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The importance of microclimate and plant species richness for alpine arthropods in a Dryas heath at Finse

Vegard Nordbø
Master of Science in Animal biology

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A huge thanks to Cathrine Strømø for giving me a push in the right direction when it seemed farfetched to finish this master's thesis. It is caring people like you NMBU needs!

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Vegard Nordbø

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Abstract

Alpine ecosystems are characterized by low temperatures, strong winds, and high solar radiation, which can lead to harsh living conditions for flora and fauna. As climate changes, larger climatic variations and the number of extreme events are expected to increase. This affects the microclimate and plant richness. Few studies to date investigate how arthropods are affected by microclimate and plant richness. This study aimed to investigate how temperature, soil moisture, and plant richness affect arthropod composition and distribution to get a better understanding of how arthropods are affected by changing climate. The study was conducted at Mount Sanddalsnuten, Finse, in the southwest of Norway. 25 plots with high variations in temperature and soil moisture were used. 125 pitfall traps were placed evenly across the plots, and TMS-4 data loggers recorded temperature and soil moisture in each plot. The study found that 15158 arthropods, 3492 beetles, and 11666 other arthropods were collected in 24 plots at Sanddalsnuten, Finse, from June 20th to August 2nd. Linear models were used to analyze how microclimate and plant richness affected arthropod composition. The study found evidence that increasing temperatures affected parasitoids, the total number of beetles, beetle richness, and omnivore beetles negatively. Neither soil moisture nor plant richness was found to influence the arthropod community at Mt. Sanddalsnuten. Arthropod response to plant richness and microclimate changes are less studied, but time series monitoring programs can help to understand how arthropods respond.

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INTRODUCTION

Alpine ecosystems are known to have low temperatures throughout the year and long winters in northern and southern regions (Körner, 2021). Strong wind and high solar radiation are also common. These factors contribute to harsh living conditions for both flora and fauna. When looking at the alpine ecosystems at a smaller scale, we find that temperature, soil moisture, wind, and solar radiation vary greatly within short geographical distances (Geiger et al., 2009; Graae et al., 2018), as alpine ecosystems often comprise of diverse microclimates (Opedal et al., 2015; Rae et al., 2006). Microclimatic factors, like temperature and soil moisture, play an essential role in understanding the distribution and abundance of arthropods (Hodkinson, 2005; Bellard et al., 2012). Microclimatic factors may also affect the plant species and their distribution (Graae et al., 2018). Vegetation is vital in alpine areas, as it serves as cover from wind, precipitation, and solar radiance for arthropods (Rae et al., 2006). Plants may represent microhabitats for arthropods as they can serve as protection from environmental conditions and food for herbivores and omnivores (Rae et al., 2006).

Alpine and arctic environments are one of the habitat types most affected by climate change (Inouye, 2020). The annual mean temperature has increased by approximately 1°C globally in the last two centuries (IPCC, 2018), and the rate of increase is particularly high at higher altitudes and latitudes (IPCC, 2014). Roos et al. (2022) reported an observed increase in temperature of +0.36°C per decade at Finse. As temperature drives biological processes in alpine environments, changes in the ecological structure in alpine ecosystems are expected as the temperature changes (Bellard et al., 2012). As the climate is warming, climate change may also lead to larger climatic variations and an increased number of extreme events (Panchen et al., 2022). Extreme events, like floods (Hanssen-Bauer et al., 2009), can change the morphology of the landscape (Bellard et al., 2012) through an earlier onset of the melt in spring or heavy precipitation. Such events may defragment habitats. With an increase in temperature and extreme events, we will likely experience significant changes in species distributions in these environments (Cardoso et al., 2020).

Plants and arthropods, amongst others, are affected by climate change. Climate change may affect the time of activity, distribution, competition, food availability, and morphology of arthropods (Bellard et al., 2012; Cardoso et al., 2020). Arthropods may move to higher elevations as the temperature rises. A Konvicka et al. (2003) study showed that 12-15 butterfly species (Depending on the analysis) were ascending to higher altitudes. Lower-altitude living arthropods ascending onto higher altitudes may outcompete species suited for extreme climatic conditions. Another consequence is that climate changes can also create a temporal mismatch between plants and pollinators (Hegland et al., 2009). Engler et al. (2011) report that plants in mountainous areas are highly affected by both temperature and precipitation. The florae in alpine areas, like the Norwegian Scandes, with rising temperature and precipitation, are expected to be less sensitive to climate change than those with temperature increases alone (Engler et al., 2011). Plants are known to be able to respond to higher temperatures by changing phenology and the composition of plant species (Oberbauer et al., 2013; Klanderud & Birks, 2003; Steinbauer et., al 2018), which again affects arthropods.

Arthropods are the largest animal phylum in the world and can be found almost everywhere (Giribet & Edgecombe, 2019). Several arthropod species have phenology adapted to alpine and arctic areas (Høye & Forchhammer, 2008a). Dipterans are often the most abundant arthropod family in alpine areas (Høye & Forchhammer, 2008a). Arthropods support key ecosystem processes in alpine areas due to their wide range of lifestyles. Detritivores affect decomposition and help with nutrient cycling, while pollinators have a plant-pollinator relationship that can affect plant distribution (Høye, 2020). Like plants, arthropods are also affected by the temperature at a small scale (microclimatic) and a larger scale (climatic) (Convey et al., 2018; Høye, 2020). Arthropod life cycles are influenced by microclimatic conditions (Høye, 2020) due to their size-limited mobility. It is essential to investigate how arthropods are affected by microclimate to understand better how they react to a changing climate. Plant species are essential for the ecosystem structure in alpine areas. They require different climatic conditions, and microclimate may affect their distribution (Ohler et al., 2020). Plants may serve as food for arthropods (Birkemoe et al., 2016). They may also indirectly affect arthropod abundance through plant composition and shelter arthropods from the environment (Rae et al., 2006). It is important to investigate the relationship between plants and arthropods in alpine areas to understand how they react to microclimatic factors.

Mount Sanddalsnuten at Finse, Norway, is home to one of the ITEX (The International Tundra Experiment, Henry & Molau, 1997) alpine study sites. Several studies are done at and near the ITEX site at Mt. Sanddalsnuten. Most of these studies explore how primary producers are affected by changes in climate, but studies of other organisms are also carried out (Roos et al., 2022). Dryas heath is the best-documented vegetation type in this area (Roos et al., 2022). The well-documented ITEX site makes Finse a perfect place for new studies on other and less well-known organism groups, such as arthropods, and their response to microclimate and plant richness.

There are several methods to sample arthropods, but all have their challenges. Wind easily affects malaise traps (Yi et al., 2012) and was therefore excluded at sites such as Finse. As a result of the cold temperatures at Finse, winged arthropods fly low, and ground-dwelling arthropods are already at ground level (Høye & Forchhammer, 2008b). Hence pitfall trapping is a natural choice. Pitfall trapping effectively collects active ground living species, while less active and flying species may be underrepresented (Woodcock, 2005). Several other Finse-based studies have used pitfall trapping (Ottesen, 1996; Bråten et al., 2012; Hågvar et al., 2017). As pitfall trapping is best suited to ground-living arthropods, Coleoptera – and Carabidae in particular – is one of the better-known insect groups where species identification is possible, even for people not very experienced with insect identification. Carabids have been investigated in several earlier studies from Finse, and the species in the areas are also well known (Ottesen, 1996; Bråten et al., 2012; Hågvar et al., 2017; and more).

In the present study, I will use pitfall trapping at Finse to answer whether microclimate and plant species richness determine the distribution of alpine arthropods in a Dryas heath.

- I expect that temperature is a stronger predictor of arthropods than soil moisture within this vegetation type and that species richness of plants has the largest effects on herbivores but also increases the total species number of beetles as well as the abundance of the other trophic groups.

I will identify carabid beetles to species, whereas the other arthropods will only be sorted to higher taxonomical levels and be placed in the proper trophic group.

METHODS

Study area

The study was conducted on the southwestern slope of Mount Sanddalsnuten, Finse (60.626 °N; 7.522 °E) at 1450-1530m a.s.l in the southwest of Norway (Figure 1). The climate at Finse is Alpine-oceanic (Moen, 1998), with an average summer temperature of 9.2°C and 199.3mm of precipitation (at 1210m a.s.l., Norskklimaservicesenter 2022, Appendix A1). The study was conducted in the summer months, June-August 2021.

