AGRICULTURAL UNIVERSITY OF ICELAND

Icelandic Ecosystems

What Effect Does Soil Temperature Have on Soil Organic Matter and Vegetation density and diversity in a Forest Ecosystem?

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- **Dead Sitka spruce. Photo: JWVR**

Contents

Introduction

In the following pages, we the students of the Agricultural University of Iceland will lead a discussion on soil characteristics and vegetation types of a geothermal area in the South of Iceland. Based on soil samples and vegetation measurements we have taken at the sight, we will present our results and interpret them. Before we go deeper into our research, we will take a closer look at the sight that we have chosen and give some general information on geothermal ecosystems in Iceland.

The area that this paper will deal with lies in the South of Iceland, inside the town of Hveragerði, next to the Campus of the Agricultural University of Iceland. The area often referred to as “Reykir í Ölfusi”, lies at the border of a volcanic active zone (Hengilssvæði), surrounded by low and high temperature fields and is known for its strong geothermal activity (Rammaáætlun, 2007). Additional to the geothermal ecosystem itself (we will refer to geothermal areas as unique ecosystems in the content of this paper), there are two other ecosystems found here, a 50 year old Sitka spruce Forest (Picea sitchensis) and a grassland adjacent to the forest, both affected by the soil warming (Forhot, 2008). Our research was exclusively done within the forest although the influence of the adjacent grassland might nonetheless be mentioned.

On May 29th of 2008, an earthquake on the Richter Scale of 6,3 hit the area and opened up new below ground geothermal channels, leading to a soil temperature increase at the surface, and bringing upon change in the surrounding environment (Forhot, 2008). Based off of this event we developed following research question: *What effect does soil temperature have on soil organic matter (SOM) and vegetation composition/cover in a forest ecosystem?*

We will connect our writings not only to the research we have done, but also to other papers and researches on this area which have been conducted and published throughout the last 8 years following the event of the earthquake. Due to the above described unique circumstances, this area has been of great interest for scientists, pHD students and others interest groups from many different countries. Since 2008, it has solemnly been used for research purposes.

Background

Due to Iceland’s unique position on the globe and the wide seismic and volcanic activity, geothermal areas are a very common phenomena (Baldursson, 2014). Most often these areas lie on the volcanic belt, which pulls from the Southwest to the Northeast through the country (Elmarsdóttir et al., 2015). Geothermal areas can be described as those places, where heat comes to the surface by thermal conductivity or cooling magma. To be more precise, rainwater or snowmelt sinks down into the earth crust, is heated below by hot rock or cooling magma and finds its way up again through little cracks in the rock, travelling towards a cooler surface to even out its temperature (Baldursson, 2014). The heat manifests itself in many ways at the surface; as geysirs, hot springs, hot creeks, fumaroles or mud pots (Friðleifsson, 1979).
There are two types of geothermal areas in Iceland: low temperature fields on the one hand and high temperature fields on the other. Low temperature fields are defined as those areas where

temperatures stay below 200 degrees Celsius at 1 km depth. Approximately 250 low temperature fields exist throughout the country, most of which are concentrated around the volcanic active zone. High temperature (Figure 1).fields on the other hand are those areas where temperatures exceed 200 degrees Celsius at 1 km depth and only 20 of these areas are found in Iceland, all of which are situated on the volcanic active zone (Baldursson, 2014).

