Brynja Hrafnkelsdottir for insects that could not be identified with the available resources.

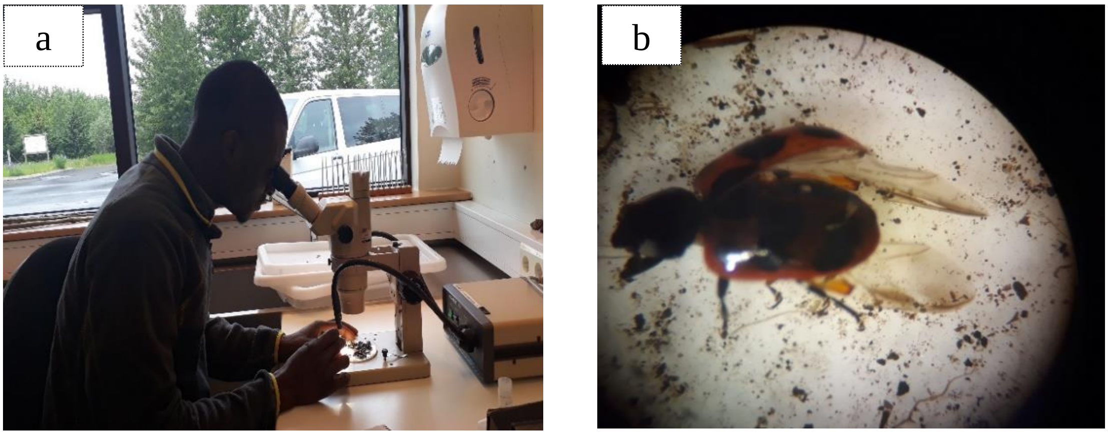

Figure 5. (a) Specimen being observed under microscope. (b) Ladybird beetle observed under microscope.

2.5 Data analysis

Multivariate analysis (Non-Metric Multidimensional Scaling) was used in comparing arthropod diversity between treatments using R Core Team (2018). Analysis of Variance was used in separating mean arthropod abundance between reclamation treatments and to assess differences in catch/trap/week for various arthropod groups. The confidence level was set at 95% for all analyses. Results were presented in descriptive statistics using graphs and tables with Microsoft Excel.

3. RESULTS

3.1 Effect of land reclamation treatment on the diversity of arthropods

A total of 2,430 invertebrates belonging to seven taxonomic groups; Coleoptera, Diptera, Hemiptera, Hymenoptera, Lepidoptera, Arachnidae and Collembola were recorded in the study. One group, Carabidae (Coleoptera) was identified to the species level. In total eight Carabidae species were recorded (Table 1). Three species, outside Carabidae, were recorded: *Dilophus femoratus*, *Dolichopus plumpies* (Diptera) and *Mitopus morio* (Arachnidae). In terms of abundance, Diptera recorded the highest abundance constituting 62.4% of all individual species collected, followed by the Arachnidae with 15.6% (Fig. 6). The least abundant orders were the Lepidoptera and Hemiptera with 0.4 and 0.3%, respectively.

Arthropod richness across reclamation treatments revealed that various reclamation treatments tend to support specific arthropod groups. The grass, birch and willow treatment recorded the highest coleopteran richness (6) whilst the least coleopteran richness was recorded in the grass and fertilizer treatment. The Arachnidae had the highest richness (3) in the matured birch ecosystems (restored birch forest and native birch forest) but recorded two species under all other treatments. On the other hand, the least Diptera richness (2) was recorded in the restored birch forest. Parasitic wasp spp. (Hymenoptera) were found in all treatments except control A and grass, birch and spruce. Collembola spp. was, however, common to all reclamation treatments (Table 1).

Table 1. Arthropod richness under different reclamation treatments (1, control A; 2, grass and fertilizer; 3, grass, birch and willow) and reference sites (A, grass, birch and spruce; B, restored birch forest and C, native birch forest).