The study area comprises 25 plots in an alpine Dryas heath community (Figure 1). The plots were chosen to include the highest possible variation in temperature and soil moisture while maintaining a high cover of *Dryas octopetela*. The higher elevation plots are more wind-exposed than lower elevation plots. The distance between the plots was always at least three meters and never more than 35 meters.

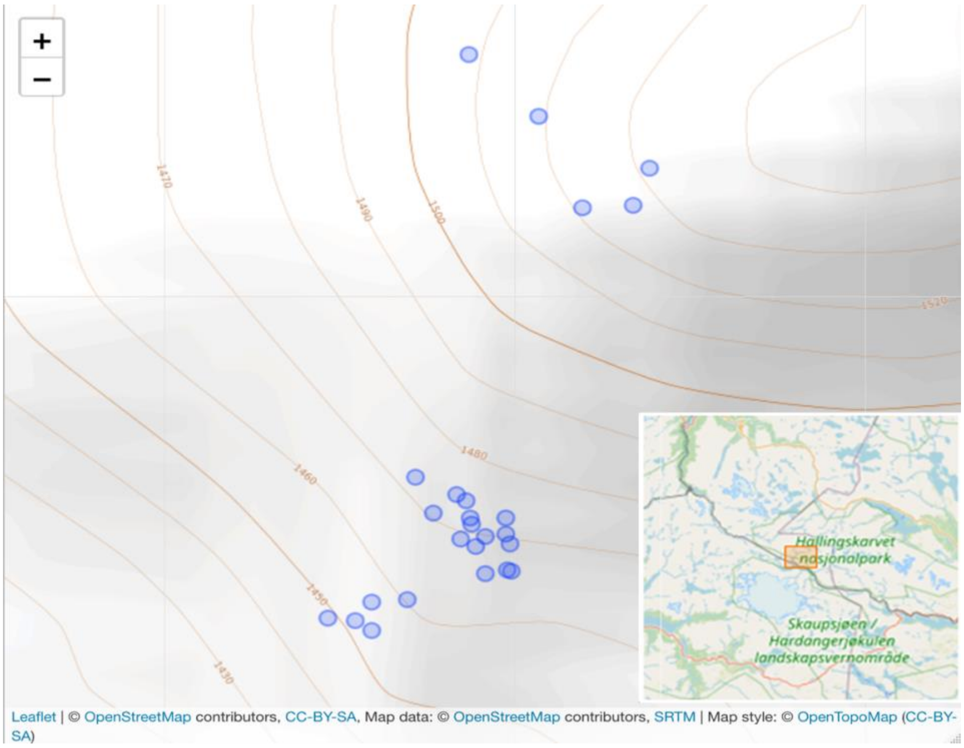

Figure 1: Map of the study area at Sanddalsnuten, Finse, with the 25 study plots (blue circle) in total. Each line represents an incline of 10 meters in elevation. The map in the lower right corner is a zoomed-out version of the main map.

Each plot comprised five pitfall traps, a vegetation area, and a data logger (Figure 2). A 50cm x 50cm vegetation area marked the center of each plot, and plant species richness was measured inside the vegetation area. A TMS-4 data logger (Wild et al., 2019) was placed near the vegetation area, collecting temperature and soil moisture data. The five pitfall traps were scattered around the vegetation plot with a minimum distance of one meter.

Figure 2: Picture of a plot. Five pitfall traps (A-E) were scattered around a 50cm x 50cm vegetation area (red square) where plant species richness was recorded. The data logger is placed in the soil next to the red square.

Data collection in the field

Arthropods were collected by pitfall traps, 6.5 cm in diameter and 7.5 cm tall. The pitfall traps were dug ~7.5 cm into the soil so that the lip of the cup was slightly below the ground surface. Plywood roofs were used to prevent rainwater from flooding the traps (Bråten et al., 2012). The plywood roofs were placed approximately three cm above the ground. The pitfall traps were filled with a 7:1:2 ratio of propylene glycol, ethanol, and water (~70ml). I used this mixture to ensure the arthropods were conserved and did not decompose.

Four pitfall traps were placed in each plot on the 20th of June 2021. On the 21st of June 2021, I added a fifth pitfall trap to each plot. All pitfall traps were emptied and stored in small jars with 70% ethanol on the 2nd of August 2021.

Each of the 25 plots had a TMS-4 data logger that continuously recorded temperature two centimeters above the ground and soil moisture right below the ground level. Data were recorded every 15 minutes.

Ruben Erik Roos performed vegetation analysis inside the vegetation area (Figure 2) in 2020 and 2021. Vegetation analyses were performed on 16 vegetation areas in 2020 and the other nine in 2021. A plant species was recorded as present if the plot had any living occurrence of the plant species.

Laboratory processing

All arthropods from the pitfall traps were sorted in the lab at NMBU from August to late November 2021 (Figure 3). Arthropods were sorted into groups in petri dishes using tweezers and needles. They were examined in a Leica MS5 stereo microscope, counted, and put in glasses with 70% ethanol. Beetles were separated from the other taxonomical groups for further identification. Arthropods were systematically sorted using taxonomical keys by Sømme (2015) and divided into orders or functional groups. Collembola and Acari were not counted or identified.

Carabids were sorted into species using taxonomical keys in Lindroth et al. (1985) and Lindroth et al. (1986). In contrast, Staphylinidae was only sorted into family due to the high number of similar species at Finse (Ottesen, 1996).

Other arthropods were sorted into easily identifiable taxonomical groups and then into known feeding groups (Table 1). Feeding groups of carabids were based on species information, whereas all staphylinids were sorted as predators (Table 2).

Figure 3: Overview of arthropod sorting in the lab.

Temperature and soil moisture data

Data from June 20th to the 2nd of August. 2021, were collected at all 25 plots at Sanddalsnuten. Raw soil moisture data collected from the TMS-4 data loggers were transformed according to the TMS-4 transformation guide (Wild et al., 2019). I used "sandy loam A," one of the soil types with medium-sized grit (Figure 4), when converting raw soil data into volumetric soil data, as I did not have data on the soil from each plot. The following equation was used to convert raw soil moisture data to volumetric soil moisture:

$$y = -0.0000000038x^2 + 0.000339449x - 0.214921782$$

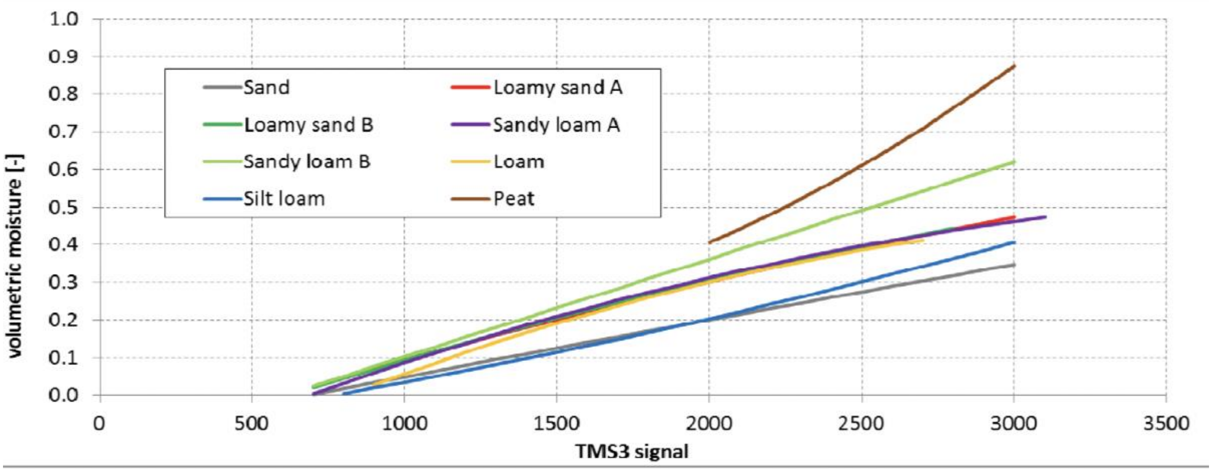

Figure 4: This graph is an example illustration, from Wild et al. (2019), of how soil moisture content alters according to the soil type. To calculate the volumetric soil moisture content, the TMS3 signals (raw soil data), measured by the TMS-4 data logger, are multiplied by an equation tailored to the specific soil types. Equations used to convert raw soil moisture data (TMS3 signals) to volumetric soil moisture are provided by Wild et al. (2019). This thesis uses Sandy Loam A.

