Graminoids Benefit from Decreased Competition in a Tundra Plant Environment

Minna Rolfson Bergenhorn

Faculty of Science

UNIVERSITY OF GOTHENBURG

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Abstract

Global warming is currently changing both the diversity and structure of the Arctic vegetation. Warmer air temperatures are thawing permafrost making more nutrients available for plant uptake, while at the same time climate conditions become too challenging for some species. Shifts in dominating species on both local and regional scales have been observed, which is believed to change the climate further. More specifically an expansion of shrubs has been observed at several locations in the Arctic. Still, little is known about how these changes in both biotic and abiotic factors affect Species-species interaction. To investigate possible outcomes, plant species were removed from designated areas in an Arctic tundra landscape in northern Sweden. Plants were removed based on their mycorrhizal associations, either arbuscular, ericoid, ecto, or non-mycorrhizal, or depending on their dominance, for four consecutive years. Changes in plant abundance in all treatment areas were reported both prior to and post the experiment to see what plants seem to have made use of the opened niches. Based on their plant functional types, graminoids increased from the treatment whilst there was a decrease in both shrubs and forbs. Generally, species that benefitted the most from the treatment were those with either arbuscular or no mycorrhizal associations. The changes are found to be due to the characters of the plant functional type rather than their mycorrhizal associations.

Keywords: *Climate change, Arctic, Tundra, Species competition, Tarfala Valley, Northern Sweden, Mycorrhiza, Plant functional types.*

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1. Introduction

1.1 Background

Global warming triggers a series of changes in the Arctic, causing air temperatures to increase three times as fast as the global average (AMAP 2021), alters precipitation patterns and induces permafrost thaw (IPCC 2021). These environmental changes are affecting ecosystem composition and plant functional trait variation across the tundra biome (Elmendorf et al., 2012; Bjorkman et al., 2018; Thomson et al., 2021). Snow depth is increasing over many parts of the Eurasian arctic and subarctic (Callaghan et al., 2012) which alters the nutrient cycle, delays the snow melt and the start of the growing season (Mörsdorf & Cooper, 2021). Warmer climate has generally promoted an increase in vascular plants across the Arctic (Elmendorf et al., 2012; Myers-Smith et al., 2020), but may cause sensitive species to decline or disappear completely (Wookey, 2007). Further, local responses may vary depending on the environment as well as the plant functional types (PFTs) and could last over decades due to tundra plants long life span (Campbell et al., 2021; Elmendorf et al., 2012). Currently a variety of dominating PFTs can be found across the Arctic environments and can for instance be evergreen or deciduous shrubs as well as graminoids or herbaceous plants (Shaver et al., 1998). Thus, due to the ongoing changes and disappearances in both species and PFTs in the Arctic, it is important to gain a better understanding of Species-species interaction. What species can take advantage when new niches are opening up?

1.2 Shrubification

An expansion of shrubs, both deciduous and evergreen, have been observed across the tundra biome (Elmendorf et al., 2012; Björk & Vowles, 2018; Mekonnen et al., 2021). This so called shrubification is thought to be driven by higher summer air temperatures which has been observed as the advance, both northwards and upwards of woody plants and the tree line (Zhang et al., 2013; Callaghan et al., 2011). Especially the expansion of deciduous shrubs has been widely observed, although with an heterogenous spread across the Arctic (Mekonnen et al., 2021). Greening of the arctic and an expansion of tall shrubs like these effectively reduces the albedo during the snow-less months, but also during snow melt when their branches become visible. These shrubs canopies trap more snow resulting in a higher insulation which increases winter soil temperatures (Björk & Vowles, 2018; Beringer et al., 2005; Juszak et al., 2015). Further, increasing abundance of easily decomposed litter from deciduous shrubs have been observed to increase carbon (C) turnover rates (Björk & Vowles, 2018). As shrubs expand

across the Arctic, they compete for other species niches and alters ecosystem composition. Although predicted to disturb or even cause extinction of ambient vegetation, local responses to shrubification will probably vary (Mod & Luoto, 2016). As an example, a decline in lichens have been observed as a result of increasing shrub abundance (Cornelissen et al., 2004).