		Reclamation treatment			**Reference site**		
Arthropod taxa	**Species/Genus**	**1**	**2**	**3**	**A**	**B**	**C**
Coleoptera	*Amara quenseli*	x	x	x	x	x	
	Nebria gyllenhali					x	x
	Hypnoidus riparius	x					
	Coccinella undecimpunctata			x			
	Otiorhyncus arcticus		x	x	x		x
	Patrobus septentrionis	x				x	
	Notiophilus biguttatus			x	x		
	Omalium excavatum					x	
	Carabidae spp.			x			
	Staphylinidae *spp.*			x		x	x
Diptera	*Dilophus femoratus*	x	x	x	x		x
	Dolichopus plumpies	x					
	Chironomidae spp.	x	x	x	x	x	x
	Other flies	x	x	x	x	x	x
Hymenoptera	Parasitic wasp spp.		x	x		x	x
Hemiptera	Aphididae spp,		x		x	x	
Lepidoptera	Noctuidae spp.	x		x	x		
Arachnidae	*Mitopus morio*	x	x	x		x	x
	Araneae spp.	x	x	x	x	x	x
	Acari spp.					x	x
Colembolla	Collembola spp.	x	x	x	x	x	x

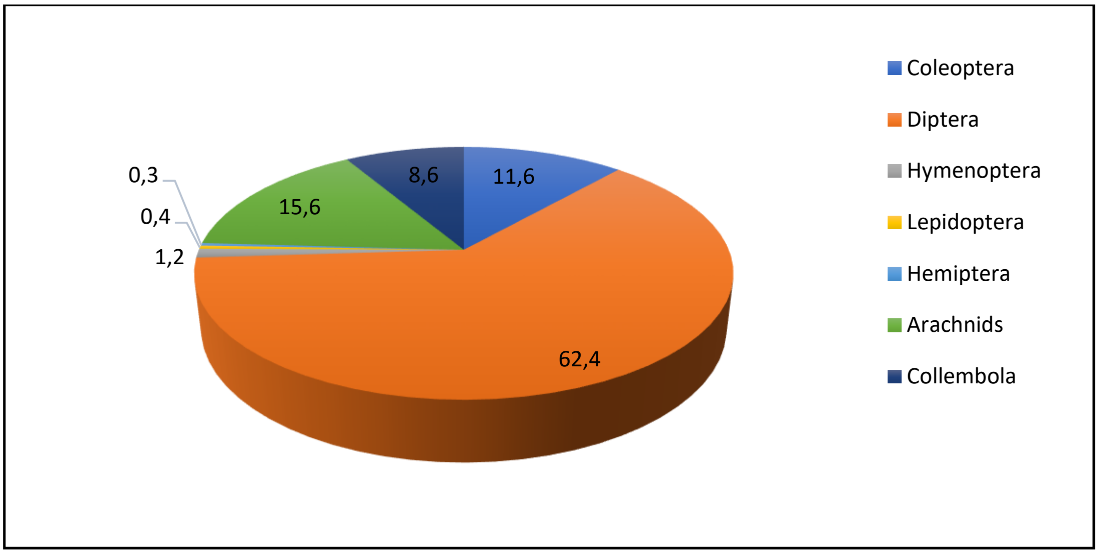

Figure 6. Percentage composition of arthropods collected in the study.

Non-Metric Multidimensional Scaling (NMDS) revealed a significant effect of reclamation treatment on the diversity of the arthropod community (PERMANOVA, F = 2.46, p = 0.002). The non-overlapping polygons of native birch forest and restored birch forest show that the arthropod communities in these sites were significantly different from all other treatments. However, the overlap of polygons for all treatments in Geitasandur shows that the arthropod community of Geitasandur did not differ significantly between treatments (Fig. 7).