The total mean temperature and soil moisture for each plot was calculated from the data collected while the pitfall traps were out. The temperature and soil moisture data used in the statistical analysis are presented in Appendix B1.

Statistical analysis

All data were analyzed using R version 4.2.1 (R Core Team, 2021) and RStudio version 2023.03.0+386 (2023.03.0+386) (RStudio Team, 2021). P-values below 0.05 is viewed as statistically significant.

One plot was excluded from the statistical analysis due to the loss of a data logger. Plot 16 only contained data from four pitfall traps, as one was destroyed. Detritivores, including the cockroach *Ectobius lapponicus,* were excluded from the statistical analyses due to the low number of specimens.

The relationship between the explanatory variables (soil moisture, temperature, plant species richness, elevation) was examined using Pearson's correlation to test for collinearity. Elevation was excluded from all analyses due to high collinearity with the other explanatory variables. Variance Indication Factor (VIF) was further used to investigate whether there was any multicollinearity between the remaining explanatory variables.

I plotted histograms and performed Shapiro-wilk tests for all the response variables to test whether the data were normally distributed. They turned out to be mostly right-skewed and not normally distributed. Thus, I log-transformed the response variables and performed the Shapiro-Wilk test again. After log-transforming, all response variables except the number of beetle species were normally distributed. The number of beetle species was further examined using a Spearman rank correlation test.

A Linear Model (lm) was used for the statistical analysis. Araneae, Diptera, Ichneumonoidae, Opiliones, and herbivore insects were used as response variables for all the arthropods except the beetles (Table 1). Predators, herbivores, omnivores, the total number of beetle individuals, and the total number of beetle species were used as response variables (Table 2). Temperature, soil moisture, and plant species richness were the explanatory variables in all analyses.

A model consists of a response variable (functional group and group from Tables 1 and 2) and all the explanatory variables (mean temperature, mean soil moisture, and plant species richness):

$$Response\ variable \sim mean\ temperature\ +\ mean\ soil\ moisture\ +\ plant\ species\ richness$$

Statistically significant results (*p<0.05*) are marked in bold.

RESULTS

A total of 15158 arthropods were collected in the pitfall traps, of which 3492 were beetles and 11666 were other arthropods (Table 1 and 2).

Table 1: Total number of arthropods, excluding Coleoptera, collected in 24 pitfall traps at Sanddalsnuten, Finse, from 21. June – 2. August 2021. Overview of functional group and order.

Functional group	Order	Number of individuals
	Arachnids	
Predators	Aranea	1094
Herbivores	Opiliones	2140
	Insects	
Mixed feeders	Diptera	7256
Herbivores	Hemiptera	8
	Lepidoptera	523
	Hymenoptera	4
	Total	535
Parasitoids	Hymenoptera (Ichneumonoidae)	636
Detritivore	Blattodea (*Ectobius lapponicus*[1)]	5

[1]Ectobius L. is not used in statistical analysis.

Table 2: Beetle species and their functional groups, collected in 24 pitfall traps at Sanddalsnuten, Finse, from 21. June – 2. August 2021. In total, 13 different beetle species were represented in the pitfall traps. Note that species from the family Staphylinidae are not identified further. There were, in total, 3492 Coleopterans.

Group	Species	Number of individuals
Predator	*Calathus melanocephalus*[1]	614
	Carabus problematicus[1]	1
	Coccinella septempunctata[1]	2
	Cymindis vaporariorum[2]	281
	Nebria nivialis[2,3]	168
	Nebria rufescens[3]	5
	Notiophilus aquaticus[2]	25
	Patrobus septentrionis[2]	316
	Staphylinidae sp.[1]	363
	Total	1775
Herbivore	*Byrrhus fasciatus*[1]	213
	Otiorhynchus nodosus[1]	16
	Total	229
Omnivore	*Amara alpina*[2,3]	1240
	Amara quenseli[2,3]	247
	Total	1487
Detritivore[4]	*Thanatophilus lapponicus*[1]	1

[1] Functional groups are determined according to literature: Sverdrup-Thygeson, 2021

[2]Functional groups are determined according to literature: Hågvar & Pedersen, 2015.

[3]Functional groups are determined according to literature: Hågvar et al., 2017.

[4] Detritivore will not be used as a response variable

Temperature, moisture, elevation, and plant richness

The temperature at the study sites fluctuated from ~3°C to ~16°C (Figure 5), with a mean temperature of 10.2°C (Appendix B1). The highest difference in daily temperature between the two plots was ~4°C (Appendix C1, C3).

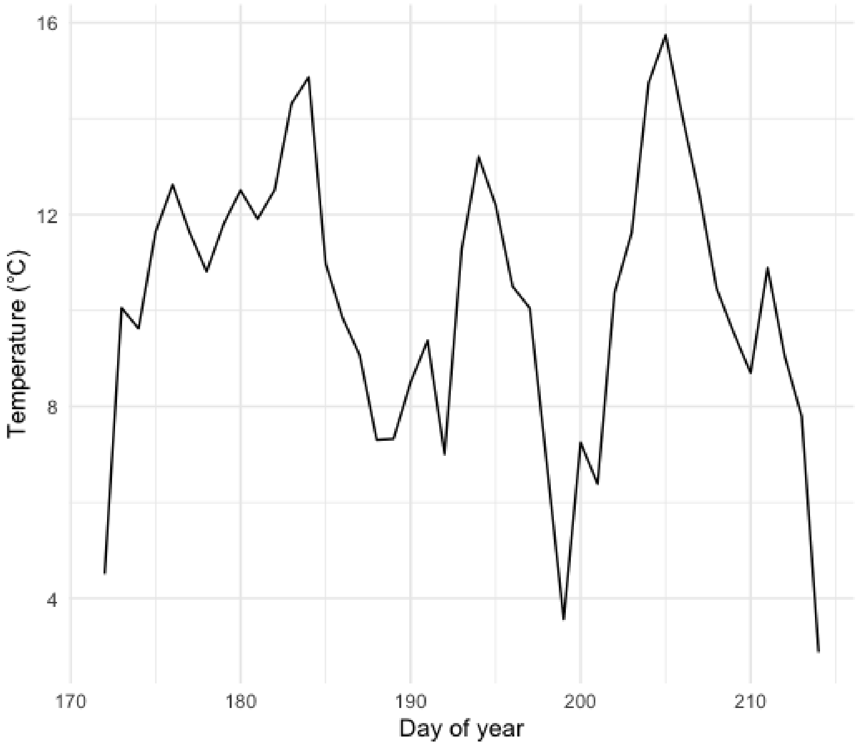

Figure 5: Total mean temperature from all 24 data loggers at Mt. Sandalsnuten from June 20th to August 2nd. (See Appendix C1 and C3 for the individual temperatures from the data loggers)

The total mean volumetric soil moisture from June 20th to August 2nd. ranged from ~0.18 to ~0.30 (Figure 6). At the wettest, the study site measured 12% more soil moisture than at the driest, close to a doubling in the volumetric soil moisture. The mean volumetric soil moisture for all the plots was 0.23. Two shorter periods had lower soil moisture content (Figure 6). Large individual differences in soil moisture content existed between the plots throughout the study. The highest daily volumetric soil moisture difference between the two plots was ~0.4 (Appendix C2, C4).