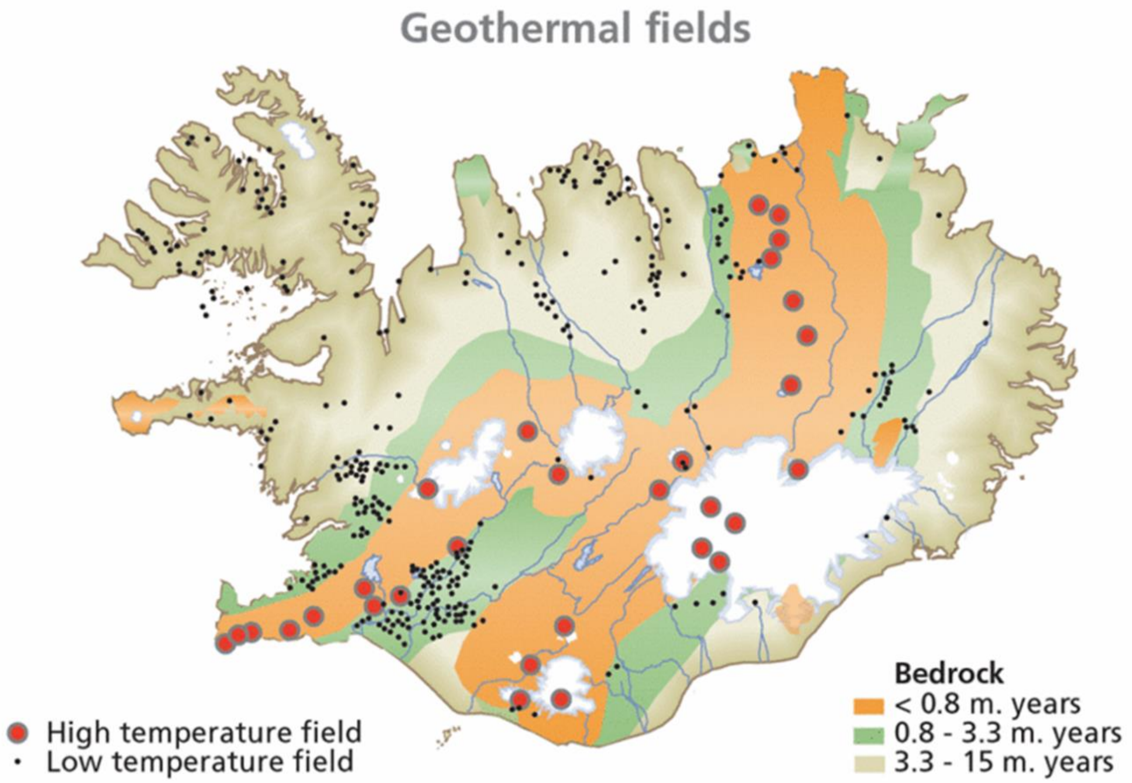

Figure 1: Geothermal fields of Iceland

Geothermal areas are often referred to as “little islands”. As it says in a paper by Icelandic scientists; “*the environment of geothermal areas is often unique and characterised by a steep gradient in soil temperature and humidity, high acidity and an unusual concentration of minerals and elements*” (Elmarsdóttir et al., 2015, p.1). These conditions create unique circumstance for vegetation, which could be quite different from the surrounding (Merret& Clarkson, 1999).
pH values usually decrease with increasing heat, as well as organic carbon contents in the soil (Elmarsdóttir et al., 2015). The latter could be traced back to higher decomposition rates at higher temperature. Poisonous gases such as hydrogen sulphide (H2S) are expelled into the atmosphere, where they can have a negative impact on surrounding vegetation and organisms, including people (Elmarsdóttir et al., 2015).

Geothermal areas in Iceland are and have been used for all kinds of purposes. In the past they were used mainly to wash clothes or to bathe in (Guðmundsson, 1980). In the 20th century, the first house was heated up by means of geothermal heat in Mosfellssveit (Guðmundsson, 1980). Drilling holes and using geothermal areas to heat up houses became increasingly popular in the following decades, where the preferable temperature for the water extracted from these holes ranged between 60 and

130 degrees Celsius (Guðmundsson, 1980). Today, most of Iceland towns are heated up like this (Guðmundsson, 1980).
Another huge factor connected to the use of geothermal areas is the energy harvest. In 2010, 26% of Iceland's total energy production was won by geothermal means (Orkumál, 2010). This number has stayed steady throughout the last few years (Orkumál, 2014).
With growing demands for energy but also with increasing tourism, geothermal areas (low as well as high temperature fields) demand a bigger need for protection (Guðmundsson, 1980). Due to the unique ecosystem of the geothermal areas, the few plant species found and also the soil are sensitive, and become depleted quite quickly if not treated correctly (Elmarsdóttir et al., 2015). Recent studies have shown that not only poisonous gases deplete moss growth, but also trampling by tourists or locals leave traces which have negative effect on these areas (Helgadóttir et al. 2013 & Bruns et al. 2013). The increase in tourism will give rise to larger discussion about the protection value of these areas in the future. More studies concerning the above mentioned issues are still to be conducted.