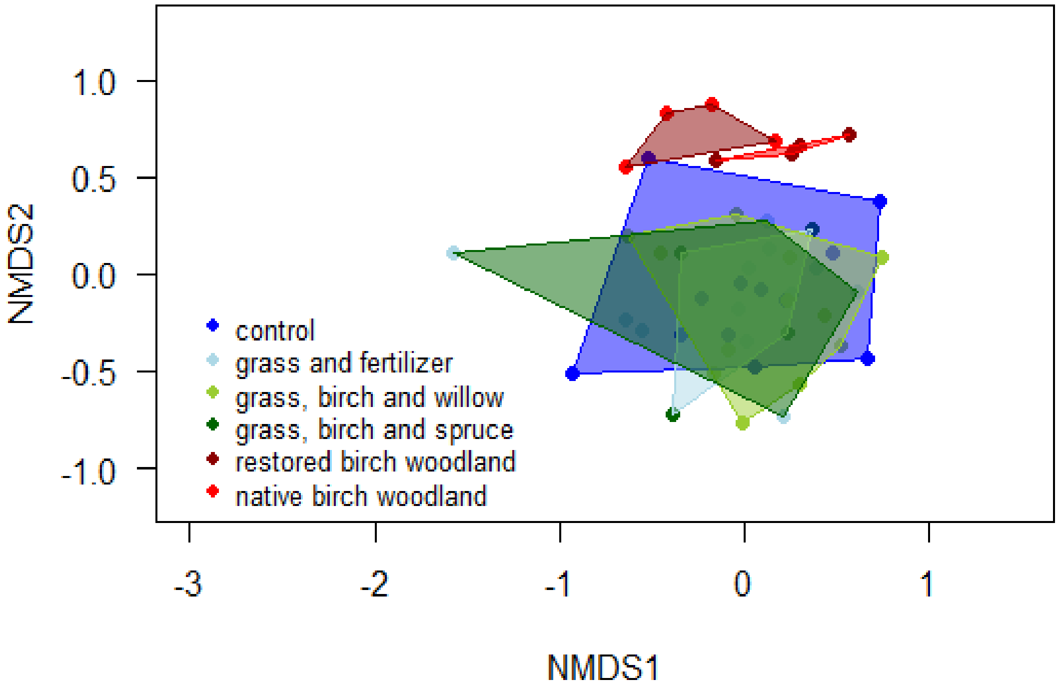

Figure 7. Non-Metric Multidimensional Scaling (NMDS) polygons of arthropod community in different reclamation sites.

3.2 Effect of reclamation treatment on the abundance of arthropods

The mean arthropod catch/trap/week did not differ significantly between reclamation treatments ($p = 0.26$, F = 2.85). However, the highest mean catch/trap/week (37.5) was recorded in the grass, birch and spruce site followed by the grass, birch and willow site with 25.6 catch/trap/week. The least mean catch/trap/week (12.1) was recorded in the restored birch forest (Fig. 8).

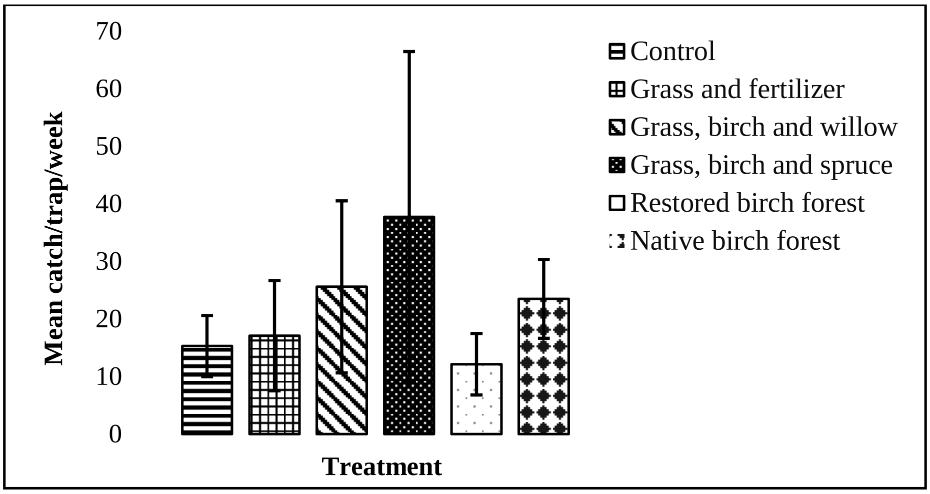

Figure 8. Mean arthropod catch per trap per week under different reclamation treatments.