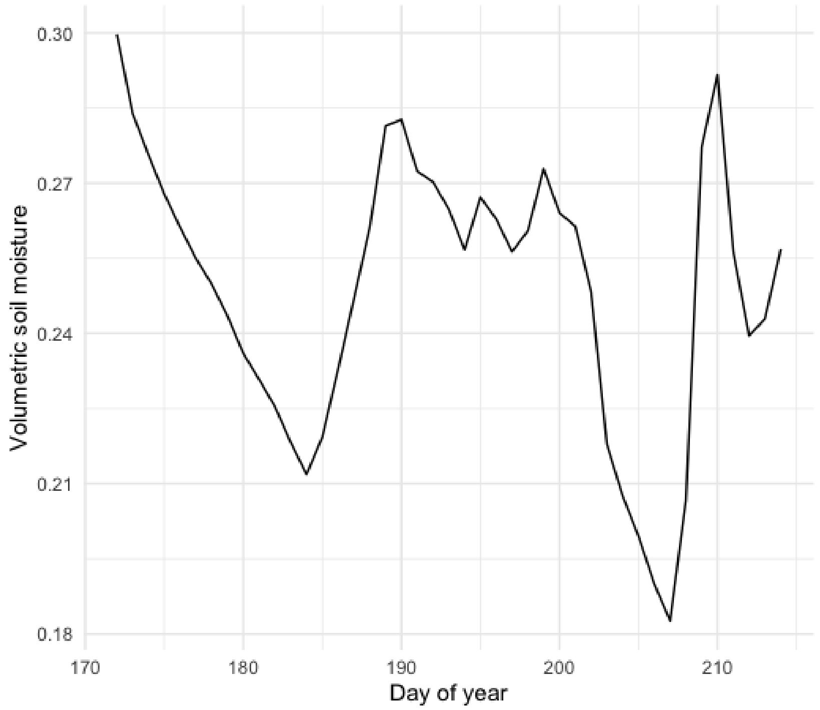

Figure 6: Soil moisture (total mean of 24 data loggers) from June 20th to August 2. 2021 at Mt. Sandalsnuten, Finse. (See Appendix C2 and C4 for individual soil moisture from the data loggers)

Temperature, elevation, soil moisture, and plant species richness were all correlated. The temperature decreased with an increase in elevation ($r = -0.66, P = 0.0004, \alpha = 0.05$). Plant species richness was also found to decrease with an incline in elevation ($r = -0.58, P = 0.003, \alpha = 0.05$). Elevation was not used in further statistical analysis to avoid multicollinearity. Plant species richness increased with an increase in temperature ($r = 0.51, P = 0.01, \alpha = 0.05$), while soil moisture decreased with increasing temperatures ($r = -0.45, P = 0.03, \alpha = 0.05$). Multicollinearity was low ($VIF < 2$) for the remaining explanatory variables (Temperature, Soil moisture, and plant species richness) and is not a significant concern for the regression model.

The effect of temperature, moisture, and plant richness on arthropod groups without beetles

Neither number of Araneae, Opiliones, Diptera, and herbivore insects showed a significant linear relationship with either of the explanatory variables (Table 3-6). However, the number of parasitoids *decreased* with increasing temperatures ($P = 0.004$) (Figure 7, Table 7). The model with parasitoids explained ~56.7% of the variation.

Table 3: A linear regression model with the number of Araneae as a response variable. The number of Araneae is log-transformed.

Model: Araneae ~ mean temperature + plant species richness + mean soil moisture

	Araneae (Predators)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	2.97	-7.55 – 13.50	0.562
Mean temperature	0.02	-1.03 – 1.07	0.971
Plant species richness	0.08	-0.02 – 0.17	0.100
Mean soil moisture	-2.08	-5.92 – 1.76	0.272
Observations	24		
R^2 / R^2 adjusted	0.242 / 0.128		

Table 4: A linear regression model with the number of Opiliones as a response variable. The number of Opiliones is log-transformed.

Model: Opiliones ~ mean temperature + plant species richness + mean soil moisture

	Opiliones (Herbivores)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	12.57	2.54 – 22.60	0.017
Mean temperature	-0.68	-1.68 – 0.32	0.170
Plant species richness	-0.07	-0.16 – 0.03	0.148
Mean soil moisture	-2.08	-5.74 – 1.58	0.250
Observations	24		
R^2 / R^2 adjusted	0.362 / 0.266		

Table 5: A linear regression model with the number of Diptera as a response variable. The number of Diptera is log-transformed.

Model: Diptera ~ mean temperature + plant species richness + mean soil moisture

	Diptera (Mixed feeders)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	7.68	1.02 – 14.33	0.026
Mean temperature	-0.17	-0.83 – 0.50	0.608
Plant species richness	-0.04	-0.10 – 0.02	0.196
Mean soil moisture	0.61	-1.82 – 3.03	0.608
Observations	24		
R^2 / R^2 adjusted	0.210 / 0.091		

Table 6: A linear regression model with the number of herbivore insects as a response variable. The number of herbivore insects is log-transformed.

Model: Herbivore insects ~ mean temperature + plant species richness + mean soil moisture

	Herbivore insects		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-7.23	-19.30 – 4.84	0.226
Mean temperature	0.78	-0.43 – 1.98	0.193
Plant species richness	0.09	-0.02 – 0.20	0.108
Mean soil moisture	1.05	-3.35 – 5.46	0.624
Observations	24		
R^2 / R^2 adjusted	0.369 / 0.274		

Table 7: A linear regression model with the number of parasitoids as a response variable. The number of parasitoids is log-transformed.

Model: Ichneumonoidae ~ mean temperature + plant species richness + mean soil moisture

	Ichneumonoidae (Parasitoids)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	17.43	8.98 – 25.88	<0.001
Mean temperature	-1.30	-2.14 – -0.46	**0.004**
Plant species richness	-0.04	-0.12 – 0.03	0.238
Mean soil moisture	-2.56	-5.64 – 0.52	0.098
Observations	24		
R^2 / R^2 adjusted	0.567 / 0.502		

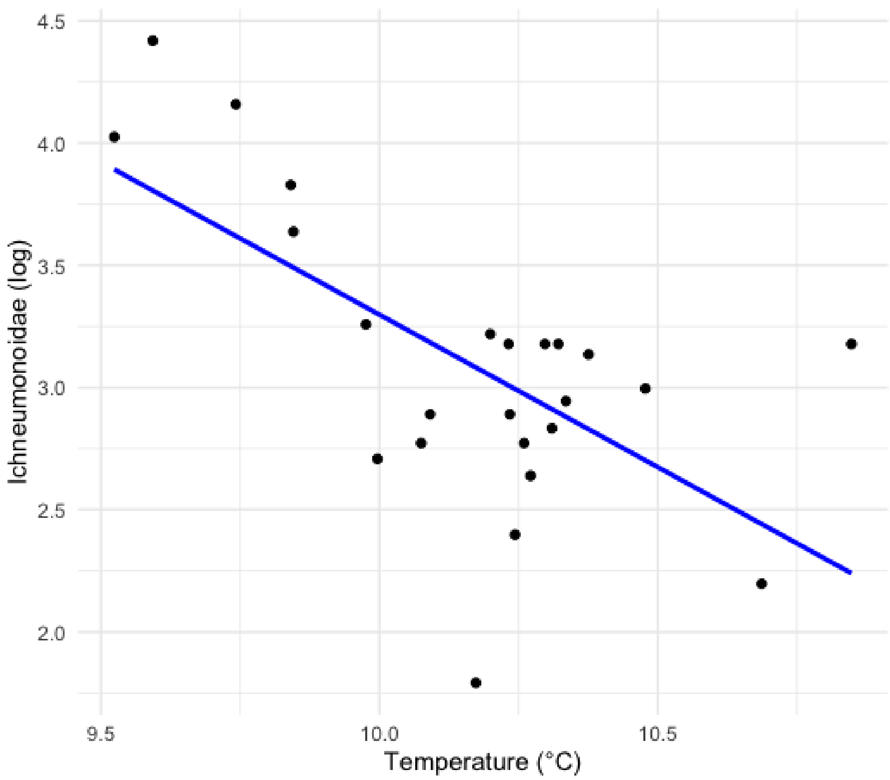

Figure 7: Regression plot of the negative linear relationship between temperature and Ichneumonoidae. The number of parasitoids decreases as temperature rises (Regression line in blue).

The effect of temperature, moisture, and plant richness on Coleoptera

Similar to the parasitoids, the total number of beetles decreased with increasing temperatures (Table 8, Figure 8), whereas plant species richness and soil moisture did not affect beetle numbers. The model explained ~34.4% of the variation in the beetle data.

Table 8: A linear regression model with the total number of beetles as a response variable. The total number of beetles is log-transformed.

