University of Southeast Norway
Faculty of Technology, Natural Sciences and Maritime Sciences
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Effects of sheep grazing on alpine vegetation, a study from Forrolhogna National Park in Central Norway

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This thesis is worth 60 study points

1. Abstract

Alpine areas in Norway have a long history of domestic herbivory, and understanding the impact of grazing on alpine vegetation is therefore important for sustainable management of these areas. Domestic herbivory has the potential to modify alpine plant communities by establishing an equilibrium between the natural vegetation dynamics and the dynamics induced by the herbivores. A low to moderate grazing pressure can create a heterogenetic plant community through biomass removal, trampling results in open patches for plants to establish, and the release of nutrients through urine and feces, while high grazing pressure can lead to homogeneous plant communities, where the few grazing adapted species dominates. This study examines how alpine vegetation in two study sites in Forrolhogna National park in Central Norway is affected by grazing by domestic sheep. Ten study plots were analyzed, six of the plots had been fenced for the last 15 years to exclude sheep, while four were available for grazers. Data was collected in 2003, 2008 and 2017 in both grazed and ungrazed plots. The aim of this study was to test whether there are differences in species richness, –diversity and plant cover in grazed plots and plots that have not been grazed for 15 years, and how these plant responses is changed over time between 2003 and 2017. The cover of graminoids had decreased in ungrazed plots compared to grazed plots, and also decreased from 2003 to 2017. Other functional groups of vascular plants showed only small responses to the changed grazing regime caused by the absence of grazers. However, species richness had increased and the species diversity had decreased from 2003 to 2017 unaffected by the absence or presence of grazers. The grazing pressure in the study sites is relatively low, and the results of this study implies that the difference between low grazing pressure and no grazing is too weak to show extensive differences between grazed and ungrazed plots in 2017, after fifteen years of herbivore exclusion. The results suggest that other environmental factors might have greater impact than grazing on the vegetation of the study sites.

This study emphasizes the importance of long-term studies for understanding the processes of vegetation change and grazing by large herbivores, impacted by weather and climate. It provides a basis for further research in this study area, which may give valuable knowledge for the sustainable management in alpine areas in Norway

Contents

Preface

Five years of studies are hereby passed upon submission of this master thesis. The process has been exciting and challenging, including a steep learning curve the last year.

This process was not performed in solitude; I owe it to my supervisors Stefanie Reinhardt and Siri Lie Olsen that I was able to write this thesis. Thank you for giving me the opportunity to work on this project and for your constructive criticism, good discussions and help.

I will also like to thank Juraj Šovčík. Without him, the fieldwork would not be finished and the process would stop where it started.

Finally, a big thank you is addressed to Birgitte and Jens, friends and family for keeping me nourished and sane.

15. May 2018, Bø i Telemark

Aina Katrine Blæsterdalen

2. Introduction

Herbivores in alpine areas shape the species composition and richness of alpine vegetation through their selective grazing (Evju, Austrheim et al. 2009, Evju, Halvorsen et al. 2011). Many factor can influence plant community and composition, for instance weather, climate and bedrock, but type of herbivores, intensity and frequency of grazing events (Hobbs and Huenneke 1992, Augustine and McNaughton 1998, Callaway, Brooker et al. 2002, Dirnböck, Dullinger et al. 2003, Evju, Austrheim et al. 2009).

Herbivory

Herbivory, that is grazing by herbivores on vegetation, is defined as feeding on parts of the organism, but not killing it (Hobbs 1996). The effect of herbivores on a plant can be complex, but among many things, it depends on what part of the plant that are consumed. Disturbance or destruction of roots can reduce the uptake of water and nutrients, consummation of leaves leads to reduced photosynthetic area, and consuming of leaves, stems and branches leads to reduced ability to compete with the surrounding plants. The density of grazers affects the structure and composition of the plant cover (Begon, Townsend et al. 2006). Grazers are systematically removing preferred species by overgrazing those, and thereby change the structure and diversity of the plant community (Bazely and Jefferies 1986, Olofsson, E Hulme et al. 2004). High grazing pressure increases the cover of graminoids, while palatable herbs, herbs vulnerable to trampling and woody species decrease (Austrheim, Mysterud et al. 2008). High grazing pressure from herbivores can suppress forest and shrub formation, resulting in increased grassland areas (Olsson, Austrheim et al. 1999, Cingolani, Posse et al. 2005, Wehn, Pedersen et al. 2011). Intensive razing may have a negative impact on species richness by limit all plant growth, while moderate grazing can increase species richness through removal of dominant species (Austrheim, Gunilla et al. 1999, Austrheim and Eriksson 2001).

After moderate grazing pressure, the herbivores leave the vegetation patches at different stages of recovery, making the area heterogenic in both succession phase and species composition (Bullock, Hill et al. 1995). Trampling through damage on the vegetation inflicted by the grazers feet leads to more leads to more available area for species to grow, thus grazing is enhancing recruitment (Austrheim and Eriksson 2001).

However, where the grazing pressure is intense, tolerant and/or resistant species are favored and can become dominant, making the species composition and succession phase more homogenized (Augustine and McNaughton 1998, Austrheim and Eriksson 2001).

The nutrient content of plants is one of many plant characteristics that makes them favorable for herbivores (Mattson Jr 1980). Grazers affect nutrient availability in two general ways; 1) modifying the quantity and quality of plant litter ready for decomposition through defoliation of the plants (Hobbs 1996, Begon, Townsend et al. 2006) and 2) returning nutrients as nitrogen and ammonia to the soil through urine and feces (Ruess and McNaughton 1987). This nutrient cycle is important for plant growth, as nitrogen is the limiting factor for productivity in terrestrial ecosystems (Seagle, McNaughton et al. 1992, Hobbs 1996). Studies show that soil affected by herbivore activity have higher amounts of nitrogen than unaffected soil, which again affects the species composition (Ruess and McNaughton 1987, Hobbs 1996).

Plant responses

The defoliation process of the selective grazing is dealt with differently by different plant species, and is, together with the survivorship- and growth rate of the plants, a critical deciding factor of the changes in plant species communities in resonse to herbivory (Augustine and McNaughton 1998).

The grazing resistance concept as described by Painter (1985) assumes that resistant species are less damaged than others under comparable environmental condition, and these resistant abilities can be divided into avoidance and tolerance: avoidance involves mechanisms that diminishes the likelihood for grazing, while tolerance involves mechanisms that increases the growth after grazing events. The avoidance mechanisms consists of morphological attributes such as thorns, and biochemical adaptions such as poison or other inedible compounds; these mechanisms reduce the plant tissue accessibility and palatability(Briske 1996).

Species that have an increased ability to compensate for removed plant tissue have a higher tolerance for grazing than plants without this ability. These compensating species (for instance graminoids) can be dominant in areas with high grazing pressure (Coughenour 1985, Briske 1996, Augustine and McNaughton 1998, Gurevitch, Scheiner et al. 2002, Evju, Austrheim et al. 2009). The plants` tolerance is affected by the nutrients available, weather conditions and the intensity and frequency of grazing events during regrowth. Species which are highly productive and fast growing or non-edible and slow-growing are avoided by the grazers, while slow-growing and edible plants can be outcompeted or consumed (Briske 1996).

Smaller grasses and herbs can be outcompeted by the shading from taller herbs and shrubs in productive communities. The strong competitive effect in these communities could be reduced by the foliage removal of grazers and grazers can thereby increase the species richness and -diversity (Austrheim and Eriksson 2001, Hester, Bergman et al. 2006). In less productive areas the shading effect is not as obvious as in rich and productive areas.

Grazing in Norwegian mountain ecosystems

In Norway, as in many other countries, mountain areas are used for livestock grazing and for the collection of animal feed. This results in a cultural landscape where the forest is suppressed for the benefit of grass, herbs and other herbivore favored vegetation (Austrheim, Gunilla et al. 1999, Olsson, Austrheim et al. 1999).

The livestock has been and still is moved from the main farm in the lowlands to mountain summer farms during the growing season, where they graze freely throughout the summer. Thus the alpine plant communities, as they are today, are influenced by a seasonal grazing land use over decades (Olsson, Austrheim et al. 2000). Optimal grazing pressure results in a rich biodiversity, which makes the land use both ecologically, and economically sustainable (Austrheim, Gunilla et al. 1999, Olsson, Austrheim et al. 2000, Austrheim and Eriksson 2001).

In 2003, 2.36 million domestic herbivores grazed the alpine pastures in Norway, where the Norwegian white sheep (*Ovis aries)* make up the majority (88%) (Gundersen 2005). This could be a key driver for the vegetation composition (Austrheim, Gunilla et al. 1999, Rusch, Skarpe et al. 2009).

Sheep prefers shorter species with leaves of moderate roughness such as graminoids, sedges and rushes, where parts of the plant are consumes and roots and stems are left undamaged (Erschbamer, Virtanen et al. 2003, Wehn, Pedersen et al. 2011). The semi-natural mountain ecosystem in Norway is a habitat for plant species that have adapted

to a certain grazing pressure, and these species could be affected by changes in the grazing regime.
Grazing in the Norwegian mountains has a huge influence on the vegetation (Olsson, Austrheim et al. 1999, Körner 2003). It is important to improve land management, and make it robust for changes in both climate and livestock management it is important to increase our knowledge on the impact of domestic livestock grazing on the alpine ecosystem.

Aim of the study

The aim of this study is to quantify effects of domestic herbivory in alpine vegetation over 15 years.
In 2003, a research project was established by the Norwegian Institute for Nature Research (NINA) to examine how alpine vegetation respond to grazing by domestic animals. The current study follows up vegetation analyses that where conducted in 2003 and 2007.
With this knowledge in mind, the following questions are asked:

1) Is there a difference in species richness, -diversity and plant cover between grazed plots and plots that have not been grazed for 15 years?
2) Is there a change in species richness, -diversity and plant cover over time for ungrazed plots

3. Materials and methods

Study area

The study area is located in Forrolhogna national park in the central Scandinavian mountains (figure 1). There are two study sites: Berghøgda (UTM coordinates map datum WGS 84, zone 32 V, 07600, 51300) and Båttjønnhøgda (WGS 84, zone 32 V, 04600, 636960).

The mean temperature in Bergkåk (the closest weather station) in 2017 were 11.3 ºC in the warmest month July and 0.69 ºC for the coldest (January) (The Norwegian Meteorological Institute 2017). In 2003, when the study started, the mean temperature in July was 15.32 ºC and the mean for January was -4.5 ºC. The precipitation is evenly distributed throughout the year with an average of 750 mm (1970-2005) (Bergkåk, Norwegian Meteorological Institute).

The study sites are located in the alpine area above the tree line. Berghøgda is located at 900-1000 masl, while Båttjønnhøgda is located at 1000-1100 masl. Sediments from river and moraines cover the bedrock. The most widespread bedrock is chist, which contain elements as phosphorus, potassium and lime that stimulates plant growth (www.villrein.no 2017).

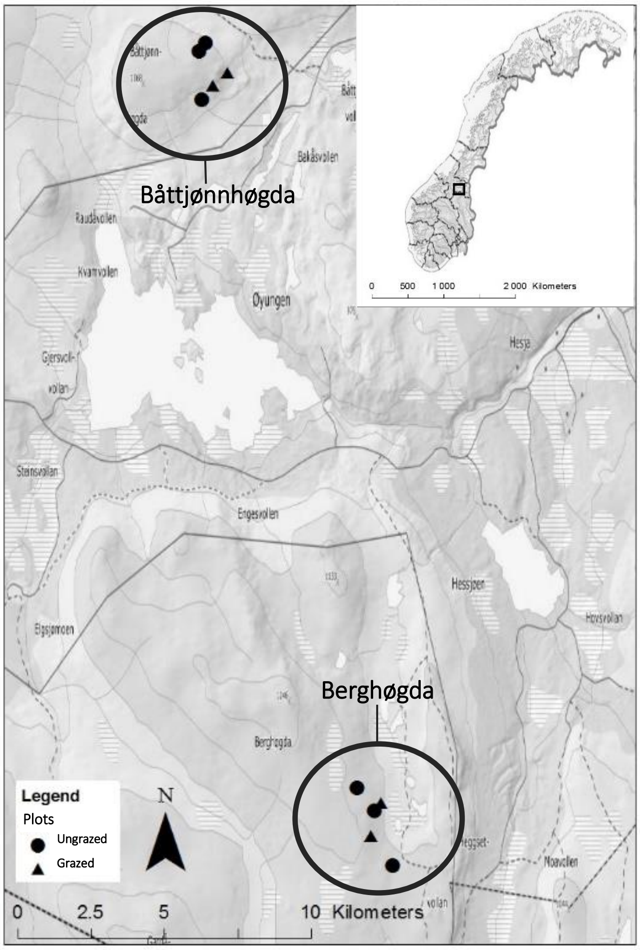


Figure 1. Study area with the study sites Berghøgda and Båttjønnhøgda, and the four grazed (triangles) and six ungrazed (circles) plots.

Lichen heath dominates the vegetation in both study sites. Shrub species communities consists of *Betula nana*, *Empetrum nigrum ssp. hermaphroditum* and *Vaccinium myrtillus*. *Salix herbacea* dominates the snow-beds, graminoids such as *Deschampsia cespitosa*, *Anthoxantum odoratum*, *Carex bigelowii, Avenella flexuosa and forbs such as Alchemilla alpina and Viola biflora* dominate the alpine meadows.

Berghøgda has a higher species richness than Båtjønnhøgda, were nutrient demanding species is observed in Berghøgda (f.eks. *Dryas octopetala*), and Berghøgda is therefore regarded as more nutrient rich than Båttjønnhøgda.
Sheep graze freely in the areas of Berghøgda and Båttjønndalen in the summer months between June and August, and the sheep herds belong to different farms. The grazing pressure relatively low in both areas (Gjersvold 2017).
Forrolhogna national park belongs to wild reindeer management area 22, with a population size of 2000 of wild reindeer, however, according to the managing organ Statens Naturoppsyn, they roam very rarely in the study sites (www.villrein.no 2017).

Study design

Vegetation analyzes where conducted first in 2003, and then again in 2007/ 2008/ 2009 (from now summarized as 2008) by NINA. We conducted another resampling in July-August 2017.
The study plots where 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 meters in 5 minutes was classified as grazing and included in the analysis). The telemetry data showed a high preference for snow-beds and meadows in both areas and by all sheep individuals (Rusch, Skarpe et al. 2009).
Ten 50 x 50 m2 plots were selected randomly from patches with clusters telemetry records (Rusch, Skarpe et al. 2009), the plots where divided into 100 5 x 5 m^2 sub-plots. There were five plots in every study area, ten all together (figure 1). One line of sub-plots on each side of the 50 x 50 m^2 plot was used as buffer area, and 64 sub-plots were analyzed per plot *(figure 2).*
Fences were put around six out of ten study plots to exclude grazers. The fences were put up every year in the start of the grazing season, and taken down at the end, every year since the start of the project in 2003. The other four non-fenced study plots have been kept as control plots where grazing is assumed to occur as normal.

Statistical analyses

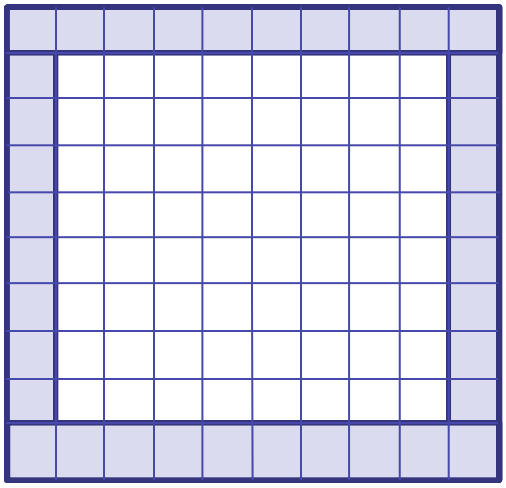


Figure 2. An overview of a study plot. Its 50 x 50 m^2 divided into 5x5 m^2.
One line of sub-plots on each side was used as a buffer and not considered in the measurements.

All vascular plant species were recorded and their percentage cover was estimated visually in each of the analyzed subplots (buffer subplots excluded). Additionally, cover of lichens, bare ground, stones, water, and moss was estimated in percentage in each sub plot. Nomenclature follows Mossberg and Stenberg (2012). Increase and decrease of vascular plant species is a visual comparison of the cover % between ungrazed/grazed and 2003/2017.

The dataset consists of vascular plant species abundance in 64 sub plots in ten plots located in two study sites. The species were grouped into five functional groups to isolate species with the same attributes and with similar responses to grazing.
(see species grouping in table 2 in appendix).

Pteridophytes are vascular plants that propagates with spores and have generational exchange with a haploid gametophyte and a diploid sporophyte.

Graminoids are plants with one embryonic leafs, such as grasses, sedges and rushes. They usually have linear leaves and wind-pollinated flowers.

Forbs are non-woody plants where the plant parts over ground withers.

Shrubs are multi-strained woody plants. *Salix* and *Betula* species are grouped separate.

Betula* & *Salix are plant species in *Betula*- and *Salix* genera. These species are considered as an own functional group due to different grazing responses compared to shrubs (Vowles, Gunnarsson et al. 2017).

Species richness of vascular plants, which is a count of number of plant species present in each plot (Spellerberg and Fedor 2003), plant cover of each species in each plots, and vascular plant species diversity, calculated for each plot, which is a quantitative measure of the species richness and –abundance were used for further analyses. Species diversity was estimated applying the Shannon Index (H), and is calculated as follows

$$\mathrm{H} = \sum_{i=1}^{s} pi \ln * pi$$

Where **pi** is the proportion (n/N) of individuals of one particular species found in a subplot, **ln** is the natural logarithm, **∑** is the sum of the calculations, and **s** is the number of species.

