University of South-Eastern Norway
Faculty of Technology, Natural Sciences and Maritime Sciences
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Master's Thesis
Natural Sciences and Environmental Health
Spring/Autumn 2020

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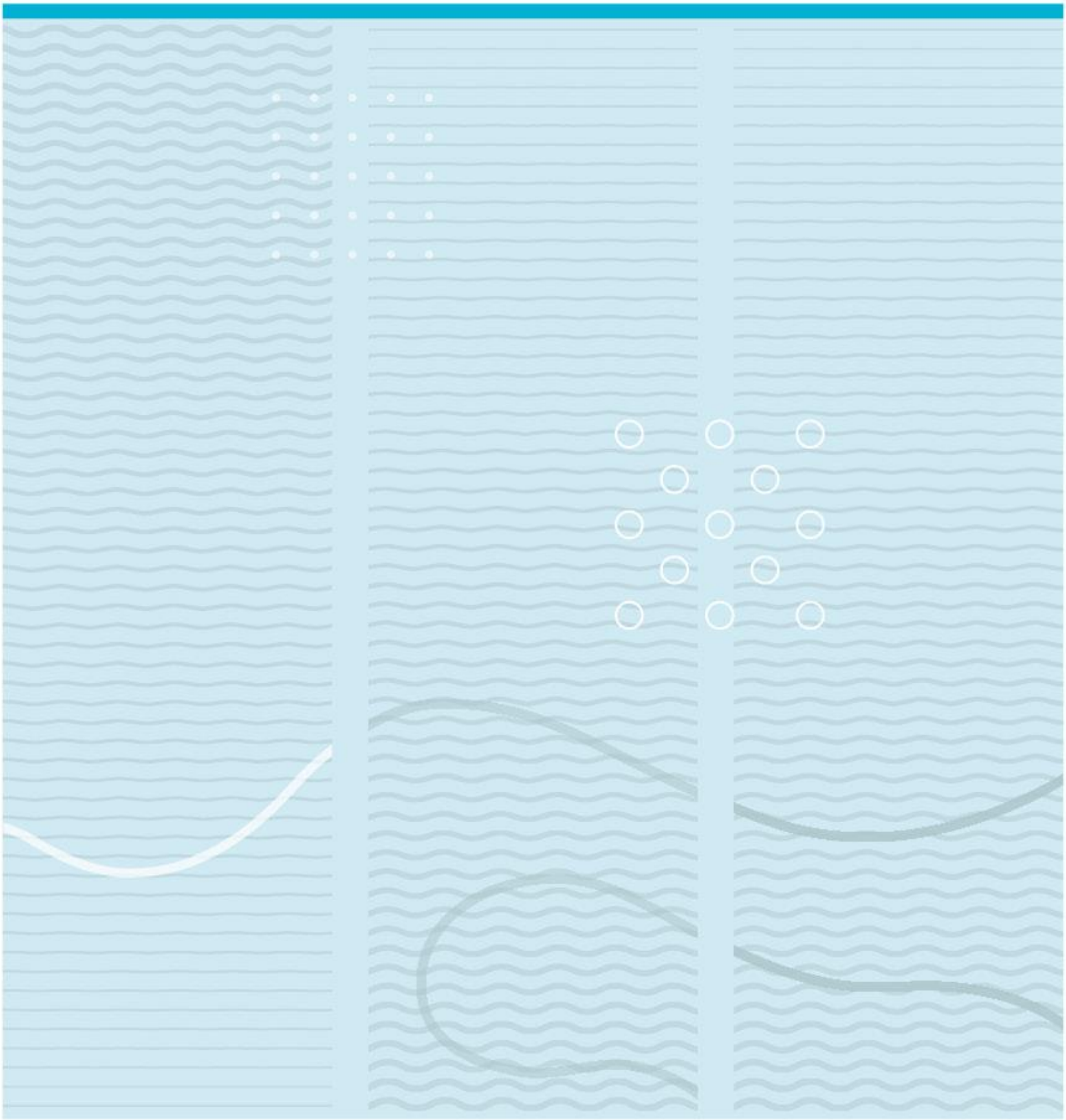
Effect of sheep grazing and fertilization on species richness, diversity, and biomass in an alpine area in Central Norway



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This thesis is worth 60 study points

Abstract

Impact of herbivores in different ecosystems is an important subject in ecology. Herbivores have been shown to have a large and complex impacts on ecosystems around the world that can drive changes of plant community structures though different mechanisms. Most studies looking at how herbivores affect plant communities in alpine ecosystems have been performed in enclosure studies, and over shorter periods of time. In this thesis, I investigated how free ranging sheep (*Ovis aries)* affect alpine plant communities over 15 years in two study sites in Forrolhogna National park Central Norway. I analysed eight 50 x 50 m plots. Four plots had been fertilized in the beginning of the project in 2003, and then each year until 2006, while the other four had no treatment done to them. All plots were available for grazers. I counted sheep pellets groups inside plots to see how sheep distributed themselves inside plots. The aim of this study was to see whether species richness, -diversity and functional plant group cover changed in control plots and fertilized plots over 15 years and if these changes contributed to more nutritious plants that increased grazing from sheep. Species richness and diversity increased in control and fertilized plots, while cover of graminoids decreased in both control and fertilized plots. Sheep showed no selection for fertilized plots over control plots. The grazing pressure in the study area are relatively low and the results of my study suggest that other factors such as temperature and precipitation might have a greater impact on the vegetation than fertilization and grazing.

This study emphasizes the importance of long-term studies for understanding how vegetation processes respond to fertilization and how this affects grazing pattern for herbivore in the long run.

Contents

Foreword

I would like to thank my supervisors Stefanie Reinhardt and Siri Lie Olsen for all the advice, guidance and support through this entire process. I would also like to thank Konstanse Skøyen for all her help with the field work, without you I would never have been able to finish the field work at all. I would also thank my patient boyfriend Per Erik Sønstebø, my sister Linda Marie Vikje, and friends for all their support through this process.

15.05.2020, Lunde
Hilde Kristine Vikje

1 Introduction

1.1 The role of herbivores on ecosystems

Large herbivores have proven to have large and complex impacts on ecosystems around the world that can drive changes of plant community structures though mechanisms such as 1) directly affecting individual plants by defoliation(Barthelemy, 2016), 2) trampling that can have effects on soil microclimate (temperatures and water balance) and soil structure by compacting the soil and decreasing vegetation cover (Augustine & McNaughton, 1998) and 3) by converting and redistributing plant biomass into highly decomposable excreta rich in labile nutrients within the ecosystem(Grellmann, 2002; Hobbs, 1996).

Most herbivores are highly selective feeders, and favour grazing on different plants (Kausrud, Mysterud, Rekdal, Holand, & Austrheim, 2006). When grazers systematically remove preferred species by overgrazing those, they change the plant species composition and plant standing crops (Bazely & Jefferies, 1986). Herbivores can by grazing affect competitive conditions between species and can promote or reduce plant diversity. Diversity is promoted when colonisation is enhanced, or extinction is reduced. When grazing balances competitive interactions between plants, this reduces extinction, and dispersal and recruitments of plants are promoted by herbivores (E. S. Bakker & Olff, 2003). Size and numbers of herbivores have an impact on plant community structure through grazing pressure and disturbance/ destruction of plants and roots, which can reduce plants uptake of water and nutrients. Herbivores can also create open patches for species to grow (Austrheim & Eriksson, 2001).

Enclosure studies of sheep have shown that high grazing pressure by herbivores can suppress forest and shrub formation, resulting in increased grassland areas(Austrheim, Gunilla, Olsson, & Grøntvedt, 1999; Cingolani, Posse, & B. Collantes, 2004; Wehn, Pedersen, & Hanssen, 2011), however if grazing becomes too intensive species richness will decrease because of limitation of plant growth, favouring a change towards more tolerant and/or resistant species, making for a more homogenized species composition and succession phase ((Augustine & McNaughton, 1998; Austrheim & Eriksson, 2001). Moderate grazing pressure increase species richness through removal of dominant species (Augustine & McNaughton, 1998);(Austrheim & Eriksson, 2001)) and leaves the vegetation in patches of different stages of recovery, making an area more heterogenic in both species composition and succession phase (Bullock, Hill, Silvertown, & Sutton, 1995). Size differences between herbivores determine their foraging selectivity, food quality requirements and their grazing pattern. Bulk feeders grazing on dominant plants may have different effects on plant species diversity than small grazers, feeding selectively on high quality, subordinate herbs (E. S. Bakker & Olff, 2003).

Plants have evolved different strategies to cope with grazing, and these are usually one of the factors deciding change in species composition in response to herbivory (Augustine & McNaughton, 1998). Two of these strategies to cope with herbivory are tolerance and resistance. Tolerant species are species that could rapidly regrow after a grazing event, usually have a high photosynthetic rate, high leaf production or low apical meristem (typical of graminoids) (Strauss & Agrawal, 1999). Resistant species avoid grazing by having evolved strategies that diminishes the likelihood of being grazed, like low digestibility, attributes such as thorns, chemical defences, or small/low stature (Strauss & Agrawal, 1999).

1.2 Effects of added fertilization and sheep grazing on alpine vegetation

Plant growth is in many terrestrial ecosystems limited by the availability of nitrogen (E. Bakker, Olff, Boekhoff, Gleichman, & Berendse, 2004). Low availability of nitrogen causes low plant productivity, that again implies slow growth and infrequent reproduction, and this makes it hard for a plant to be able to avoid/recover from herbivory (Mattson, 1980). Environmental factors such as soil, weather, biotic agents etc play a role in how individual plants vary greatly in both nutrient quality and quantity. The presence of herbivores in an ecosystem can affect nutrient availability to plants in two ways 1) they can accelerate turnover directly by excreting nutrients that are readily available for uptake by microbes and plants (W. Ruess & McNaughton, 1987) 2) they influence turnover indirectly by modifying the quality and quantity of plant litter available for decomposition by removing this(Hobbs, 1996).

Several studies have shown that herbivore selectivity is a scale-dependent process, and in many cases determined by plant quality such as a plants nitrogen content (Kausrud et al., 2006; Villalba & Provenza, 1999). Some plant species are clearly nitrogen demanding while others are nitrogen-deficiently-tolerant and usually nitrogen poor (Mattson, 1980). The plant vigour hypothesis (Crawley, 1997; Price, 1991) proposes that herbivores perform best on faster growing plants, because plant growth rate is usually correlated with high nitrogen content. Given this hypothesis I would assume that grazing would cause plants with an increased nitrogen content and then again drive processes that over time change plant composition to one that would be more favourable to herbivores.