Model: Total number of beetles ~ mean temperature + plant species richness + mean soil moisture

	Total number of beetles		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	13.26	4.43 – 22.09	0.005
Mean temperature	-0.87	-1.75 – 0.01	**0.052**
Plant species richness	0.02	-0.06 – 0.09	0.692
Mean soil moisture	1.15	-2.07 – 4.37	0.466
Observations	24		
R^2 / R^2 adjusted	0.344 / 0.246		

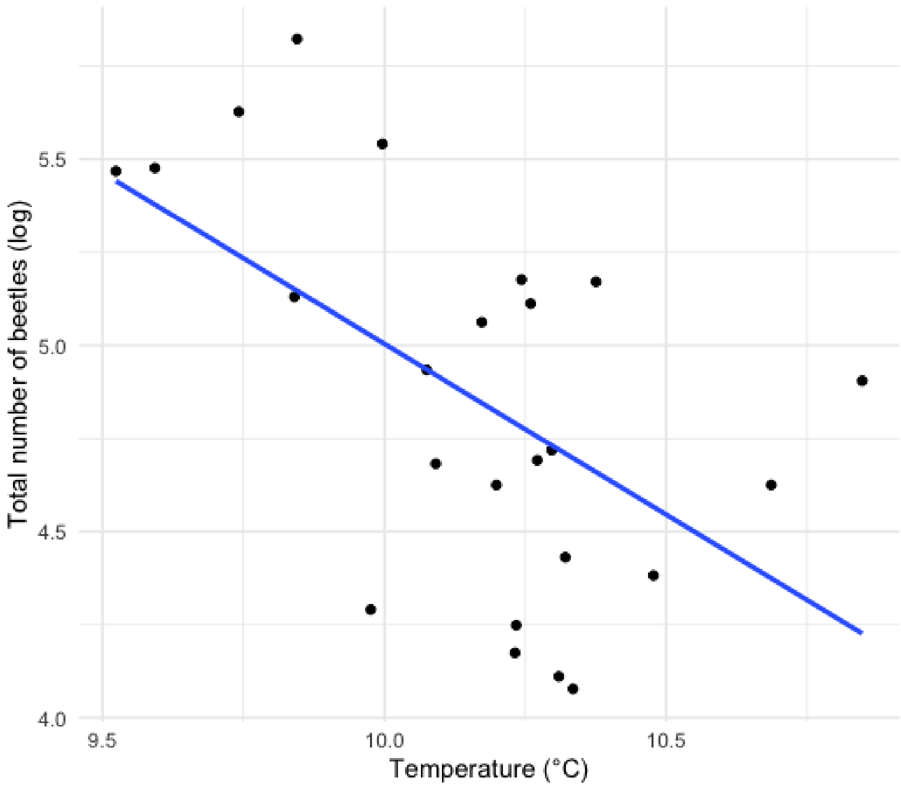

Figure 8: Regression plot of the negative linear relationship between temperature and the total number of beetles. The total number of beetles decreases as temperature rises (regression line in blue).

The number of beetle species was not normally distributed according to the Shapiro-Wilk test for normality ($p = 0.01$). The model in Appendix D1 showed a negative effect from temperature. Spearman's rank correlation test also resulted in a negative correlation ($R=-0.59$, $P = 0.002$, $\alpha = 0.05$) between temperature and the number of beetle species (Figure 9). Plant species richness and soil moisture did not significantly affect the total number of beetle species.

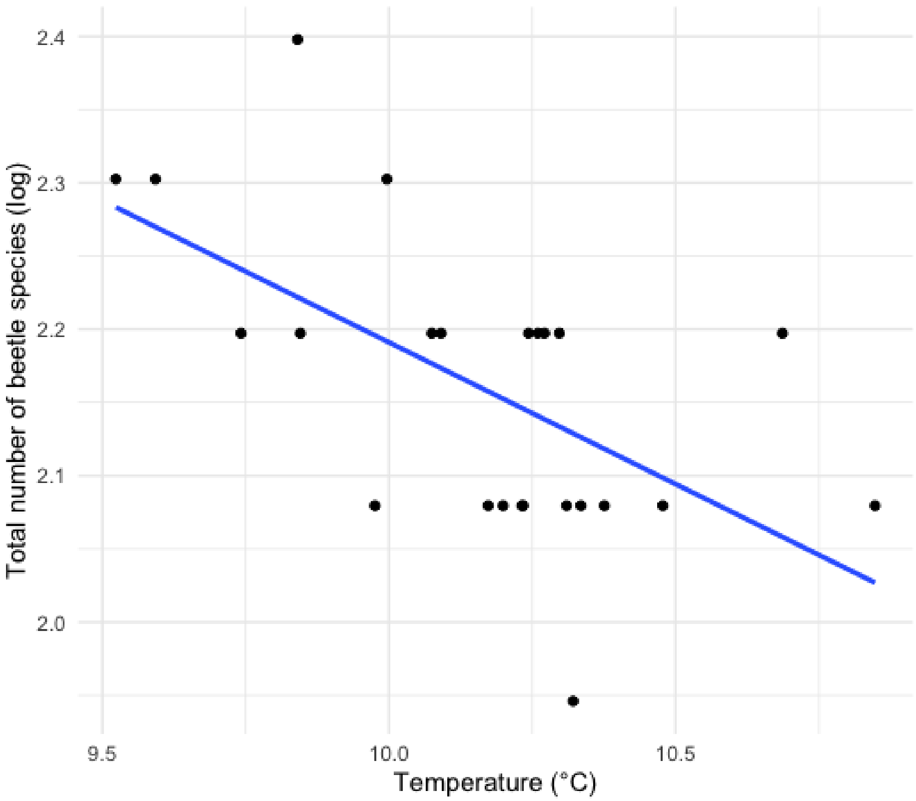

Figure 9: Regression plot of the negative linear relationship between temperature and the total number of beetle species. The total number of beetle species decreases as temperature rises (regression line in blue).

Analyses of the number of beetles in different feeding groups showed that only the omnivorous beetles had a clear effect of temperature (Table 9, 10, 11): the number of omnivorous beetles decreased with increasing temperature. This model explains ~32.6% of the variation in Omnivore beetles (Table 9, Figure 10).

Table 9: A linear regression model with the number of omnivore beetles as a response variable. The number of omnivore beetles is log-transformed.
Model: Omnivore beetles ~ mean temperature + plant species richness + mean soil moisture

	Omnivore beetles		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	16.30	5.24 – 27.36	0.006
Mean temperature	-1.18	-2.28 – -0.07	**0.038**
Plant species richness	-0.01	-0.11 – 0.09	0.777
Mean soil moisture	-1.09	-5.13 – 2.94	0.579
Observations	24		
R^2 / R^2 adjusted	0.326 / 0.224		

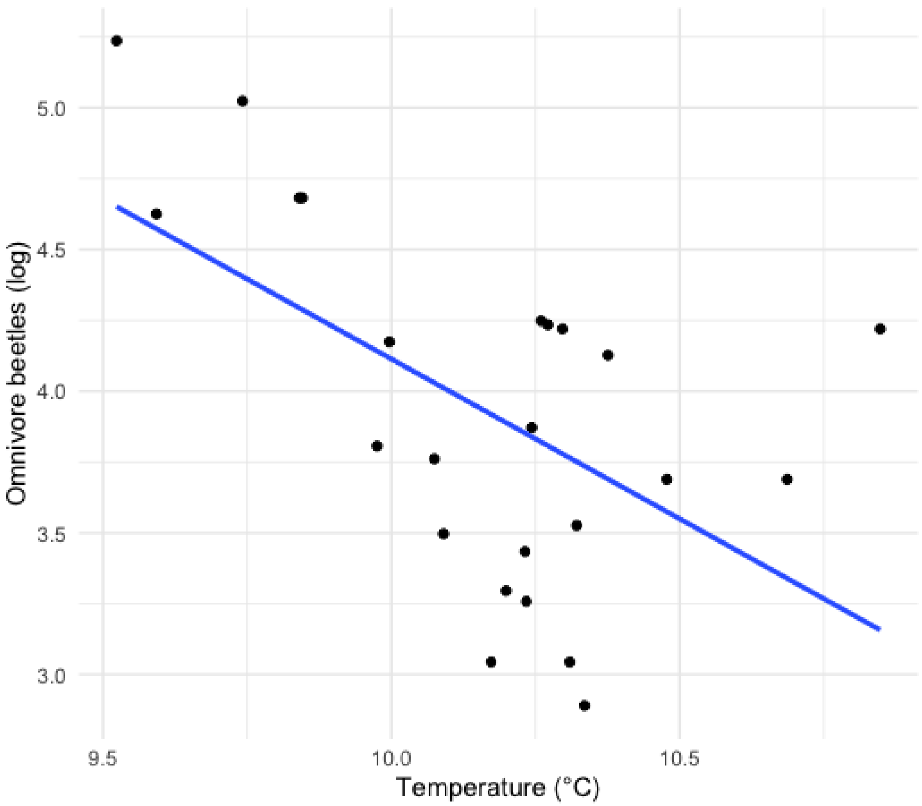

Figure 10: Regression plot of the negative linear relationship between temperature and the omnivore beetles. The number of omnivore beetles decreases as temperature rises (regression line in blue).