To get a first overview over the collected data, multivariate statistics were used. Principal component analysis (PCA) was conducted on the plots in relation to the environmental factors (Whitlock and Schluter 2009). Species richness and –diversity is included as environmental factors. The aim with the PCA was to summarize the data and find the main patterns and relationship within the distribution. This was conducted for 2003 and 2017. A detrended correspondence analysis (DCA) was conducted on the species abundance for each vascular species, where the functional groups were applied post-hoc (Hill and Gauch 1980). DCA was conducted for 2003 and 2017. To capture the main tendencies in the dataset and to reduce noise, species with a cover of <2% in each plot was excluded in the DCA. The DCA and PCA was performed in R with package Vegan (Oksanen, Blanchet et al. 2018).

Welch´s t-test was used to compare the means of species richness and plant cover for the functional groups in grazed and ungrazed plots within the two study sites, for 2003 and 2017 (Whitlock and Schluter 2009).

Paired t-test was used to test if the cessation of grazing had changed the mean of species richness and plant cover in the functional groups, and species diversity in each plot from 2003 to 2017 in ungrazed and grazed plots.

Analysis of variance (ANOVA) was carried out to test whether the mean of species richness and plant cover in the functional groups, and species diversity in each plot was different bewteen 2003, 2008 and 2017.(Whitlock and Schluter 2009).
Statistic tests used to test differences between grazed and ungrazed plots, and differences between years are shown in table 1.

Table 1. Overview over statistic tests, differences to be tested, analyzed data and statistic program applied.

Differences/changes to be tested	Data to analyze	Statistical test	Statistic program
Ungrazed plots vs. grazed plots 2017	• Species richness of functional groups pr. plot • Plant cover of functional groups pr. plot • Species diversity pr. Plot	Welch's two sample t-test	R
2003 vs. 2017 in grazed plots and ungrazed plots	• Species richness of functional groups pr. plot • Plant cover of functional groups pr. plot • Species diversity pr. Plot	Paired t-test	R
2003 vs. 2008 vs. 2017 in grazed plots and ungrazed plots	• Species richness of functional groups pr. plot • Plant cover of functional groups pr. plot • Species diversity pr. plot	One-way ANOVA	Microsoft Excel

4. Results

A survey of vascular plants in both study site resulted in a total of 97 species. In 2003, 47 species were recorded in Berghøgda and Båttjønnhøgda in 30, for 2008, there were 44 species in Berghøgda and 31 in Båttjønnhøgda and in 2017 there were 44 species in Berghøgda and 30 in Båttjønnhøgda.

The principal component analysis for the relation between the plots and the environmental factors in 2017 is relatively homogenous *(figure 3).* However, there are outliers as Båttjønnhøgda 7 (grazed) which is an extreme snowbed where the snow melted in early August, and Båttjønnhøgda 5 (ungrazed) which is dominated by stones and moss. The plots in do not have any systematically differences within or between the study sites, due to the homogeneity in the distribution of the environmental factors, and they are therefore quite comparable. Plots in 2003 in Berghøgda *(figure 14 in appendix)* relates to a somewhat higher degree to species richness and diversity, while plots in Båttjønnhøgda relates to stone, bare ground and litter. This is a repeated pattern for 2017. DCA results of species as well as sample plots in relation to DCA axis 1 and DCA axis 2 are shown *(figure 4).* The environmental variables were post-hoc introduced and show that the variation in species composition expressed along axis 1 is correlated with species diversity and species richness, DCA axis 2 is correlated with bare ground and lichen. The distribution in species abundance in 2003 is showed *(figure 15 in appendix).*

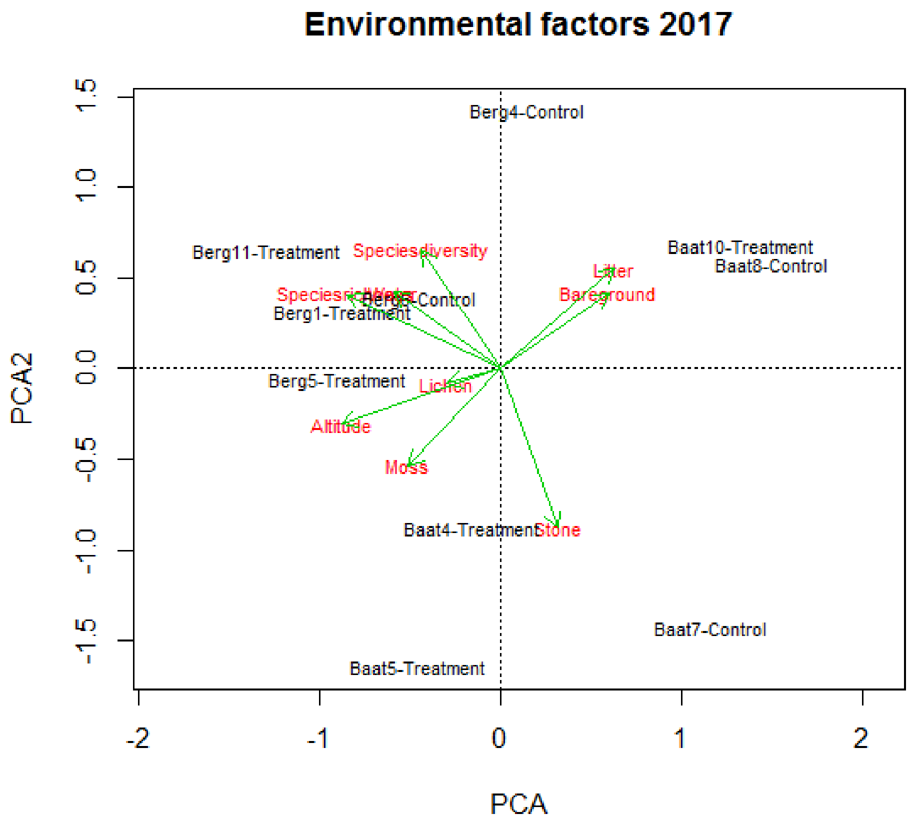


Figure 3. Principal Component Analysis for environmental factors in 2017. Environmental factors shown in red. Treatment: non-grazed. Control: grazed

«Bat» and «Berg» denote plots in Båttjønndalen and Berghøgda, respectively. Treatment indicated non-grazed plots, while control indicated grazed plots.

For PCA for 2003 see figure 13 in appendix.

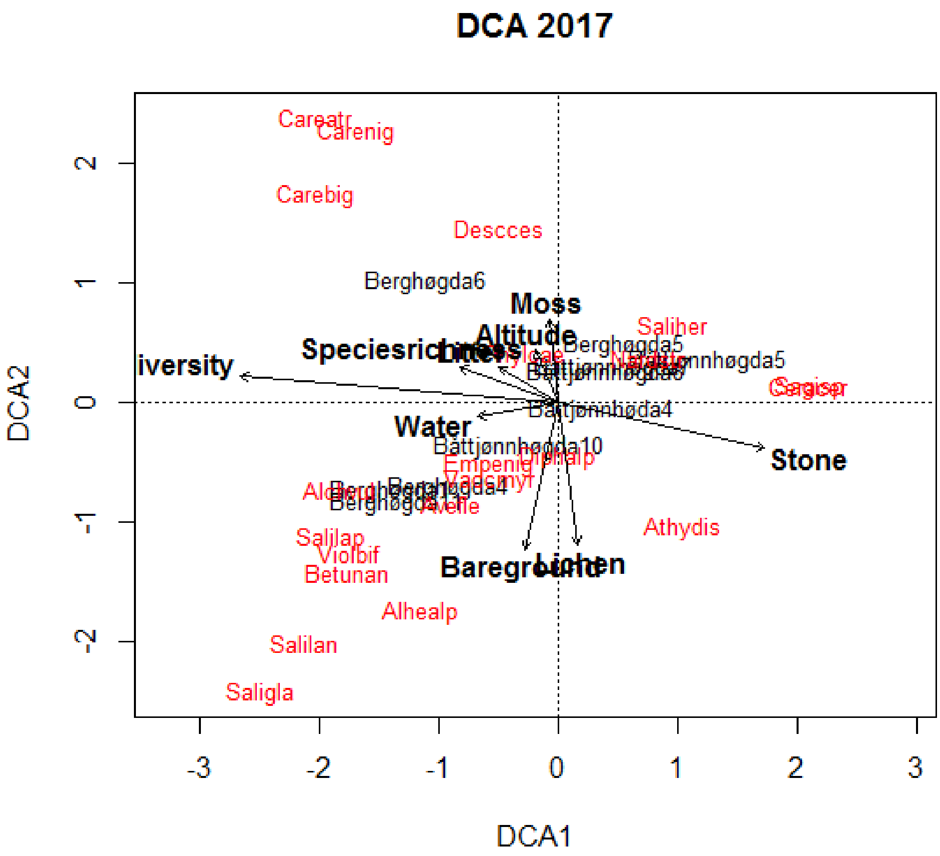


Figure 4. Detrended Correspondence analysis with species abundance (red), and environmental factors (black arrows). For abbreviations of species names, see table 2 in appendix. To increase the ordination plot legibility, species with >2% cover were removed.

Differences in species richness, plant cover and species diversity between ungrazed and grazed plots 2017

Berghøgda

There was a statistically significant difference in species richness between ungrazed plots and grazed plots in Berghøgda in 2017 for pteridophytes (p-value: 0.03) graminoids (p-value: 0.05) and shrubs (p-value: 0.00) *(table 3 in appendix)*. Species richness of pteridophytes and graminoids was lower in ungrazed compared to grazed plots, while species richness of shrubs was higher in ungrazed plots *(figure 5 A).* In 2003 there was no difference in species richness grazed and ungrazed plots *(table 3 and figure 16 A in appendix).*

A statistically significant difference in plant cover was found for pteridophytes (p-value: 0.00), graminoids (p-value: 0.05) and *Salix* & *Betula* (p-value: 0.00) *(table 3 in appendix)* in 2017, where the cover of pteridophytes and *Salix* & *Betula* was higher in ungrazed plots, and where graminoids showed an opposite trend *(figure 5 B).* in 2003 there was a significant difference in plant cover between grazed and ungrazed plots for forbs and *Salix* & *Betula* (table 3 appendix), where forb cover was higher in grazed plots, and *Salix* & *Betula* covers more in ungrazed plots *(figure 16 A in appendix).*

There was a statistical significant difference in species diversity between ungrazed and grazed plots for Berghøgda (p-value: 0.00) in 2017 *(table 4 in appendix),* where the diversity has decreased in ungrazed plots *(figure 7).* The species diversity for Berghøgda in 2003 showed no difference between grazed and ungrazed plot *(table 4 in appendix).*

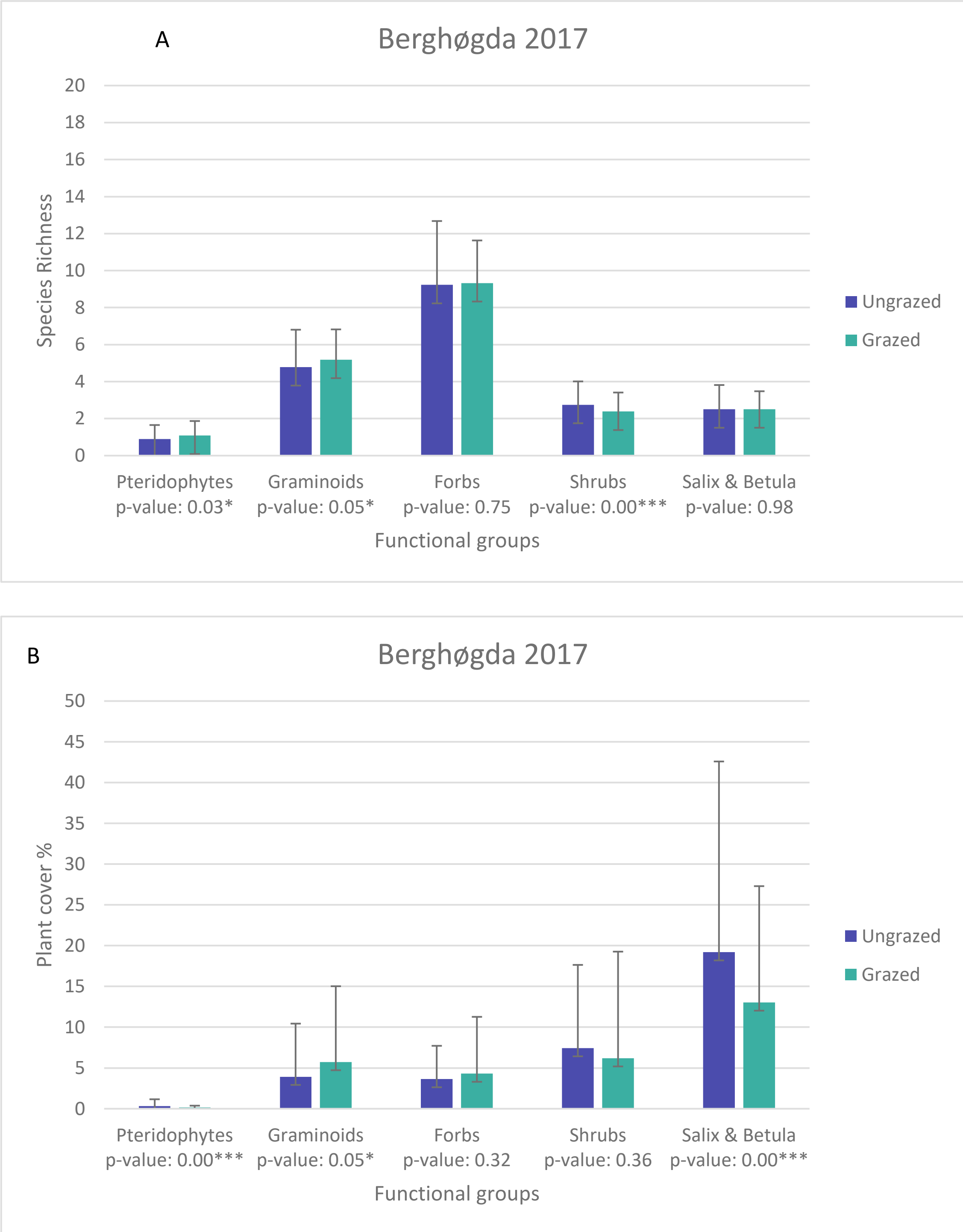


Figure 5. Species richness (A) and plant cover (B) in Berghøgda in 2017. Species richness (NO. of species) and plant cover (%), respectively, of the different functional groups in ungrazed and grazed plots in Berghøgda in 2017.

*Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

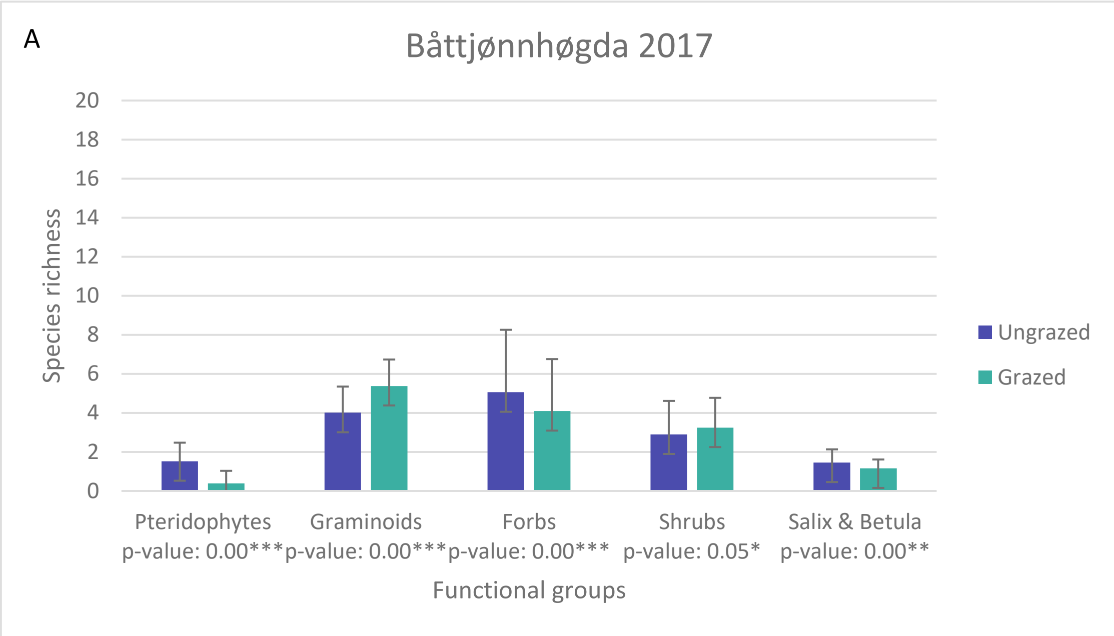
Båttjønnhøgda

There was a statistically significant difference in species richness between ungrazed and grazed plots in Båttjønndalen in 2017 for all functional groups: Pteridophytes (p-value: 0.00), graminoids (p-value: 0.00), forbs (p-value: 0.00), shrubs (p-value: 0.05), *Salix* & *Betula* (p-value: 0.00) *(table 3 appendix).* Species richness of pteridophytes, forbs and *Salix* & *Betula* was higher in ungrazed plots, whereas the richness of graminoids and was lower *(figure 6 A).* In 2003, species richness differed between grazed and ungrazed plots for pteridophytes (p-value: 0.00), graminoids (p-value: 0.01) and shrubs (p-value: 0.00) *(table 3 appendix),* with an higher species richness in ungrazed plots *(figure 17 A appendix).*

There was a statistically significant difference in plant cover for pteridophytes (p-value: 0.00), graminoids (p-value: 0.00) and *Salix* & *Betula* (p-value 0.00) (table 3 appendix) in 2017, where cover of pteridophytes and shrubs was higher in ungrazed plots and graminoid cover was lower *(figure 6 B).* In 2003 the cover of all functional groups differed between ungrazed and grazed plots: the cover of pteridophytes (p-value: 0.00) and shrubs (p-value: 0.00) was higher in ungrazed plots, and the cover of graminoids (p-value: 0.00), shrubs (p-value: 0.00) and *Salix* & *Betula* (p-value: 0.00) was lower *(table and figure 17 B in appendix).*

There was a statistical significant difference in species diversity between ungrazed and grazed plots in Båttjønnhøgda (p-value: 0.00) in 2017 *(table 4 in appendix),* where the diversity had increased in ungrazed plots compared to grazed plots *(figure 7).* The species diversity between ungrazed and grazed plots was unchanged in Båttjønnhøgda in 2003 *(table 4 and figure 23 in appendix).*

A visual estimate of the cover in each study site shows that the abundance of Graminoids as *Avenella flexuosa*, *Anthoxanthum odoratum* and *Nardus stricta*, species in *Salix* and *Betula* genera *Salix glauca*, *Salix lanata*, *Salix herbacea* and *Betula nana* and the forbs *Viola biflora*, *Geranium sylvaticum*, *Omalotheca supina* and *Rumex acetosa* covers more area in ungrazed plots compared to grazed plots. *Deschampsia cespitosa* covers less in ungrazed plots compared to grazed plots in Båttjønnhøgda.



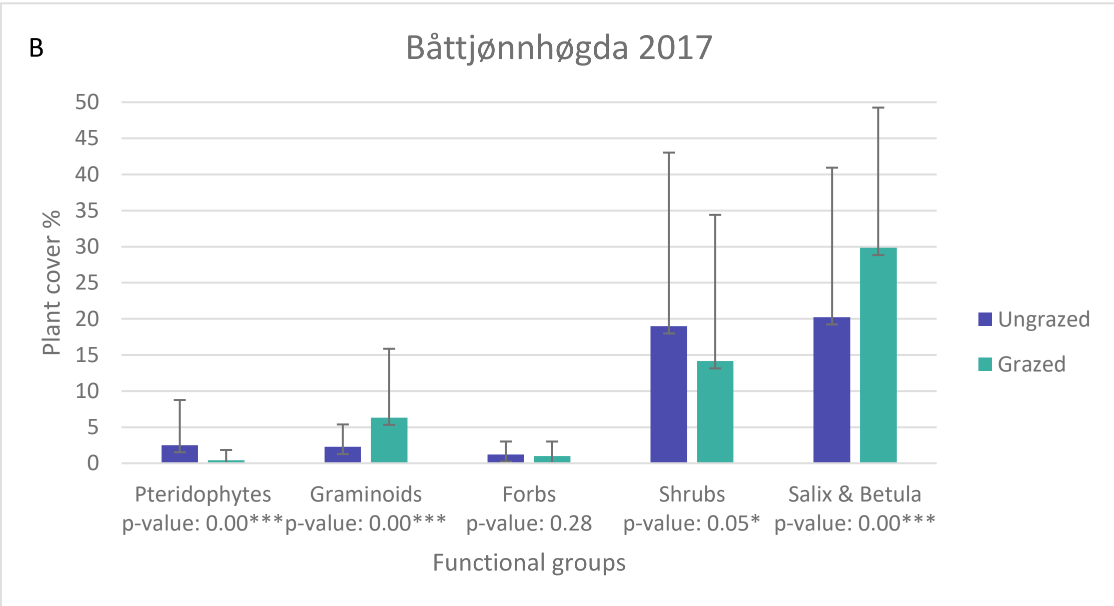


Figure 6. Species richness (NO. of species) (A) and plant cover (%) (B) in 2017, respectively, of the different functional groups in ungrazed and grazed plots in Berghøgda in 2017.

*Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

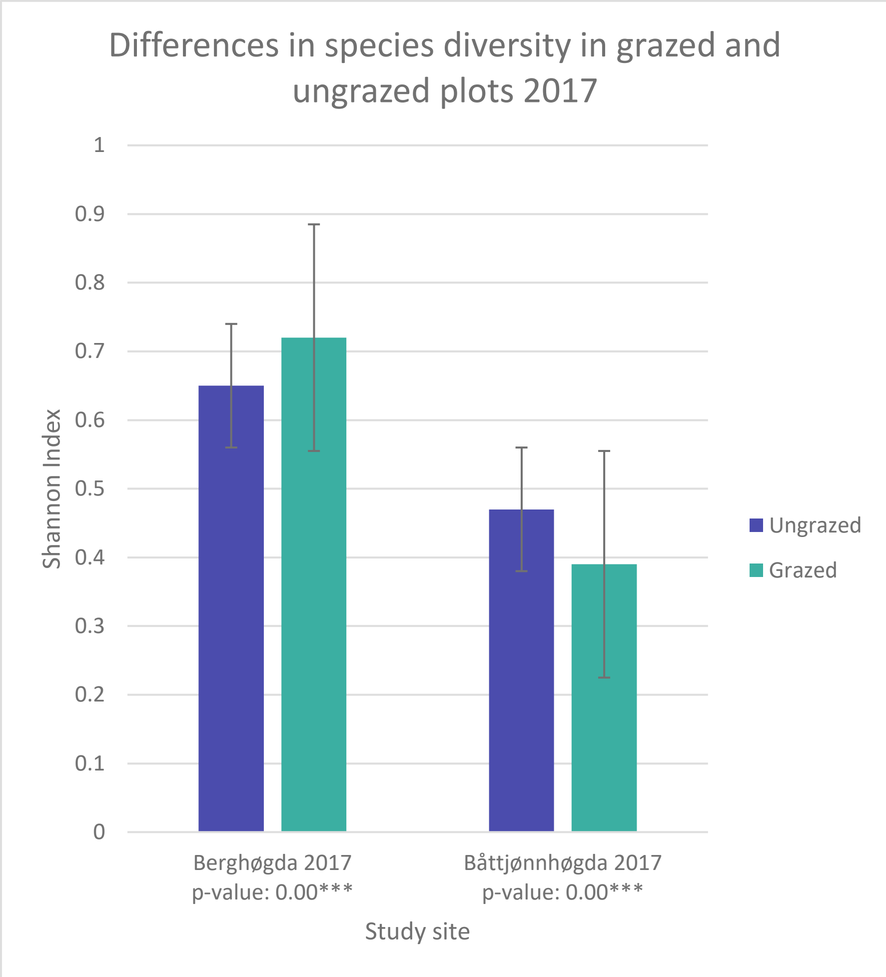


*Figure 7. Species diversity (Shannon Index) in ungrazed and grazed plots in the two study sites in 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

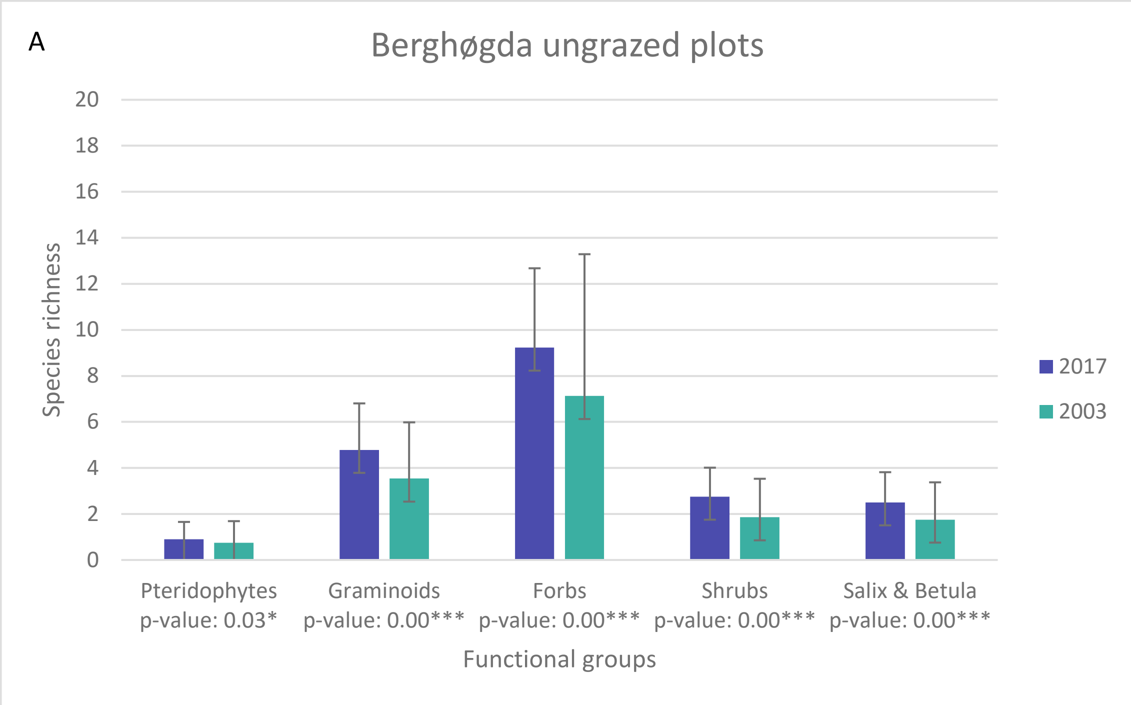
Changes in species richness, plant cover and species diversity between 2003, 2008 and 2017 in ungrazed plots

Berghøgda

There were statistically significant changes in species richness from 2003 to 2017 for ungrazed plots in Berghøgda. Pteridophytes (p-value: 0.03), graminoids (p-value: 0.00), forbs (p-value: 0.00), shrubs (p-value: 0.00) and *Salix* & *Betula* (p-value 0.00*) (table 5 in appendix)* all show an increase in species richness from 2003 to 2017 *(figure 8 A).* When comparing data from all three years, all functional groups except pteridophytes show a significant increase in species richness from 2003 to *2017 (table 6 in appendix, and figure 9 A in results)*. All functional groups in Berghøgda grazed plots show a statistically significant change *(table 5 in appendix),* with an overall increase in species richness from 2003 to 2017 *(figure 21 A in appendix).*

The cover of graminoids (p-value: 0.00), forbs (p-value: 0.00) and *Salix* & *Betula* (p-value: 0.00) *(table 5 appendix)* had changed statistically significant from 2003 to 2017, all showing an increase in cover *(figure 8 B).* When comparing data from all three years, there was a statistically significant decrease from 2003 to 2017 for graminoids (p-value: 0.00), forbs (p-value 0.00) and *Salix* & *Betula* (p-value: 0.04) *(table 5 in appendix).* The changes in plots for Berghøgda grazed plots showed that pteridophytes (p-value: 0.00), graminoids (p-value: 0.00) and forbs (p-value: 0.00) *(table 5 appendix)* had all decreased from 2003 to 2017 *(figure 21 B).*

There was a significant change in species diversity for Berghøgda (p-value: 0.00) *(table 7 in appendix)* between 2003 and 2017 in ungrazed plots, towards higher species diversity in 2017 than 2003 *(figure 12).* When comparing data from all three years, the species diversity did not change in these plots over time (p-value: 0.25) *(table 8 in appendix and figure 13 in results)*. The grazed plots in Berghøgda showed a change in diversity from 2003 to 2017 *(table 8 in appendix)* towards increased diversity in 2017 compared to 2003 *(figure 24 in appendix).*



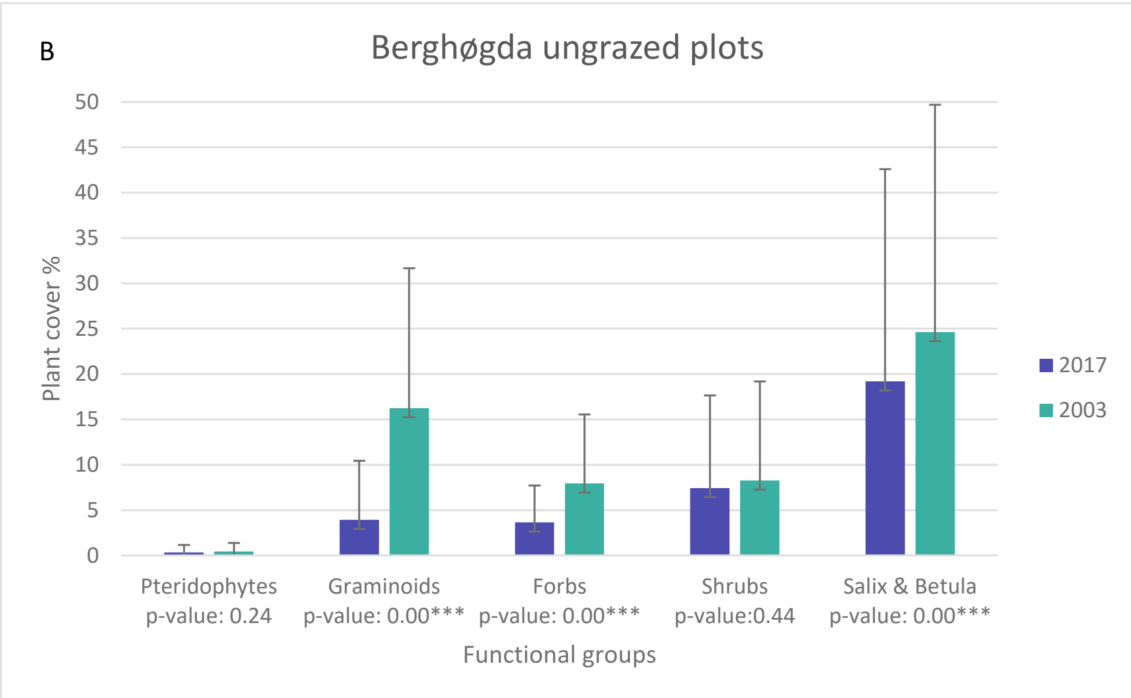
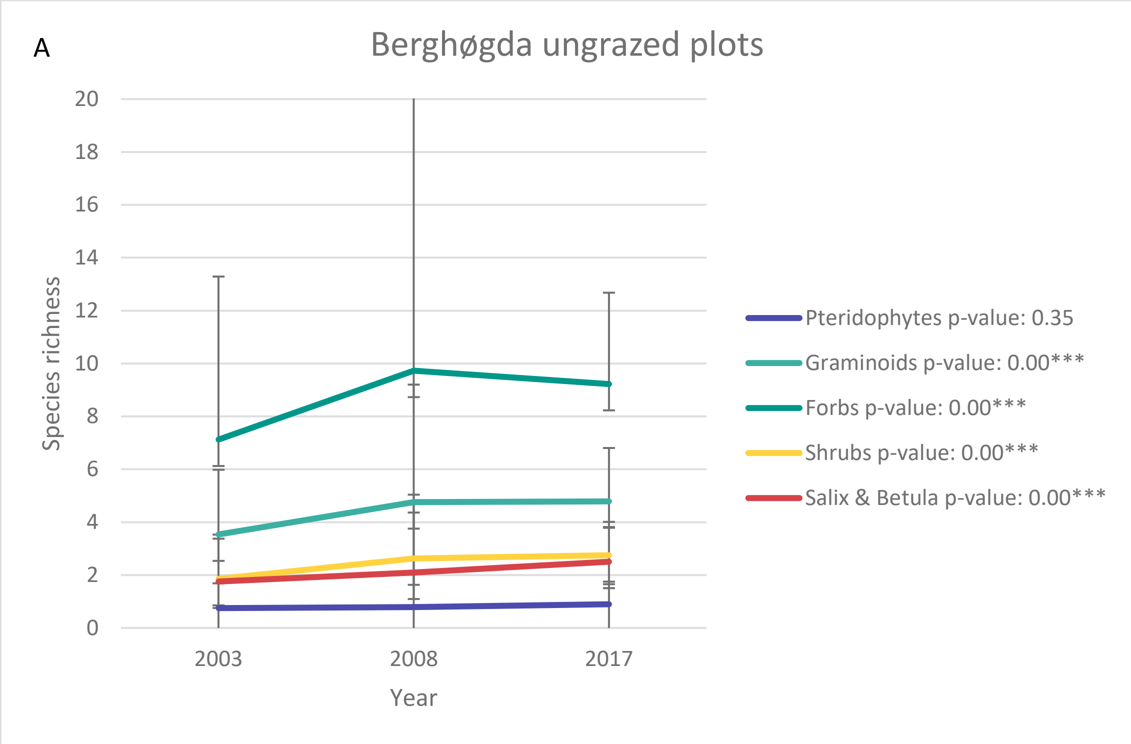


*Figure 8. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in ungrazed plots in Berghøgda in the two study sites in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*



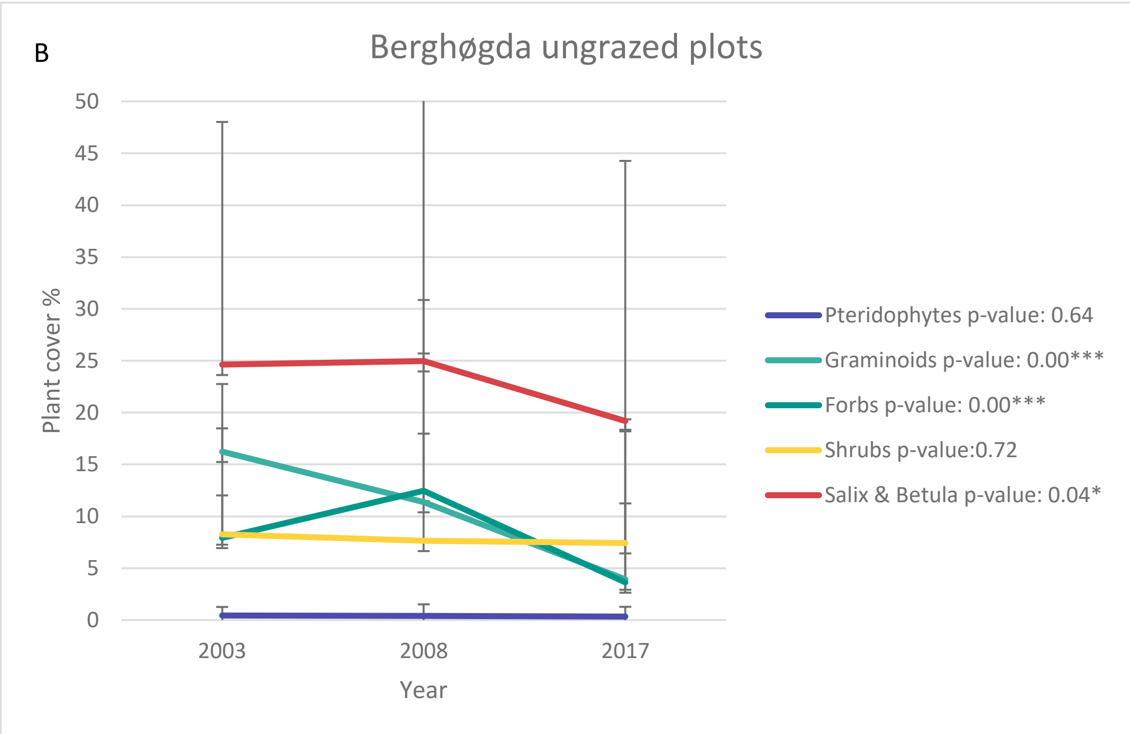


Figure 9. Species richness (No. of species) (A) and plant cover (%) (B) respectively, in ugrazed plots in Berghøgda between 2003, 2008 and 2017.

*Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

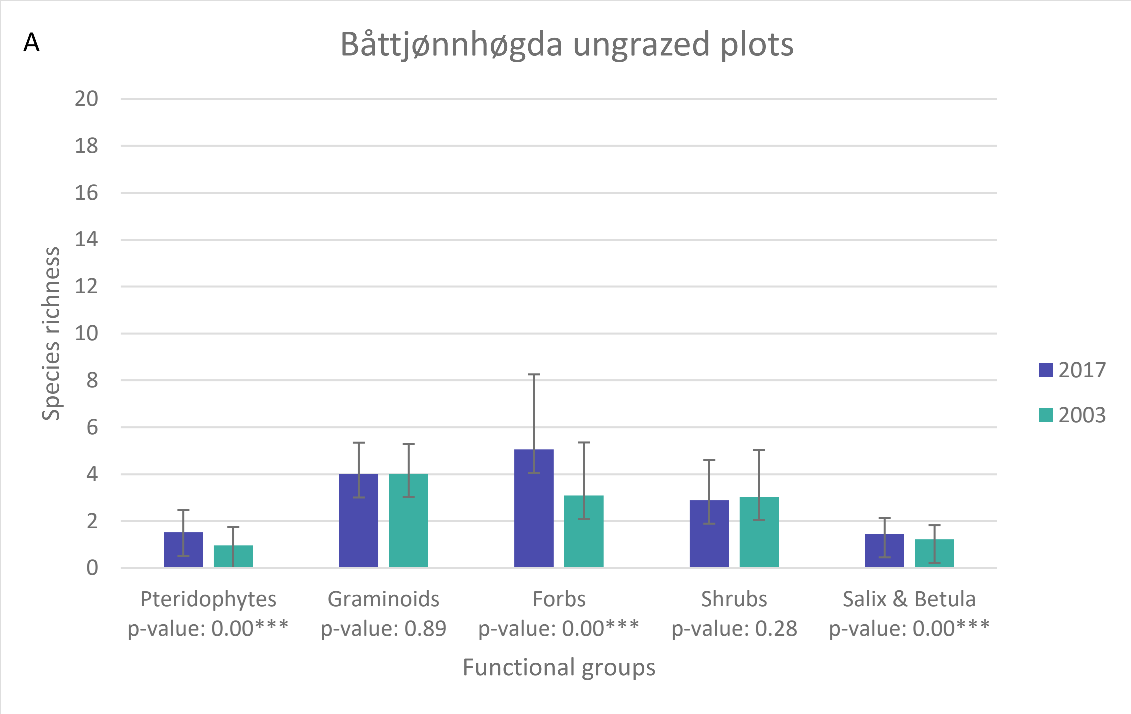
Båttjønnhøgda

There where statistical significant changes in species richness of pteridophytes (p-value: 0.00), forbs (p-value: 0.00) and *Salix* & *Betula* (p-value: 0.00) *(table 5 appendix)* in ungrazed plots in Båttjønnhøgda, with a shift towards higher species richness from 2003 to 2017 *(figure 10 A).* When comparing data from all three years, significant changes were found for pteridophytes (p-value: 0.00), forbs (p-value: 0.00), shrubs (p-value: 0.03) and *Salix* & *Betula* (p-value: 0.00) *(table 6 appendix),* all increasing in species richness *(figure 11A).* In Båttjønnhøgda grazed plots, graminoids (p-value: 0.00), forbs (p-value: 0.00) and shrubs (p-value: 0.00) *(table 5 appendix)* increased in species richness from 2003 to 2017 *(figure 22 A appendix).*

The cover off graminoids (p-value 0.00) *(table 5 appendix)* had changed statistically significant from 2003 to 2017 towards reduced cover *(figure 10 B).* When comparing data from all three years, a significant difference was found for graminoids (p-value: 0.00), forbs (p-value: 0.00) and shrubs (0.05) *(table 6 appendix)* with a shift towards a decrease in plant cover. In Båttjønnhøgda grazed plots, the cover of graminoids (p-value: 0.00) and forbs (p-value: 0.00) decreased in from 2003 to 2017, while shrubs cover (p-value: 0.01) *(figure 22 B and table 5 in appendix).*

There was a significant change in species diversity for the ungrazed plots in Båttjønnhøgda (p-value: 0.00) *(table 7 in appendix)* towards lower species diversity in 2003 than 2017 *(figure 12 and 13).*

A visual estimate of the cover in each study site shows that the graminoid species *A. flexuosa*, *C. bigelowii*, *D. cespitosa* and *N. stricta* have a decreased in both study sites, while *Empetrum nigrum* in Båttjønnhøgda and *Vaccinum myrtillus* in Berghøgda have an increase in area covered. *B. nana* and *Salix glauca* have decreased in plant cover from 2003 to 2017. *Botrychium lunaria* and *Astragalus frigida* was not present in 2003, where *B. lunaria* was found in grazed plot, *A. frigida* was found in a ungrazed plot, both in Berghøgda 2017.



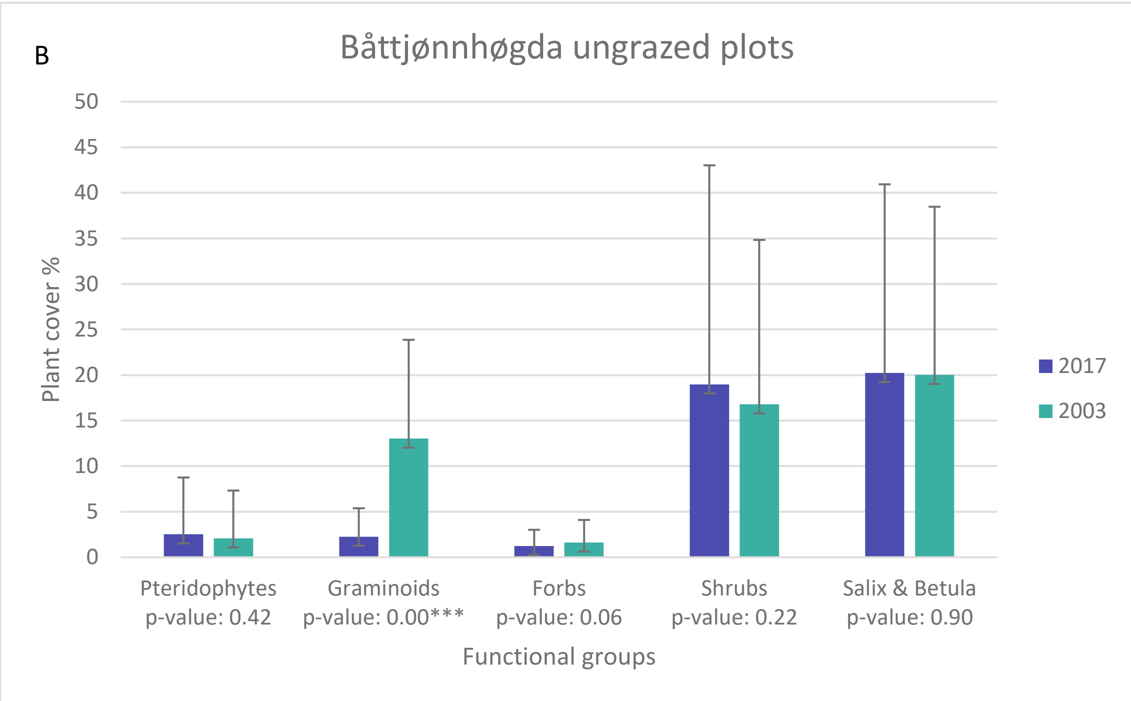
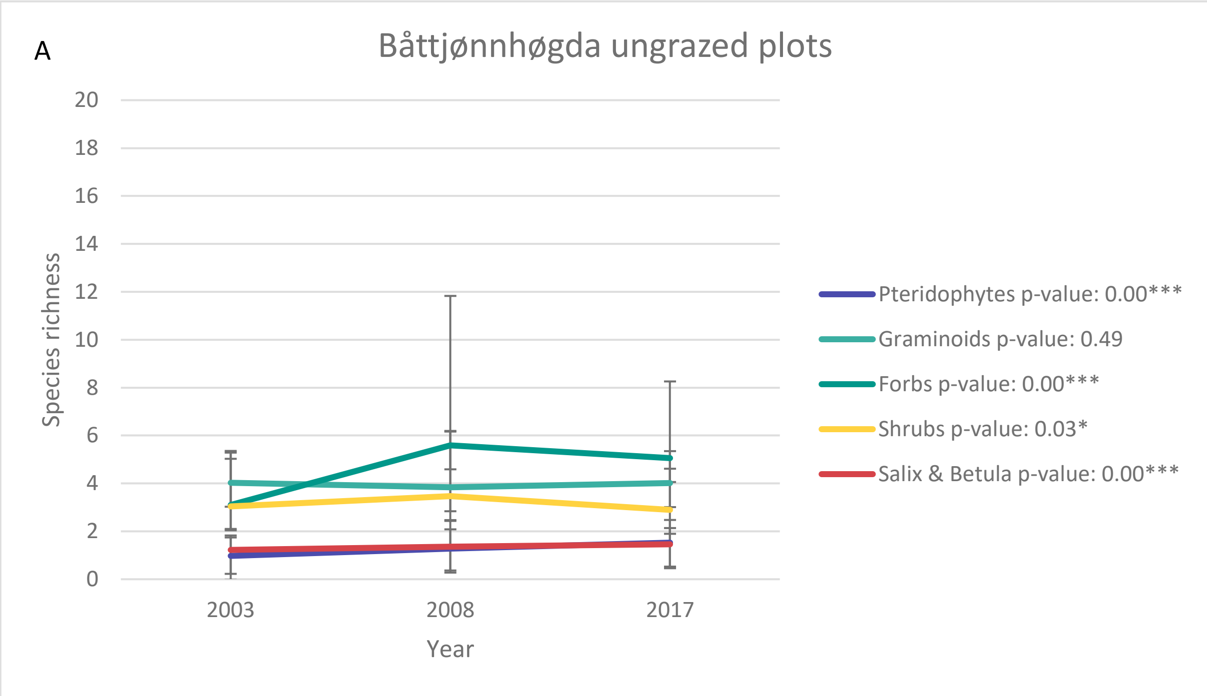


*Figure 10. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in ungrazed plots in Båttjønnhøgda in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*



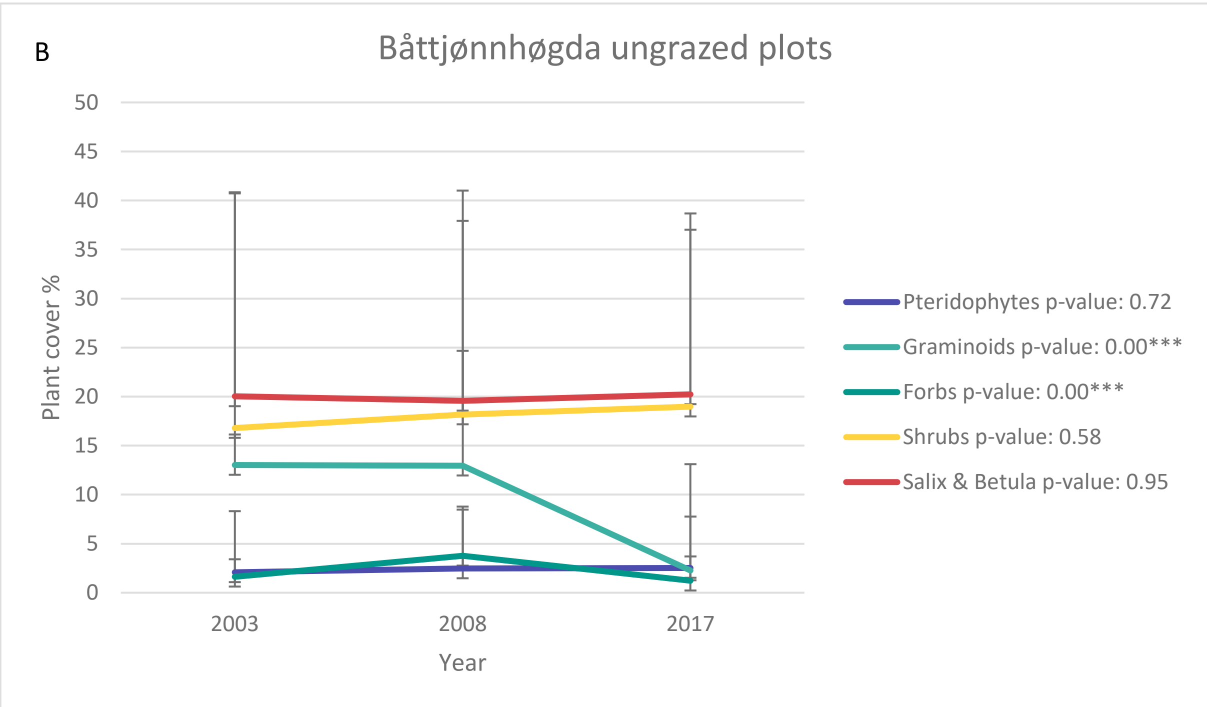


Figure 11. Species richness (No. of species) (A) and plant cover (%) (B) respectively, in ugrazed plots in Båttjønnhøgda between 2003, 2008 and 2017.

*Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

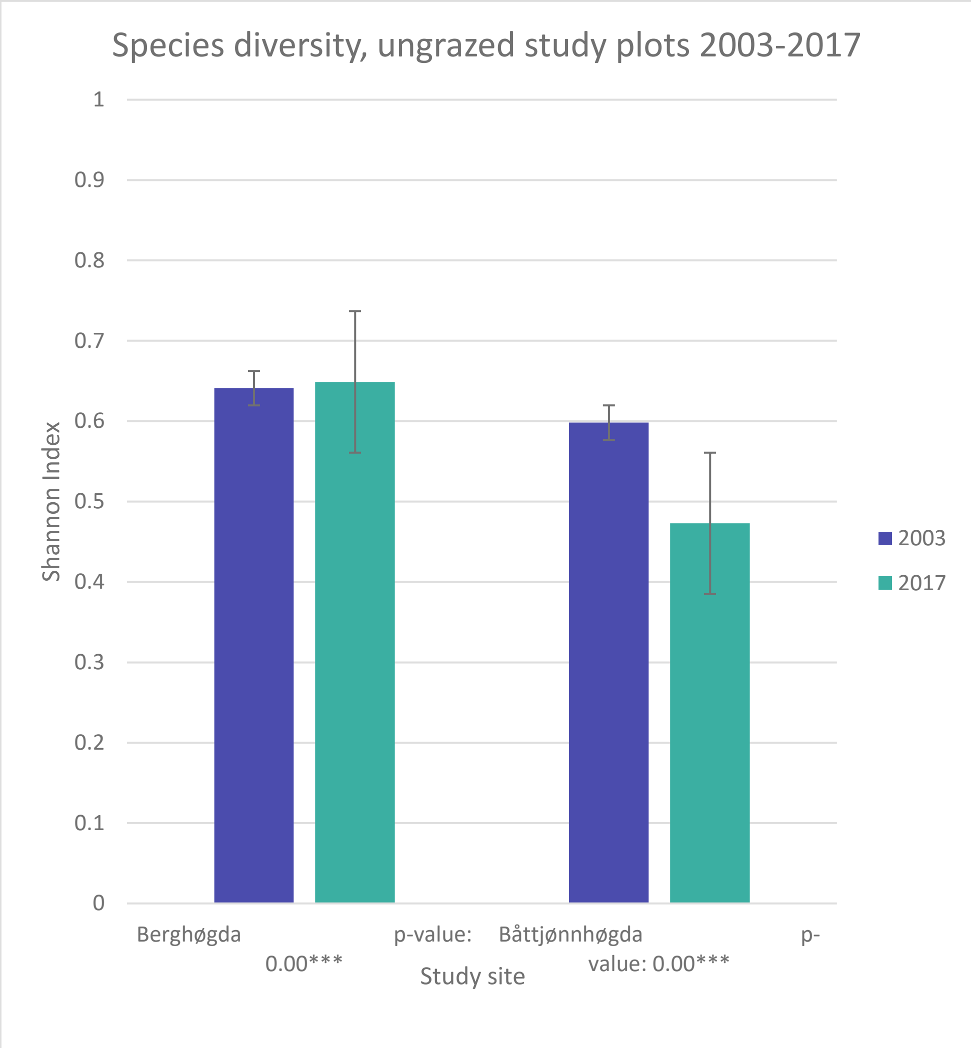


*Figure 12. Species diversity (Shannon Index) in ungrazed plots in Berghøgda and Båttjønnhøgda between 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

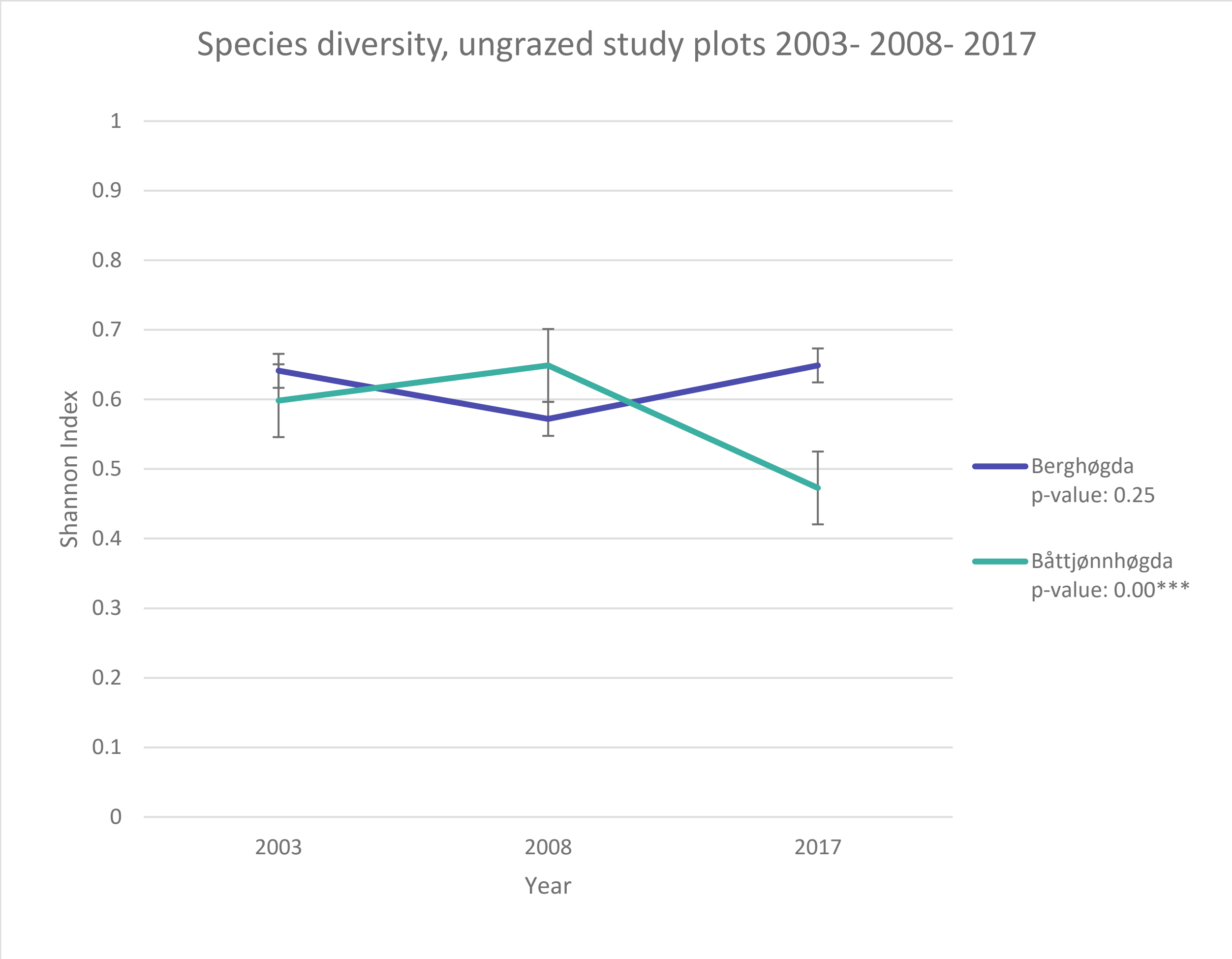


*Figure 13. Species diversity (Shannon Index) in ugrazed plots in Berghøgda and Båttjønnhøgda between 2003, 2008 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

5. Discussion

Alpine areas in Norway have a long history of domestic herbivory. This modification of alpine plant communities is likely to establish an equilibrium between the natural vegetation dynamics and domestic grazers (Mayer, Kaufmann et al. 2009). According to Krahulec et al. (2001), long-time exclusion of sheep will influence the species diversity, abundance and biomass of plants inducing changes in the plant community. The study grazing pressure in the study sites Berghøgda and Båttjønnhøgda is relatively low, and after 15 years without grazing, the vegetation has been affected only to a small extent. A few functional groups, such as graminoids have decreased in plots where grazers are absent, whereas other changes in the plant community was unaffected by the absence of grazers.

Vascular plant species adaption to herbivory

The adaption to grazing differs between functional groups of vascular species. Graminoids form a homogeneous group of species that mainly respond positively to grazing, through either avoidance (non-palatable species such as *Nardus stricta)*, or tolerance (fast recovery, for example the palatable *Avenella flexuosa)* (Painter 1958, Rekdal 2001, Austrheim, Mysterud et al. 2008). The cover of graminoid species had decreased in both study sites in ungrazed plots from 2003 to 2017, which show an negative response to the cessation of grazing. Forbs represents a heterogenic group in terms of grazing responses, where some species are small and negatively affected by trampling, while others need gaps created by the grazers to settle, and some species are dependent on the seed distribution possibility introduced by herbivores (Bullock, Hill et al. 1995). Forbs also differ in palatability, where for example *Solidago virgaurea, Bistorta vivipara* and *Geranium sylvaticum* are preferred, and *Alchemilla alpina* not preferred (Rekdal 2001, Austrheim, Mysterud et al. 2008). The richness of forb species had increased in both study sites in ungrazed plots from 2003 to 2017, which could be explained by the decline in competitive graminoid cover. Evergreen shrubs are rarely grazed, these plants invest in leaves with high concentration of secondary plant compounds (Mulder 1999, Rekdal 2001) and show small or inconsistent response to grazing. *Salix* and *Betula* species are preferred by sheep, especially *Salix* species (Rekdal

2001). *Salix* and *Betula* species showed an increase in species richness from 2003 to 2017 in both study sites, which could be caused by the accession of grazing. Sheep avoid pteridophytes, and exclusion of grazers is therefore considered to have no direct effect on these species (Krahulec, Skálová et al. 2001, Rekdal 2001). However, an increase in species richness for pteridophytes is observed from 2003 to 2017 in both study sites, which could be explained by the reduced cover of graminoid species, opening up for the pteridophytes to access light and nutrients.

Differences in species richness, plant cover and species diversity between ungrazed and grazed plots

Species richness in ungrazed plots is likely to be lower compared to grazed plots. When grazing ceases, the biomass canopy removal, trampling that creates gaps in the vegetation and nutrient supply by herbivore feces ends (Bullock, Hill et al. 1995, Austrheim, Gunilla et al. 1999, Krahulec, Skálová et al. 2001). This may favor tall species, such as shrubs, which are strong competitors for light. Species richness of shrubs in Berghøgda, and richness of forbs and species in the *Salix* & *Betula* genera in Båttjønnhøgda were higher in ungrazed compared to grazed plots in 2017, whereas graminoid species richness in Båttjønnhøgda and graminoid cover in Berghøgda were higher in grazed plots than ungrazed plots. These findings comply with the findings of Oba et al. (2001), where enclosure plots had more shrub- and herb cover than graminoid species in arid-zone grasslands.

The graminoids rely on grazers in order to maintain dominance; when *Salix* & *Betula* and other shrubs increase in numbers, graminoids are suppressed (Austrheim and Eriksson 2001, Krahulec, Skálová et al. 2001, Hester, Bergman et al. 2006). The findings from both study sites, where *Salix* & *Betula* species and shrubs increases at the expense of graminoids, when grazers are excluded, support the exploitation ecosystems hypothesis, predicting that grazing controls the distribution of tall species (Fretwell and Barach 1977, Mayer, Kaufmann et al. 2009). Further, the decline of the competitive graminoid *D. cespitosa* can explain some of the increase in forb species in Båttjønnhøgda ungrazed plots, as according to Krahulec et al (2001), *D. cespitosa* dominated stands can outcompete low-stature species.

Changes in species richness, plant cover and species diversity between 2003, 2008 and 2017

Studies comparing the grazing and non-grazing effects on vegetation over time show a shift towards strongly competitive grasses and herbs gaining dominance in plant communities, followed by a loss of less competitive species (Oksanen, Fretwell et al. 1981, Virtanen 2000, Erschbamer, Virtanen et al. 2003, Mayer, Kaufmann et al. 2009). The total increased species richness between 2003, 2008 and 2017 for both Berghøgda and Båttjønnhøgda show the same trend in both grazed and ungrazed plots, thus the vegetation response is not caused by grazing, but rather by other environmental factors as climate and weather. The changes in the nutrient poor site Båttjønnhøgda follows the same trend in increasing species richness as Berghøgda. The increase in species richness over time could be a response of warmer climate. The global mean temperature is increasing, and it is expected to observe an upward movement of lowland- and sub-alpine species (Steinbauer, Grytnes et al. 2018).
To estimate the degree of climate-driven increase in species richness in these study sites, further studies with a longer time-scale are needed. *Botrychium lunaria* and *Astragalus frigida* were not present in 2003 and 2008, but were found in the study plots in 2017. *B. lunaria* and *A. frigida* are affiliated with pastures, and is declining with the retrogression of grazing (Bele 2018). *B.lunaria*, which is a pteridophyte, was found in a grazed plot. This species could move upwards due to the increase in temperature, and become more frequent.

The impact of herbivory on species diversity

The absence of grazing decreases species diversity (Virtanen 2000, Dullinger, Dirnböck et al. 2003, Erschbamer, Virtanen et al. 2003, Austrheim, Mysterud et al. 2008). Absence of grazers makes the vegetation grow unobstructed, meaning that tall plants will grow undisturbed, and reach a height where they can outshade low-stature plants and lessen coexistence between species (Bullock, Hill et al. 1995, Virtanen 2000, Austrheim and Eriksson 2001, Hester, Bergman et al. 2006). The absence of grazing reduces species and plant abundance through end of feces- and urine supply, seed dispersal, and removal of plant biomass, which implies that grazing is a factor controlling the species diversity (Erschbamer, Virtanen et al. 2003).

Most plant communities exist in equilibrium determined by, among other environmental factors, plant biomass reduction caused by herbivory that limits the growth of highly competitive species (Huston 1979, Rosenzweig and Abramsky 1993). When the top-down control by grazers is lost, an increase in species diversity over time in the plant community is expected, until a few dominant species have outcompeted lower-stature plants which will result in a decrease species diversity. This will result in a hump-shaped pattern in the species abundance curve (Huston 1979, Rosenzweig and Abramsky 1993, Proulx and Mazumder 1998). This curve is found for species diversity between 2003, 2008 and 2017 in ungrazed plots for Båttjønnhøgda, and also grazed plots for Berghøgda and Båttjønnhøgda. Species diversity in the nutrient rich site Berghøgda was lower in ungrazed plots compared to grazed plots, which is in accordance with the study of Virtanen (2000), where they found out that the absence of grazing led to an increase of highly competitive grasses, on behalf of weak competitors in an exclosure experiment with reindeer and rodents.
Species diversity in Båttjønnhøgda however, was higher in ungrazed plots than in grazed plots. This may be due to lack of available nutrients in Båttjønnhøgda, making it hard for species to increase in dominance following grazer exclusion (Proulx and Mazumder 1998, Austrheim and Eriksson 2001). Species diversity in ungrazed in Berghøgda on the other hand, decreased from 2003 to 2008, and then increased from 2008 to 2017, pointing to no net changes in plant species diversity in the nutrient rich study site. This suggest that the species diversity had decreased unrelated to treatment in both study sites, which may be due to other environmental factors as weather and climate.

In a manipulated experiment, where the vegetation was treated with no, low and high grazing pressure for four years, Austrheim et al. (2008), the effects of low grazing pressure had the lowest effect on the vegetation. They found the biggest differences caused by grazers when comparing high grazing pressure with no grazing at all. The grazing pressure in Berghøgda and Båttjønnhøgda is relatively low, and the results implies that the difference between low grazing pressure and no grazing is to small to show extensive results.

6. Conclusion

The vegetation of the fenced (to exclude sheep) study plot showed slight responses to the absence of grazers. The cover of graminoids was significantly lower in ungrazed plots than in grazed plots, and also in all plots in 2003 compared to 2017. Pteridophytes, forbs, shrubs and species in the *Salix* and *Betula* genera was affected in a small degree by the absence of grazers, both when compared grazed and ungrazed plots, as well as when comparing 2003 and 2017. The alpine vegetation of the study sites Berghøgda and Båttjønnhøgda is exposed to a quite low grazing pressure, and the difference between low grazing pressure and no grazing seems to be too small to result in significant changes for the functional groups. However, species richness and diversity changed over 15 years regardless of the presence of sheep. Species richness increased, while species diversity decreased from 2003 to 2017, suggesting that other environmental factors than grazing is determining richness and diversity of vascular plants in the study sites.

The impact of grazing depends beside other factors on the grazing intensity. High grazing pressure may lead to decreased species richness, -diversity and plant cover, while low grazing pressure results in small changes towards increased species richness, -diversity and plant cover. The alpine vegetation of the study sites Berghøgda and Båttjønnhøgda had been exposed to a quite low grazing pressure over decades, mybe the difference between low grazing and no grazing is to weak, and therefore no significant changes or only some significant changes can be seen between grazed and ungrazed vegetation.

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8. Appendix

Species list

Table 2. List of species found in the study sites, divided into functional groups. Abbreviations where used in the multivariate ordination analysis.

Pteridophytes	
Species	Code
Athyrium distentifolium	Athydis
Botrychium lunaria	Botrlun
Diphasiastrum alpinum	Diphalp
Equisetum arvense	Equiarv
Equisetum sylvaticum	Equisyl
Hyperzia selgao	Hypesel
Lycopodium clavatum	Lycocla

Graminoids	
Species	Code
Agrostis mertensii	Agromer
Anthoxanthum odoratum	Anthodo
Avenella flexuosa	Avefle
Catrex atrata	Careatr
Carex bigelowii	Carebig
Carex nigra	Carenig
Carex vaginatum	Carevag
Deschampsia cespitosa	Descces
Eriophorum vaginatum	Eriovag
Eriophorum angustifolum	Erioang
Festica rubra	Festrub
Festuca ovina	Festovi
Festica vivipara	Festviv
Hierocloe odorata	Hierodo
Juncus trifidus	Junctri
Luzula frigida	Luzufri
Luzula multiflora	Luzumul
Luzula spicata	Luzuspi
Luzula sudetica	Luzussu
Nardus stricta	Nardstr
Phleum alpinum	Phlealp
Poa alpina	Poaalp
Trichophorum cespitosum	Tricces

Forbs	
Species	Code
Alchemilla vulgaris	Alchvul
Achemilla alpina	Alhealp
Astragalus frigidus	Astrfri
Bartsia alpina	Bartalp
Bistorta vivipara	Bistviv
Campanlua rotundifola	Camprot
Cerastium alpinum	Ceraalp
Cerastium cerastoides	Ceracer
Coeloglossum viride	Coelvir
Epilobium anagallidifolium	Epilana
Erigeron uniflorus	Eriguni
Euphrasia frigida	Euphfri
Gentianella nivalis	Gentniv
Hieracium alpinum	Hieralp
Leontodon autumnalis	Leonaut
Myosotis decumbens	Myosdec
Omalotheca supina	Omalsup
Omalotheca norvegica	Omalnor
Oxyria digyna	Oxyrdig
Parnassia palustris	Parnpal
Petasites frigidus	Petafri
Pinguicula vulgaris	Pingvul
Plantago major	Planmaj
Pyrola minor	Pyromin
Pyrola rotundifola	Pyrorot
Rubus chamaemorus	Rubucha
Sagina sp.	Sagisp
Saxifraga oppositifola	Saxiopp
Saxifraga stellaris	Saxiste
Sibbaldia procumbens	Sibbpro
Silene acaulis	Sileaca
Taraxacum croceum	Taracro
Thalictrum alpinum	Thalalp
Tofieldia pusilla	Tofipus
Trientalis europaea	Trieeur
Veronica alpina	Veroalp
Viola biflora	Violbif
Viola sp.	Violsp.
Ranunculus acris	Ranuacr
Geranium sylvaticum	Gerasyl
Geum rivale	Geumriv
Potentilla crantzii	Potecran
Potentilla erecta	Poteere
Rhodiola rosea	Rhodros

Rumex acetosa	Rumeace
Saussurea alpina	Sausalp
Silene dioica	Siledio
Solidago virgaurea	Solivir

Shrubs	
Species	Code
Andromeda polifolia	Andrpol
Arctous alpinus	Arctalp
Dryas octopetala	Dryaoct
Empetrum nigrum	Empenig
Harrimanella hypnoides	Harrhyp
Loiselura procumbens	Loizpro
Phylodoce caerulea	Phylcae
Vaccinium myrtillus	Vaccmyr
Vaccinium uliginosum	Vacculi
Vaccinium vitis-idea	Vaccvit
Juniperus communis	Junicom
Sorbus aucuparia	Sorbauc

Salix & Betula	
Species	Code
Betula nana	Betunan
Betula pubescens	Betupub
Salix glauca	Saligla
Salix herbacea	Saliher
Salix lanata	Salilan
Salix lapponica	Salilap
Salix reticulata	Saliret

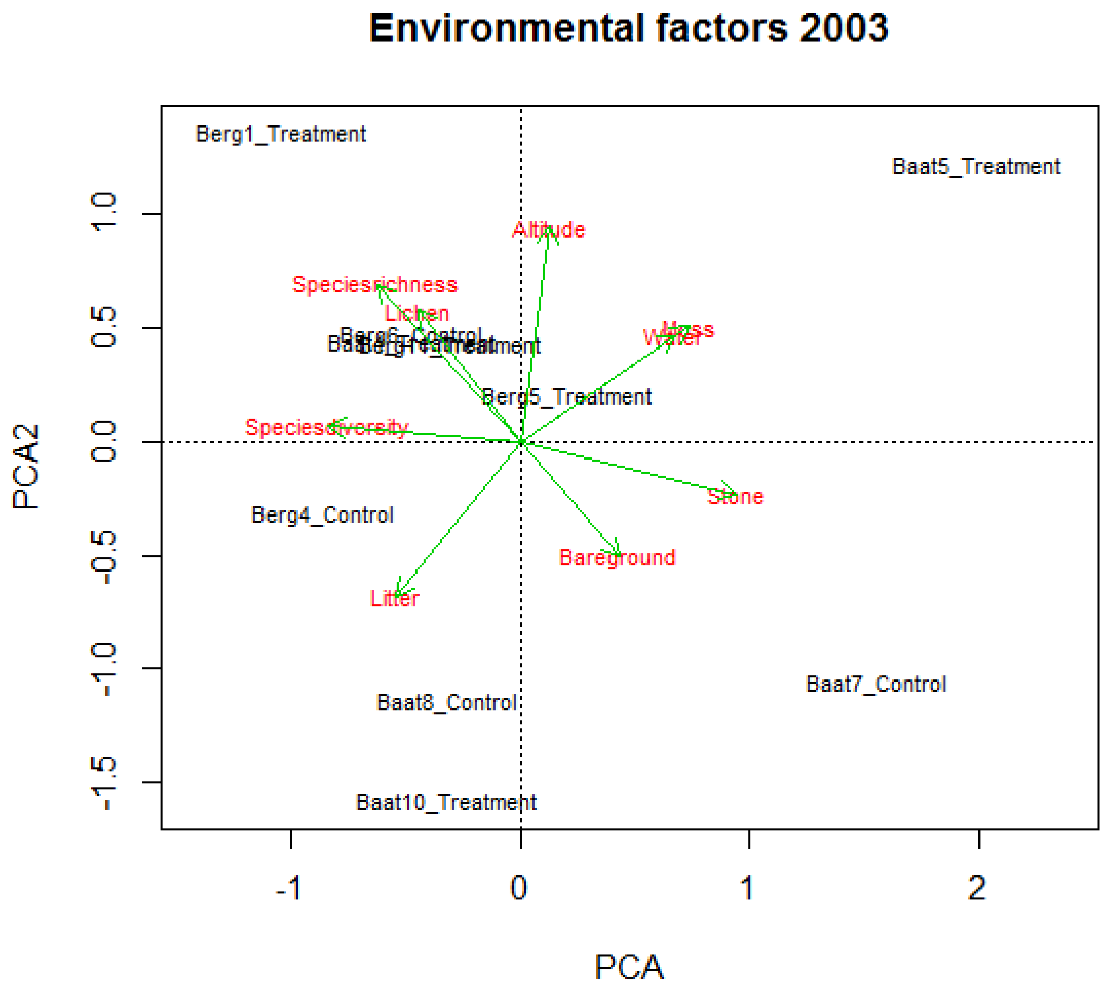


Figure 14. Principal Component Analysis for environmental factors 2017, respectively. The plots in relationship with the treatment. Environmental factors shown in red with green arrows. Treatment: non-grazed. Control: grazed

«Bat» and «Berg» denote plots in Båttjønndalen and Berghøgda, respectively.

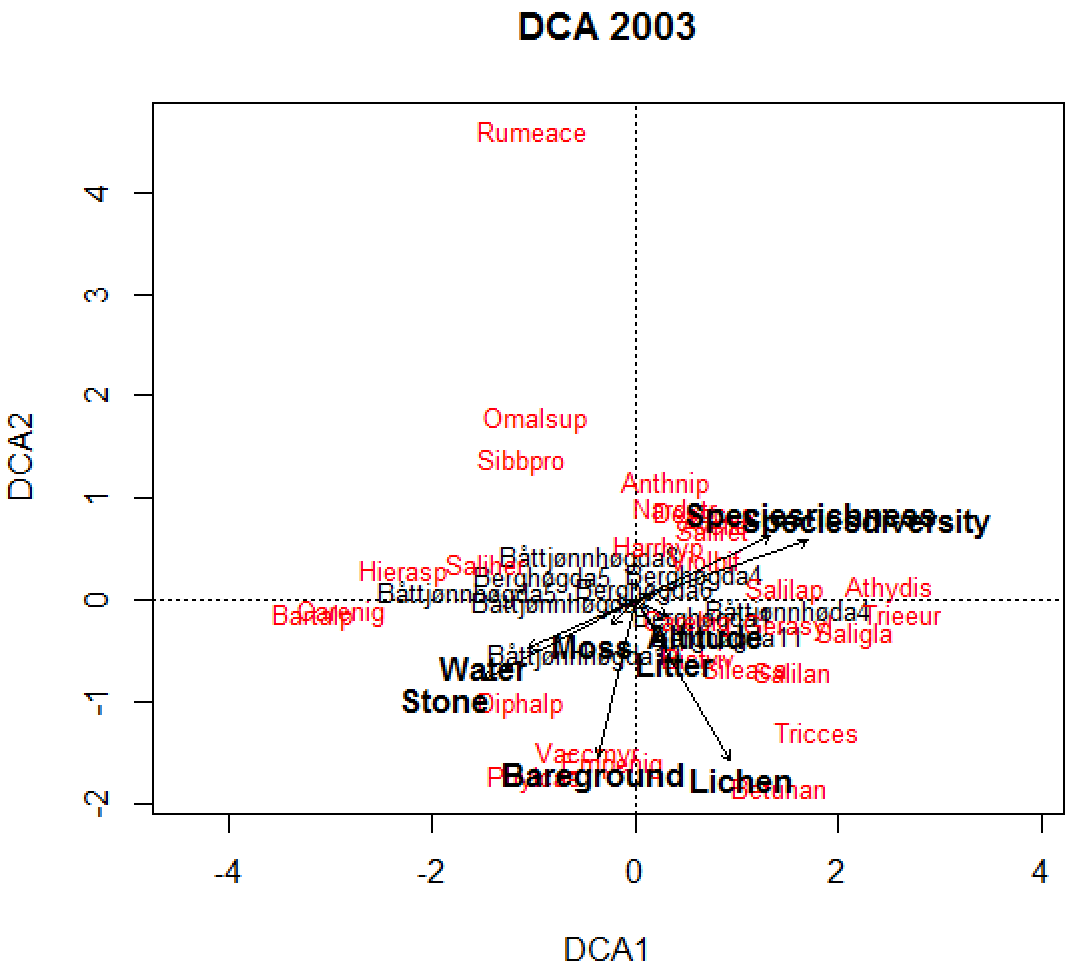


Figure 15. Detrended Correspondence analysis with species abundance (red), and environmental factors (black arrows). Abbreviations of species names see table 2 in appendix

To increase the ordination plot legibility, species with >2% cover are removed.

Differences in species richness, plant cover and species diversity between ungrazed and grazed plots 201

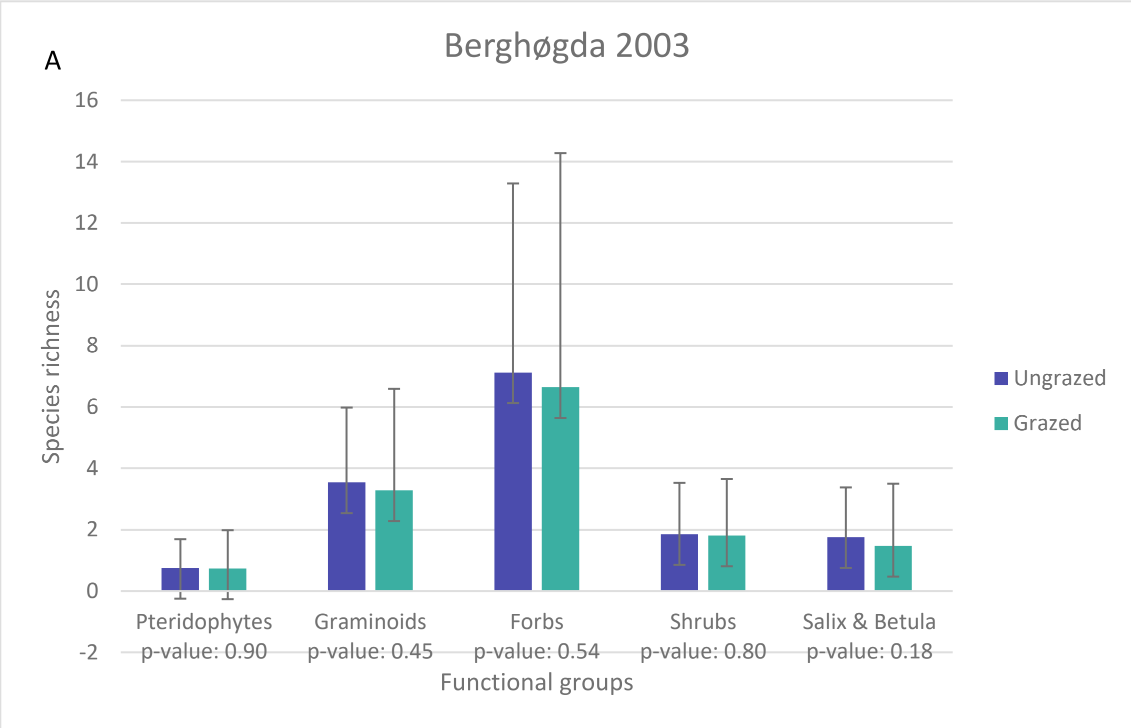
Table 3. Degrees of freedom and p-value for tests of differences in species richness and plant cover between grazed plots and ungrazed plots, for both first year with applied treatment 2003 and 2017. Statistically significant p-values at the 0.05 level are marked with *, 0.01 are marked with

Welch Two Sample t-test for differences in ungrazed plots and grazed plots Båttjønnhøgda 2003				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	317.86	0.00***	202.68	0.00***
Graminoids	244	0.01**	217.98	0.00***
Forbs	287.01	0.99	209.32	0.00***
Shrubs	290.61	0.00***	303.34	0.00***
Salix & Betula	311.46	0.87	280.08	0.00***

Welch Two Sample t-test for differences in ungrazed plots and grazed plots Båttjønnhøgda 2017				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	317.91	0.00***	218.95	0.00***
Graminoids	270.32	0.00***	145.18	0.00***
Forbs	302.69	0.00***	248.85	0.28
Shrubs	293.63	0.05*	301.01	0.05*
Salix & Betula	317.88	0.00***	283.92	0.00***

Welch Two Sample t-test for difference treatment/no treament Berghøgda2003				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
pteridophytes	220.25	0.9039	229.95	0.5983
Graminoids	216.84	0.4564	230.61	0.1131
Herbs	232.22	0.5495	156.28	0.00249
Shrubs	253.11	0.8082	317.87	0.06164
Salix & Betula	230.1	0.1825	292.78	#######

Welch Two Sample t-test for for difference treatment/no treament Berghøgda2017				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	266.1	0.03224	233.31	0.00325
Graminoids	306.09	0.05156	208.85	0.05846
Herbs	318	0.7584	185.3	0.3288
Shrubs	305.35	0.004606	226.39	0.3678
Salix & Betula	314.35	0.9838	315.76	0.0037



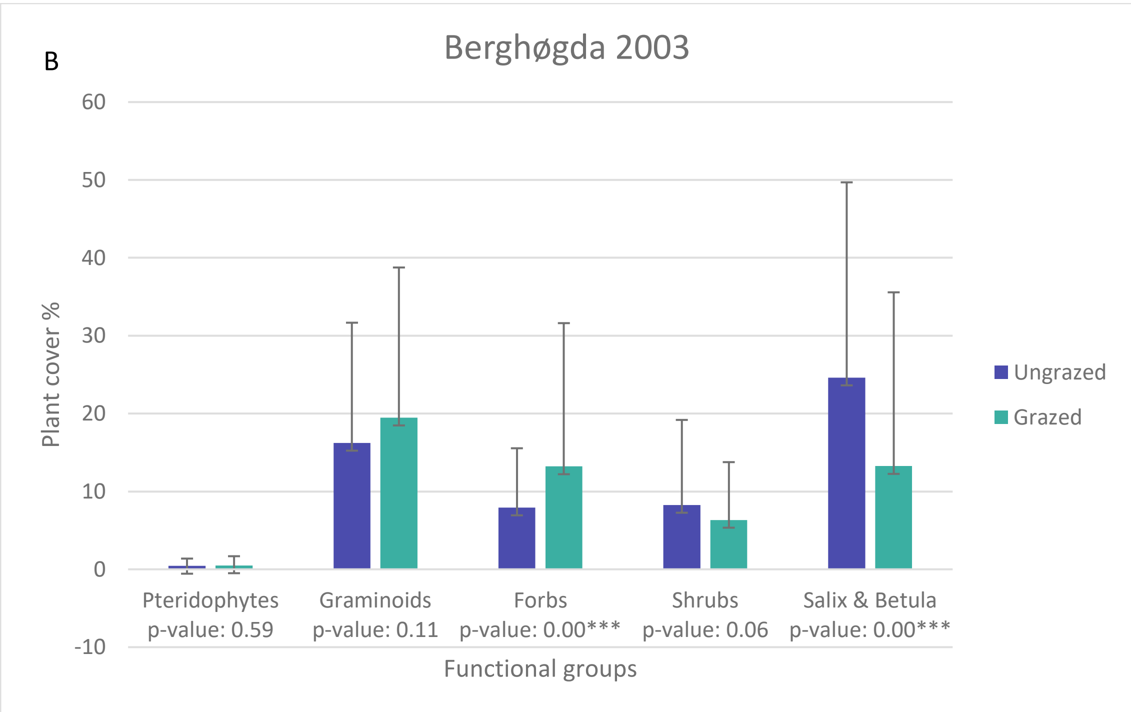


*Figure 16. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in grazed plots in Berghøgda in the two study sites in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

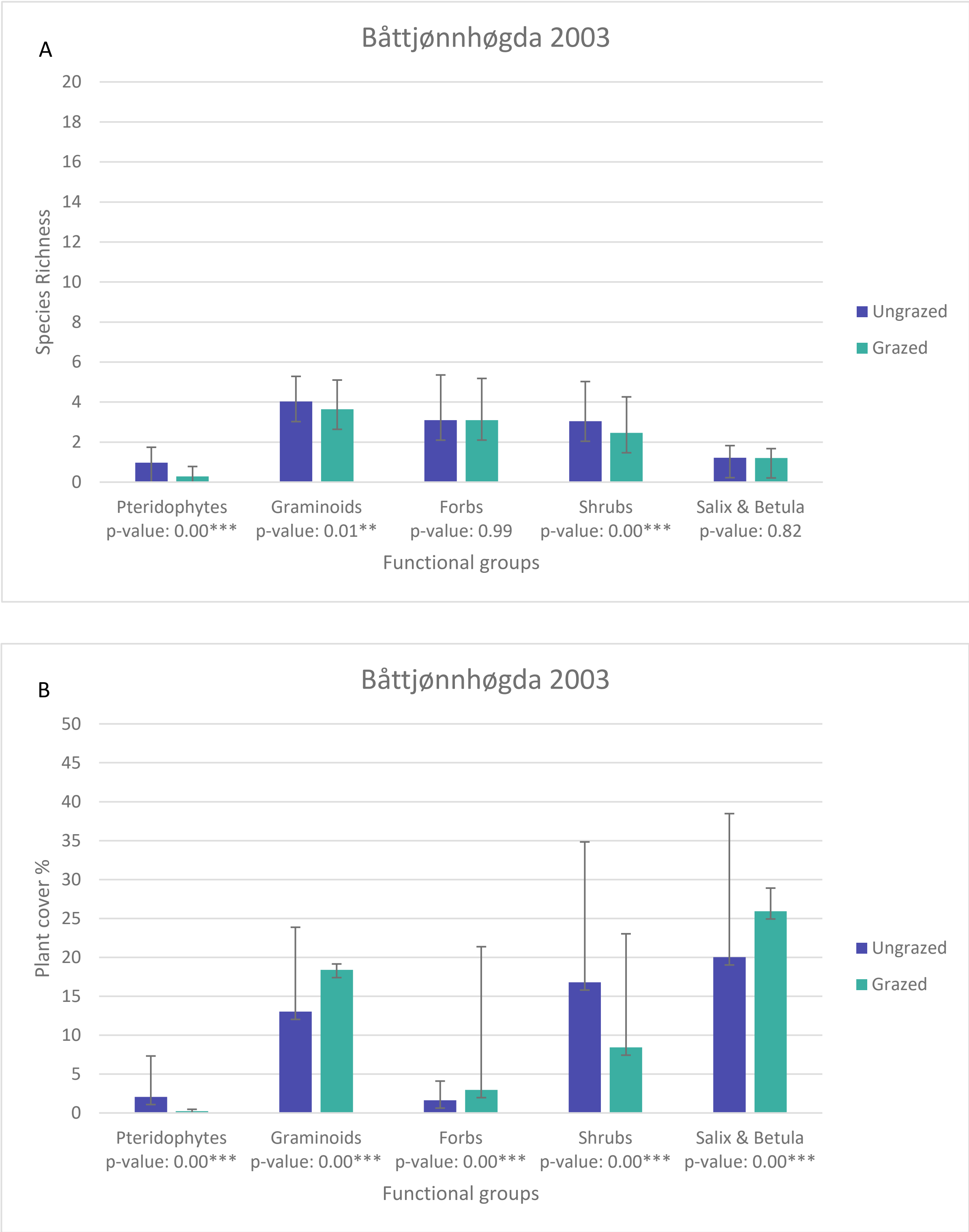


*Figure 17. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in grazed plots in Båttjønnhøgda in the two study sites in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

Table 4. Degrees of freedom and p-value for tests of differences in species diversity between grazed plots and ungrazed plots, for both first year with applied treatment 2003 and 2017. Statistically significant p-values at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***

Welch Two Sample t-test for differences in plant diversity in grazed and ungrazed plots 2017		
	Species richness	
Study site and treatment	Df	P-value
Berghøgda 2003	245.77	0.27
Båttjønnhøgda 2003	271.05	0.30
Berghøgda 2017	312.63	0.00
Båttjønnhøgda 2017	289.13	0.00

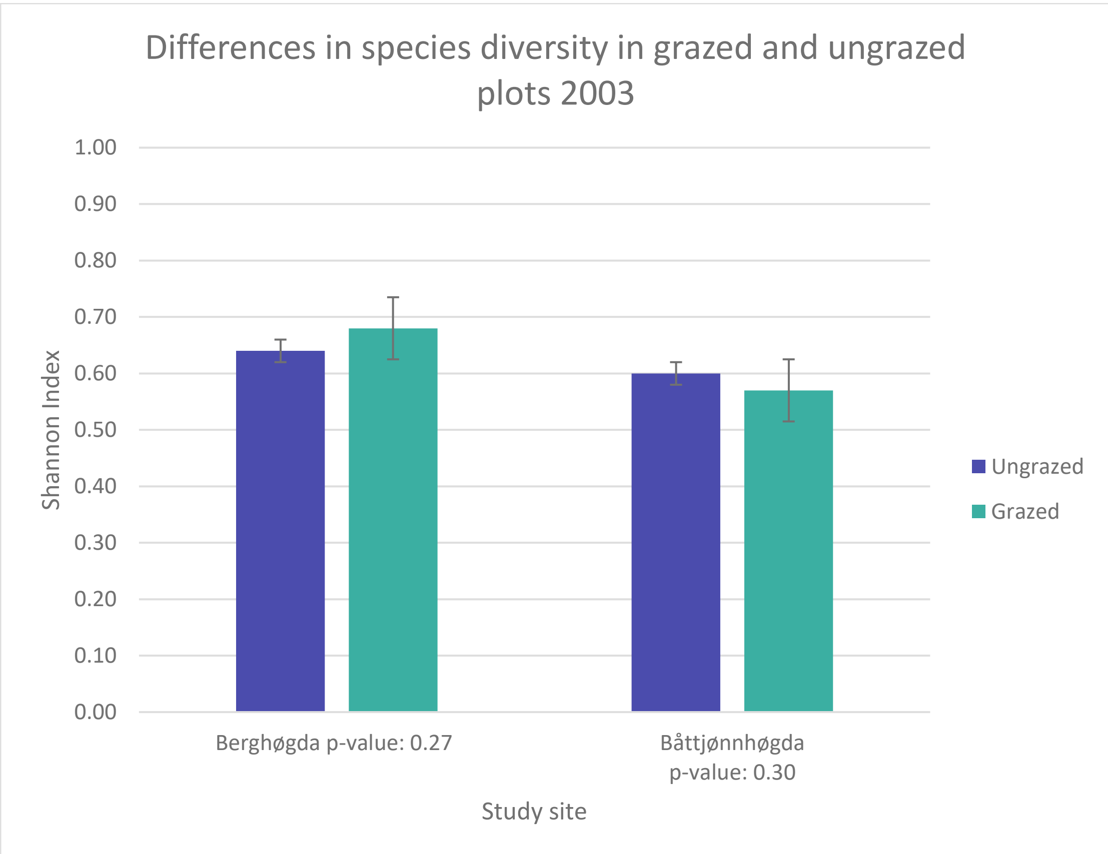


*Figure 18. Species diversity (Shannon Index) in ungrazed and grazed plots in the two study sites in 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

Changes in species richness, plant cover and species diversity between 2003, 2008 and 2017 in ungrazed plots

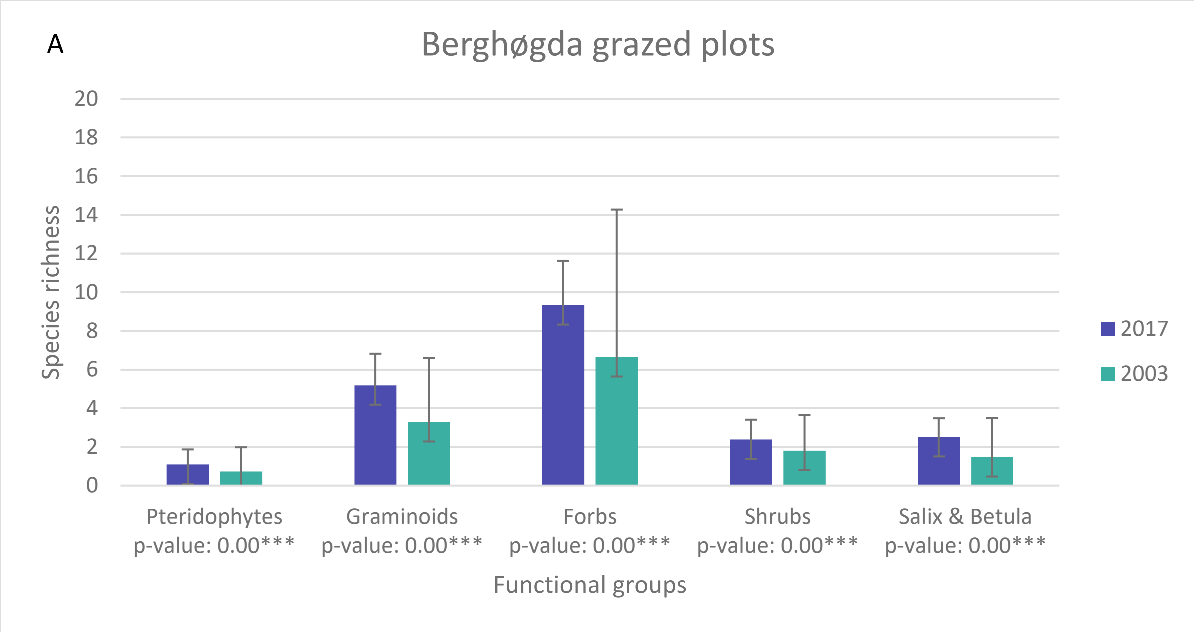
Table 5. Degrees of freedom and p-value for tests of changes in species richness and plant cover from 2003 to 2017- for both ungrazed and grazed plots. Statistically significant p-values at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***

Paired *t*-test for difference in treated sites in 15 years Berghøgda				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	191	0.03*	191	0.24
Graminoids	191	0.00***	191	0.00***
Forbs	191	0.00***	191	0.00***
Shrubs	191	0.00***	191	0.44
Salix & Betula	191	0.00***	191	0.00***

Paired t-test for difference in control sites in 15 years Berghøgda				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	127	0.00***	127	0.00***
Graminoids	127	0.00***	127	0.00***
Forbs	127	0.00***	127	0.00***
Shrubs	127	0.00***	127	0.89
Salix & Betula	127	0.00***	127	0.91

Paired t-test for difference in treated sites in 15 years Båttjønnhøgda				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	191	0.00***	191	0.42
Graminoids	191	0.89	191	0.00***
Forbs	191	0.00***	191	0.06
Shrubs	191	0.28	191	0.22
Salix & Betula	191	0.00***	191	0.90

Paired t-test for difference in control sites in 15 years Båttjønnh				
	Species richness		Plant cover	
Functional group	Df	P-value	Df	P-value
Pteridophytes	127	0.11	127	0.15
Graminoids	127	0.00***	127	0.00***
Forbs	127	0.00***	127	0.00***
Shrubs	127	0.00***	127	0.01**
Salix & Betula	127	0.37	127	0.11



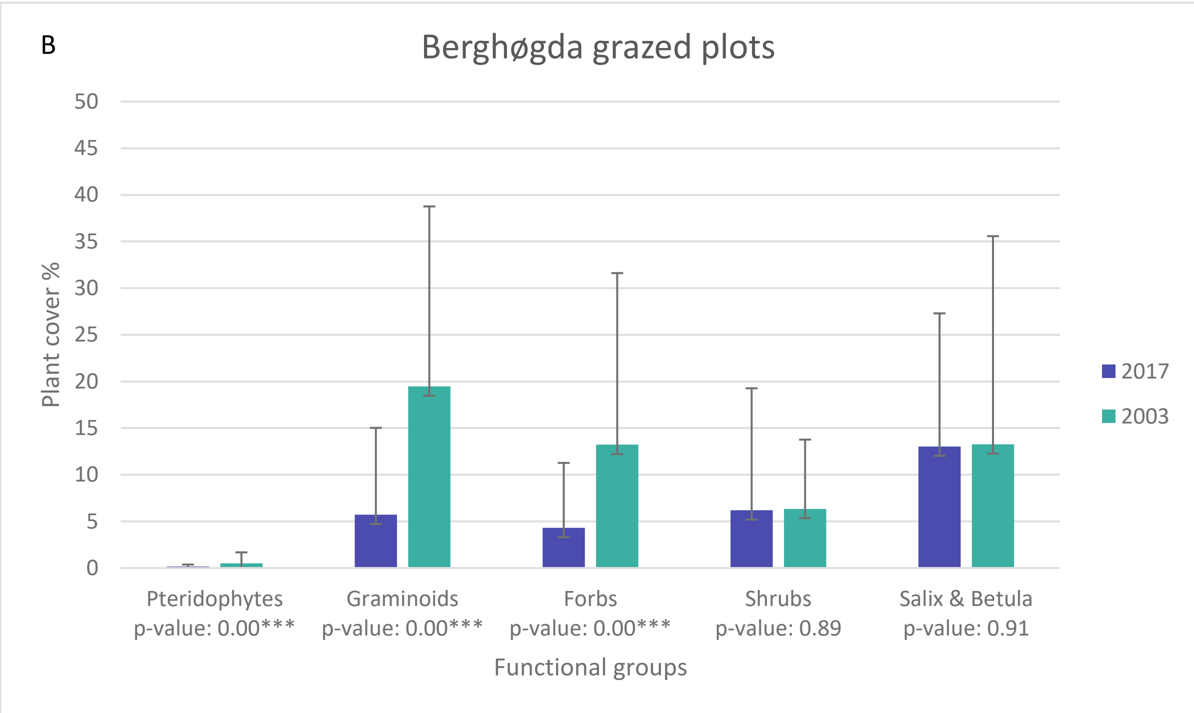
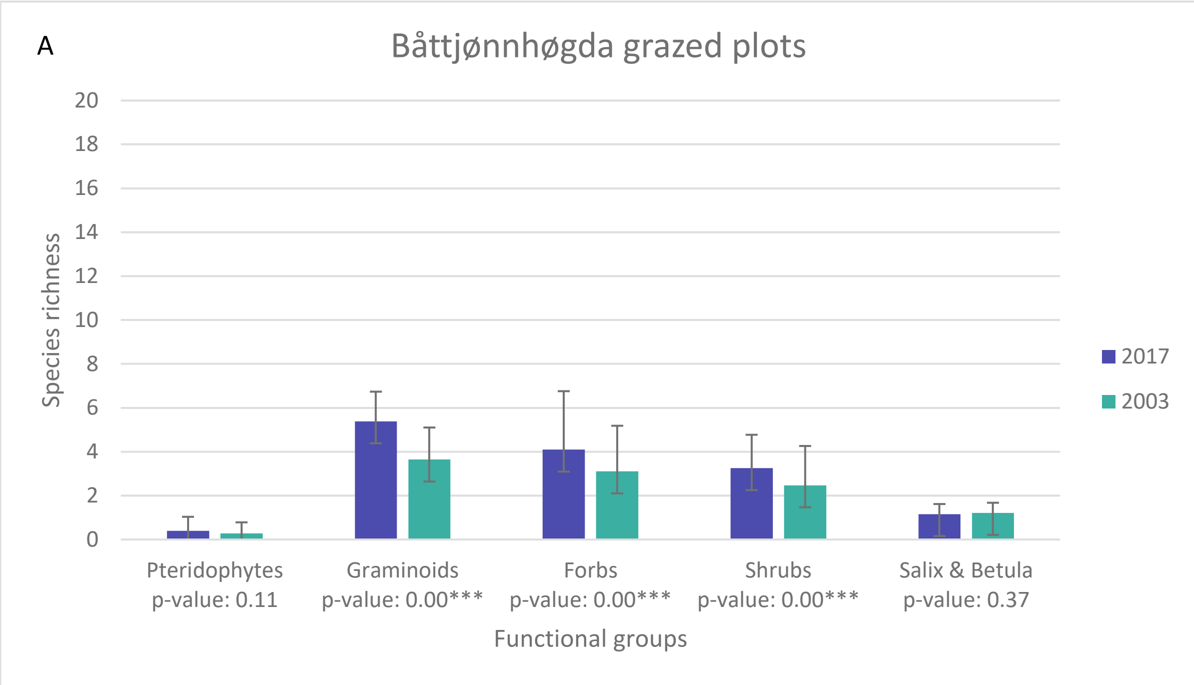


*Figure 19. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in grazed plots in Berghøgda in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*



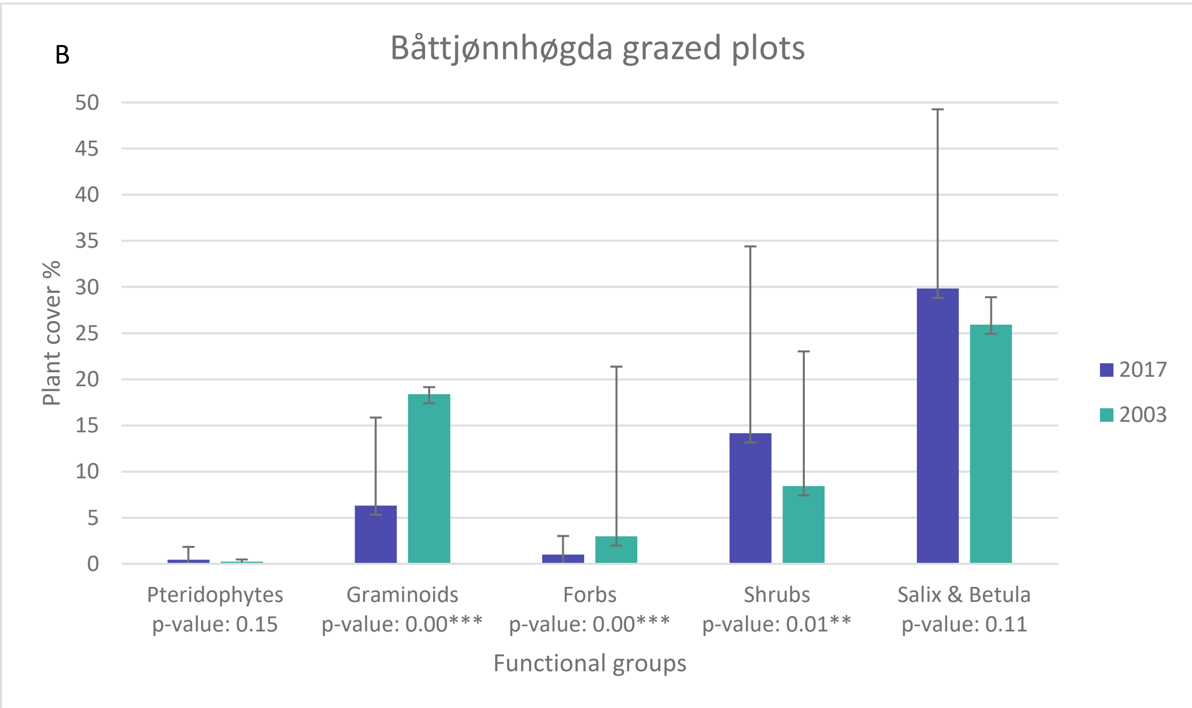


*Figure 20. Species richness (No. of species) (A) and plant cover (%) (B) respectively, of the different functional groups in grazed plots in Båttjønnhøgda in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

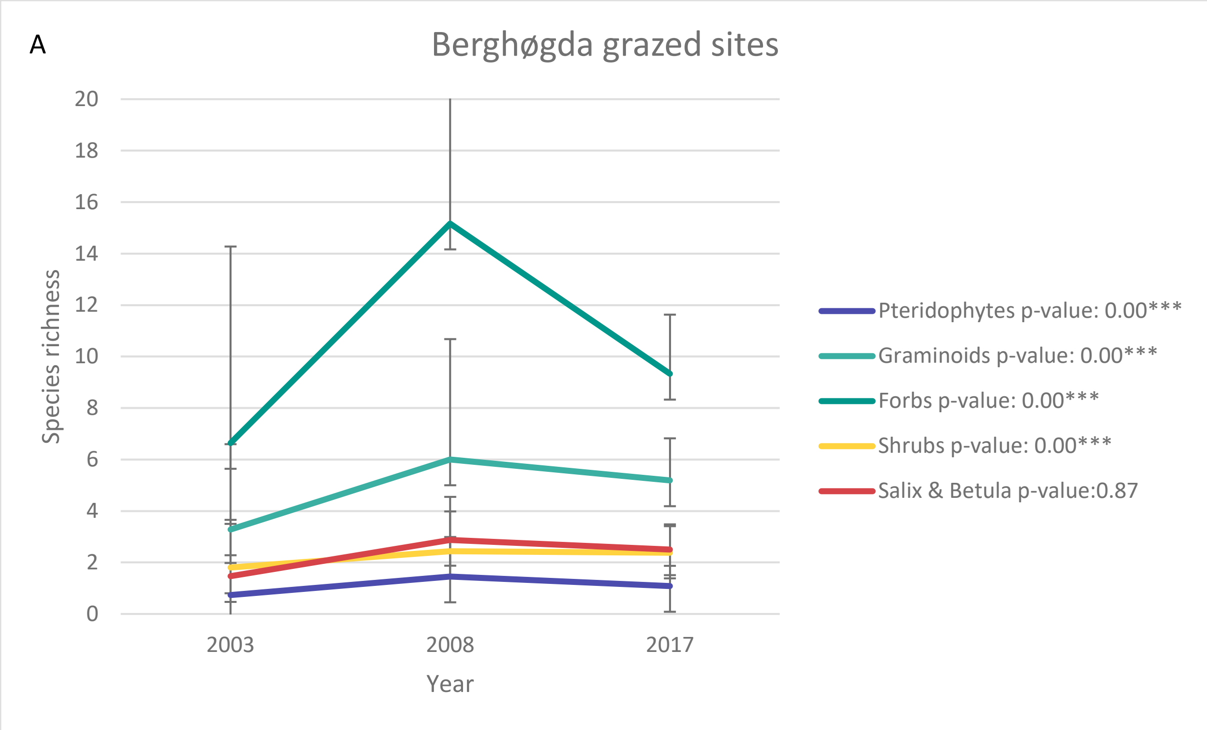
Table 6. Degrees of freedom and p-value for changes in species richness and plant cover over 15 years: 2003- 2008- 2017 in grazed plots and ungrazed plots. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***

ANOVA-test for difference between treated plots in 2003, 2008 and 2017, Berghøgda				
	Species richness		Plant cover	
Functional group	df	P-value	df	P-value
Pteridophytes	2.00	0.35	2.00	0.64
Graminoids	2.00	0.00***	2.00	0.00***
Forbs	2.00	0.00***	2.00	0.00***
Shrubs	2.00	0.00***	2.00	0.72
Salix & Betula	2.00	0.00***	2.00	0.04*

ANOVA test for difference between control plots for 2003, 2008 and 2017, Berghøgda				
	Species richness		Plant cover	
Functional group	df	P-value	df	P-value
Pteridophytes	2.00	0.00***	2.00	0.00***
Graminoids	2.00	0.00***	2.00	0.00***
Forbs	2.00	0.00***	2.00	0.00***
Shrubs	2.00	0.00***	2.00	0.72
Salix & Betula	2.00	0.87	2.00	0.87

ANOVA test for difference between treated plots for 2003, 2008 and 2017, Båttjønnhøgda				
	Species richness		Plant cover	
Functional group	df	P-value	df	P-value
Pteridophytes	2.00	0.00***	2.00	0.72
Graminoids	2.00	0.49	2.00	0.00***
Forbs	2.00	0.00***	2.00	0.00***
Shrubs	2.00	0.03*	2.00	0.58
Salix & Betula	2.00	0.00***	2.00	0.95

ANOVA test for difference between control plots for 2003, 2008 and 2017, Båttjønnhøgda				
	Species richness		Plant cover	
Functional group	df	P-value	df	P-value
Pteridophytes	2.00	0.38	2.00	0.37
Graminoids	2.00	0.00***	2.00	0.00***
Forbs	2.00	0.02*	2.00	0.00***
Shrubs	2.00	0.01**	2.00	0.02*
Salix & Betula	2.00	0.67	2.00	0.24



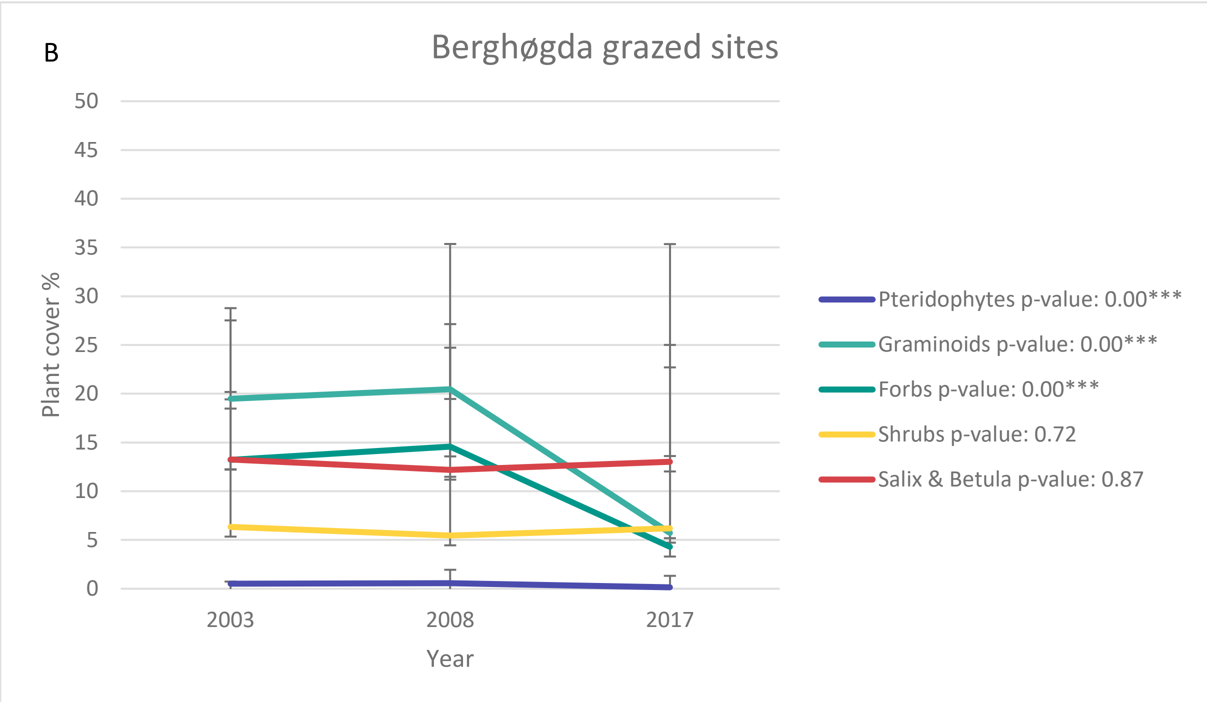


*Figure 21 A and B. Changes in species richness (NO. Of species) in study sites for 2003, 2008 and 2017, grazed sites. Error bars show the standard deviation in the distribution. Statistically significant p-values at the 0.05 level are marked with *, 0.01 are marked with*

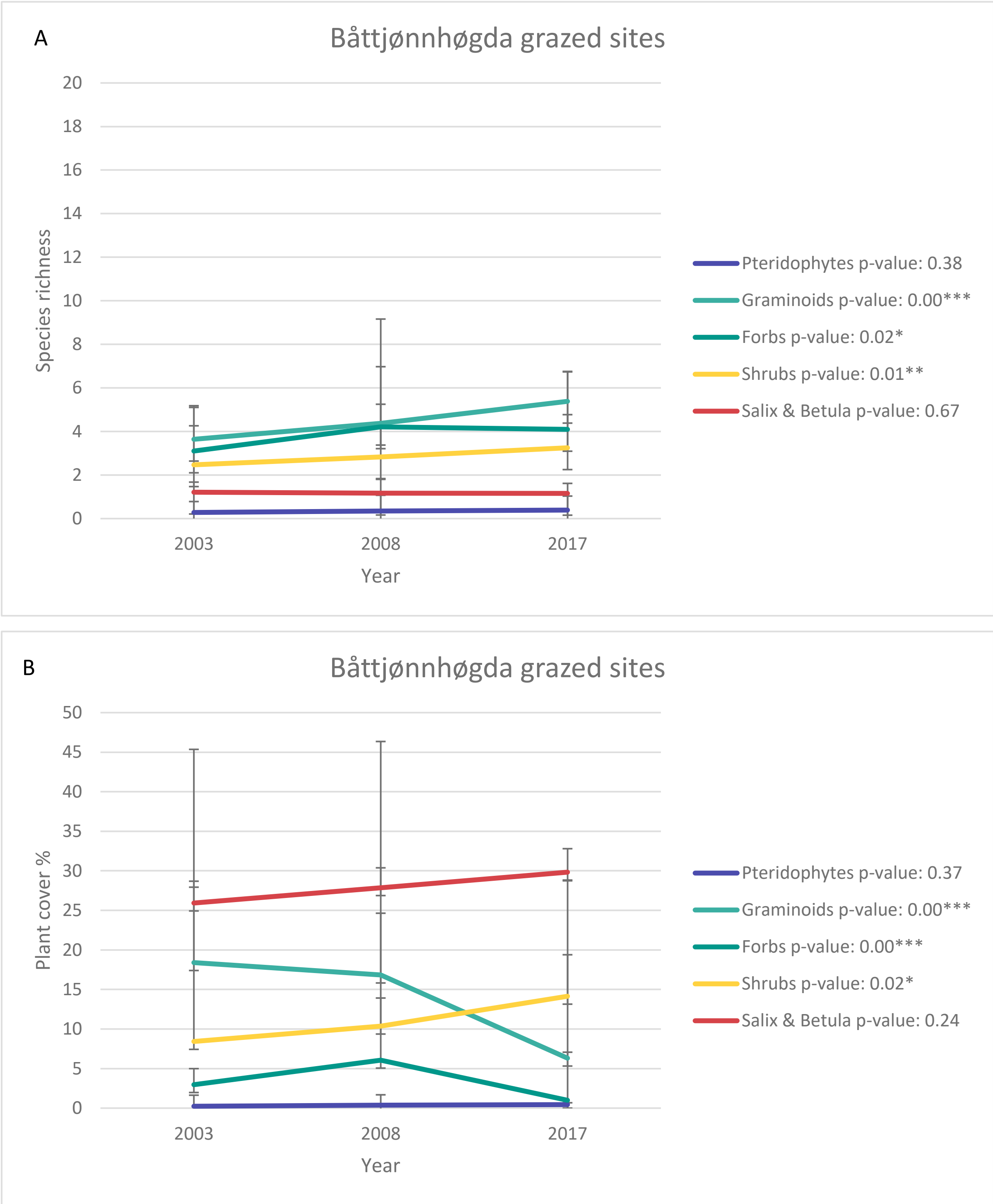


*Figure 22 A and B. Changes in plant cover % in study sites for 2003, 2008 and 2017, grazed sites. Error bars show the standard deviation in the distribution. Statistically significant p-values at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked*

Table 7. Degrees of freedom and p-values for tests of differences in species diversity in 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***

Paired t-test for differences in species diversity after 15 years		
	Species richness	
Study site and treatment	Df	P-value
Berghøgda ungrazed plots	191	0.00***
Båttjønnhøgda ungrazed plots	191	0.00***
Berghøgda grazed plots	127	0.00***
Båttjønnhøgda grazed plots	127	0.00***

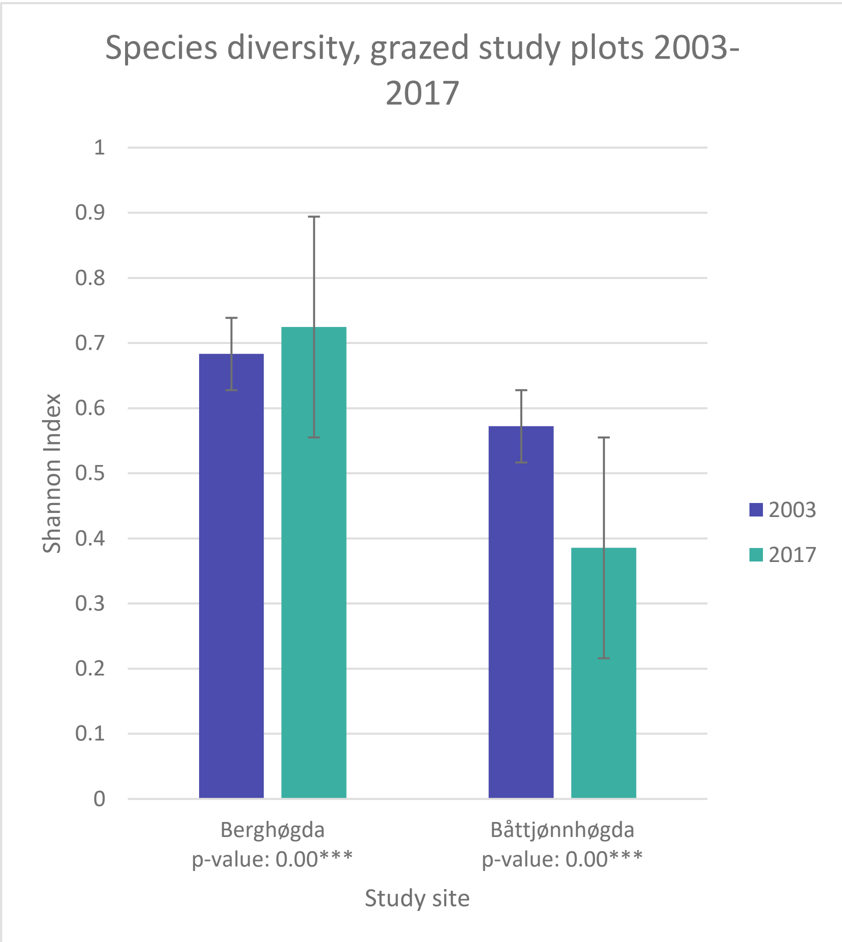


*Figure 23. Species diversity (Shannon Index) in grazed plots in Berghøgda and Båttjønnhøgda between 2003 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*

Table 8. Degrees of freedom and p-values for tests of changes in species diversity in 2003- 2008- 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with

ANOVA anaysis for changes in species diversity over 15 years		
	Species richness	
Study site and treatment	Df	P-value
Berghøgda ungrazed plots	2	0.25
Båttjønnhøgda ungrazed plots	2	0.00***
Berghøgda grazed plots	2	0.00***
Båttjønnhøgda grazed plots	2	0.00***

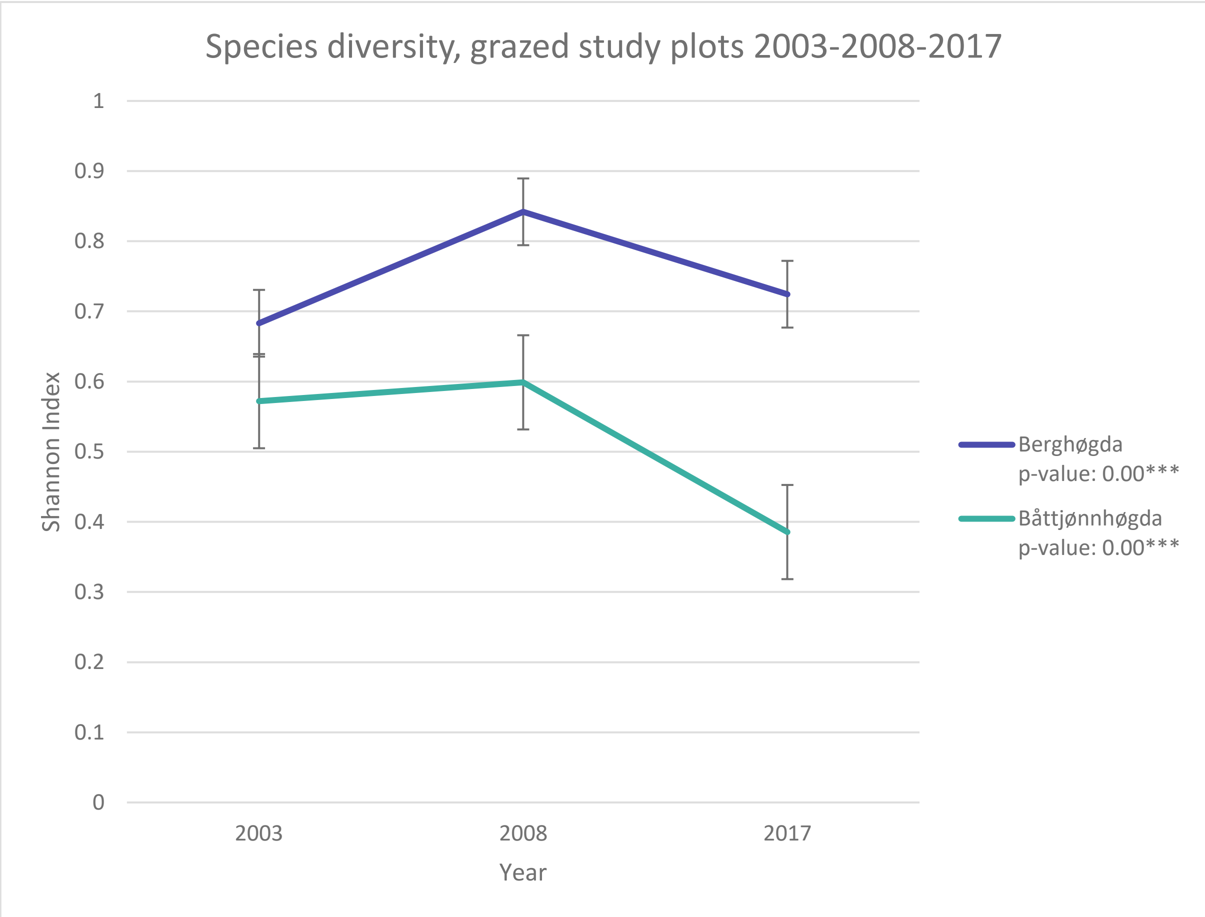


*Figure 24. Species diversity (Shannon Index) in grazed plots in Berghøgda and Båttjønnhøgda between 2003, 2008 and 2017. Statistically significant differences at the 0.05 level are marked with *, 0.01 are marked with ** and 0.00 are marked with ***. Error bars show the standard deviation.*