Alpine ecosystems provide rather extreme climatic conditions for plants (Körner, 2003), but even so most mountain ecosystems around the world have long traditions for use as summer pastures to livestock grazing (Körner, 2003). Use of mountain areas for livestock grazing have a long tradition many places around the world (Körner, 2003), and pasturing have influenced alpine vegetation in temperate zone mountains for at least 7000 years (Patzelt, Li, Wang, & Appel, 1996). This have led to a diverse cultural landscape where forest is suppressed for the benefit of grass and herbs because of human activity and livestock grazing (Körner, 2003). Alpine habitats constitute about 50 % of the area of Norway and have traditions of being used for livestock grazing since the Bronze age (Evju, 2009).Traditionally livestock in Norway have been moved from the main farm in the lowlands and up into the summer farm in the mountains to graze freely in the Mountains during summer (Austrheim et al., 2008).Traditionally livestock consisted of dairy cattle (*Bos Taurus*), goats (*Capra aegagrus hircus*), horses (*Equus caballus*) and sheep (*Ovis aries*) (Kausrud et al., 2006). Today the main large domestic herbivores in alpine areas in the southern regions of Norway is sheep (Austrheim et al., 2008). Numbers from the Norwegian Agriculture Agency state that 2 449 003 sheep was sent out on pasture in 2016 (Landbruksdirektoratet, 2020). Because sheep can utilize grass forage resources in landscapes too poor to use for more intensive agricultural purposes, sheep husbandry is still a cornerstone of the economy in many rural areas of Norway (Kausrud et al., 2006). Sheep grazing can have a fundamental effect on ecosystem structure and function, primarily through changes in plant quality, structure, and biomass (Mulder, 1999). To understand the relationship between herbivore performance and plant community development in the long term, we also need to know how the herbivores use of their habitat is affecting the ecosystem productivity depending on the population density over longer time frames. Few studies have been conducted on the subject in northern alpine areas with "natural" densities of sheep, as most of them have been enclosure experiments with relative high numbers of sheep per km^2, or for a shorter time frame (Austrheim et al., 2008; Mysterud & Austrheim, 2005). My study area has like many other mountain areas in Norway long traditions in use of mountain areas for summer grazing pastures to domestic livestock and have experienced grazing long before the beginning of my study (Gundersen et al., 2017). Based on this I would assume the regional species pool is highly likely to include species that area adapted to a certain level of grazing (Austrheim & Eriksson, 2001).

1.3 Aims of study

The aim of this study was to investigate the interaction of grazing and fertilization by sheep on alpine vegetation.
Based on earlier literature, my questions for this study is:

1) Is there a difference in species richness, diversity and plant cover between fertilized plots and unfertilized control plots for 15 years?
2) Does fertilized plots attract more sheep than control plots?

2 Materials and methods

2.1 Study area

The study area is located in the Forollhogna National park in the central Scandinavian mountains, in Hessdalen, Holtålen municipality in Trøndelag county (figure 1). The study was conducted in two sites: Berghøgda (UTM coordinates map datum WGS 84, zone 32 V, 07600, 51300) and Båttjønnhøgda (WGS 84, zone 32 V, 04600, 636960). The study sites are located in the alpine area above the tree line. Berghøgda is located at 900-1000 mamsl, while Båttjønnhøgda is located at 1000-1100 mamsl.

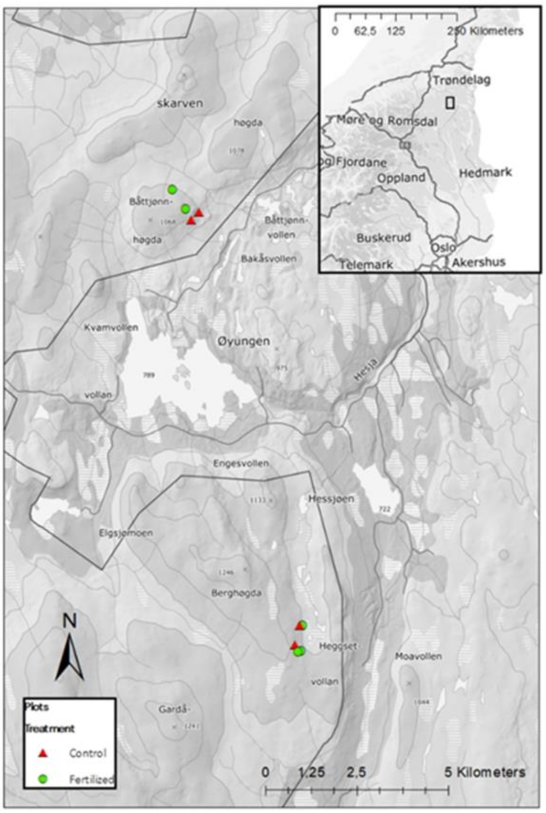


Figure 1 Map over study area Hessdalen, with study sites Berghøgda and Båttjønndalen made using ArcGis. The triangles show unfertilized plots, while the green dots show fertilized plots.

The bedrock of the study sites consists mainly of metamorphic rocks such as phyllite and schist in both study sites. The vegetation in the study areas consists of shrub species *Betula nana, Empetrum nigrum* ssp. *hermaphroditum* and *Vaccinium myrtillus* in both study sites. *Salix herbacea* dominates in snow-beds, and graminoids such as *Deschampsia cespitosa, Anthoxantum odoratum, Carex bigelowii, Avenella flexuosa* and forbs such as *Alchemilla alpina* and *Viola biflora* dominate the alpine meadows.

Mean temperature for Røros Lufthavn weather station number 10380 ((625 mamsl), which is the closest weather station with complete weather data for 2003 to 2018) in 2018 were 15.7 °C for the warmest month, July, and -9.8 °C for the coldest, January. Annual precipitation for 2018 was 447,1 mm (Røros, Norwegian Meteorological Institute, 2020). Since the vegetation analyses was done for different plots in different years, 2007, 2008, 2009, 2017 and 2018, I have chosen to add 2007, 2009 and 2017 in the temperature table to better be able to interpret my data(Figure2).

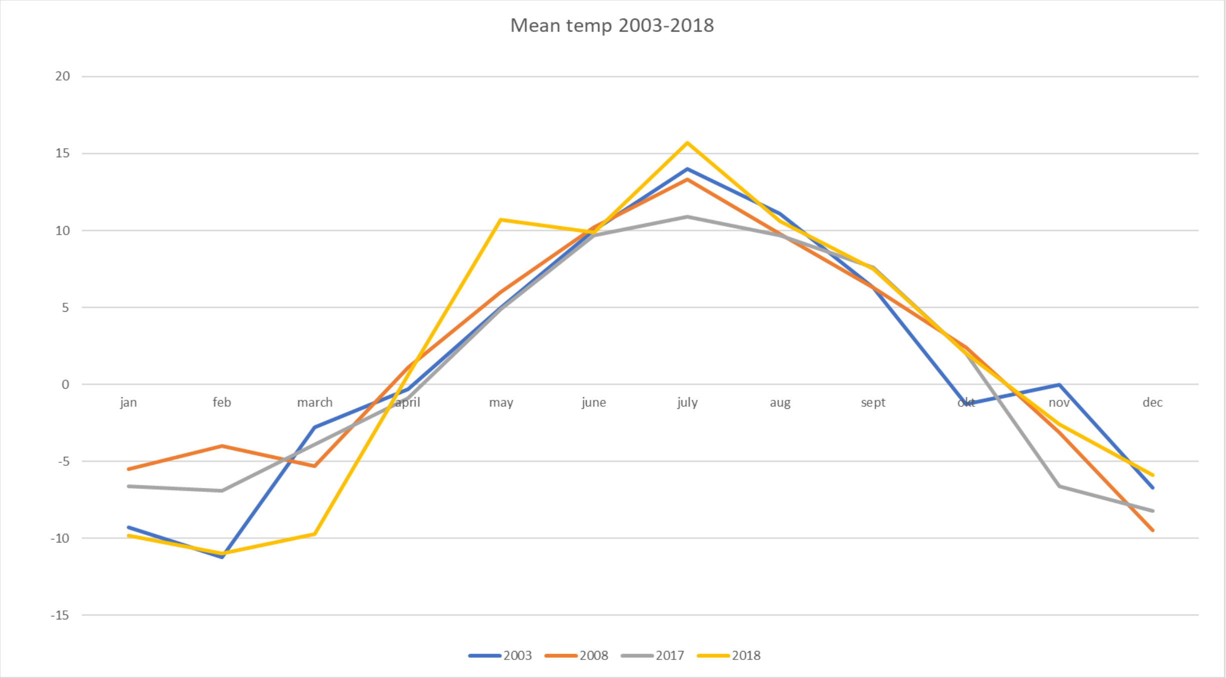


Figure 2 Mean temperatures for each month for Røros airport, in Røros the closes weather station for my study area for each month for the years vegetation analyses was done 2003,2007,2008, 2017 &2018.

Sheep graze freely in both study sites during the summer months between June and August. The sheep belong to different farms, and grazing pressure is relatively low (NIBIO, 2019). Both study sites belong within the grazing area of Ålen beitelag-Vest and in 2018 a total of 2420 sheep was released to graze in the area (337 km^2), and it is estimated to be 7 sheep per km^2(NIBIO, 2019)(Figure 3).