Table 10: A linear regression model with the number of herbivore beetles as a response variable. The number of herbivore beetles is log-transformed.

Model: Herbivore beetles ~ mean temperature + plant species richness + mean soil moisture

	Herbivore beetles		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	-7.23	-19.30 – 4.84	0.226
Mean temperature	0.78	-0.43 – 1.98	0.193
Plant species richness	0.09	-0.02 – 0.20	0.108
Mean soil moisture	1.05	-3.35 – 5.46	0.624
Observations	24		
R^2 / R^2 adjusted	0.369 / 0.274		

Table 11: A linear regression model with the number of predator beetles as a response variable. The number of predator beetles is log-transformed.

Model: Predator beetles ~ mean temperature + plant species richness + mean soil moisture

	Predator beetles		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	9.73	-0.80 – 20.27	0.068
Mean temperature	-0.68	-1.73 – 0.37	0.192
Plant species richness	0.05	-0.04 – 0.15	0.272
Mean soil moisture	2.87	-0.98 – 6.71	0.135
Observations	24		
R^2 / R^2 adjusted	0.336 / 0.237		

DISCUSSION

Main findings

The aim of this study was to investigate how microclimate and plant species richness affected Alpine arthropods in a Dryas heath. I found that temperature significantly affected the distribution of parasitoids, the total number of beetles, the number of beetle species, and omnivore beetles. Overall, the number of parasitoids, total number of beetles, number of beetle species, and omnivore beetles all were negatively impacted by an increase in temperature, suggesting that a general increase in temperature in alpine areas will result in fewer parasitoids, beetles, and beetle species. Temperature was not found to significantly affect the other trophic groups, indicating that only certain groups of arthropods will decrease with higher temperatures. Soil moisture and plant richness did not affect any of the trophic groups or the number of carabids (species). However, temperatures were found to correlate with soil moisture and plant richness, showing that temperature itself is not solely responsible for changes in the arthropod community at Mt. Sanddalsnuten. Soil moisture decreased with rising temperatures, while plant richness increased with higher temperatures. This multicollinearity between the predictor variables did not significantly affect the regression analyses due to a low VIF.

Temperature, soil moisture, and plant richness

Temperature is often seen as one of the main drivers of climate change in alpine areas (Bellard et al., 2012). Finse has high precipitation rates (Appendix A2) and a moderate climate warming of +0.36°C (Roos et al., 2022). As a part of the Norwegian Scandes, Finse is said to be an area less sensitive to climate change (Engler et al., 2011). Other areas, like the Spanish Pyrenees, are more prone to climate change due to low precipitation amounts (Engler et al., 2011). Scharn et al. (2022) found soil moisture to be an important driver for the plant community at the Latnjajaure Field Station in northern Sweden. This does not match my findings at Mt. Sanddalsnuten, which showed no significant correlation between soil moisture and plant richness. On the other hand, I found a positive relationship between temperature and plant richness. Steinbauer et al. (2018) also report that temperature increases plant richness. This is expected as temperature and precipitation increase simultaneously (Engler et al., 2011), making lower-altitude plants migrate upwards while the preexisting plant species can stay. I also found a negative relationship between temperature and soil moisture. Soil moisture decreased as temperature increased (Figure 5, Figure 6), which is natural as temperature evaporates more moisture as temperature increases.

Plant richness and microclimatic effect on arthropods

Arthropods are said to be sensitive to climate change (Høye & Culler, 2018), and microclimates are just as important for their dispersal and abundance due to their small size. Little is known about how arthropods are affected, especially in polar and alpine areas, as microclimatic effects on arthropods are not a widely studied topic (Høye & Culler, 2018). This limited knowledge about arthropods is starting to be a bottleneck in understanding how arthropods respond to climate and microclimate (Warren et al., 2018).

In this study, parasitoids, the total number of beetles, beetle richness, and omnivore beetles responded negatively to an increase in temperature. At the same time, the other trophic groups were not affected by temperature. Rae et al. (2006) argued that wind, temperature, and soil moisture affected the arthropod composition at the treeline level. While it is not defined as an alpine area, one would expect arthropods to react similarly in alpine areas. My findings on temperature match those that Rae et al. (2006) found, but I did not find any evidence that soil moisture affected the composition of arthropods at Mt. Sanddalsnuten. A study by Høye et al. (2018) saw a change in arthropod composition driven by local soil moisture and vegetation, just as Rae et al. (2006). This indicates either that my results were biased in a way or that soil moisture affects arthropods in some areas but not all.

2021 was a warm year at Finse temperature-wise. The mean temperature in the summer months was 9.2°C, 1.6°C warmer than the mean summer temperature from 2004-2021 (Norsk klimaservicesenter (Norwegian service center for climate), 2021; Appendix A1). This raises the question of whether we would have large yearly fluctuations in arthropod composition or if the composition would be like in an average temperature year. 2021 was precipitation-wise a dry year with summer precipitation of 199.3mm, 70mm lower than the average precipitation from 2004-2021 (Norsk klimaservicesenter (Norwegian service center for climate), 2021; Appendix A2). This shows that even if one expects a parallel increase in temperature and precipitation, yearly fluctuations might affect the arthropod community and plant richness.

Plant richness did not affect trophic groups or the number of Coleopterans (species). This contrasts with Rae et al. (2006) paper which argues that alpine plant communities influence arthropod community composition. Plant richness used in this thesis was partially measured in 2020 and partially in 2021 and may have affected my results.

Future research

A knowledge gap exists in understanding arthropod response to microclimate and plant richness. Larger vertebrate groups and plant species migrating upwards have been studied, but arthropod response is less studied, although they are important in all ecosystems.

It can be hard to investigate arthropod response to plant richness and microclimate with little information to compare it to. It is recommended to include them in time series monitoring programs (Post & Høye, 2013) to understand better how arthropods react to climate, microclimate, and plant richness changes. With time series data, it will be easier to distinguish between yearly fluctuations and more considerable changes in arthropod communities.

Having several transects on Mt. Sandalssnuten with different soil moisture levels would be interesting. The plots used in this thesis did vary greatly and may have affected the results (Appendix C2, C4). If transects were placed towards the top of Mt. Sanddalsnuten, time series data could help to tell if plant species and arthropods were moving up the mountain.

Conclusion

I found that parasitoids, the total number of beetles, beetle richness, and omnivore beetles are affected by the temperature at Mt. Sanddalsnuten. However, microclimate and plant species' effects on arthropods need to be further studied to understand how they react to changes in a changing climate.

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APPENDIX

Appendix A

Table A1: Overview of the mean June – August temperature (°C) from 2004 to 2021. The mean temperature from this period is calculated at the end of the table. Data retrieved from https://seklima.met.no/years/mean(air_temperature%20P1Y),mean(air_temperature_anomaly%20P1Y%201991_2020),sum(precipitation_amount%20P1Y),sum(precipitation_amount_anomaly%20P1Y%201991_2020)/custom_period/SN25830/nb/2021-01-01T00:00:00+01:00;2022-12-31T23:59:59+01:00 and modified in Excel. The months June – August was extracted, and the mean temperature was calculated.