3.2.1 Distribution of Coleoptera under different reclamation treatments

Amara quenseli recorded the highest mean collection per trap per week under all treatments except native birch forest that had *Staphylidae spp*. as the dominant collection per trap (1.4). *Nebria gylenhali* recorded a mean of 0.6 and 0.9 individuals per trap in the restored birch forest and the native birch forest, respectively (Fig. 9).

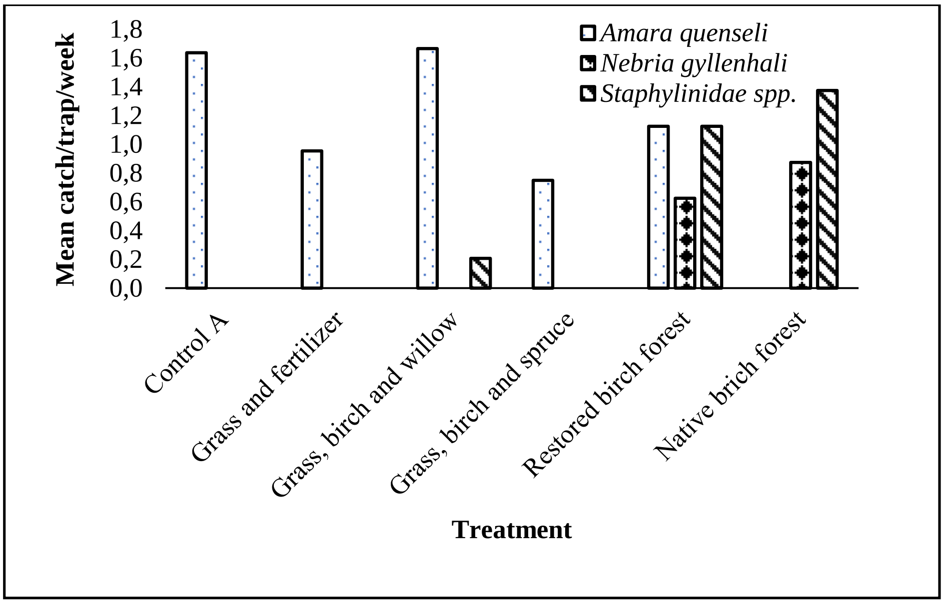

Figure 9. Mean catch per trap per week for the most abundant Coleoptera.

3.2.2 Distribution of Diptera under different reclamation treatments

Other flies recorded the highest catch per trap under most reclamation treatments except the restored birch forest where *Chironomidae spp.* recorded the highest catch per trap. *Dilophus femoratus* occurred as the second most abundant catch per trap in all treatments except the native birch forest (Fig. 10).

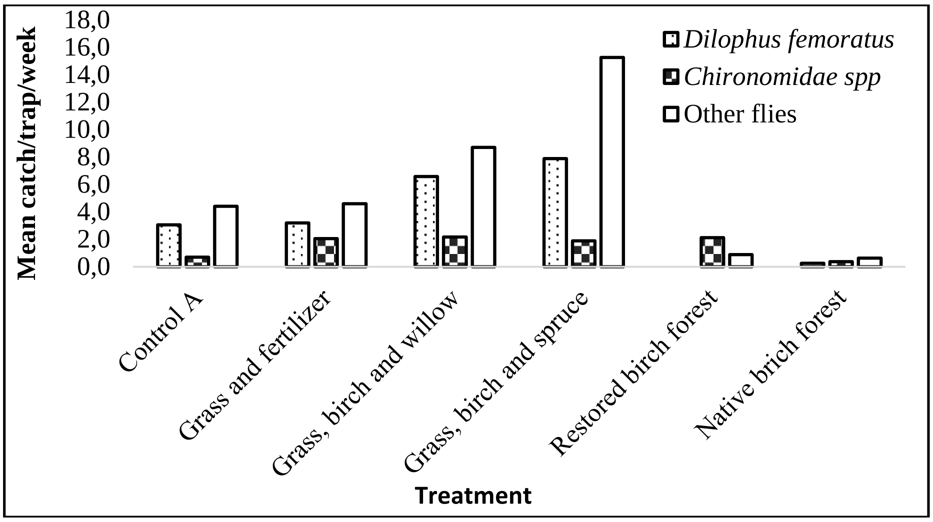

Figure 10. Mean catch per trap of dipterans under different treatments.

3.2.3 Distribution of other insects under different reclamation treatments

The parasitic wasp spp. was the most abundant catch per trap in most reclamation treatments except the control A and the grass, birch and spruce. However, Noctuidae and aphids recorded higher catches per trap, 0.2 and 0.1 under control A and grass birch and spruce treatments, respectively (Fig. 11).

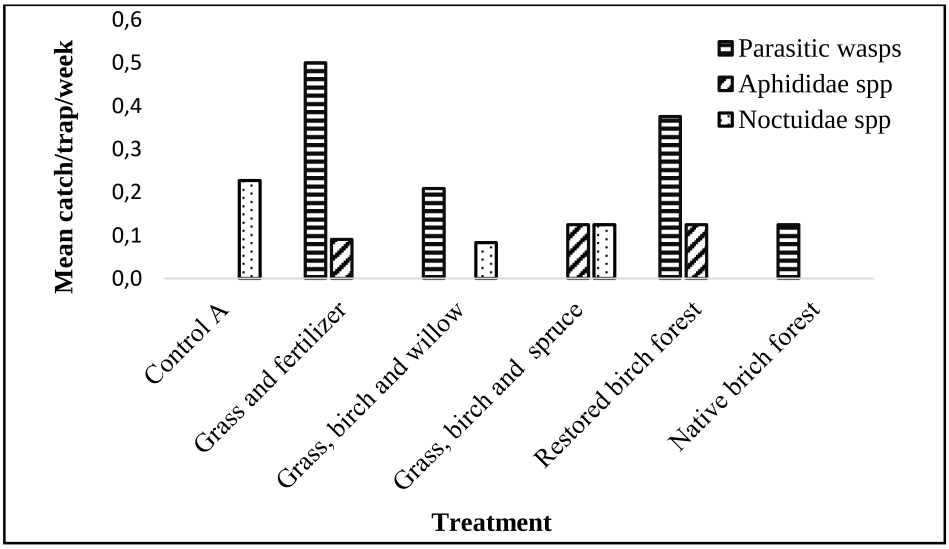

Figure 11. Mean catch per trap of other insects under different treatments.

3.2.4 Distribution of Arachnidae under different reclamation treatments

Spiders dominated among arachnids in all reclamation treatments with the highest (3.3) mean catch/trap/week recorded under grass birch and spruce. *Mitopus morio*, which was the only Arachnidae species identified, was found in all treatments, but was most common in the native birch forest. Mites had the least catch per trap recording of 0.1 mean catch/trap/week in the restored birch forest and the native birch forest (Fig. 12).

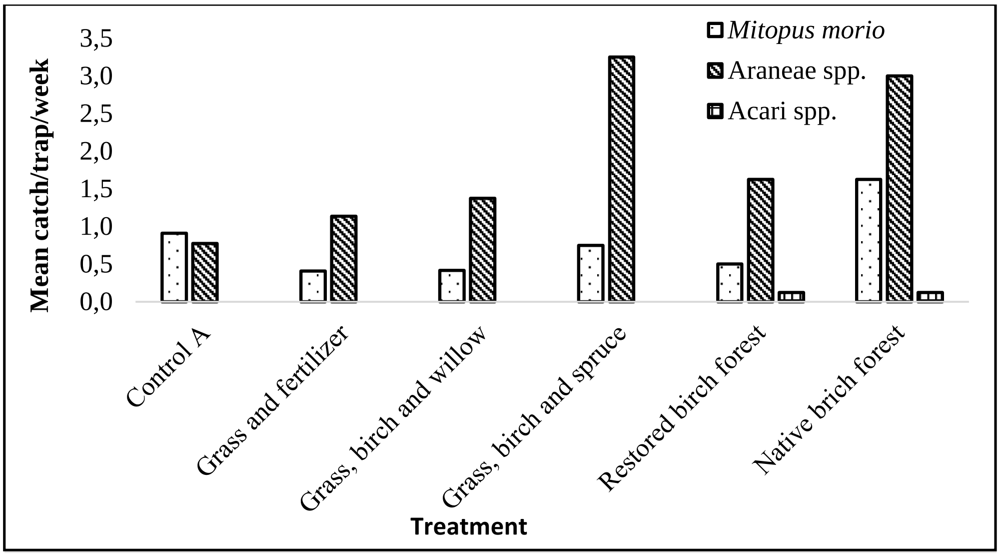

Figure 12. Mean catch per trap per week of arachnids under different treatments.

3.3 Arthropod abundance under birch community succession

There was no significant difference in arthropod abundance under different birch successions (p = 0.328, F = 3.708). The highest mean catch/trap/week (37.8) was recorded under grass, birch and spruce whilst the lowest (12.1) was recorded in the restored birch forest (Fig.13)

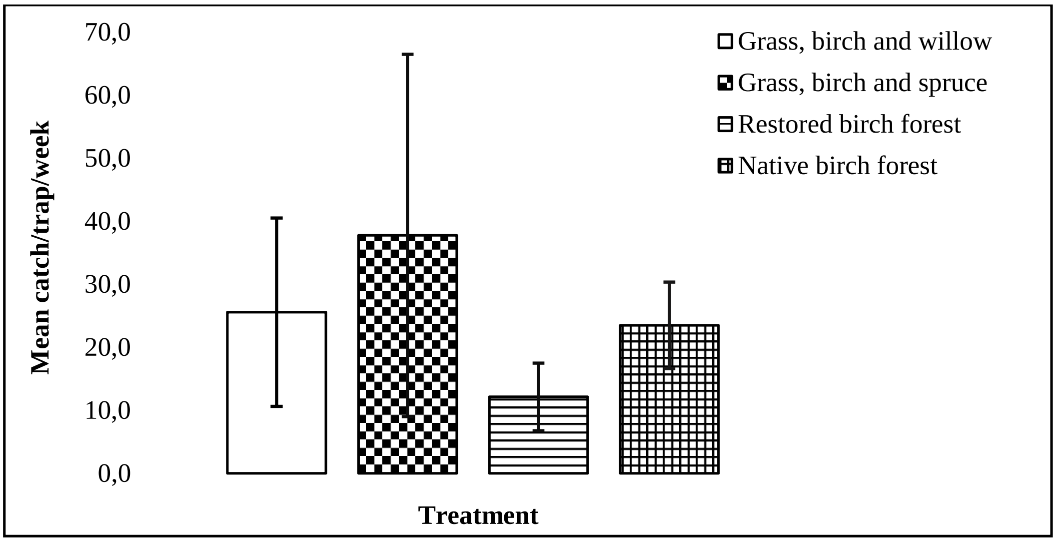

Figure 13. Mean arthropod catch/trap/week under different birch ecosystems.

4. DISCUSSION

4.1 Diversity and abundance of arthropods under different reclamation treatments

Insect community richness varied slightly when compared with Halldorsson et al. (2004) who studied arthropod communities in Geitasandur and Gunnlaugsskogur. For instance, *Nebria gylenhali*, which was recorded in Geitasandur in the grass, birch and willow site, was not found in any of the reclamation treatments at Geitasandur in the present study. This species only occurred in the matured birch ecosystems (restored birch forest and native birch forest). Again, species such as *Quedius fulvicolis*, *Calathus menacephalus*, and *Oxylopoda spp* were recorded in the study of Halldorsson et al. (2004) but this study did not include identification of these or other Staphylinidae species. On the other hand, *Partrobus septentrionis*, which was recorded under control A (untreated eroded land), was not found in the study of Halldorson et al. (2004). Moreover, the occurrence of lady bird beetles (*Coccinella undecimpunctata*) in Geitasandur was dissimilar to the findings of Halldorsson et al. (2004). This reveals a variation in the association of various arthropods with reclamation treatments over time. These changes in insect response to reclamation treatments could be attributed to changes in bio-physical conditions along successional stages.

The NMDS revealed a similarity in the insect community of Geitasandur with Carabidae beetles and Arachnids being dominant in most sites. This confirms the results of Konig et al. (2011) who indicated that Carabidae and Arachnids are often pioneer predators that feed on resident Collembola. The presence of these taxonomic groups suggests the habitats are still at early successional stages with minimum differences in microclimatic conditions, which explains their ability to support similar arthropod groups. This similarity in arthropod richness response to reclamation treatments at Geitasandur was equally reported in Halldorsson et al. (2004).

Although vegetation development is known to be associated with increasing carabid community richness (Gobbi et al. 2006), the findings of the present study do not conform to this hypothesis because some reclamation treatments of Geitasandur recorded a significantly higher arthropod richness and abundance than the matured birch ecosystems. This tends to suggest that arthropod communities could be formed even without dense vegetation cover, which conforms to the "predator first hypothesis" of Hodkinson et al. (2002). This finding also agrees with Bråten et al. (2012) who recorded rich invertebrate communities in younger glacial retreated forelands than older forelands with higher vegetation cover in Norway.

This observation perhaps points out the advantage of open bare ground landscapes in supporting arthropod biodiversity in arctic climates. Bare ground conditions tend to favour arthropod activities by providing relatively warmer microclimates through their ability to absorb and slowly release heat at night, and more importantly bare ground areas enhance easy movement of predators in search of prey (Hågvar & Pedersen 2015). These conditions might have accounted for the high arthropod catches in treatments with patches of open bare grounds (control A; grass and fertilizer; grass, birch and willow; and grass, birch and spruce treatments) over the restored birch forest.

Therefore, with a good food supply, the bareground system could be a safe habitat for several arthropod species. Chironomidae spp. and moss could have been the main source of food for omnivorous arthropods (*Amara quenseli* and *Mitopus morio*) in treatments such as the control A and grass and fertililizer treatments. In Norway, chironomidae constituted a good portion of the diet found in the guts of pioneer predators in post-glacier receded sites (Hågvar & Pedersen 2015).

Despite the general abundance of most Coleoptera in Geitasandur, S*taphyilinidae spp*. occurred predominantly in the matured birch ecosystems. This confirms the results of Kauffmann (2001) who reported Staphylinidae among late colonizers. This finding also agrees with Halldorsson et al. (2004) who recorded a higher abundance of Staphylinidae (*Atheta spp*) in Gunnlaugsskogur (restored birch forest) as compared to the reclamation treatments at Geitasandur. The occurrence of *Mitopus morio* as the second most abundant Arachnidae under most reclamation treatments might be an outcome of the generalist feeding habit of the species (Hågvar & Ohlson 2013), which explains its affinity in all treatments.

Amara quenseli prefers drier soil conditions to moist conditions (Bråten et al. 2012) and this phenomenon could have accounted for the higher catches of this species among Geitasandur treatments than the matured birch ecosystems. The dense canopy cover together with herbaceous undergrowth, shielded the soil surface from solar radiation which kept soils relatively moist in mature birch ecosystems as compared to the treatments at Geitasandur. Similarly, Halldorsson et al. (2004) recorded higher abundance of this species at Geitasandur than Gunnlaugsskogur (restored birch forest). On the other hand, *Patrobus septentrionis* is known to prefer moist soil conditions (Bråten et al. 2012) and this perhaps accounted for its higher occurrence in the restored birch forest than any of the treatments at Geitasandur.

According to Gullan & Cranston (2010) the diversity of arthropods in an ecosystem tend to be an indicator of ecosystem quality and success of a reclamation treatment. The fact that some invertebrate species associated exclusively with some reclamation treatments is an indication that all reclamation methods have their unique contributions to arthropod community richness. This also highlights the variations in environmental conditions created by these treatments.

4.2 Arthropod richness in birch ecosystems

The higher arthropod biodiversity recorded in the grass, birch and spruce treatment as compared to the restored birch forest and native birch forest could be due to the horizontal habitat heterogeneity created by the tree clusters of the former. The two birch ecosystems at Geitasandur had had spruce and willow planted between birch patches, thereby creating heterogeneous tree ecosystems. This assertion supports the results of Hendrychová et al. (2012) where higher arthropod richness occurred in mosaics of natural succession sites with heterogeneous tree clusters rather than the homogeneous tree plantations in post-coal mining sites.

Aside from tree species heterogeneity, the arrangement of components might have perhaps also influenced arthropod association with these ecosystems. The birch ecosystems at Geitasandur had trees planted in clusters with open grasslands or bare ground areas occurring as a sandwich between tree clusters. This could have increased landscape diversity in favour of diverse arthropod groups. Mosaic microlimates were observed to have a positive influence on arthropod richness (Kozlov & Zvereva 2007). Basking and fast-running arthropods prefer small, sunny and non-vegetated patches within the landscape. Similarly, ants were found to have higher diversity in open mosaics of patch vegetation than closed canopy covered landscapes (Holec & Frouz 2005). Perhaps insect association with a reclamation treatment is not only an outcome of plant species used in restoration but could also be influenced by the patterns in which elements are arranged.

5. CONCLUSION

Reclamation treatments applied in restoring degraded land tend to have implications on the specific arthropod species that can associate with the new habitat created. Some arthropod groups were limited to specific reclamation treatment(s). Again, arthropod abundance in a restored land area could be influenced by the type of reclamation treatment applied. Therefore, achieving a well-developed vegetation cover should not be the ultimate outcome of a reclamation treatment, but the impact of the reclamation treatment on the biodiversity of arthropods should also be considered.

In Ghana, there has been little research on the influence of land reclamation methods on faunal biodiversity. The outcome of this study is a trigger for ecologists to examine the biodiversity outcomes of the tree plantations predominantly used for land reclamation in Ghana. Such studies would guide future reclamation works to enhance faunal biodiversity in degraded rangelands.

Recommendations

Future reclamation works should adopt treatments with high plant diversity with horizontal habitat heterogeneity since heterogeneous landscapes supported more arthropod diversity than homogeneous landscapes.

Further studies should be conducted across seasons with a multi-year comparison of arthropod biodiversity since the climatic conditions of the study period could have also influenced arthropod activities.

Again, subsequent studies on the topic should consider multiple-sampling methods to capture all arthropod groups to provide a more holistic outcome on arthropod biodiversity.

ACKNOWLEDGEMENTS

I wish to express my gratitude to UNU-LRT for this opportunity to study in Iceland and the financial support provided during this programme. Again, I wish to thank the Agricultural University of Iceland and the Soil Conservation Service of Iceland for the laboratory equipment and the serene environment provided for this study.

Institutions are made of individuals, I therefore want to express my gratitude to some individuals who contributed to the successful completion of this work. I wish to thank the staff of UNU-LRT (Dr Hafdís Hanna Ægisdóttir, Berglind Orradóttir and Halldóra Traustadóttir) for all their guidance and encouragement during this project.

I am grateful to my supervisor, Dr Gudmundur Halldorsson for his intellectual contribution and guidance that made this work a success. I am also indebted to Isabel Barrio for her support in data analysis and editing of this work and Brynja Hrafnkelsdóttir for help with identification work. I also wish to express my gratitude to Nana Esi Aidoo for her assistance during field data collection.

Finally, I wish to express my gratitude to Prof. Gabriel Teye, Vice Chancellor of the University for Development Studies (UDS), Dr Elliot H. Alhassan, Dean, Faculty of Natural Resources and Environment (FNRE) and Mr William J. Asante, Head, Department of Forestry and Forest Resources Management, for granting me the opportunity to attend this programme.

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APPENDICES

Appendix 1: PERMANOVA for arthropod richness

	df	Sums of Sqs	Mean Sqs	F. Model	R^2	Pr (>F)
fTTM	5	2.4857	0.49714	2.4594	0.22648	0.002**
Residuals	42	8.4898	0.20214		0.77352	
Total	47	10.9755			1.00000	

Significant at 0.05**

Appendix 2: ANOVA for mean arthropod catch/trap/week for all treatments

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1712.23	5	342.446	1.455692	0.258417	2.852409
Within Groups	3763.94	16	235.2463			
Total	5476.17	21				

Appendix 3: ANOVA for insect abundance in birch ecosystems

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1319.032	3	439.6774	1.297407	0.328519	3.708265
Within Groups	3388.894	10	338.8894			
Total	4707.926	13				