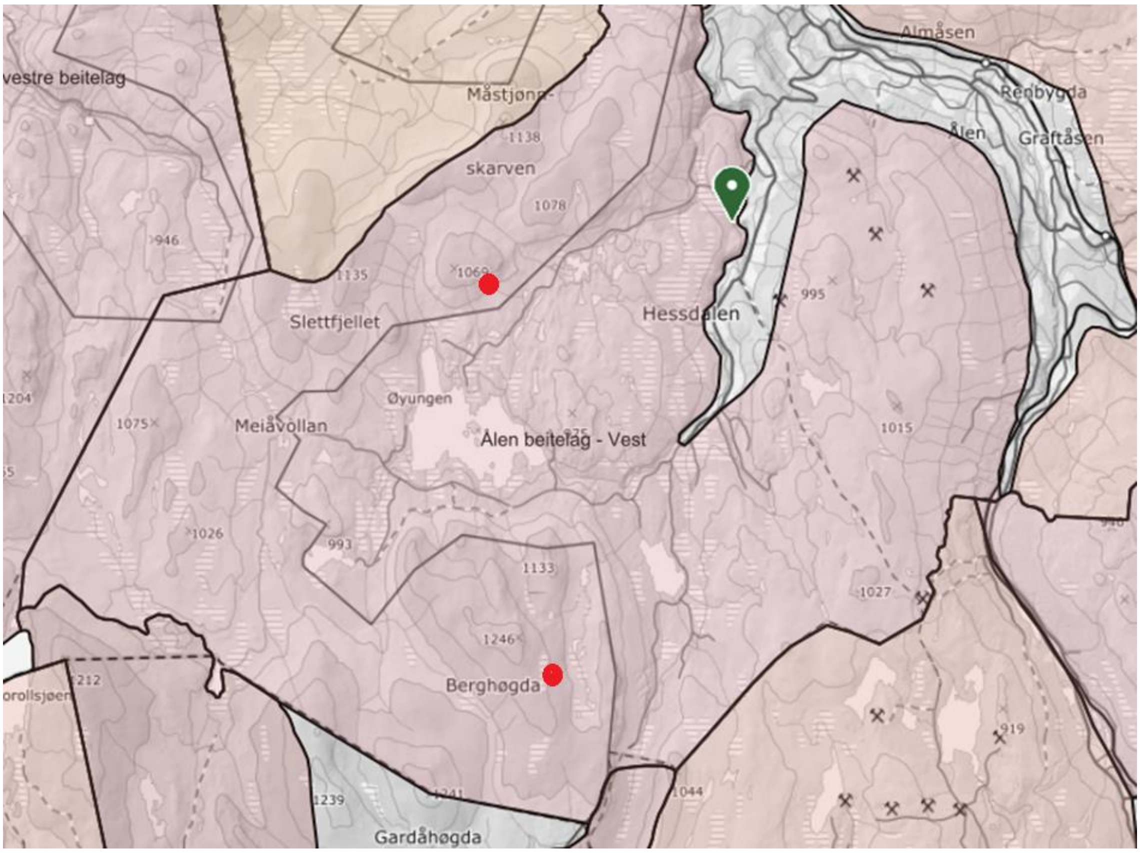
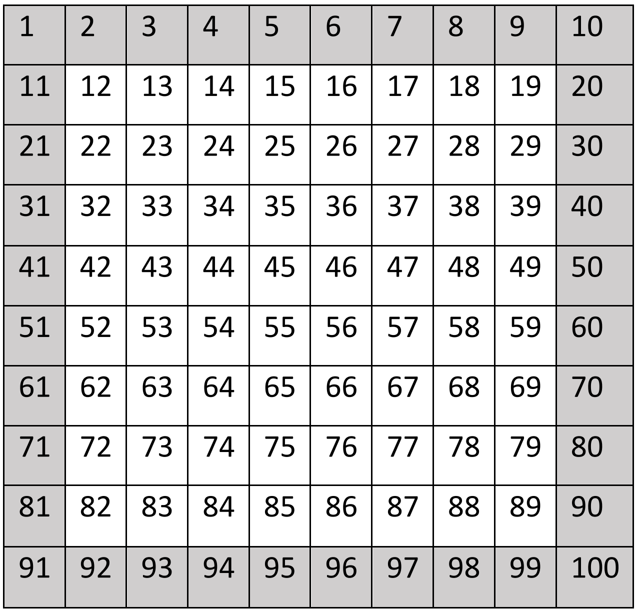


Figure 3 Map over grazing areas, Ålen beitelag-vest use areas around both study sites(marked with red dots), (Kilden, 2020)

2.2 Study design

This thesis is a part of a long-term project initiated by the Norwegian Institute for Nature Research (NINA) to investigate the effects of sheep grazing on alpine vegetation. The study plots were selected by NINA in 2003 from telemetry data recorded with Televilt Simplex GPS collars. This indicated where ewes of Norwegian white sheep grazed (movement of 7-30 metres in 5 minutes was classified as grazing and included in the analysis) (Rusch, Skarpe, & Halley, 2009). The telemetry data showed a high preference for snow-beds and meadows in both areas and by all sheep individuals (Rusch et al., 2009). Ten 50 x 50 m^2 plots were selected randomly from patches with clusters telemetry records (Rusch et al., 2009). The plots were divided into 100 5 × 5 m2 sub-plots (Figure 4). One line of sub-plots on each side of the 50 × 50 m^2 plot was used as a buffer area and was not analysed, and 64 sub-plots were analysed per plot. At most plots, the numbering of the 5 × 5 plots started at the north-eastern corner and ended at the south-western corner. In two cases the numbering is different (Bat04 & Bat09). The first sub-plot measured in each plot was in the upper left corner (nr. 12), and then continuing to the right excluding the buffer zone. In this study a total of 8 plots were looked at, 4 unfertilized and 4 fertilized plots. 3 plots in Båtjønndalen and 5 in Bergshøgda. The fertilized plots were treated with NPK 20-4-11 fertilizer, i.e. fertilizer containing 20 % nitrogen, 4 % phosphor and 11 % potassium. The NPK fertilizer was distributed by hand each year from 2003 to 2006, approximately 25 kg N/plot = 100 kg N/ha.



1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99	100

Figure 4 An overview of a study plot with numbering to show how a plot was organised into sub-plots. Each plot is 50 x 50 meter divided into 5 x 5 meter sub-plots. The grey border illustrates the buffer zone and not considered in the measurements.

2.3 Data collection

Vegetation analyses used in this study were conducted in 2003 and 2007/2007/2009 for untreated and fertilized plots by NINA. The untreated plots were then recorded again in 2017 by Aina Blæsterdalen (Blæsterdalen, 2018), while I did vegetation analyses for all the fertilized plots in August 2018. In each of the 64 analysed sub-plots (buffer sub-plots excluded) all vascular plant species were recorded, and their percentage cover was estimated visually. Additionally, cover of lichens, mosses, bare ground, stones, and water was estimated in percentage in each sub-plot. Nomenclature follows Mossberg and Stenberg (Mossberg, 2012).

Physical and chemical properties of the soil were assessed from 10 topsoil samples per site taken from 0-5 cm with a 220 mm diameter soil corer and lumped into one composite sample per plot in 2003 (Rusch et al., 2009). The analyses were conducted at "Laboratoire d'Analyses des Sols' of the National Institute for Agronomic Research (Rusch et al., 2009). The results of the soil samples taken for each plot is shown in figure 5.

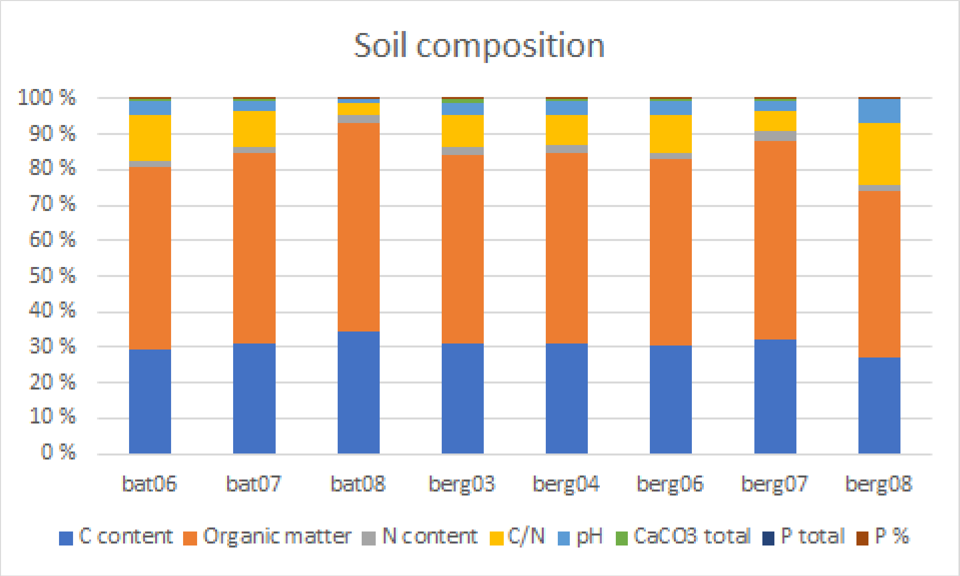


Figure 5 Carbon content, organic matter, nitrogen, C/N relationship, pH, calsium and phoshorus content in the soil for each plot

Sheep pellets sampling

To investigate how sheep moved inside the plots, groups of pellets from sheep were counted in each sub-plot in both control plots and fertilized plots. I assume in this study that high densities of sheep pellet groups mean a higher density of sheep. As sheep pellet group varied between few and big pellets and small and many, one pile was defined as a group of sheep pellets containing between 40-120 pellets. To ensure that the sheep pellets were from the same year, piles counted were dark in colour, and was holding good shape, not falling apart. The pellet groups were counted in the beginning of August (Campbell, Swanson, & Sales, 2004).

2.4 Statistical analyses

The plant species were grouped into four functional groups to isolate species with the same traits (see species grouping in table 1 in appendix):

Graminoids are plants with one embryonic leaf, such as grasses (*Poaceae*), sedges (*Cyperaceae*) and rushes (*Juncaceae*) The leaves are usually linear and have wind-pollinated flowers.

Forbs: Vascular plants without significant woody tissue above or at the ground. Forbs may be annual, biennial, or perennial but always lack significant thickening by secondary woody growth and have perennating buds borne at or below the ground surface. Forbs also include ferns such as, horsetails, lycopods and whisk-ferns.

Shrubs: Perennial, multi-stemmed woody plants that are usually less than 0.5 meters in height. They usually have several stems arising from or near the ground.

Betula and Salix are plant species in the *Betula* and *Salix* genera, and are grouped into a separate functional group due to different grazing responses compared to shrubs (Vowles et al., 2017).

To examine change in species richness, diversity and functional plant group cover for each treatment, I used data from 2003 and 2007/2008/2009, and Blæsterdalen's (Blæsterdalen, 2018) vegetation analyses for 2017 as well as my own data from 2018. Species diversity was estimated by applying the Shannon Index, which is calculated as follows:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

Where p_i is the proportion (n/N) of individuals of one species found in a subplot, In is the natural logarithm, **Σ** is the sum of the calculations, and **s** is the number of species.

Most ecological data tend to be overdispersed since species tend to occur at higher densities in locations that are better suited, and not so much in other places. This will give us high densities in some plots and a lot of zeros in others (Richards, 2007). My data was overdispersed, tested by plotting a histogram and qqplots, and to get more normally distributed data a log10 transformation was used on the biomass data of the functional groups of plants.

Linear mixed models allow us to control both for overdispersion in our statistical test and to model the process that drives overdispersion. The use of linear mixed effect models allows the incorporation of random factors like time, sampling location and to avoid pseudo replications by taking into account the different plots (Harrison et al., 2018; Winter, 2013). Parameters included in the models are richness (gaussian variable), diversity (gaussian variable), plant cover for each functional group(gaussian variable) as response variable, treatment (factor with 2 levels, fertilized and untreated) and year (factor with year 2003,2008 and 2018 as levels) as fixed effects. “id” was fitted as random effect in all models to account for repeated observation of individuals in the vegetation analysis. GLMM was used for analyses checking for correlation between sheep pellets groups and fertilization and plant functional groups since the data was not normally distributed by plotting a histogram and qqplot. Parameters included in the model was sheep pellet count (poisson distribution) as response variable, treatment (factor with 2 levels, fertilized and untreated) and the different functional groups (graminoids, forbs, shrub and Salix and Betula)(Zuur, 2013).