Year	**June**	**July**	**August**	**Mean June-August temperature**
2004	4,7 °C	7,4 °C	9.6 °C	7.2 °C
2005	3.2 °C	NA	7.5 °C	5.4 °C
2006	6.1 °C	11.5 °C	10.2 °C	9.3 °C
2007	4.9 °C	6.9 °C	7.7 °C	6.5 °C
2008	3.9 °C	9.6 °C	7.9 °C	7.1 °C
2009	5.2 °C	9.1 °C	8.2 °C	7.5 °C
2010	5.7 °C	9.9 °C	8.9 °C	8.2 °C
2011	5.4 °C	10.5 °C	8.6 °C	8.2 °C
2012	3.4 °C	6.8 °C	8.4 °C	6.2 °C
2013	5.5 °C	9.6 °C	8.5 °C	7.9 °C
2014	5.7 °C	11.9 °C	8.6 °C	8.7 °C
2015	2.5 °C	5.6 °C	8.2 °C	5.4 °C
2016	6.1 °C	8.1 °C	7.9 °C	7.4 °C
2017	4.6 °C	7.3 °C	7.0 °C	6.3 °C
2018	7.7 °C	12.6 °C	7.2 °C	9.2 °C
2019	6.2 °C	9.8 °C	9.5 °C	8.5 °C
2020	6.3 °C	5.0 °C	9.1 °C	6.8 °C
2021	7.7 °C	11.3 °C	8.6 °C	9.2 °C
Mean Temperature (June-August 2004-2021)	5.3 °C	9.0 °C	8.4 °C	7.6 °C

Table A2: Overview of the mean June – August precipitation (mm) from 2004 to 2021. The mean temperature from this period is calculated at the end of the table. Data retrieved from https://seklima.met.no/years/mean(air_temperature%20P1Y),mean(air_temperature_anomaly%20P1Y%201991_2020),sum(precipitation_amount%20P1Y),sum(precipitation_amount_anomaly%20P1Y%201991_2020)/custom_period/SN25830/nb/2021-01-01T00:00:00+01:00;2022-12-31T23:59:59+01:00 and modified in excel. The months June – August was extracted, and the mean precipitation was calculated.

Year	**June**	**July**	**August**	**Mean June-August Precipitation**
2004	63,9	53,7	119,1	236,7
2005	73,8	94,2	76,1	244,1
2006	65,5	95,9	92,5	253,9
2009	22,8	90,6	168	281,4
2010	43,1	104,5	114,3	261,9
2012	47,6	75,6	84,8	208,0
2013	102,5	49,7	149,5	301,7
2014	36,1	90	80	206,1
2015	31,1	72,2	139,5	242,8
2016	67,6	87,6	148,7	303,9
2017	97,5	95	100,8	293,3
2018	76,4	40,8	224,6	341,8
2019	110	111,6	184,6	406,2
2020	58,1	125,8	74,2	258,1
2021	74,2	103,2	21,9	199,3
Mean precipitation (June-August 2004-2021)	64,7	86,0	118,6	269,3

**Excluding 2007-2008, 2011 - no recorded data*

Appendix B

Table B1: Mean temperature and volumetric soil moisture for each plot and overall, from all data loggers, in the study period.

Data logger	Mean temperature (°C)	Mean volumetric soil moisture
1	9.840554	0.18085250
2	10.271410	0.22766440
3	10.847770	0.06565979
4	10.375590	0.16104410
5	10.297080	0.20220760
6	9.975512	0.22374590
7	10.231820	0.20950870
8	10.090890	0.18121130
9	10.259630	0.26695750
10	10.477570	0.19948460
11	10.198940	0.13751330
12	10.309720	0.17359290
13	10.173060	0.33327270
14	10.321220	0.28412250
15	10.074870	0.20164620
16	10.334810	0.19562010
17	9.592803	0.27685480
18	9.845452	0.39723690
19	9.741951	0.29777690
20	9.523630	0.19623500
21	10.243430	0.31126270
22	10.686360	0.17749220
23	10.234120	0.31084860
24	9.996330	0.29561960
Total mean	10.16436	0.2294763

Appendix C

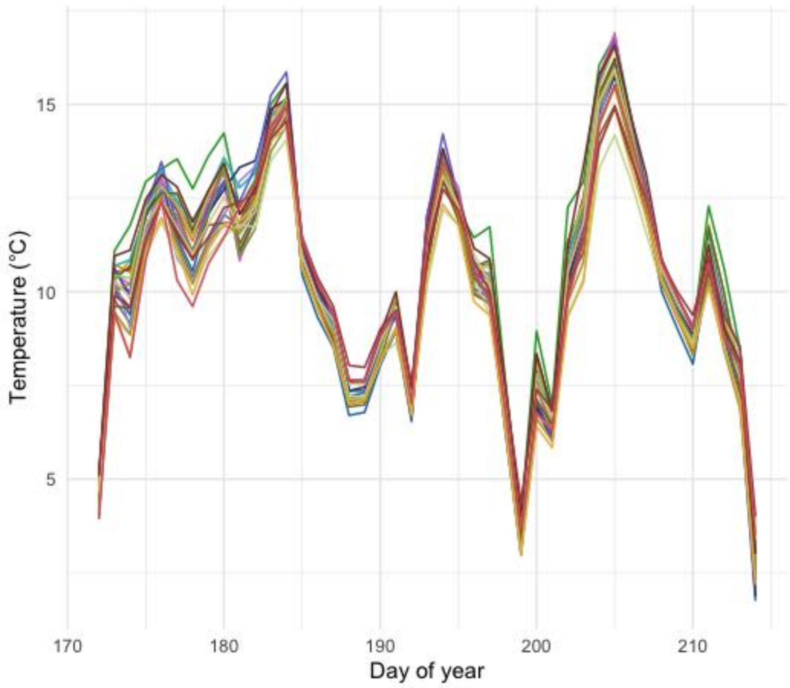

Figure C1: Daily mean temperature for all data loggers. Measured from June 21. To August 2.

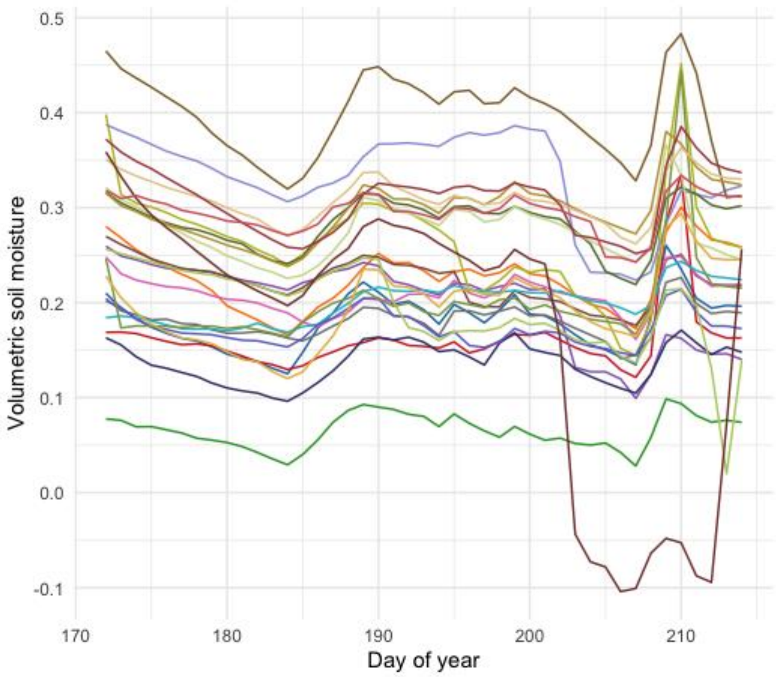

Figure C2: Daily mean soil moisture for all data loggers. Measured from June 21. To August 2.