Geothermal heat in Reykir was first used in 1922 to heat up summerhouses, where hot water was led from the source into kitchen, bathroom and heaters (Sveitarfélag Ölfus, 2009). Only a few years later, the whole town was heated up by means of hot water (Sveitarfélag Ölfus, 2009).
In 1930 the first greenhouse was powered with the same water (Litla- Geysi) as was used to heat up the first summer house, by letting the water run through the greenhouse (Sveitarfélag Ölfus, 2009). Within the next years this one source of hot water diminished, so that the additional use of three other sources maintained the flow of hot water.
In 1941 a hole was drilled at “Litla Geysi”, which is not in use anymore, but another little geyser in the area is still used (Hvegargerðisbær, n.d). Many other streams, hot springs, geysers and mud pots were found in this area, some of which are still in use (Hvegargerðisbær, n.d).
Currently the two holes that were originally drilled provide the town buildings with heat, power the greenhouses and the pool of the town (Hvegargerðisbær, n.d).
As mentioned before, the earthquake in 2008 had big effect on the area. The town of Hverargerði moved by 14 cm to the North East. Temperatures increased, giving rise to more steam, new mud pots etc (Khodayar& Björnsson, 2010).

Methodology

The surface ground temperature of the forest has previously been measured in spots and varies from 0°C (control) to 52°C . These temperatures reflect the additional geothermal heat, not including the original ground temperature (Forhot, 2008). These measured areas have been designated into 1 m^2 plots throughout the forest for various temperature gradients and for each gradient there were 5 plots available. This experiment included 3 plots for each gradient assessed and included 0°C (control), 1°C, 3°C, 5°C and 10°C. The assessment involved 2 soil samples and 3 plant cover estimations for each gradient. Thus, the total of amount data is 10 soil samples and 15 plant-cover estimations.
The soil samples were used to analyse the amount of organic and inorganic material present. The soil was extracted using a metal soil auger and 3 holes (5-8cm deep) comprised one sample. The top

layer of earth was first cleared to remove the organic debris that did not classify as soil and would distort the results. Because there were three plots for each gradient and only two samples required, in order to avoid bias, a number from 1-3 was randomly picked using pieces of paper with the numbers written on them. Soil was taken from a small sampling area, adjacent to the larger 1 m^2 plot, which was used for additional research as ours. Back at the laboratory the soil was then dehydrated at 60°C for 24 hours and then sifted to remove any debris. Two teaspoons were then put into a porcelain glass, weighed and heated at 103°C for another 24 hours. The content was weighed again and finally the remaining content was heated at 200°C for another 24 hours to remove the organic material.

The plant-cover estimations involved analysing plant species composition and coverage in a 50x50cm frame (Figure 2). The Braun-Blanquet scale (Table 1.) was used as a reference to estimate species coverage. Due to the small allotted sample area, all 3 plots for each gradient were used for this. Moss, liverworts and lichen were not identified by individual species and neither were trees and shrubs.

Table 1: Plant cover estimations.

Coverage	Grade	
< 1%	1	Species is visible in the frame but extremely rare
1-5%	2	Species is rare but has a measurable coverage
6-25%	3	Species is somewhat frequent
26-50%	4	Species is very frequent
51-75%	5	Species is dominant
76-99%	6	Species is very dominant
100%	7	Complete coverage

Figure 2: Frame used to estimate plant coverage and diversity.

Results

The gradients were marked alphabetically from A to E, A being the 0°C control plots and E the 10°C plots. Numbers from 1-3 were also assigned to each plot (graph). Measurements showed following:
At the control plot A four types of vegetation were found: dead organic matter, moss, 4 species of flowering plants and trees/shrubs (Figure 3). Most of the flowering plants stayed below 20% cover, moss made up around 20% cover on average and the dead organic matter 40 % on average, which was clearly most dominant.