I then used Aikake Information Criterion to choose the most parsimonious models (Winter, 2013) the AIC finds the most parsimonious models as a balance between variation explained by the model (decrease value) and number of parameters included (increases value)(Winter, 2013). All data analysis was performed in R version 3.4.1(R Core Team, 2019), using package “lme4” (Bates, Mächler, Bolker, & Walker, 2015). I used package “lmerTest”(Kuznetsova A, 2017) to test significance by getting p-values. P-value are significant if the value is <0.05 (Luke, 2017).

3 Results

3.1 Species richness and diversity

The most parsimonious model with the lowest AIC of species richness included the factors year (factor) * treatment (factor). The data show that there is a significant increase for species richness for 2003 and 2008 in control plots (Figure 6). Estimates show that there is an increase from 2003 to 2008, but that there is decrease again in 2018 (Figure 7), however not significantly. Fertilized plots show a significant increase in species richness for all years, with highest increase in 2018.

FIXED EFFECTS	**ESTIMATE**	**SE**	**95% CI**		**DF**	**T-VALUE**	**P-VALUE**
***RICHNESS**			Lower	Upper			
INTERCEPT	16.894	3.232	10.559	23.229	8	5.227	0.001***
YEAR 2008	6.234	0.467	5.318	7.151	1473	13.337	0.000 ***
YEAR 2018	0.902	0.463	-0.005	1.811	1473	1.948	0.051 .
FERTILIZED	-3.315	4.569	-12.270	5.639	8	-0.726	0.488
FERTILIZED*YEAR 2008	1.378	0.644	0.114	2.641	1473	2.138	0.033*
FERTILIZED*YEAR 2018	8.655	0.641	7.397	9.913	1473	13.485	0.000***

*Figure 6 Result of linear mixed effects model of species richness from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

A total of 71 plant species was found in 2003, with an increase of species to 102 in 2008, and then a decrease to 68 in 2018 (Figure 2 in appendix). A visualization of the data in a boxplot (Figure 7) supports my findings.

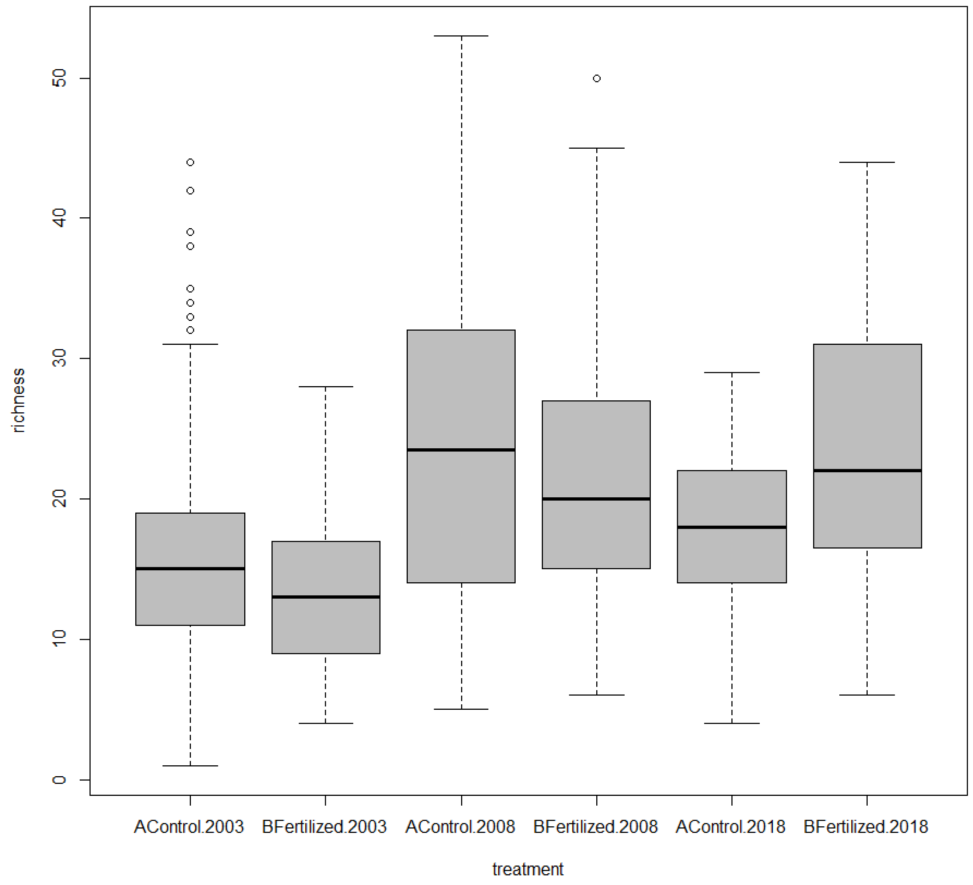


Figure 7 A boxplot for species richness of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

The most parsimonious model with the lowest AIC of species diversity included the factors year (factor) * treatment (factor). The data show that there is a significant decrease in species diversity from 2003 to 2018, while fertilized plots show a significant increase in diversity from 2003 to 2008 and 2018 (Figure 9). We can see that diversity change from being slightly higher in control plots compared to fertilized plots in 2003 to

2008, to fertilized plots having highest diversity compared to control plots in 2018(Figure 8). A visualization of the data in a boxplot (Figure 9) supports my findings.

FIXED EFFECTS	**ESTIMATE**	**SE**	**95% CI**		**DF**	**T-VALUE**	**P-VALUE**
***DIVERSITY**			Lower	Upper			
INTERCEPT	0.740	0.092	0.558	0.922	8	7.979	0.000***
YEAR 2008	0.009	0.017	-0.023	0.042	1	0.586	0.558
YEAR 2018	0.085	0.017	-0.218	-0.152	1	-11.153	0.000***
FERTILIZED	0.031	0.131	-0.388	0.126	8	-0.998	0.347
FERTILIZED*YEAR 2008	0.104	0.023	0.059	0.150	1	4.527	0.000***
FERTILIZED*YEAR 2018	0.204	0.023	0.159	0.250	1	8.892	0.000***

*Figure 8 Result of linear mixed effects model of species diversity from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

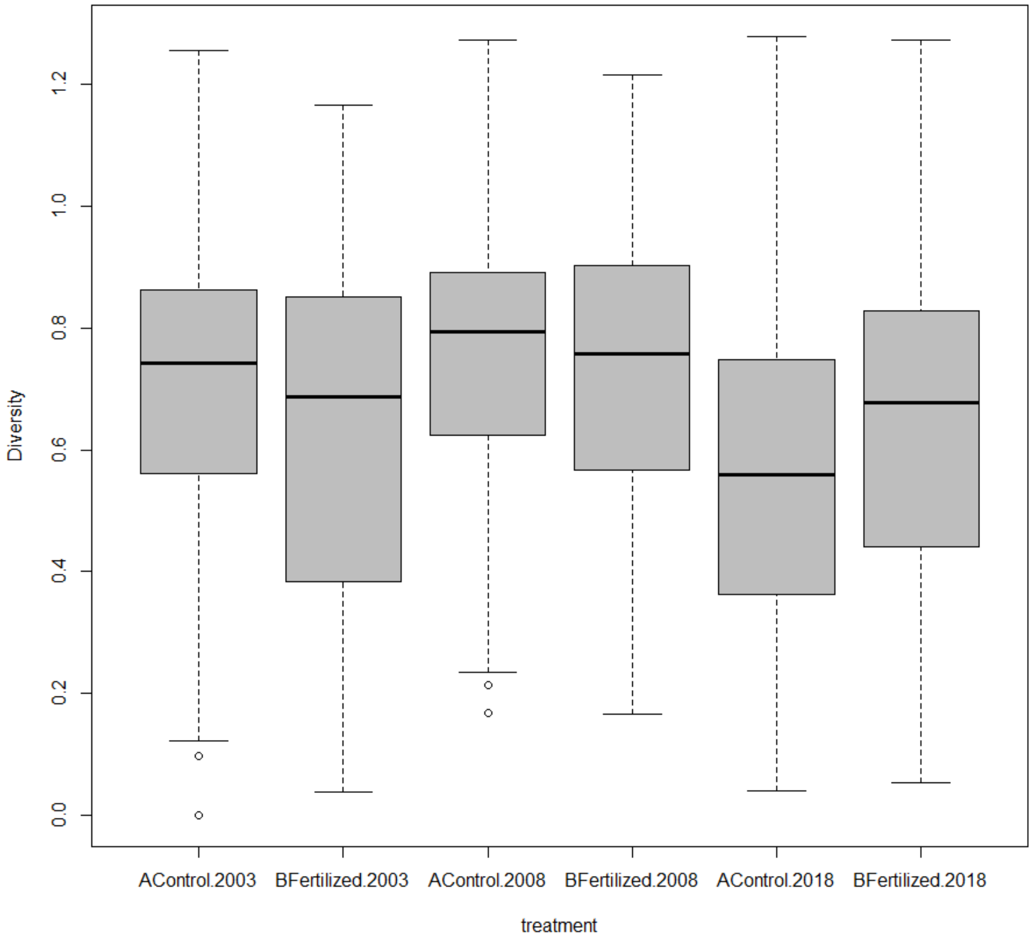


Figure 9 A boxplot for species diversity of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

3.2 cover percentage of functional groups

The most parsimonious model with the lowest AIC of graminoid cover included the factors year (factor) * treatment (factor). Analyses show that there is a significant decrease graminoid cover from 2003 to 2018 in control plots (Figure 10). Estimates of cover show that there is a slightly lower cover of graminoids in fertilized plots in 2003 than in fertilized plots, this is however not significant. Graminoid cover in fertilized plots show a slightly, but significant increase from 2003 to 2008, but a decrease in cover from

2003 to 2018 also in fertilized plots. In 2003 control plots had a higher cover compared to fertilized plots, but this have changed in 2018 to fertilized plots having a higher cover compared to control plots. A visualization of the data in a boxplot (Figure 11) supports my findings. A visual estimate of the cover of graminoids show that species covering most area in graminoid cover was *Avenella flexuosa*, *Deschampsia cespitosa*, *Anthroxantum nipponicum* and *Carex bigelowii*.