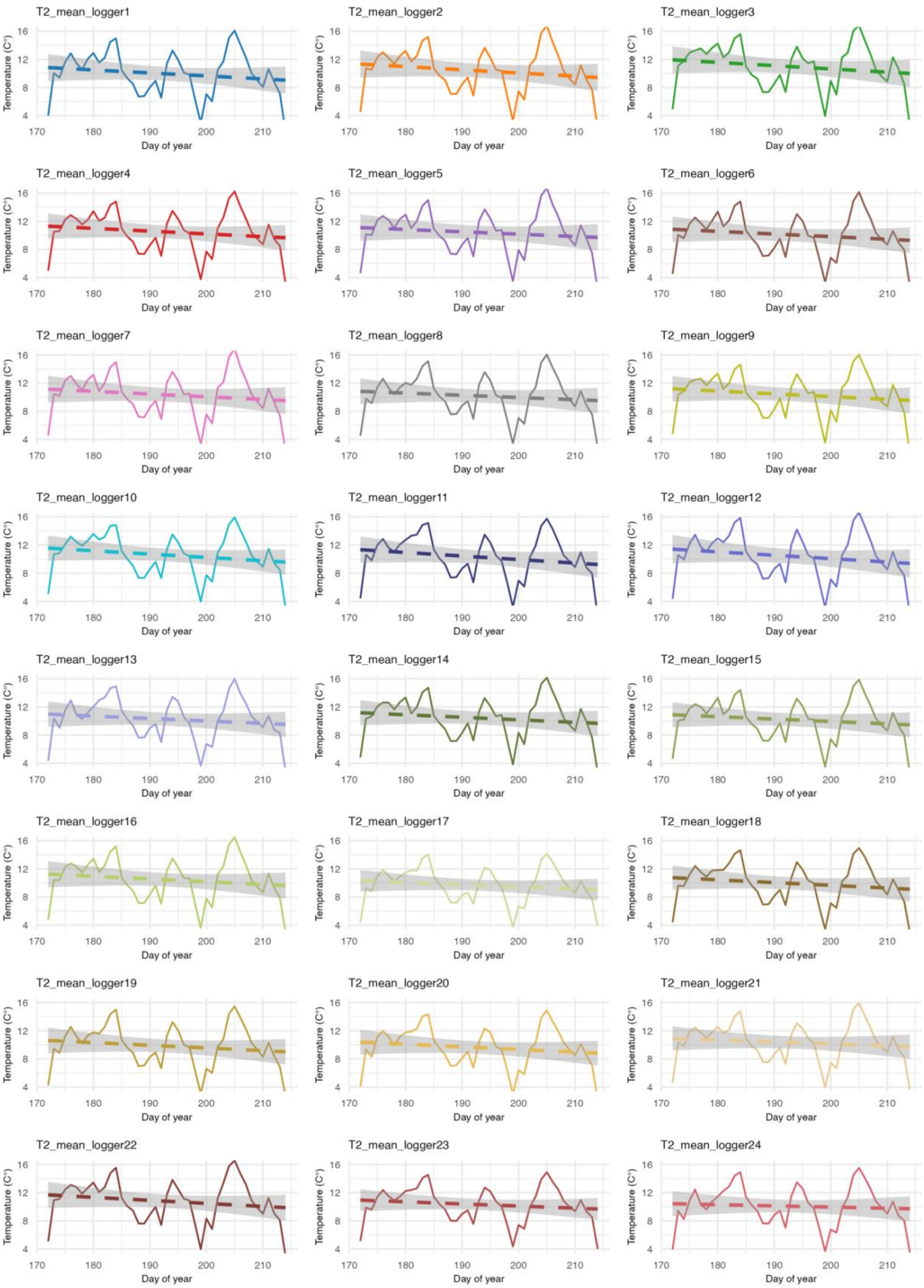

Figure C3: Individual mean temperature for the 24 data loggers at Sanddalsnuten from June 20th to August 2. The confidence interval (0.05) is marked by a grey area.

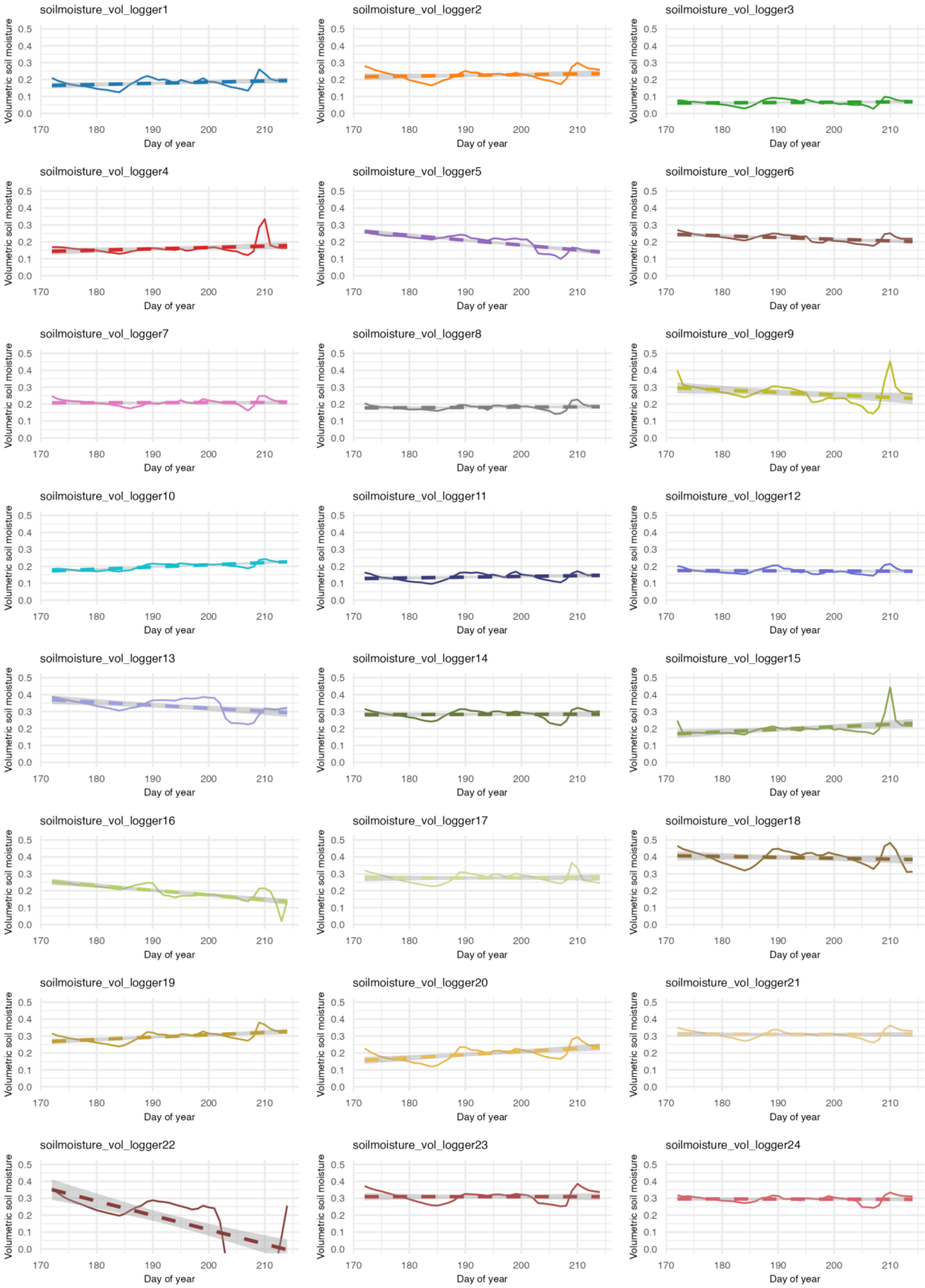

Figure C4: Individual mean volumetric soil moisture for the 24 data loggers at Sanddalsnuten from June 20th to August 2. The confidence interval (0.05) is marked by a grey area.

Appendix D

Table D1: A linear regression model with the number of beetles species as a response variable. The number of beetles species is log-transformed, but not normally distributed. This model would have explained ~43.8% of the variation in the number of beetle species if the response variable were normally distributed.

Model: Number of beetles species ~ mean temperature + Plant species richness + mean soil moisture

	Number of beetle species		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	5.12	3.49 – 6.75	<0.001
Mean temperature	-0.29	-0.46 – -0.13	**0.001**
Plant species richness	0.01	-0.00 – 0.03	0.152
Mean soil moisture	-0.44	-1.04 – 0.15	0.135
Observations	24		
R^2 / R^2 adjusted	0.438 / 0.354		

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway