Fall 2019

An Evaluation of Soils on Sólheimajökull Glacier Foreland: Using Invertebrates and Decomposition as Bio-indicators of Soil Quality

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Iceland and Finland: Climate Change and the Arctic

November 21, 2019

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Acknowledgements

I would like to thank everyone that assisted me with this project. First, I would like to thank Alex Tyas and Dan Govoni for helping me formulate my ideas into a testable experiment and for their support throughout the ISP period. Additionally, I am grateful to Dan for lending me a microscope and dissolved oxygen probe as well as assisting me with statistical analyses and graphs. I would also like to thank Eliot Chalfin-Smith for his help at the glacier. He assisted with measuring distances between sites and carrying soil samples. Lastly, I want to thank the staff at Arcanum Mountain Guides for their hospitality during my time at Sólheimajökull Outlet Glacier.

Abstract

Anthropogenic climate change has led to the retreat of glaciers globally. As glaciers melt, they expose the underlying land- termed the glacier foreland. These forelands provide a natural laboratory for studying ecological succession after a massive disturbance, which is in this case glaciation. In this study, soil invertebrates and decomposition are used as bio-indicators of the soil quality in the foreland of Sólheimajökull Outlet Glacier. Soil cores were collected from five sites (A-E) located 300m apart moving away from the glacier terminus. The abundance of each observed invertebrate taxa and the dissolved oxygen (DO) levels were taken for 30 soil samples (6 from each site). Total organism and taxa count increased in sites of increasing distance from the glacier terminus. Results showed a significantly low abundance of annelids closest to the glacier, a low abundance of nematodes farthest from the glacier (Site E), no difference in arthropods and a high abundance of rotifers at Site E. Site E also exhibited a significantly low change in dissolved oxygen. This data points to significant differences in taxa and decomposition at the location farthest from the glacier terminus and suggests a shift in the soil quality. Changes in species interactions, nutrient levels and the possibility of a retrogressive succession stage are all theories for this apparent shift.

Key words: climate change; Sólheimajökull; glacier foreland; ecological succession; invertebrates; decomposition

1. Background Information

1.1 Glacier Retreat

Glaciers are valuable tools for reconstructing climate dating back thousands of years and can serve as indicators of current climate change. As atmospheric temperatures continue to rise, glaciers are melting at an alarming rate. Fluctuations in glacier extent before 1900 can be attributed to internal climate variation (Reichert, Bengtsson & Oerlemans, 2002). However, the recent changes in glacial extent and mass are not fully explained by internal climate variability and thus point to anthropogenic forcings (Reichert, Bengtsson & Oerlemans, 2002). Glaciers in Iceland have been monitored since 1930 and from 1951 to present, the Glaciological Society has been in charge of monitoring (Sigurđsson et al., 2007). The extent of Iceland's glaciers has fluctuated over the past century with periods of significant recession paired with periods of growth. However, after 2010, every glacier in Iceland was retreating (Sigurđsson et al., 2007).

1.2 Sólheimajökull Outlet Glacier

This study took place at Sólheimajökull Outlet Glacier in the South of Iceland. Sólheimajökull is categorized as a surge glacier that is part of the larger Mýrdalsjökull Glacier (Figure 1). This type of glacier is characterized by periodic cycles of increased flow with movement 10-100 times faster than its normal flow speed (National Snow & Ice Data Center). Thus, the terminus of the glacier advances and then melts due to thinning of the ice. The margins of Sólheimajökull became 70-100m thicker between the years 1960 and 1996 but later thinned by 120-150m from 1996 to 2010 (Schomacker et al., 2012). This outlet glacier is a prime example of how alarmingly fast the recession of a glacier can occur; Sólheimajökull has retreated approximately the length of an Olympic size swimming pool every year (Icelandic Met Office).

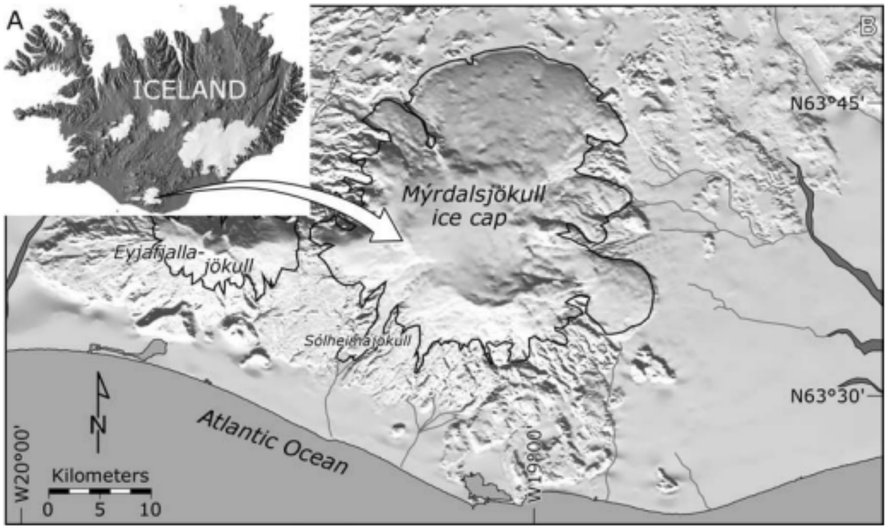

Figure 1. Map of Mýrdalsjökull Glacier and Sólheimajökull Outlet Glacier in reference to the country of Iceland (Schomacker et al., 2012).

1.3 Ecological Succession in Glacier Forelands

When glaciers retreat, land that has been trapped under the ice for hundreds to thousands of years is exposed. For this reason, glacier forelands- land directly in front of the glacier terminus- provide an excellent environment to study primary succession. During this process, dead organic material builds up and microbial and invertebrate communities are introduced (Nicol et al., 2005). Both elements provide a nutrient-rich environment for plants and later, for animals to flourish. Forelands are also important to study because they can help scientists predict succession patterns in regions that will experience deglaciation in the near future (Hagvar, 2012). For the purpose of this project, I look only at the soil quality in the glacier foreland as one component of the overall process of ecological succession.

1.4 Evaluating Soil Quality

The term ‘soil quality’, also referred to as ‘soil health’ can have many different meanings depending on the context in which it is discussed. For the purpose of this study, soil quality will from here on be defined as the biological productivity of the soil in reference to decomposition rate and biodiversity of micro-fauna. Both factors are described in more detail in the following sub-sections.

1.4a. Soil Invertebrates

Soil invertebrates are incredibly diverse and range from micro-fauna that are smaller than 200μm to macro-fauna that are visible to the human eye. Invertebrates play many key roles in the maintenance of soil quality such as: integrating litter into the soil profile, sustaining the structure and creating pores in the soil, interacting with microbial communities and supporting the colonization and growth of plant species (Lavelle et al., 2006). In addition, soil invertebrates often have mutualistic relationships with their environment (Lavelle et al., 2006). Lastly, soil fauna can often serve as a better bio-indicator of soil quality than microbes because they are higher in the food chain (Neher, 2001).

Two phyla- Nematoda and Annelida- are the most common soil fauna that have been used in previous studies to evaluate soil quality. According to multiple studies, nematodes (Figure 2) may be the most useful as bio-indicators of soil quality. Nematodes belong to the phylum Nematoda and most, termed "free-living nematodes", are not parasitic to plants (McSorley, Entomology & Nematology UF). The organisms play key roles in regulating decomposition, the detritus food web, and providing nitrogen to plants through the process of mineralization (Neher, 2001). Additionally, some species of nematodes are resistant to unfavorable environmental conditions and are able to survive desiccation (Neher, 2001).

Figure 2. Phylum Nematoda from OCCC Biology Labs**.**

*Figure 3***.** Phylum Annelida from Natural Resources Conservation

Another common soil invertebrate belongs to the phylum Annelida (Figure 3). Annelid worms differ from nematodes because they have a coelom (body cavity), circulatory system and segmented body (Crow, Entomology & Nematology UF). There are over 10,000 species of Annelida with sizes ranging from millimeters to meters in length. Similar to nematodes, annelids help promote decomposition by breaking down the organic matter in the soil (Crow, Entomology & Nematology UF).

1.4b. Decomposition

Decomposition is a crucial ecological process in which organic material is broken down and nutrients are returned to the soil. Larger soil fauna begins the process by consuming detritus and then smaller microorganisms secrete chemicals that work to enhance the breakdown of the organic material. I use decomposition as an indicator of soil quality because it is connected to the biological productivity of the soil and amount of available nutrients to organisms and plants alike. For arctic ecosystems in particular, one study found decomposition rates to be lower in comparison to temperate latitudes due to a thinner active layer of the soil (Bekku et al, 2004). As climate change causes temperatures in the Arctic to increase, decomposition has the potential to increase which would in turn alter the makeup of the soil and thus the function of the entire ecosystem (Bekku et al., 2004). Decomposition can be measured by the change in dissolved oxygen (DO) because decomposers use oxygen during the process of breaking down organic matter. Therefore, the greater the decrease in DO, the more decomposition is occurring.

2. Research Question

Glacier forelands are ideal places to research primary succession and how soil and plant communities recover from a disturbance such as glaciation. With increasing atmospheric temperatures, glaciers are melting and receding at an unprecedented rate. Previous studies have used soil invertebrates as indicators of soil health in a larger study of primary succession. For example, Lei et al. used nematode populations to assess primary succession in a glacier fore-field in China (2015). However, there is limited research on the soils of Iceland's Sólheimajökull Outlet Glacier foreland. For my research, I ask the question: how does soil quality differ in the foreland of Sólheimajökull Outlet Glacier as distance from the glacier terminus increases? More specifically, how do abundances of soil invertebrate taxa and decomposition differ in these locations? My null hypotheses for the experiment are that there will be no difference in the abundances of invertebrate taxa nor between rates of decomposition for each of my locations. I predict that abundances of all taxa found will increase as distance from the glacier terminus increases because the soil will have been exposed for longer, allowing ample time for the colonization of many organisms. Similarly, I predict that decomposition will increase as distance from the glacier terminus increases because if biodiversity is higher in sites farther from the glacier, nutrient turnover would be greater, thus promoting the breakdown of organic material. I hope to compare my findings to similar research in order to contribute data on the soil of one specific glacier in Iceland.

3. Materials & Methods

3.1 Location

In order to analyze soil invertebrates in Sólheimajökull's glacier foreland, I compared taxa in five sites of increasing distance from the terminus of the glacier. The locations were named A-E with Site A being closest to the glacier and Site E being farthest away. Sampling was done as close to the glacier terminus as possible for Site A and each successive location was 300m away from the previous. To mark locations, I used a 300m rope and walked South towards the coast, maintaining a mostly straight trajectory. Unfortunately, data on the retreat of the glacier with corresponding dates was difficult to obtain. Additionally, Sólheimajökull's recession is characterized by surge events and has not had a steady retreat. Thus, for the purpose of the study, I assumed that increasing distance from the tongue of the glacier indicates a greater span of time that the foreland has been exposed. Coordinates of each site location were recorded and mapped using ArcGIS (Figure 4). Note that on the map, Site A and B appear to be on the glacier but were actually located on the foreland.

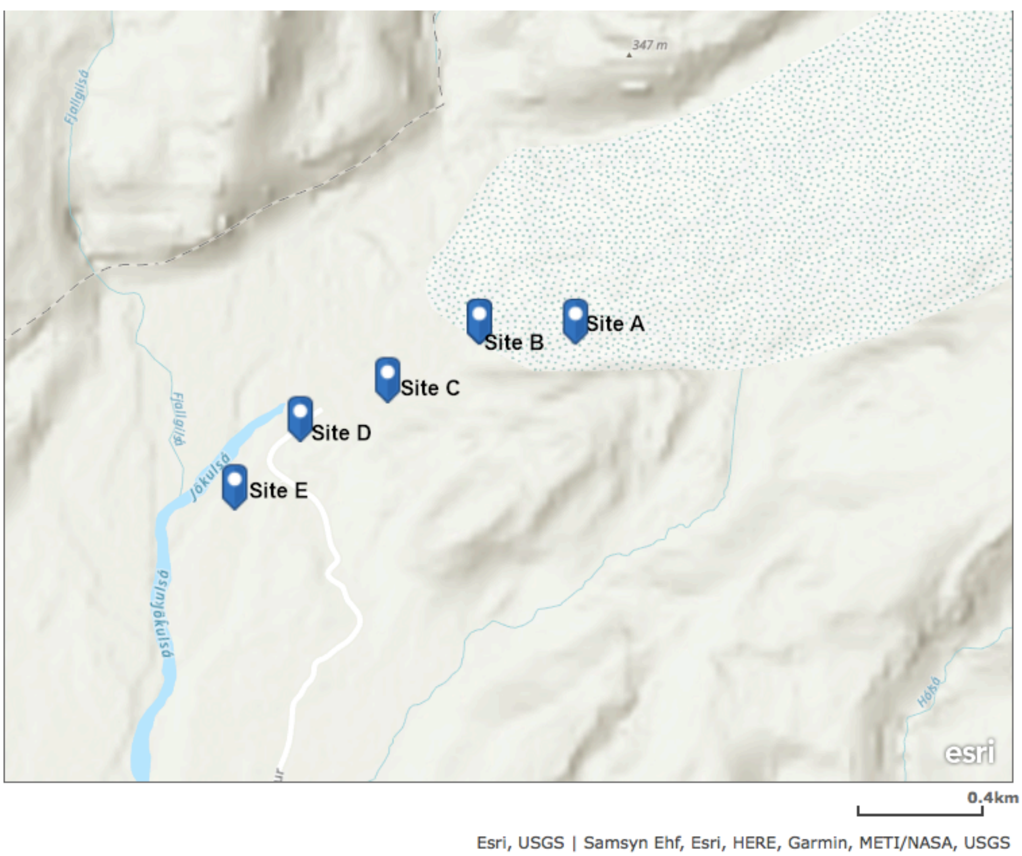

Figure 4. ArcGIS Map of Sampling Sites

3.2 Sampling

At each site (A-E), I collected a soil core of 9cm in diameter and 15cm in depth using a plastic cylindrical coring device. I took 8 samples at each site that were approximately 0.5m apart, moving 0° N from the first sample. If the soil was impenetrable with the corer, I moved in increments of 0.5m at 0° N until I could take a core. The soil samples were stored in plastic bags and labeled with the correct site and replicate number. I also recorded the coordinates using the compass app on my phone, which were then used to create Figure 4. The samples were placed in the freezer approximately 30 hours after collection.

3.3 Soil Analysis

3.3a Invertebrates

I chose to look at invertebrates and decomposition as an indication of the quality of the soil in the glacier foreland. In order to look at both variables, I divided my soil cores in half and looked at 100ml of soil under the SZ51 Olympus Stereo Microscope. Soil samples were removed from the freezer 4 hours prior to inspection to allow for thorough defrosting. Each sample took approximately 2 hours to analyze and the number of each different taxa, total organisms and number of taxa were recorded. Among each site, the samples were chosen at random and only six of the eight replicates were analyzed due to time sensitivity.

3.3b Dissolved Oxygen

Next, to measure decomposition, I used the YSI Handheld DO meter to record the DO of water before and after adding it to the soil. I used 250mL of soil and 300mL of cold water. I first measured the DO of just the water and then added it to a plastic container with the soil and allowed it to sit with the lid sealed for a total of six hours. After the allotted time, the lid was removed and the soil was mixed before taking the final DO measurement. For Site A, B and C, DO measurements were recorded every two hours within the six-hour period. For Sites D and E, DO was only taken at the six-hour mark. Therefore, only values from hour six are included in the analysis of the data. Procedures were repeated for all 5 sites with 6 replicates per site, using the same samples as in the invertebrate analysis.

3.4 Data Analysis

For the invertebrate data, I compared the abundances of the four observed taxa at each site. I ran an ANOVA test for both Annelida and Nematoda and then the Tukey HSD post hoc test in order to determine where the differences between abundances lied. The data was not normal for Arthropoda nor Rotifera, so non-parametric statistical tests had to be used. The Arthropoda data was analyzed using the Kruskal-Wallis rank sum test to identify significant differences between sites. The Kruskal-Wallis test was also used for the Rotifera data followed by the pairwise Wilcoxon rank sum post hoc test. Tests were run in R with the assistance of Dan Govoni. To analyze the decomposition data, I found the percent change in DO for all samples in each site. I then ran an ANOVA and the Tukey HSD post hoc test to see which sites had significantly different DO values. Both the invertebrate and decomposition data was plotted in box and whisker plots made by Dan Govoni.

4. Ethics

My project involved taking samples of the soil at Sólheimajökull Outlet Glacier to look at invertebrates. Since I was dealing with biological samples, I made sure to only sample what was necessary for my study in terms of the number of samples and size of the core. Additionally, I did not take samples on the path where visitors walk and did not trample any plants or organisms while taking the cores. Much of my data is comprised of self-reported counts of invertebrates so I made sure to be as accurate as possible in my counting and identification.

5. Results

5.1 Soil Invertebrates

After examining all 30 soil samples, I recorded a total of four different taxa. I identified the taxa as belonging to phylum Annelida, Nematoda, Arthropoda and Rotifera but was unable to formally confirm these identities. Additionally, I did not identify any specific species within each taxonomic group. Figure 5 and Figure 6 below are images taken through the microscope of two organisms that I categorized as Arthropoda and Rotifera, respectively.

Figure 5. Observed arthropod, taken through microscope.

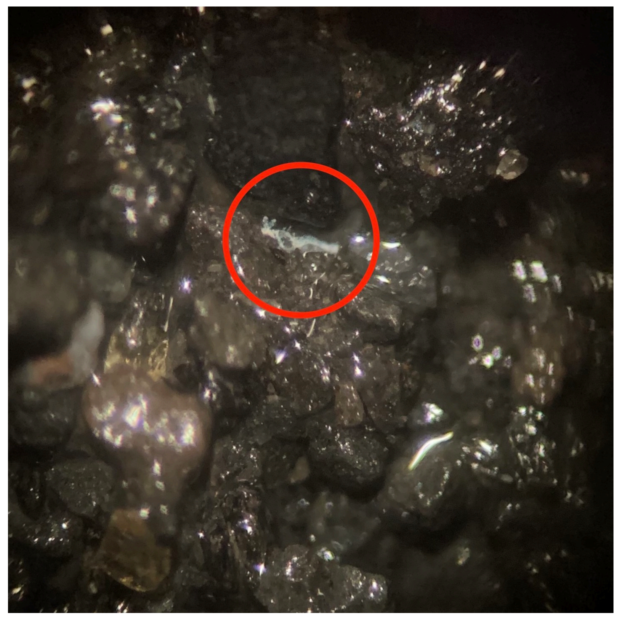

Figure 6. Observed rotifer, taken through microscope.

Broadly, I observed a trend of increasing average number of organisms in sites of increasing distance from the glacier (Figure 7). Specifically, Site A had the lowest average number of organisms, with Site E containing over double the number of observed organisms. The same trend was present for the average number of taxa observed at each site. Similar to the number of organisms, Site A displayed the lowest average number of taxa and Site D and E displayed the most (Figure 8). Again, the sites with the greatest average number of taxa (Site D and E) had double that of the site with the lowest value (Site A).

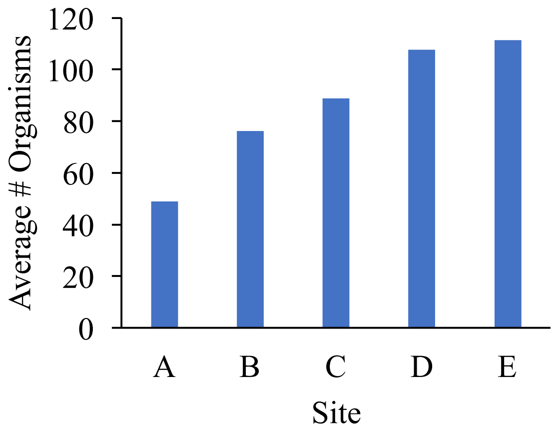

Figure 7. Average number of total organisms observed for each site.

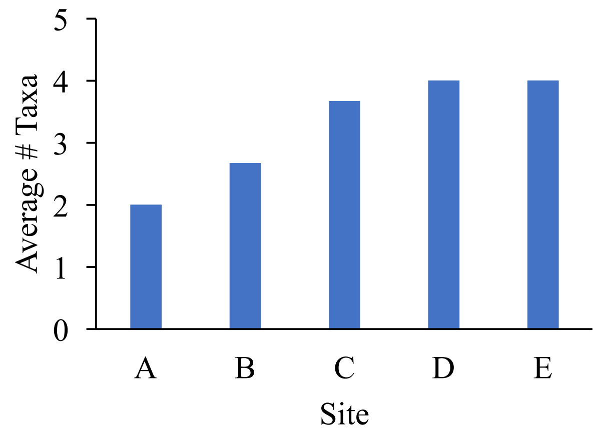

Figure 8. Average number of taxa observed for each site.

More specifically, for Annelida, abundance increased from Site A through Site D and then decreased for Site E (Figure 9a). There was a significant difference in abundance of Annelida between at least one set of sites (ANOVA, $F = 13.66$, $df = 4$, $p < 0.001$). There was a significant difference in Annelida abundance between sites A-B, A-C, A-D, A-E and B-D (Tukey HSD, $p < 0.05$).

Abundances of Nematoda were within a similar range for sites A, B, C and D but Site E's abundance was approximately 50% lower (Figure 9b). This observed difference in Nematoda abundance was statistically significant (ANOVA, $F = 12.41$, $df = 4,25$, $p < 0.001$). Furthermore, Site E was the only location in which abundances were significantly different from the rest of the sites (Tukey HSD, $p < 0.05$).

Trends for Arthropoda and Rotifera were fairly similar. The abundance of Arthropoda appeared to exponentially increase from Site A to Site E (Figure 9c). However, the observed differences were not statistically significant for any of the five sites ($X^2 = 27.5$, $df = 17$, $p > 0.05$). Rotifera, on the other hand, were absent in Site A and B, but abundance increased two-fold from sites C and D to Site E (Figure 9d). There was a significant difference between at least one pair of sites ($X^2 = 25.4$, $df = 13$, $p < 0.05$). Furthermore, a pairwise comparison revealed significant differences between sites A-D, A-E, B-D, B-E and C-E (Wilcoxon rank sum, $p < 0.05$).

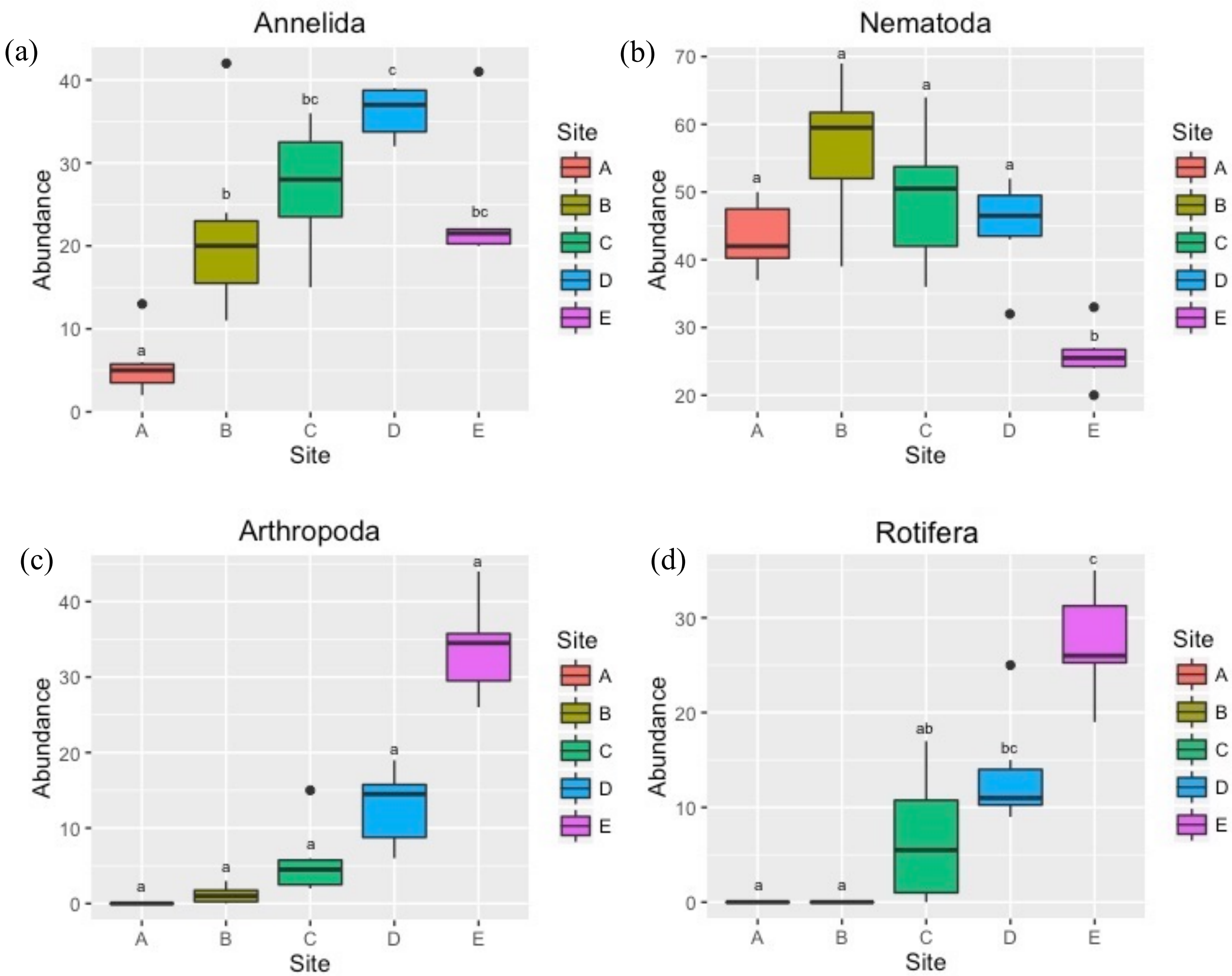

Figure 9. Box plots showing the abundances of (a) Annelida, (b) Nematoda, (c) Arthropoda and (d) Rotifera at all sites A through E. Data points that share a letter are not significantly different and black dots represent outliers in the dataset. All plots were made by Dan Govoni.

5.2 Decomposition

The percent change in DO decreased as distance from the glacier increased, with Site E losing approximately 10% less oxygen through decomposition compared to Site A, B and C (Figure 10). An ANOVA test indicated there was a significant difference between at least one pair of sites ($F = 5.74$, $df = 4$, $p = 0.002029$). Furthermore, a post hoc test showed that sites A-E, B-E and C-E were the only sites that had significantly different changes in DO (Tukey HSD, $p < 0.05$).

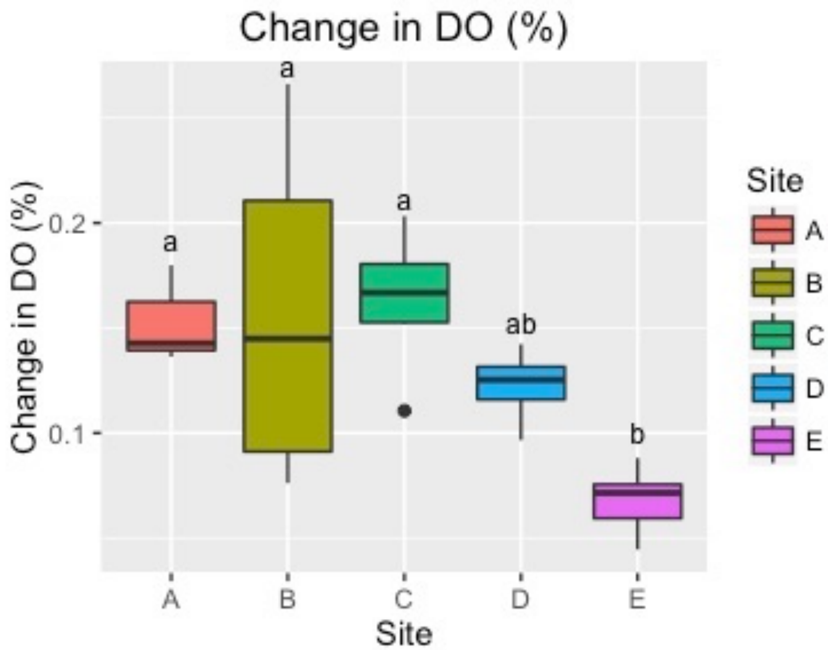

Figure 10. Percent change of DO at sites A through E. Data points that share a letter are not significantly different and black dots represent outliers in the dataset. Plot was made by Dan Govoni.

6. Discussion

6.1 Soil Invertebrate Taxa

I found there to be, on average, a higher count of organisms at sites located a greater distance from the glacier terminus. All this data can tell is that as distance from the glacier and time the ground has been exposed increased, the soil was able to support a greater number of organisms. Since I did not do any further testing of soil properties, I cannot point to any specific factors that would lead to these values. The number of taxonomic groups also increased with distance from the glacier terminus. However, since I did not have the means to differentiate species within each taxonomic group, there was not enough differentiation to evaluate biodiversity using, for example, the Shannon-Weiner index. Overall, the broad trends I found aligned with my prediction that the soil farthest away from the glacier would have had a greater amount of time for organisms to populate and return more nutrients to the soil.

Four different taxa were identified throughout the analysis of the soil samples from all five sites. I expected to see nematodes in the samples because they are the most commonly used invertebrate as bio-indicators of soil quality. Additionally, a study performed on a glacier fore-field in China used nematodes to evaluate primary succession (Lei et al., 2015). Therefore, it is logical that nematodes would be present in a similar environment. Annelids are also common soil invertebrates that have previously been observed in glacial chronosequences. Rotifers, on the other hand, are less understood in reference to glacier forelands. However, a study performed in Antarctica indicates that Rotifers can survive in harsh polar climates and are sensitive to climate change so they may also serve as good bio-indicators (Pociecha, 2010).

6.1a Annelids

Due to a significant difference in abundance of Annelida among at least one pair of sites (ANOVA, $p < 0.05$), I can reject the null hypothesis that there are no differences in abundance of Annelida among the five sites. Site A was significantly different from the rest and Site B was significantly different from Site D (Tukey HSD, $p < 0.05$). One possible explanation for these results is that Site A was closest to the glacier and was characterized by the wettest and most likely coldest soil (although temperature was not taken). Annelida thrive in soil temperatures of 10-15°C, warmer than conditions adjacent to the glacier at this time of year and are known to be abundant in woodlands and pastures (Sigurdsson & Gudleifsson, 2013). The significantly higher abundance at Site D in reference to Site B could simply be a result of more organisms overall.

6.1b Nematodes

A significant difference in abundance of nematodes among at least one pair of sites (ANOVA, $p < 0.05$) means that I can reject the null hypothesis that there are no differences in abundance of nematodes among the five sites. Furthermore, Site E was significantly different from the other four sites (Tukey HSD, $p < 0.05$). This data does not support my prediction that abundance of all taxa would increase with increasing distance from the glacier. Instead, Site E had a drastically low abundance of nematodes. An explanation for this could be that there are competing species existing in the same location. One paper suggests that some micro-arthropod species feed on particular species of nematodes, changing population dynamics and reducing overall nematode populations (Read et al., 2006). This could be occurring at Site E because it was also characterized by a high abundance of arthropods. Alternatively, the lack of nematodes and annelids similarly could be a product of retrogressive succession in which nutrient levels in the soil decline after the absence of a particular disturbance (the glacier). A study on the Franz Josef Glacier Foreland in New Zealand found that most groups of nematodes and macroinvertebrates decreased in abundance during this retrogressive phase (Doblas-Miranda et al., 2008). However, since I chose an arbitrary distance of 300m between each site and Site E was located 1500m from the glacier terminus, it may not represent enough time for the retrogressive stage to have occurred.

6.1c Arthropods

There was not a significant difference in the abundance of arthropods between the five sites ($X^2 = 27.5$, df = 17, $p > 0.05$). There were no arthropods found in samples from Site A and there was a very low count in samples from Site B. Although there was no statistically significant difference between the sites, Site E still exhibited a high abundance which is used to explain the nematode trend in the section above.

6.1d Rotifers

There was a significant difference in the abundance of rotifers ($X^2 = 25.4$, df = 13, $p < 0.05$) specifically in sites A-D, A-E, B-D, B-E and C-E (Wilcoxon rank sum, $p < 0.05$). Rotifers were very high in abundance for Site E and were significantly different from every site except D due to an outlier. Rotifers are aquatic organisms and are therefore primarily found in freshwater ecosystems but can also live in the pore water of moist soils. However, this is contradicted by the dry and sandy characteristics of Site E's soil. On the other hand, rotifers can also live in a film of water on mosses. In Svalbard, 37 species of moss-dwelling Rotifera were identified with many others known to exist in the Arctic and Antarctic (Kaya, De Smet & Fontaneto, 2010). This is the most probable explanation for the high abundance of Rotifera as the ground at Site E was covered in moss. Additionally, vegetation was fairly uniform among sites A-D, with Site E being the only site to exhibit mosses.

6.2 Decomposition

There was a significant difference in the percent change of DO (ANOVA, $p < 0.05$), with the differences existing between sites A-E, B-E and C-E only (Tukey HSD, $p < 0.05$). Therefore, Site E was significantly different than all sites besides Site D. Based on these statistics, I am able to reject the null hypothesis that there is no difference in DO between the five sites. However, this contradicts my prediction that DO would increase with increasing distance from the glacier terminus. In my analysis of the abundance of species at each site, I found a surprisingly low number of nematodes at Site E, farthest from the terminus of the glacier. Site E also happened to display a significantly low percent change in DO compared to other sites. An explanation for these results could be that nematodes play a key role in regulating decomposition. The low population of nematodes observed in samples from Site E could have influenced the decomposition rates and correlated to less oxygen consumed during the decomposition process. The same theory for the low abundance of nematodes at Site E could also be applied to the small change in DO. The theory is that the site is far enough away from the glacier and has been free of disturbance for long enough that it has entered a retrogressive phase of low nutrient levels and decreased soil quality (Doblas-Miranda et al., 2008). Decreased nutrient levels in the soil would then limit the rate of decomposition and thus the amount of oxygen consumed.

6.3 Implications

The most important results from this experiment were that abundances of four taxonomic groups (Annelida, Nematoda, Arthropoda and Rotifera) and decomposition differed between at least some of the five sampling sites. This is important because it indicates that as distance from the glacier terminus increases and time the foreland has been free of ice increases, the soil goes through biological changes that influence which species are able to survive. Previous research has found that ecological succession occurs in stages: build-up, climax and retrogressive. Biodiversity of nematodes and Phosphorus availability increased during the build-up and climax stage but decreased during the retrogressive stage (Lei et al., 2015). My data points to a possible retrogressive stage occurring at Site E, located 1500m away from the glacier terminus. What this implies is that in the future, as Sólheimajökull continues to retreat, the occurrence of another retrogressive stage is likely. In terms of soil quality, I am unable to support my two predictions. For soil invertebrates, since the number of different taxa was so low and there were differing abundances among sites, I am unable to assess whether biodiversity was different among the sites. Secondly, for decomposition, my data contradicted my prediction with the site farthest from the glacier having a significantly lower change in DO compared to the other sites.

One limitation that I ran into in my project was obtaining the right data to choose the location of the sites. Although data does exist for the retreat of Sólheimajökull outlet glacier, I could not locate specific coordinates for the glacier terminus for specific time periods. Additionally, since the retreat of Sólheimajökull is characterized by surge events, it was difficult to find the exact number of years that parts of the foreland have been exposed. As a result, I chose to measure every 300m because it was the longest distance that was feasible. Another limitation of this project was not being able to identify the taxa with certainty. I did not have access to an individual that could identify the organisms nor did I have the resources or knowledge to do it myself. In general, time was a large constraint, leading to the omission of two replicates (8 to 6) from each of the five sites. I also had to look at less than half of the volume of each soil core under the microscope because just looking at 100mL took up to two hours for each sample.

In the future, I would want to replicate this experiment, allocating more time to increase the number of sites and replicates at each site. Additionally, it would be interesting to isolate each invertebrate found to formally identify it and take the biomass. This would ideally allow for an analysis using biodiversity indexes. Compiling data on the retreat of Sólheimajökull glacier and mapping its exact location over the years would also be an extremely valuable tool for future researchers. It would allow for a proper chronosequence study that could differentiate between different stages of ecological succession- a valuable tool for a glacier receding at a rate this fast. Moving forward from this study, an interesting follow-up question I have is: how do sub-terrestrial systems influence above-ground systems (and vice versa)? Soil micro fauna (invertebrates) and decomposition are both sub terrestrial processes that have some impact on flora and fauna on the surface of the foreland. Understanding the relationship between the two systems would allow scientists to make more accurate predictions about plant communities which are important carbon sinks. Much of the flora at my sampling sites were quite similar, but once moving far enough away there was a noticeable difference. For example, the ground at Site E (1500m away) was covered in moss whereas no moss was present at any other site. This observation also leads me to believe that a distance of 300m was not sufficient to see significant differences between each site and it would therefore be beneficial to increase distance between sites.

7. Conclusions

The aim of this study was to contribute to existing data on the biological characteristics of glacier forelands. There are many studies that investigate the ecological succession of glacier forelands using invertebrates or other fauna, but no similar studies have been conducted at Sólheimajökull Outlet Glacier. Studies on Sólheimajökull look mainly at the geological formations in the foreland such as moraines to date surge events or jökuhlaups (Staines et al., 2015). The main conclusions that I can draw from my results is that there are differences in the abundances among the four taxa I observed and that decomposition at Site E was significantly different from all but one site. Studies involving the impacts of melting glaciers on surrounding ecosystems is incredibly relevant as glaciers continue to melt at a rate unprecedented by any point in recorded history. Specifically, for Sólheimajökull, this glacier has melted drastically to the point where glacier guides and residents of Iceland have seen the devastating change in their lifetime, let alone a matter of years. Climate change will very likely have an effect on succession in the glacier foreland. One study found that rising atmospheric temperatures will have a greater influence on earlier succession stages compared to later stages (Kaufmann, 2002). Although the increased speed of colonization for earlier stages may be beneficial, there is a threshold at which species diversity will most likely decline due to unfavorable environmental conditions. Overall, I cannot say whether soil quality as a whole increased or decreased moving away from the glacier terminus. However, I can say that decomposition was significantly lower at the greatest distance from the glacier and nematode and annelid abundances were significantly low whereas rotifer abundance was high. There is clearly a change in the soil at a certain distance from the glacier terminus, indicating that a similar pattern may arise as the glacier continues to recede and exposes more of the foreland.

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