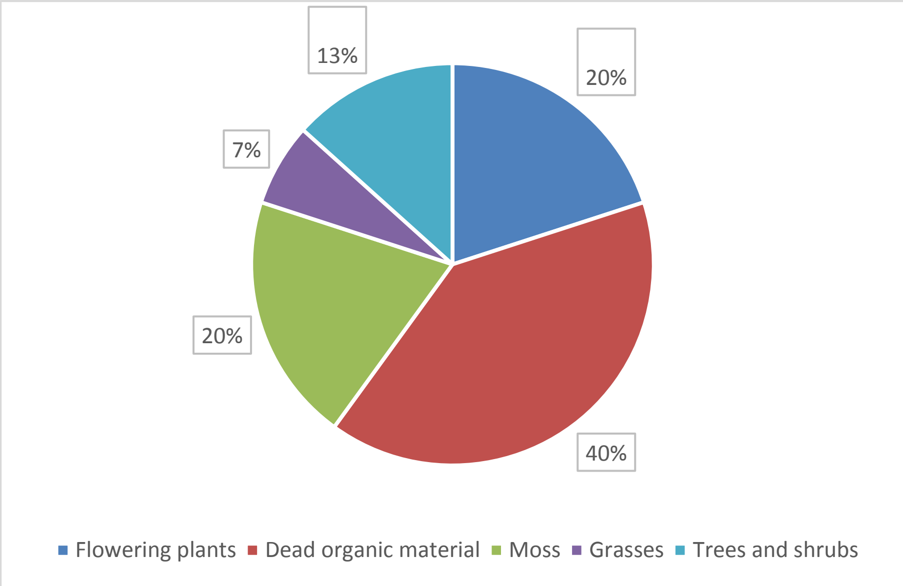

Figure 3:Average percentage of plot A.

Plot B showed no signs of vegetation, solemnly dead organic material in form of needles from the surrounding spruce trees. The dead organic material was measured in all three areas (B1,B2,B3) with an average cover of 100% (Figure 4).

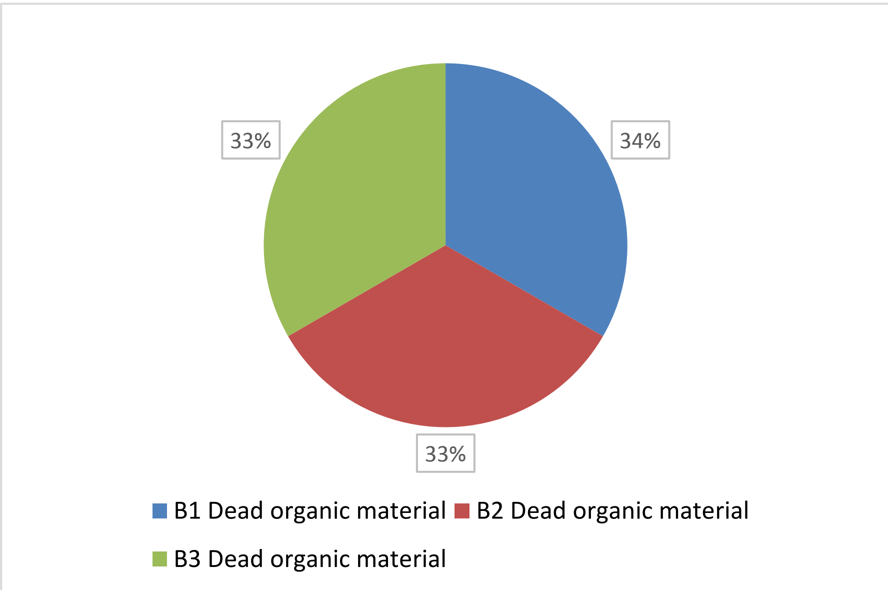

Figure 4: Average percentage of plot B

Vegetation cover in the C plot showed 1 species of flowering plant (see image), moss as well as dead organic material. The flowering plant (Equisetum arvense) as well as the moss cover stayed below 25% on average, while the dead organic material showed a cover of 100% on average (Figure 5).

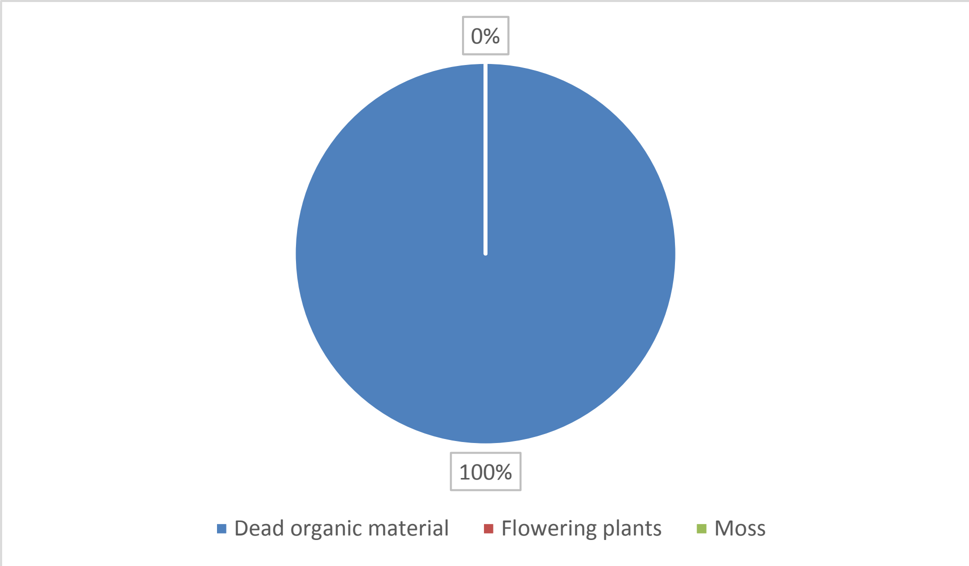

Figure 5: Average percentage of plot C.

Vegetation cover in plot D showed an increase in biodiversity of flowering plants, with 5 species, 1 more than in plot A, with a cover of 25% for several plants in one of the areas (D3). Additionally trees and shrubs were measured between 1-5% in cover on average, moss between 51-75 % and dead organic material between 67-99% cover on average, so clearly the most dominant again (Figure 6).

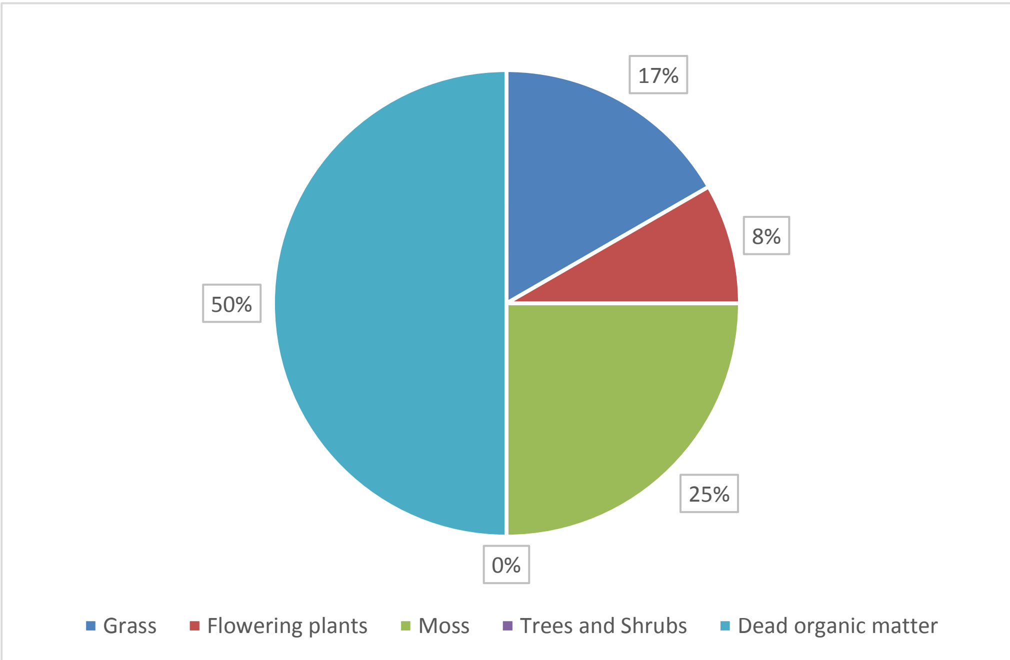

Figure 6:Average percentage of plot D.

Vegetation measurements on Plot E showed an even higher number of biodiversity, compared to the previous plots with lower temperature. The dead organic material was far lower than before, on average only 14% while the moss took over in dominance with 27% cover on average between the three areas. 7 species of flowering plants were found overall in the 3 areas of plot E, showing an increase in biodiversity once again. Amongst those seven species, four new species were found which haven't been found in any of the other plots: Male fern (Dryopteris filix-mas), common chickenweed (Stellaria media), viviparous sheep's fescue (Festuca vivipara) and kentucky bluegrass (Poa pratensis). Some of these flowering plants showed a quite dense cover compared to the previous plots, with 32% coverage (Figure 7).

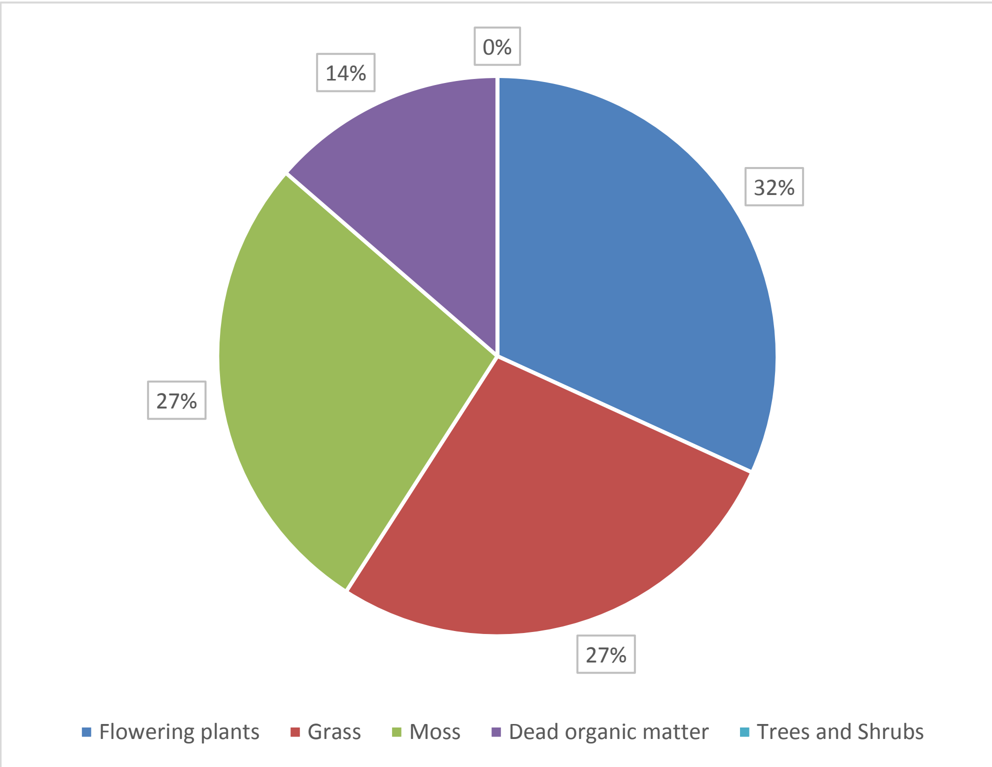

Figure 7:Average percentage of plot E.

The highest species diversity was found in A,D and E. Results show that dead organic litter composed 90% of the coverage in the A and D plots. There is also an obvious increase in moss coverage, the lowest percentage being in A,B and C and the highest in D and E (Figure 8).

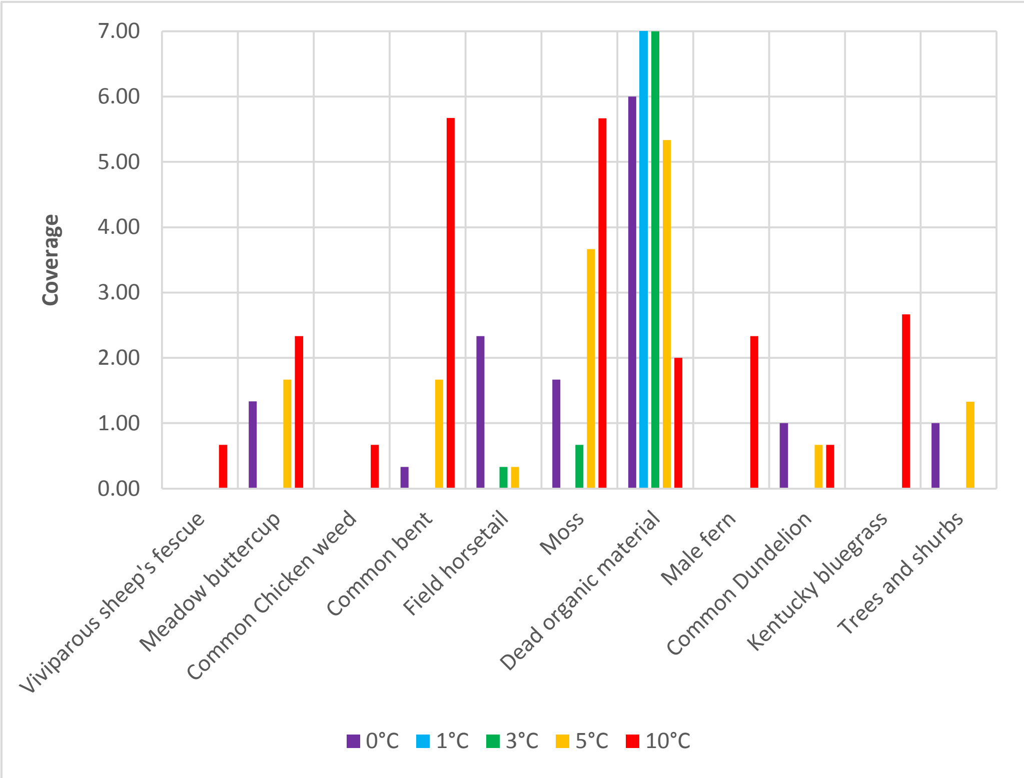

Figure 8:Average distribution of individual species.

The dead organic matter was the predominant ground cover in the forests, covering an average of 45% of the sampled areas. Flowering plants and moss were the next largest ground cover (Figure 9).

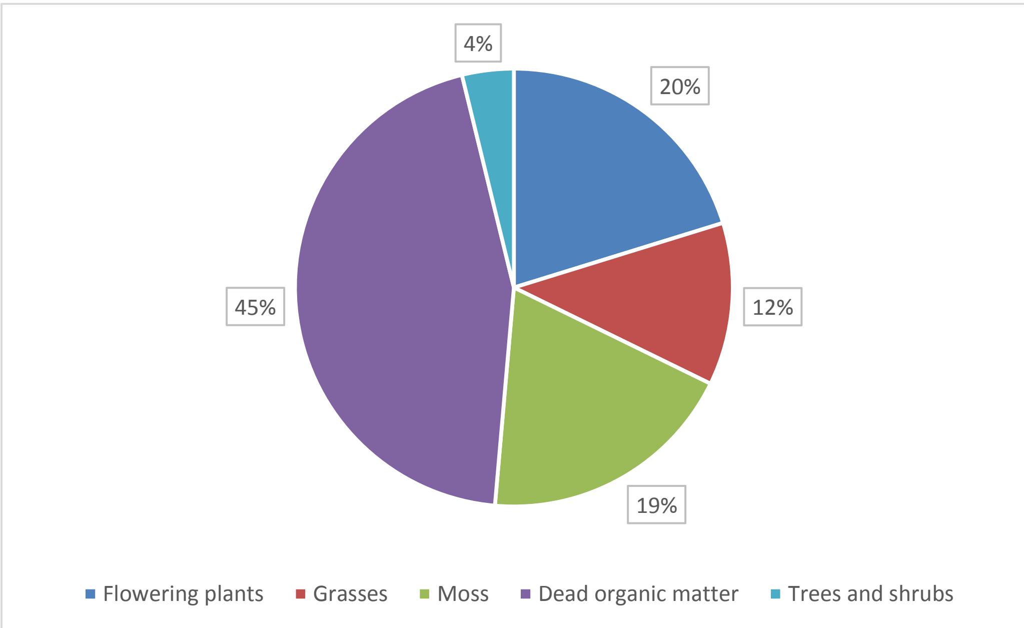

Figure 9:Average precentage for all gradients.

The soil analysis shows a correlation between soil temperature and organic matter. Although the highest percentage was measured in plot C, the overall average shows that the highest organic matter was in A, which has the lowest temperature. The soil from the E plots had the lowest organic percentage (Table 2).

Table 2:Soil results from soil analysis.

Plot	Temperature (°C)	Time	Soil OM	Average OM
A3	0	11:45	6.64%	
A3	0	11.53	6.89%	6.77%
B1	1	11:40	5.47%	
B2	1	11:31	5.10%	5.29%
C1	3	11:27	5.62%	
C3	3	11:20	7.37%	6.50%
D1	5	11:00	5.77%	
D2	5	11:07	5.62%	5.70%
E2	10	12:10	3.95%	
E3	10	12:00	5.83%	4.89%
			Samtals	5.83%

Interpretation and Discussion

Based on the empirical data and field observations, it is apparent that there is a strong correlation between undergrowth density in the forest and soil temperature. The ground cover was undoubtedly more prominent with a higher species variation in the warmer areas. The fact that we were not even able to access the 20°C area compounds this fact. It is easy to assume that the heat is the only contributing factor however the true basis is more complex.

A deeper look into the ecological dynamics shows us that a number of varying factors contribute the changes. For example there was a high mortality of the Sitka spruce where the soil was subject to a 10°C+ increase, which opened up the canopy and allowed for more sunlight to enter. It is interesting to note that the 0°C control plots had more vegetation that the 3°C plots and was also subject to more sunlight as they were at the edge of the forest.

When the needles of Sitka spruce fall to the ground they decrease the pH in the surrounding soil and use up the nitrogen reserves when decomposing, which deters undergrowth (Spoule, 2013). It must be noted that the spacing intervals between the trees was extremely dense, and therefore ground environment is not necessarily characteristic of a natural spruce forest. Forests also provide a habitat for various birds which disperse seeds in their surroundings. This could also account for the various species present in the forest.

Regarding the vegetation's response to heat, there are two interesting observations we made through our experiments, which confirm observations made in geothermal areas in general. With increasing heat, moss cover increased. At our 10 degrees plot, moss was dominant for the first

time, showing its specific adaptability to heat. As moss has small rhizoids but not roots, they don't get affected by the heat as much as other plants do. Our assumption, for the 20 degrees plot, would be an even higher dominance of moss.
Another aspect interesting to mention is that at the 10 degrees plot, 4 new species were present, which weren't found before. A reason for this could be the species adaptability to warmer soil, compared to others. They might have in means of competition pushed other species away to find a habitat in those warmer areas. Of those four species, the common bent (Agrostis capillaris) is especially well adapted to grow in warmer areas (Elmarsdóttir et al., 2015).
In regards to the soil results, it is rational to assume a lower organic percentage in warmer areas. Enzyme activity increases with heat up to a certain threshold and the decomposition of the organic matter therefore also. This would explain the lower amount found in plots D and E. The fact that the warmer areas had more growth would also affect the decomposition rate, because the breakdown of biomass also produces heat.
In light of these findings, the question arise as to whether plant ground cover and plants species diversity increases in all ecosystems that display increasing soil temperature. A study done in 2014 (Guðmundsdóttir et al, 2014) compared the plant cover density and diversity of the adjacent grasslands to the forest. The results showed that in the forests the soil temperature increase plant cover and diversity. However in the grasslands the plant cover started to decrease over 17°C. Also diversity decreased with increased heat. This suggests that the dynamic between biodiversity and heat are more ambiguous than originally thought.

Is it possible to build a connection between the results we received and global warming? Could our experimental site be an indicator for potential changes in the environment due to global warming?
Before we make any assumptions regarding those questions, it is important to remark that the effects of global warming on the environment on the one hand and those of increase in soil heat on the other hand are obviously of different kind. Global warming focuses on increase in atmospheric temperature while our research pointed at increase in soil temperature.
We could nonetheless, if we look at global warming from a broad perspective and connect that to our results try to build a connection, as it might be interesting to develop these thoughts a bit further. This connection though is not based on any research, but on our personal evaluation.

Our experiment showed that with increasing soil heat, biodiversity and also plant cover increased (if we forget about the influence of sunlight). The same could be said for global warming. With increasing atmospheric temperature, plant diversity and cover increase. The comparison between Iceland and one of the countries around the equator makes this clear.
Another factor is the decomposition rate which increases with increasing heat, whether in soil or atmosphere. Decomposition in the rainforest happens much quicker than up here. Decomposition in warmer soil happens quicker than in cooler soil, as we've remarked already. Quicker decomposition rates could in turn add to increased CO_2 respiration and therefore higher CO_2 output into the atmosphere.

Conclusion

The research strongly suggests that there is correlation between soil temperature and both plant diversity and density. Due to the limited data and the unique ecosystem dynamics it is however difficult to form conclusive opinions without further, comprehensive research that address all contributing factors.

We are also able to conclude that increased soil temperatures go along with decreasing soil organic matter, but an increase in decomposition rate of organic matter, which also generates heat.

We could conclude that despite receiving measurable results, geothermal ecosystems are very diverse, depending on many other factors than those that we have measured. Research on the grasslands has shown opposite results, suggesting that the ecosystems these little islands are found on make a difference and affect the outcome of the experiments.

Although research has been done here as well as abroad, there are gaps to fill, regarding the complexity of geothermal ecosystems.

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Pictures & tables references

Figure 1: Shows the high and low geothermal fields in Iceland. Retrieved from http://www.geoexpro.com/articles/2016/04/iceland-harnessing-the-earth on October 5th 2016.

Figure 2: Shows the frame used for estimating plant coverage and distribution. Taken by J.W.V.R on September 3rd 2016.

Figure 3: Results of calculating average for control plot A.

Figure 4: Results of calculating average for control plot B.

Figure 5: Results of calculating average for control plot C.

Figure 6: Results of calculating average for control plot D.

Figure 7: Results of calculating average for control plot E.

Figure 8: Results showing distribution of individual plant species.

Figure 9: Results of average distribution for all gradients.

Table 1: Plant cover estimation showing Braun-blanquet scale.

Table 2: Results of the soil messurements.