FIXED EFFECTS	**ESTIMATE**	**SE**	**95% CI**		**DF**	**T-VALUE**	**P-VALUE**
***GRAMINOIDS**			Lower	Upper			
INTERCEPT	1.343	0.144	1.061	1.626	8	9.332	0.000***
YEAR 2008	-0.062	0.031	-0.124	3.475	1479	-1.959	0.050 .
YEAR 2018	-0.738	0.031	-0.799	-6.763	1473	-23.415	0.000***
FERTILIZED	-0.237	0.203	-0.636	1.612	8	-1.167	0.276
FERTILIZED*YEAR 2008	0.110	0.043	0.024	1.960	1473	2.511	0.012 *
FERTILIZED*YEAR 2018	0.571	0.043	0.486	6.573	1473	13.098	0.000***

*Figure 10 Result of linear mixed effects model of graminoid cover from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

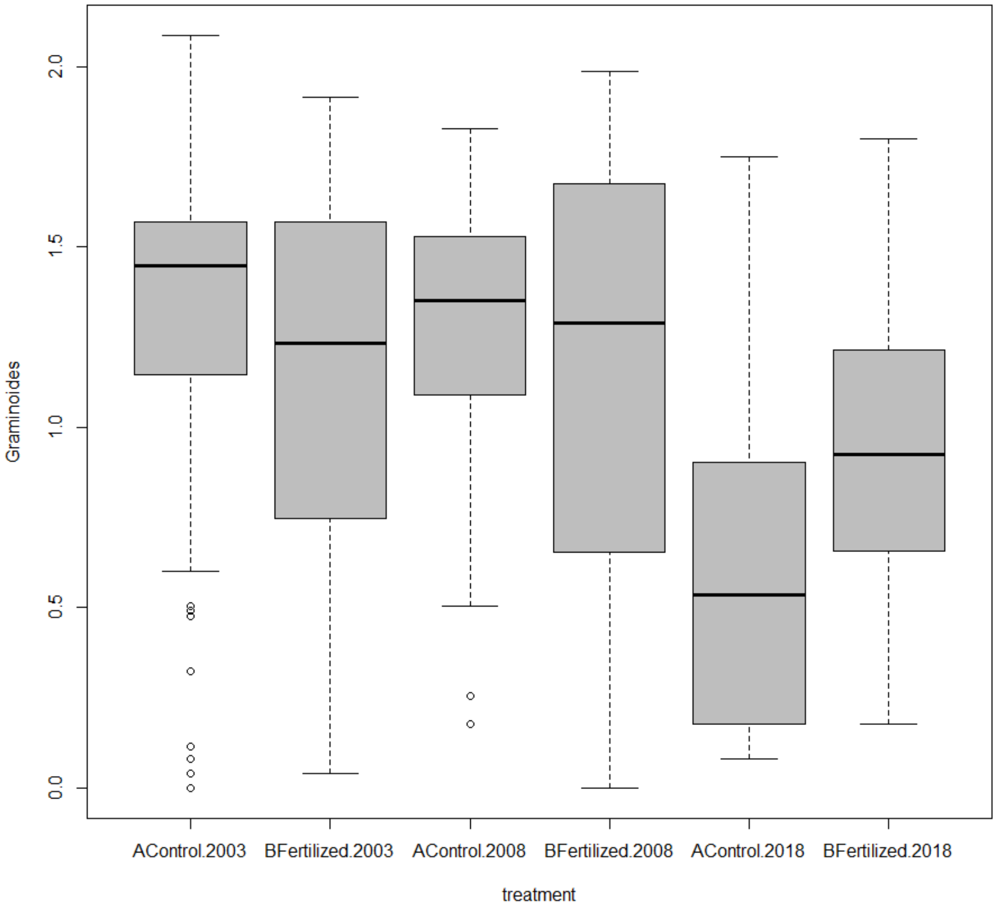


Figure 11 A boxplot for graminoid cover of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

The most parsimonious model with the lowest AIC of forb cover included the factors year (factor) * treatment (factor). Analyses show that there is a significant increase in forb cover from 2003 to 2008 but show a decrease from 2003 to 2018 (Figure 12).

Fertilized plots show a significant increase from 2003 to 2018. A visualization of the data in a boxplot (Figure 13) supports my findings.

FIXED EFFECTS	ESTIMATE	SE	95% CI		DF	T-VALUE	P-VALUE
*FORBS			Lower	Upper			
INTERCEPT	0.766	0.194	0.385	1.147	8	3.943	0.004 **
YEAR 2008	0.105	0.025	0.054	0.156	1	4.053	0.000***
YEAR 2018	0.075	0.025	-0.425	-0.324	1	-14.555	0.000***
FERTILIZED	0.007	0.274	-0.531	0.546	8	0.027	0.979
FERTILIZED*YEAR 2008	0.001	0.035	-0.069	0.071	1	0.027	0.978
FERTILIZED*YEAR 2018	0.484	0.035	0.414	0.554	1	13.570	0.000***

*Figure 12 Result of linear mixed effects model of forb cover from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

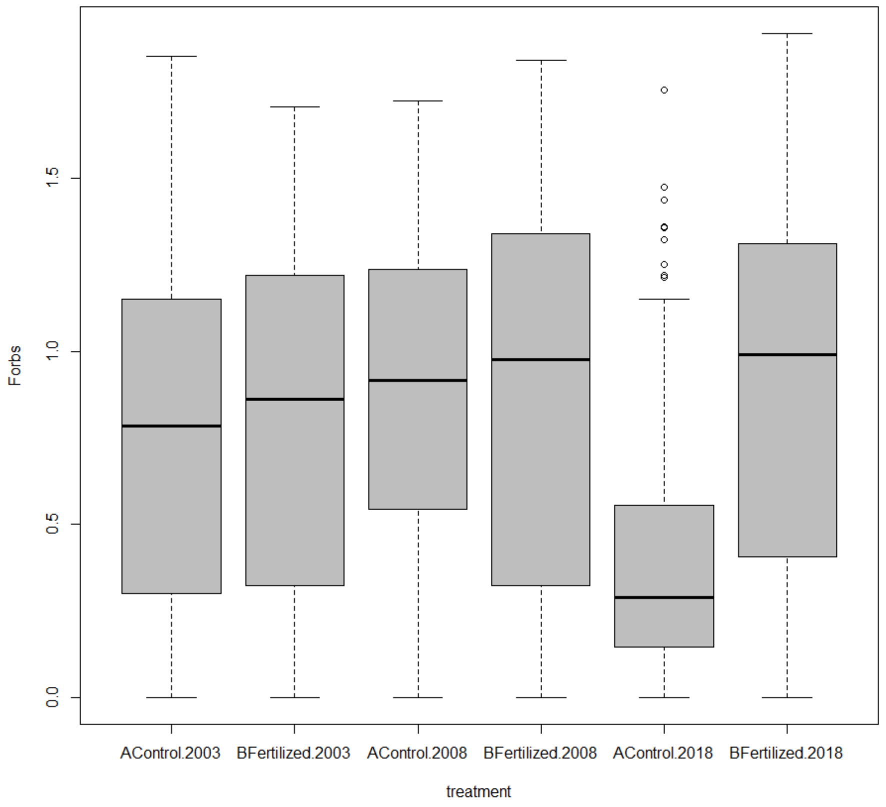


Figure 13 A boxplot for forb cover of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

A visual estimate of the cover of forbs show that species covering most area was *Alchemilla glabra, Alchemilla alpine, Geranium sylvaticum, Viola biflora, Antennaria dioica, Omalotheca supina, Bistorta vivipara and Aconitum lycoctonum.*

The most parsimonious model with the lowest AIC for shrub cover included the factors year (factor) * treatment (factor). The analyses (Figure 14) show there is no significant difference in shrub cover for the different years, 2003 to 2008 and 2018 in control plots. Fertilized plots show a significant decrease in cover from 2003 to 2008 and 2018. A visualization of the data in a boxplot (Figure 15) supports my findings. A visual estimate of shrub species show that species covering most area in plots in is *Empetrum nigrum* and *Vaccinium myrtillus*.

FIXED EFFECTS	**ESTIMATE**	**SE**	**95% CI**		**DF**	**T-VALUE**	**P-VALUE**
***SHRUBS**			Lower	Upper			
INTERCEPT	0.618	0.114	0.394	0.843	8	5.406	0.000***
YEAR 2008	0.053	0.161	-0.025	0.132	1474	1.334	0.182
YEAR 2018	0.065	0.040	-0.012	0.143	1474	1.640	0.101
FERTILIZED	-0.198	0.039	-0.514	0.118	8	-1.226	0.252
FERTILIZED*YEAR 2008	-0.293	0.055	-0.402	-0.185	1473	-5.313	0.000***
FERTILIZED*YEAR 2018	-0.175	0.055	-0.283	-0.068	1473	-3.195	0.001**

*Figure 14 Result of linear mixed effects model of shrub cover from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

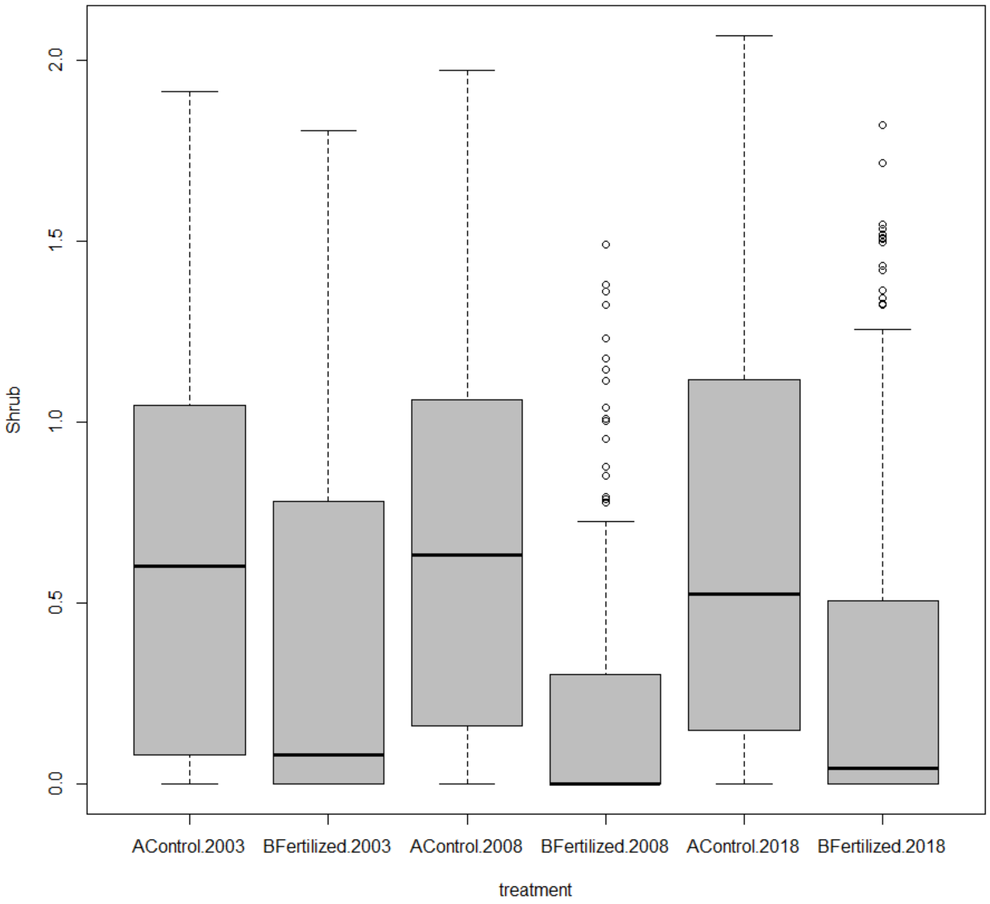


Figure 15 A boxplot for shrub cover of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown

The most parsimonious model with the lowest AIC for Salix and Betula cover included the factors year (factor) * treatment (factor). Results for analyses (Figure 16) show there is no significant difference for Salix and Betula from 2003 to 2008 and 2018 in control plots. Fertilized plots show a significant decrease in cover from 2003 to 2008, but a significant increase from 2003 to 2018. A visualization of the data in a boxplot (Figure 17) supports my findings.

FIXED EFFECTS	ESTIMATE	SE	95% CI		DF	T-VALUE	P-VALUE
***SALIX & BETULA**			Lower	Upper			
INTERCEPT	1.158	0.101	0.960	1.355	8	11.507	0.000***
YEAR 2008	0.005	0.039	-0.070	0.080	1474	0.132	0.894
YEAR 2018	0.005	0.038	-0.109	0.039	1474	-0.916	0.359
FERTILIZED	0.058	0.142	-0.220	0.336	8	0.409	0.692
FERTILIZED*YEAR 2008	0.034	0.053	-0.337	-0.129	1474	-4.389	0.000***
FERTILIZED*YEAR 2018	0.144	0.053	0.040	0.248	1474	2.726	0.006**

*Figure 16 Result of linear mixed effects model of Salix & Betula cover from plots with fixed effects treatment (control and fertilized) and year (2003, 2008 and 2018). Random effect is "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

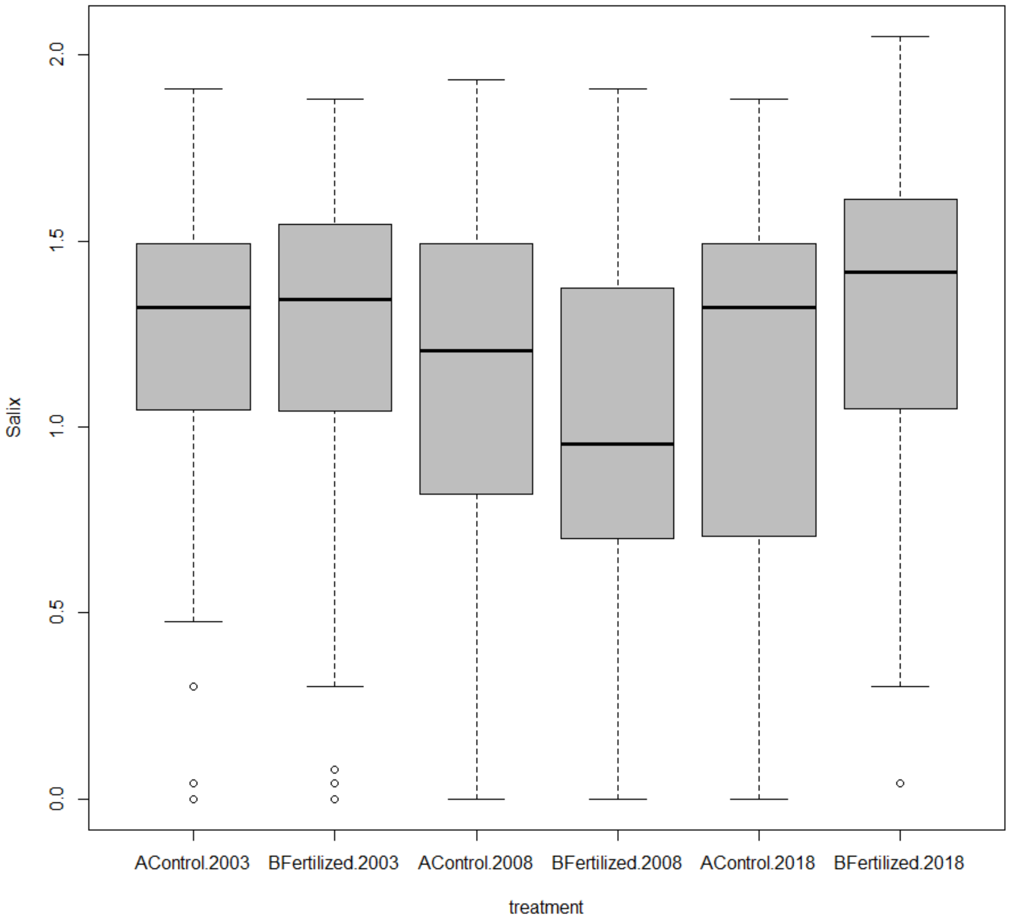


Figure 17 A boxplot for species richness of control plots vs. fertilized plots for 2003,2008 & 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

A visual estimate of the cover of Salix and Betula show that species covering most area in plots are *Salix herbacea*, *Salix glauca* and *Salix lanata.*

3.3 Sheep pellets results

The results of the Generalized linear mixed effect model (GLMM) with of sheep pellet group count (Poisson distribution) (Figure 19) show that there a significant increase in sheep pellet number with high coverage of graminoids in control plots, while there is a significant decrease in sheep pellet number with shrub cover in control plots. There is a significant increase again in sheep pellets number in Salix and Betula cover for control plots. There was a significant increase in sheep pellets number for graminoid cover in fertilized plots, there was also a significant decrease in sheep pellets count in Salix cover for fertilized plots. A boxplot visualizes number of pellets group for control and fertilized plots (Figure 19).

FIXED EFFECTS	ESTIMATE	SE	95% CI		Z-VALUE	P-VALUE
***SHEEP PELLETS**			Lower	Upper		
INTERCEPT	-0.971	1.019	-2.968	1.025	-0.953	0.340
FERTILZED	0.684	1.431	-2.120	3.489	0.478	0.632
GRAMINOIDES	0.370	0.118	0.139	0.602	3.137	0.001**
FORBS	-0.044	0.249	-0.532	0.444	-0.177	0.859
SHRUB	-0.229	0.093	-0.413	-0.045	-2.444	0.014*
SALIX & BETULA	0.473	0.131	0.216	0.730	3.609	0.000***
FERTILIZED*GRAM	0.637	0.167	0.308	0.965	3.802	0.000***
FERTILIZED*FORB	0.461	0.280	-0.087	1.010	1.647	0.099.
FERTILIZED*SHRUB	-0.431	0.276	-0.974	0.110	-1.561	0.118
FERTILIZED*SALIX	-0.977	0.163	-1.297	-0.656	-5.972	0.000***

*Figure 18 Result of generalized linear mixed effect model of sheep pellets group count with fixed effects treatments (control and fertilized) and functional group cover(graminoides, forbs, shrub and salix & betula, with a poisson distribution and random effect "plotid". Significant values 0'***', 0,001'**', 0,01'*', 0,05 '.' .*

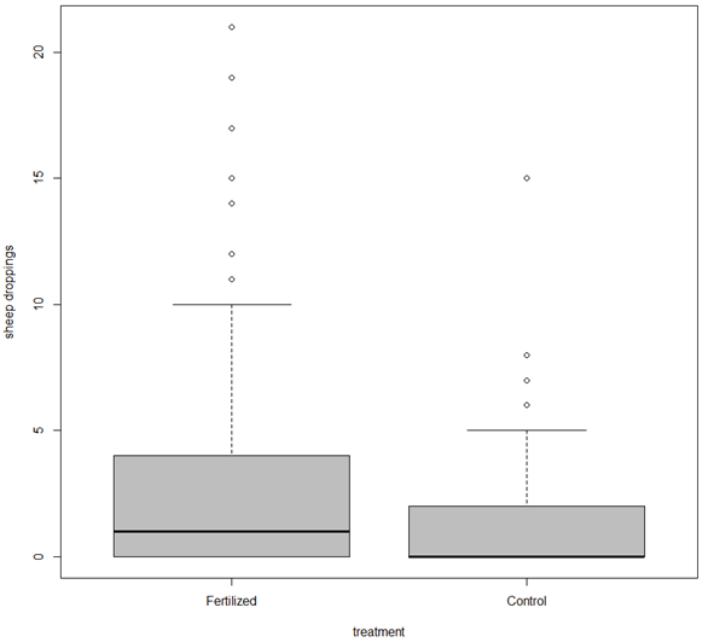


Figure 19 A boxplot for sheep pellets group count for control plots vs. fertilized plots for 2018 with median (line within the box), first and third quartiles (box), non-outlier range (whiskers), and outliers (dot) are shown.

4 Discussion

Alpine areas in Norway have a long history of domestic herbivory. Today domestic sheep are the most numerous domestic herbivores in South-Norwegian mountains (Evju, 2009). To manage these areas in a sustainable way it is essential that we understand how these grazers affect alpine plant communities through mechanisms such as grazing and fertilization. In this study conducted over 15 years, I wanted to see how sheep grazing and fertilization affects alpine ecosystems. My hypothesis assumes that fertilization will increase cover of more palatable, nutrient demanding species and that grazers such as sheep would be more attracted to fertilized plots compared to plots that have received no added fertilization.

4.1 Effects of grazing and fertilization on species richness and diversity

Species richness is dependant of several environmental factors such as water, soil nutrients, pH and temperatures (Brown, Reilly, & Peet, 2016). Alpine plants live in such an extreme environment that large between-year variations are common (DÍAz et al., 2007; Evju, Halvorsen, Rydgren, Austrheim, & Mysterud, 2010; Giménez‐Benavides, Escudero, & Iriondo, 2007), and the short growing season in alpine areas make vegetation development strongly dependent on weather conditions (Lenart, Bowyer, Hoef, & Ruess, 2002; D. A. Walker, Halfpenny, Walker, & Wessman, 1993; M. D. Walker, Webber, Arnold, & Ebert - May, 1994). Plant growth is in many alpine systems also usually limited by the availability of nitrogen in soil (E. Bakker et al., 2004).

Earlier studies on species richness under herbivory have proved to give conflicting results depending on nutrient availability. While effects of herbivores have increased plant species richness and diversity in high-productive systems, they have decreased plant species richness and diversity in low-productive ecosystems (Milchunas & Lauenroth, 1993; Olff & Ritchie, 1998; Proulx & Mazumder, 1998). Results of species richness and diversity in this thesis show an increase in species richness and diversity for both control and fertilized plots from 2003 to 2008. Species richness is however reduced again in number from 2008 to 2018, while fertilized plots continue to increase in 2018. This correlates with earlier fertilizer studies (Jonasson, Michelsen, Schmidt, Nielsen, & Callaghan, 1996) that have shown a long-lasting fertilization effect even years after fertilization was stopped. I can assume that the increase of species richness and diversity in both fertilized and control plots is due to favourable weather conditions for 2008. The further increase in fertilized plots compared to control plots in 2018 might be due to a combination of fertilization and enhanced grazing. Added fertilization is supposed to increase species competition and lead to an increase in dominant species and plant height. Reducing of light to smaller plants makes it harder for seed dispersing species to competes, and reduces species richness and diversity (Gough, Osenberg, Gross, & Collins, 2000). Intermediate grazing of sheep may however increase species richness through balance species composition through removal of more dominant species (Elisabeth Bakker, 2003; Blix, 2012).

4.2 Effects of grazing on plant functional groups

Functional grouping of species with similar traits have been a preferred approach in grazing studies, and species in this study have been grouped together in graminoids, forbs, shrubs and a salix and Betula group. Graminoid cover in this study decreases in both control plots and fertilized plots from 2003 to 2018. The decrease in cover is however not as strong in fertilized plots as in control plots. My findings contrast to earlier fertilizing studies where graminoids have usually shown a positive response to fertilization, most often dominating after several years of fertilization (Bowman, Theodose, Schardt, & Conant, 1993; Grellmann, 2002; Gaius R. Shaver et al., 2001; G. R. Shaver & Chapin, 1986; Theodose & Bowman, 1997; Tilman, 1984; Wang et al., 2010). My study area has a relatively low sheep density compared to other studies that have concluded a positive response between fertilization and herbivore density on graminoids(Blix, 2012; Mysterud & Austrheim, 2005; Wehn et al., 2011), based on this grazing pressure from sheep should not be high enough to explain the decrease in graminoid cover alone. I did not analyse lemming activity in this study, but lemmings were visually seen during field work both live animals and winter activity (piles of den litter and faeces), and a possible explanation for my contrasting results in steep decrease of graminoid cover in 2018 may be due to grazing by rodents, as graminoids are one of their preferred food plant groups, and may experience hard grazing pressure and disturbance (Grellmann, 2002; Moen, Lundberg, & Oksanen, 1993). I assume the difference in cover for control and fertilized plots may be due to plants having easier for recovering from such grazing incidents in plots with more nutrients (Mysterud & Austrheim, 2005). Another explanation may be that my functional grouping may not catch those responses that I am looking for. Functional groupings of plants represent a preferred approach in many grazing studies, but the level of detail required to successfully predict responses of functional group to grazing is debated (Lavorel, McIntyre, Landsberg, & Forbes, 1997). Species within the same functional group may responses different to grazing by herbivores and fertilization, and a response may in many cases be due to larger cover of just a few species in the functional group rather than the functional group as a whole(G. R. Shaver & Chapin, 1986). In this study I have grouped together grasses (*Poaceae*), sedges (*Cyperaceae*) and rushes (*Juncaceae*), and while grasses have shown increases in cover (G. R. Shaver & Chapin, 1986), sedges percentage cover in earlier studies did not respond significantly to fertilization treatment when grasses and sedges was divided in two groups (Mysterud & Austrheim, 2005; G. R. Shaver & Chapin, 1986; Wang et al., 2010).

Forb cover in my study show also a contrasting result compared to other fertilization studies where forb cover usually decreases because they are being outcompeted by more dominant species usually because of light depletion when fertilization is added (Gough et al., 2000). Forb cover in this study show an increase in cover for both control and fertilized plots from 2003 to 2008. While cover in fertilized plots continued to increase in 2018, cover in control plots decreased. It may be that favourable weather conditions have contributed to an increase in cover since we can see the same reaction in both control and fertilize plots.

Shrubs showed a significant decrease in fertilized plots from 2003 to 2008 and 2018, while control plots did not change between years. Earlier studies have shown that shrubs tend to decrease after fertilization due to competition from more nutrient demanding species (Grellmann, 2002). Deciduous and evergreen shrubs which are placed together in one group in this study, may respond differently to fertilization treatment (Jonasson, Michelsen, Schmidt, & Nielsen, 1999). Another explanation may be an increase in rodents as suggested for graminoid cover, as rodents' favour fertilized areas during winter, especially decreasing *Vaccinium myrtillus* and *Vaccinium uliginosum* (Grellmann, 2002). Sheep have also proven to graze on *Vaccinium myrtillus* but it is not one of the most preferred forage plants(Mysterud & Austrheim, 2005), and I would not expect that grazing would be a contributing factor for the decrease in cover due to the low sheep density. Salix and Betula cover did not change in control plots from 2003 to 2018 but cover in fertilized plots increased slightly from 2003 to 2008 and 2018.

4.3 Sheep distribution in relation to treatment?

Based on the plant vigour hypothesis stated by Price (Price, 1991), that herbivores perform better on faster growing plants, and that herbivores will try to maximize their daily intake most cost efficiently by primarily go for the richest available fodder (Mattson, 1980), I assumed in this thesis that I would find higher sheep densities in fertilized plots, based on sheep pellets group count, compared to control plots and create a change in species composition. By returning dung and urea back to the fertilized plots sheep are also assumed to keep up the fertilization effects by providing highly decomposable nutrients to plants (Barthelemy, 2016; Hobbs, 1996). Sheep may however avoid grazing near new sheep pellets as a strategy to avoid parasites (Scheile, Isselstein, & Tonn, 2018). My analyses show that there is a positive correlation between sheep pellets groups and graminoid cover, in both control and fertilized plots. I assume based on this that sheep mainly prefer areas with graminoids and do show a selection toward areas with higher cover of graminoids, but do not select fertilized plots over control plots.

5 Conclusion

The vegetation in fertilized plots in this study showed a slight response to nutrient availability compared to control plots. While cover of graminoid and forbs showed a significant decrease in control plots in 2018, cover for both functional groups maintained its cover. This may assume that even though fertilization stopped in 2006, fertilized plots may have a long-lasting effect. This thesis shows that there is a change in species richness, diversity, and functional plant group cover over the different years for both control plots and fertilized plots. Species richness and diversity was significantly higher in fertilized plots in 2018 compared to 2003. Neither fertilization or sheep grazing can alone explain the total change in the study sites, and I presume since alpine environments are found to be strongly influenced by seasonal and year-by-year fluctuations when it comes to growth of alpine plants climate that this may explain some of the trends in my dataset. It may also be that functional grouping of plants may not be able to detect responses on such a level of detail that is required.

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Appendix

Table 1 List of species found in study sites, grouped into functional groups

Graminoids
Agrostis_capillaris
Agrostis_mertensii
Anthoxanthum_nipponicum
Anthoxanthum_odoratum
Avenella flexuosa
Carex atrata
Carex atrofusca
Carex bigelowii
Carex brunnescens
Carex capillaris
Carex dioica
Carex lachenalii
Carex limosa
Carex nigra
Carex norvegica coll.
Carex panicea
Carex saxatilis
Carex sp.
Deschampsia cespitosa
Eriophorum angustifolium
Eriophorum latifolium
Eriophorum scheuchzeri
Eriophorum sp.
Eriophorum vaginatum
Festuca hyperborea
Festuca ovina
Festuca rubra
Festuca sp.
Festuca vivipara
Juncus biglumis
Juncus castaneus
Juncus filiformis
Juncus sp.
Juncus trifidus
Juncus triglumis
Luzula arcuata coll.
Luzula frigida
Luzula multiflora
Luzula sp.

Luzula spicata
Luzula sudetica
Molinia caerulea
Nardus stricta
Phippsia algida
Phleum alpinum
Poa alpina
Poa annua
Poa arctica
Poa sp.
Poaceae
Trichophorum cespitosum ssp. cespitosum
Trisetum spicatum
Forbs
Aconitum_lycoctonum
Alchemilla_alpina
Alchemilla_glabra
Alchemilla_vulgaris
Antennaria_dioica
Arabis_alpina
Astragalus_alpinus
Astragalus_frigida
Bartsia alpina
Bistorta vivipara
Campanula rotundifolia
Cerastium alpinum
Cerastium cerastoides
Cerastium fontanum ssp. fontanum
Cerastium sp.
Cirsium heterophyllum
Coeloglossum viride
Epilobium anagallidifolium
Epilobium hornemannii coll.
Erigeron borealis

Erigeron uniflorus
Euphrasia wettsteinii
Galium boreale
Galium sp.
Gentiana nivalis
Gentianella amarella
Geranium sylvaticum
Geum rivale
Hieracium sec. Hieracium
Hieracium sp.
Leontodon autumnalis
Lysimachia europaea
Minuartia biflora
Minuartia stricta
Myosotis decumbens
Omalotheca norvegica
Omalotheca supina
Oxalis acetosella
Oxyria digyna
Parnassia palustris
Pedicularis lapponica
Pedicularis oederi
Pedicularis sp.
Petasites frigidus
Pilosella officinarum
Pinguicula vulgaris
Potentilla crantzii
Potentilla erecta
Pyrola minor
Pyrola norvegica
Pyrola sp.

Ranunculus acris ssp. pumilus
Ranunculus pygmaeus
Ranunculus sp.
Rhodiola rosea
Rubus chamaemorus
Rumex acetosa
Rumex acetosa ssp. lapponicus
Sagina procumbens
Saussurea alpina
Saxifraga aizoides
Saxifraga rivularis
Saxifraga stellaris
Scorzoneroides autumnalis
Sibbaldia procumbens
Silene acaulis
Silene dioica
Solidago virgaurea
Taraxacum croceum agg.
Thalictrum alpinum
Tofieldia pusilla
Trientalis europaea
Veronica alpina
Viola biflora
Viola palustris
Viola sp.
Shrubs
Arctostaphylos_alpinus
Calluna vulgaris
Diapensia lapponica
Empetrum nigrum
Harrimanella hypnoides
Juniperus communis
Kalmia procumbens

Loiseleuria procumbens
Phyllodoce caerulea
Vaccinium myrtillus
Vaccinium uliginosum
Vaccinium vitis-idaea
Salix & Betula
betula nana
betula pubescens
salix glauca
salix herbacea
salix lanata
salix lapponum
salix phylicifolia
salix polaris
salix reticulata

Table 2 Total number of species for Berghøgda and Båttjønndalen for 2003, 2008 and 2018

Year	Mean	Min.	Max
2003	55	37	71
2008	68	42	102
2018	50	35	68

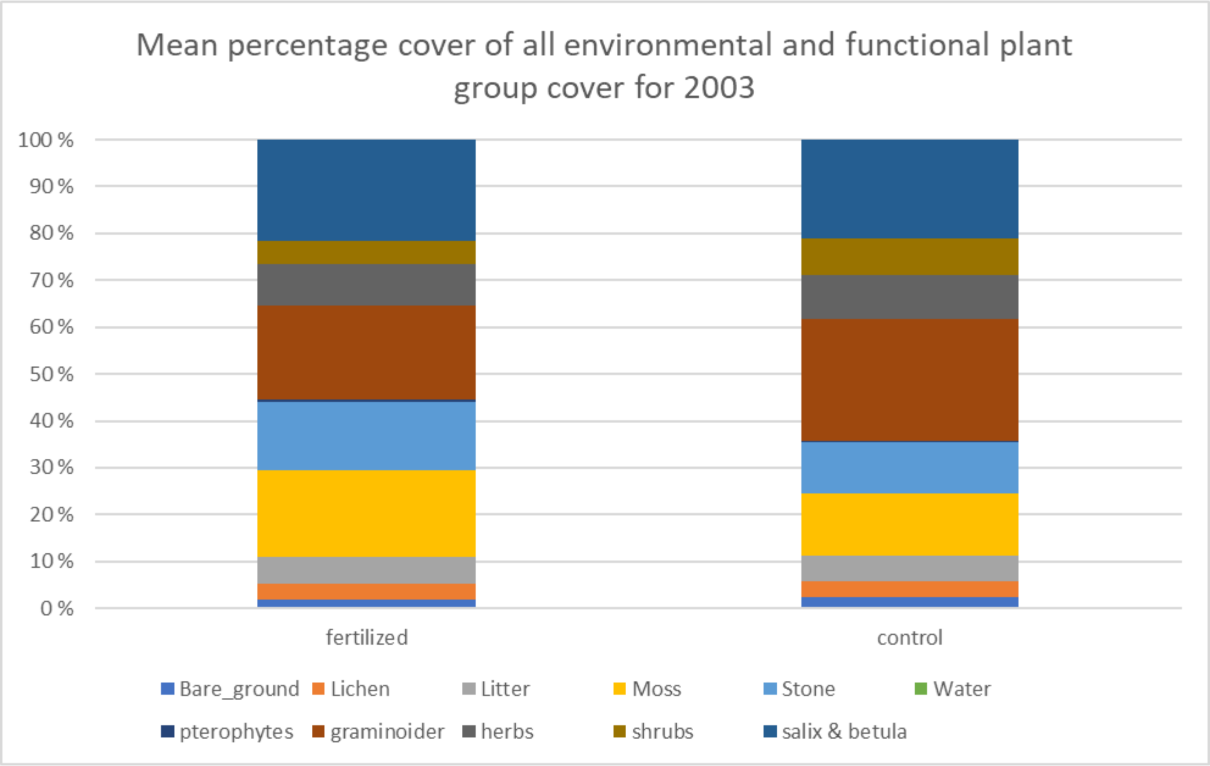

Figure 20 Mean percentage cover for environmental and functional plant cover in 2003 for control plots and fertilized plots in Båttjønnhøgda and Berghøgda

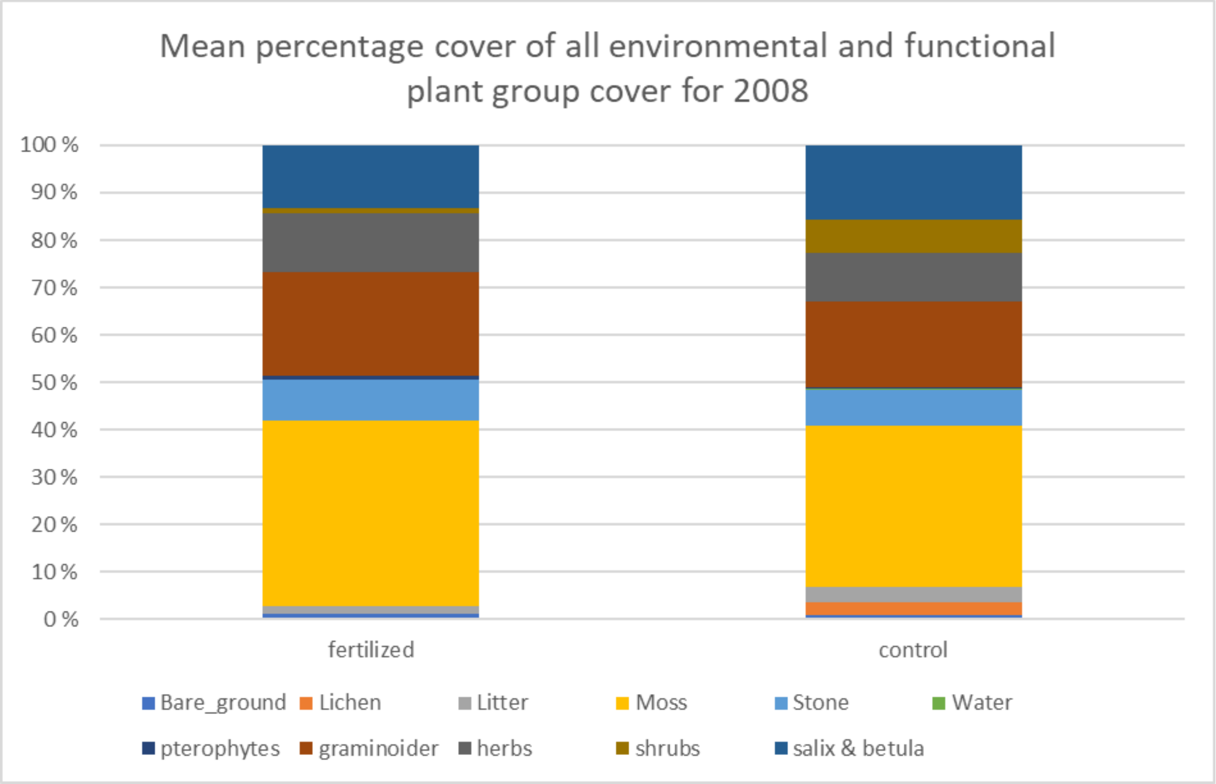

Figure 21 Mean percentage cover for environmental and functional plant cover in 2008 for control plots and fertilized plots in Båttjønnhøgda and Berghøgda

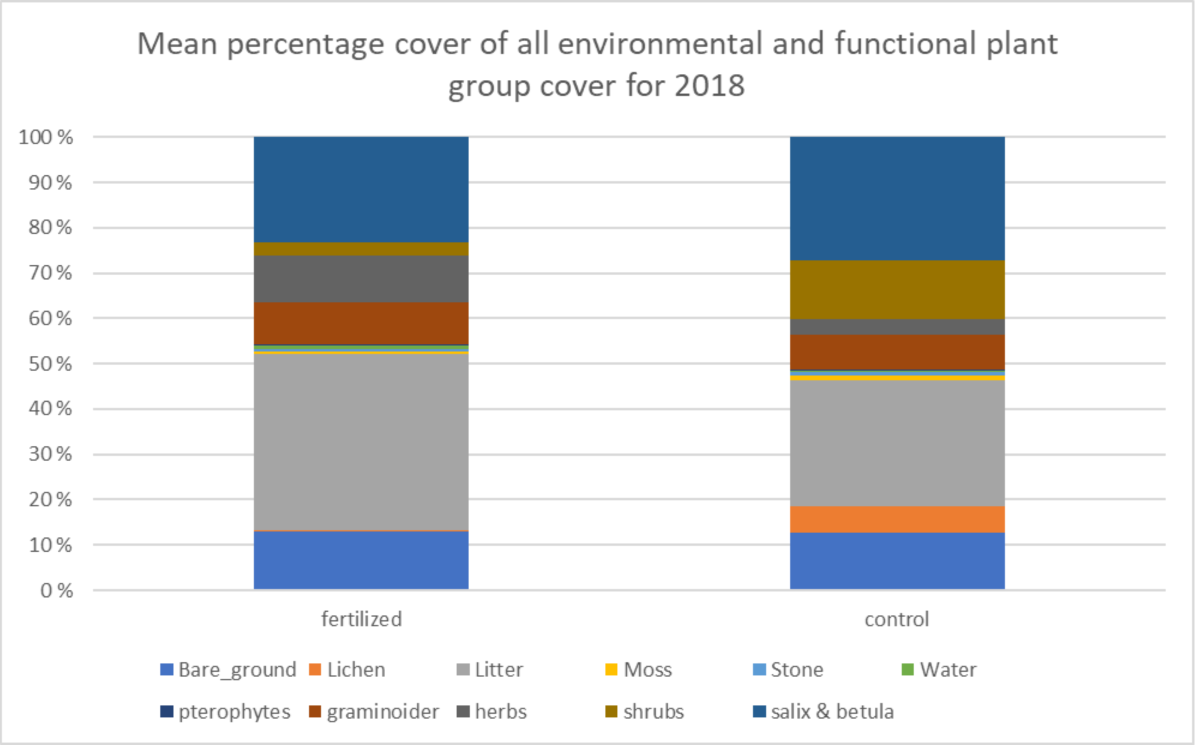

Figure 22 Mean percentage cover for environmental and functional plant cover in 2018 for control plots and fertilized plots in Båttjønnhøgda and Berghøgda

Table 3: Mean temperatures for each month for Røros airport, in Røros, the closes weather station for my study area, for each month for the year's vegetation analyses was done 2003,2007,2008, 2017 &2018

	jan	feb	march	april	may	june	july	aug	sept	okt	nov	dec
2003	-9,3	-11,2	-2,8	-0,3	5	10	14	11,1	6,3	-1,3	NA	-6,7
2008	-5,5	-4	-5,3	1,1	6	10,2	13,3	9,8	6,3	2,4	-3,1	-9,5
2017	-6,6	-6,9	-3,9	-0,9	4,9	9,7	10,9	9,7	7,6	2	-6,6	-8,2
2018	-9,8	-11	-9,7	0,6	10,7	9,9	15,7	10,6	7,5	2	-2,6	-5,9