1.3 Mycorrhizal Symbiosis

Most vegetation is associated with mycorrhizal fungi, which colonizes the roots of individual plants. Plants are more specifically colonized by the fungal *hyphae* (the fungi's long filamentous branches), which then are not rejected as parasites or pathogens, and the two individuals enter symbiosis. When several hyphae connect plant hosts with each other, they create a *mycorrhizal network*. Hyphae operates as an extension of the root system into the soil where they absorb nutrients which are then transported to the *mycelium* (hyphae network) and the plants roots (Horton et al., 2015; Smith & Read 2008). Mycorrhizal networks affect ecosystem processes and resiliency as well as community dynamics in processes such as seedling establishment and plant succession. Mycorrhizal symbionts span a large phylogenetically diverse group of fungal taxa, forming different *mycorrhizal types* (arbuscular-, ecto-, etc.). Thus, they vary in their ability to associate with symbiotic plants, with some being able to associate with a range of species whilst some only can associate with a few specific ones. Counter wise, plants also vary in their specificity to associate with mycorrhiza (Horton et al., 2015).

Arbuscular mycorrhizas (AM) can be found in a large variety of host plants and are the most widespread type of mycorrhiza (Smith & Read, 2008; Parniske, 2008). When entering symbiosis, nutrient exchange occurs in tree-shaped subcellular structures called *arbuscules* that are formed within the plant cells (Parniske, 2008). In this study, AM is mainly found in the plant functional types graminoids and forbs. Ectomycorrhizas (EM) plant hosts are mainly woody perennials, and more specifically deciduous shrubs and some forbs in this study. They can be distinguished by three different structures. A mantle of fungal tissue enclosing the plant root, the *Hartig net* which is a labyrinth inward growth of hyphae in between epidermal and cortical cells, and outwardly hyphal element growing systems. Ericoid mycorrhizas are usually found in plants belonging to the *Ericaceae* family and other vascular plants (Smith and Read, 2008), in this study they are found in some forbs but mainly in evergreen shrubs such as members from the *Vaccinioideae* (e.g *Vaccinium Vitis-idaea* or lingonberry). Some plants in

this study does not have any mycorrhizal associations, while some associate with more than one type of mycorrhiza.

1.4 Nutrient Cycling

Recent discoveries show that the warming of the Arctic region is increasing soil temperatures which causes a deeper permafrost thaw. Consequently, the soil organic matter (SOM) stored breaks down forming carbon dioxide (CO_2) and methane (CH_4) might be released into the atmosphere, amplifying global warming further (Limpens et al., 2021). Moreover, nutrients that were once frozen in SOM are becoming available for mineralization by microbes and for plant uptake. (Wang et al., 2017; Limpens et al., 2021). More nutrients available for plants could possibly stimulate even more plant growth in the arctic, which would lead to a larger uptake of CO_2 from the atmosphere (Stuart et al., 1996). Ecosystem dynamics and nutrient uptake varies with vegetation structure and is thus predicted to undergo changes in the Arctic as the vegetation undergoes changes (Chu et al., 2010; Limpens et al., 2021). As an example, graminoids and shrubs have been found to use different strategies in their nutrient uptake. Graminoids use nutrients that are released by the permafrost thaw front whilst shrubs mainly use the nutrients found in the upper soil layers (Wang et al., 2017). This difference in tactics plays a role in how plants compete and determines which plants are and will become dominating in the Arctic (Wang et al., 2017; Bjorkman et al., 2020). Further, the ongoing shrubification is believed to affect the C and N cycle in different ways. Litter from deciduous shrubs is known to be easy decomposable, increasing microbial activity. On the other hand, litter from evergreen shrubs has been observed to be more recalcitrant that instead decreases the activity (Björk & Vowles, 2018). Thus, predicting what vegetation types might dominate in the Arctic in the future is important to understand the possible consequences of global warming.

1.5 Aim

This study is an attempt to understand how the ongoing changes in a high Arctic ecosystem affects species-species interaction in Tarfala valley, northern Sweden. Depending on their mycorrhizal symbiosis (ericoid-, ecto-, arbuscular-, or non-mycorrhizal), plants were removed from designated areas to study species specific responses. The results could reflect natural ecosystem responses when community structure changes as a result of climate change. The following questions were asked prior to this study:

- How does climate change affect Species-species interaction?
- Which species will dominate whilst others disappear in the Arctic?
- Does plants mycorrhizal symbiosis have a roll in how plants respond to these changes?

2. Method

2.1 Site Description

The study site location is in adjacent to the Tarfala Research Station, driven by University of Stockholm, located in Tarfala valley (67.9°N, 18.6°E), Kiruna municipality, northern Sweden (Figure 1). Tarfala valley elevation ranges from 800-2094 m a.s.l and the study location as well as the research station lie at a height of 1135 m. Kiruna city is located 67 kilometers away and the most adjacent village, Nikkaluokta, is found 19 kilometers from the station. The coldest month is January with a mean daily temperature of -15.3 °C and the warmest month is July when the average daily temperature is 13.1 °C. In July 2021, temperatures as high as 31.4°C were measured from the local weather station, provided by the Swedish Meteorological and Hydrological Institute (SMHI). Usually, nightly temperatures stay under 0°C for almost the whole year.
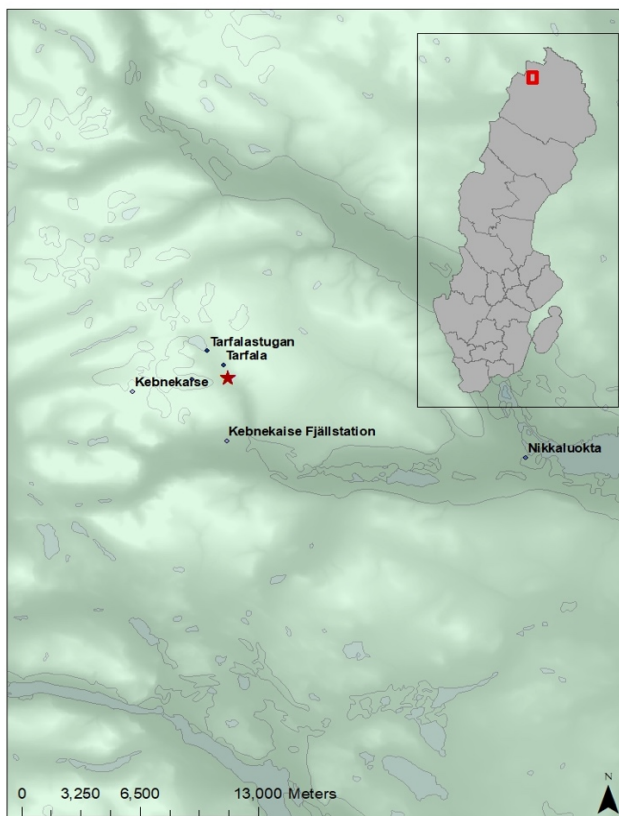
Figure 1. *Overview map of the study location, which is marked by the red star, and its surroundings.*

The high mountain valley is a part of the Kebnekaise massive and lies on the east side of the mountain. Four glaciers are located within the valley, one of them being *Storglaciären* where the first glacier mass balance research begun (NATGEO, 2022; Holmlund, 2007), as well as the lake *Tarfalajaure*. The environment is of typical high arctic character and, vegetation type found within the study area is classified as grass heathland, both moist and dry, by Swedish managing authority *Lantmäteriet*. The surrounding tundra is classified as rocky ground as well as alpine low herb meadow and vegetation in the area is grazed by reindeer (**fig. 2**). Ground cover vegetation is dominated by graminoids *Festuca Vivipara* and *Carex Bigelowii* and a variety of shrubs. Most abundant are the dwarf shrubs *Empetrum Nigrum*, *Salix Polaris, Salix Herbacea* and low shrub *Vaccinium Ulignosum*. Forbs are also found and the most dominant species is *Dryas Octapela* which is often found in a high alpine environment with dry, lime rich soil.
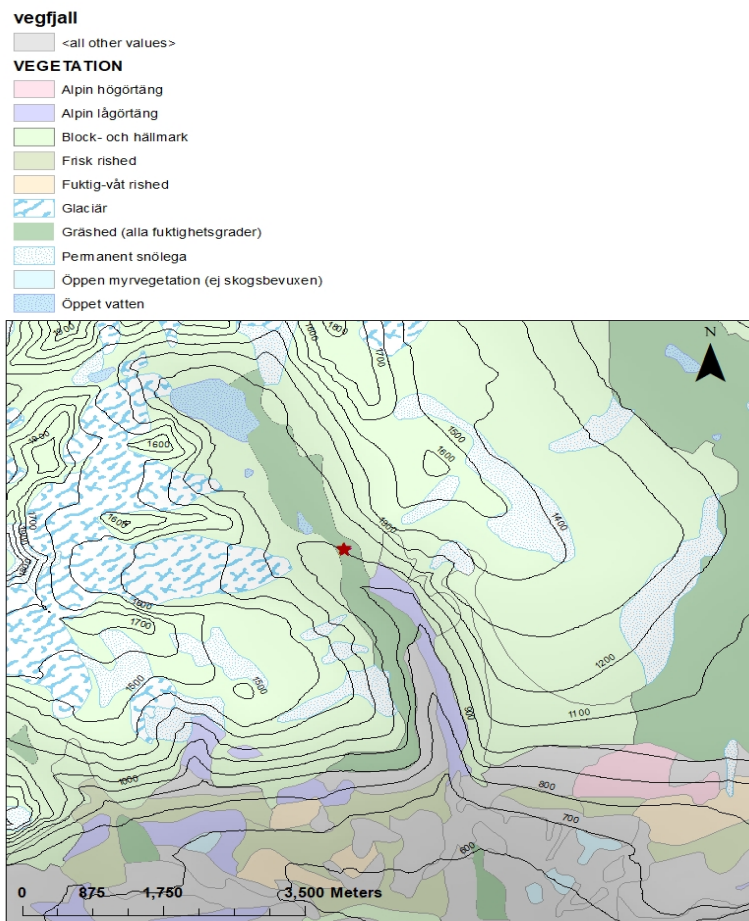
Figure 2. *Vegetation and elevation of the study location and its surrounding area. Geodata is gathered from The National Land Survey of Sweden (Lantmäteriet).*

2.2 Field Work

To test the hypothesis a vegetation survey using the point intercept method, based on the International Tundra Experiment (ITEX) design was done by Robert Björk, Senior Lecturer at

Gothenburg University. ITEX aims to understand tundra plant species responses through manipulation and transplanting at different alpine and arctic locations. In line with this design measurements are taken prior to, during and post experiment (Molau & Mølgaard, 1996). This is done to see how plant composition changes when exposed to changes through an experimental treatment. The experimental plots for this study were squares where different types of plants were cut off from depending on their mycorrhizal associations. These squares were fixed points of $1m^2$ or $4m^2$, trenched and marked with a string, in eight different locations named A-H (Walker, 1996) (Figure 3).

Figure 3*. Image of the experimental deign at the study site in Tarfala valley. Image courtesy of Robert Björk.*

The locations had four squares with four different treatments which were the following:

- All plants found with arbuscular mycorrhiza and no mycorrhiza were removed (-AM/NM).

- All plants found with ericoid or ectomycorrhiza were removed (-EM/ErM).

- Either the eight most common or the eight most rare species were removed (-SR/PD)

- Control areas where no species were removed (Ctrl).

These different squares were all numbered to differentiate between the treatments (Table 1) (Figure 4). Ctrl areas were $1m^2$ in size whilst the other areas were made to be $4m^2$.

Table 1. *Summary of which treatments were given in the 32 different squares.*

Treatment	Given in Areas
Ctrl	A1, B1, C4, D2, E1, F4, G3, H3
-EM/ErM	A3, B4, C2, D3, E4, F2, G4, H4
-AM/NM	A2, B3, C1, D1, E3, F1, G2, H1
-Eight most common	B2, D4, F3, E2, G1
-Eight most rare	A4, C3, H2
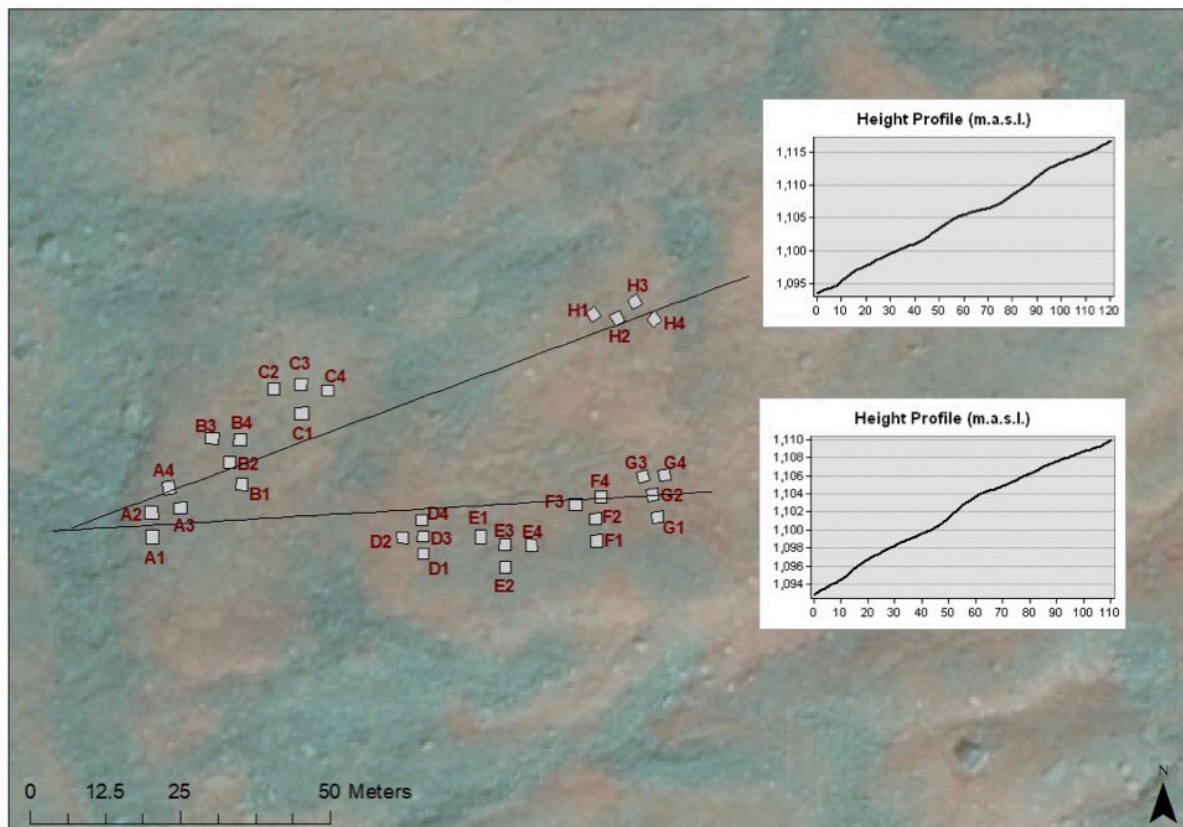
Figure 4. *Map over how the squares were located throughout the study area with height profiles stretching from locations A-G and locations A-H. Geodata is gathered from The National Land Survey of Sweden (Lantmäteriet), and coordinates curtesy of Robert Björk and Tarfala Research Station.*

2.3.1 Data Collection

Data collection included counting each plant species abundance for each square they were found in, both in the beginning of August in 2015 and 2019, to see how species composition had changed from the different treatments. The total abundance for both the years were

reported, as well as the total change of each species as either a negative or a positive number depending on if the species abundance has increased or decreased. The inventory in all squares were made in area of $1m^2$.

2.3.2 Maps and Climatic Data

Coordinates in the *SWEREF99_TM* (Swedish Reference Frame 1999, Transverse Mercator) coordinate system were taken for each square with a GPS to complete the data collection. These coordinates were then visualized on a map in ArcMAP with data from the National Land Survey of Sweden, which was downloaded through the *Swedish University of Agricultural Sciences* (SLU). Geodata used to make the wanted maps was orthophotos, a digital elevation model (DEM), as well as Swedish alpine vegetation data of the study location and its surroundings. A topographic map of Tarfala valley as well as a height profile was created from the DEM. Changes in species abundance can vary with elevation, thus it is useful to have a clear view of where the different treatment areas are located.

Weather data was gathered from the *Swedish Metrological and Hydrological Institute* (SMHI). Data from the local weather station in Tarfala was only available for the years 1995-2000, thus weather data was collected from Nikkaluokta instead. Because of Nikkaluoktas adjacency to Tarfala valley weather patterns are very similar, and weather data from 1961-2000 was available.

2.4 Data Analysis

Firstly, the total abundance of all individual species with either arbuscular or no mycorrhiza for all treatment areas both 2015 and 2019 was calculated. The same calculations were made for species with ericoid or ectomycorrhiza to see if any type of mycorrhizal symbiosis had benefited from the treatment. Secondly, the species were divided into their PFTs, which was either forb, graminoid or shrub. Total abundance of the PFTs as well as their relative amount to each other was calculated for both 2015 and 2019, to see how the treatment had changed the PFT composition throughout all areas. Thirdly, the increases and decreases of all plant species excluding the plants that were cut off was calculated, to see what species had benefited or not in areas where they were left to grow and thus possibly benefitted from other plant species removal. Index of absolute cover was calculated for all the individual species for each treatment area (hits/(98)*100). A one tailed t-test was made for all plants in groups of their mycorrhizal

symbiosis in both treatment and control areas, in order to see if the changes found were statistically significant.

3. Results

3.1 Changes in Plant Functional Types

In relation to each other, graminoids have benefitted the most across all treatments, being the only PFT with a growing population because of the experiment. Both the shrub (including low shrubs, tall shrubs, and dwarf shrubs) and forb population decreased from 2015 to 2019. The relative distribution between the three PFTs has changed significantly throughout the experiment. In 2015, the distribution was almost completely even whilst in 2019 half of the plants found at the site were graminoids. The forb population has decreased the most in relation to the other two. (Fig 5).
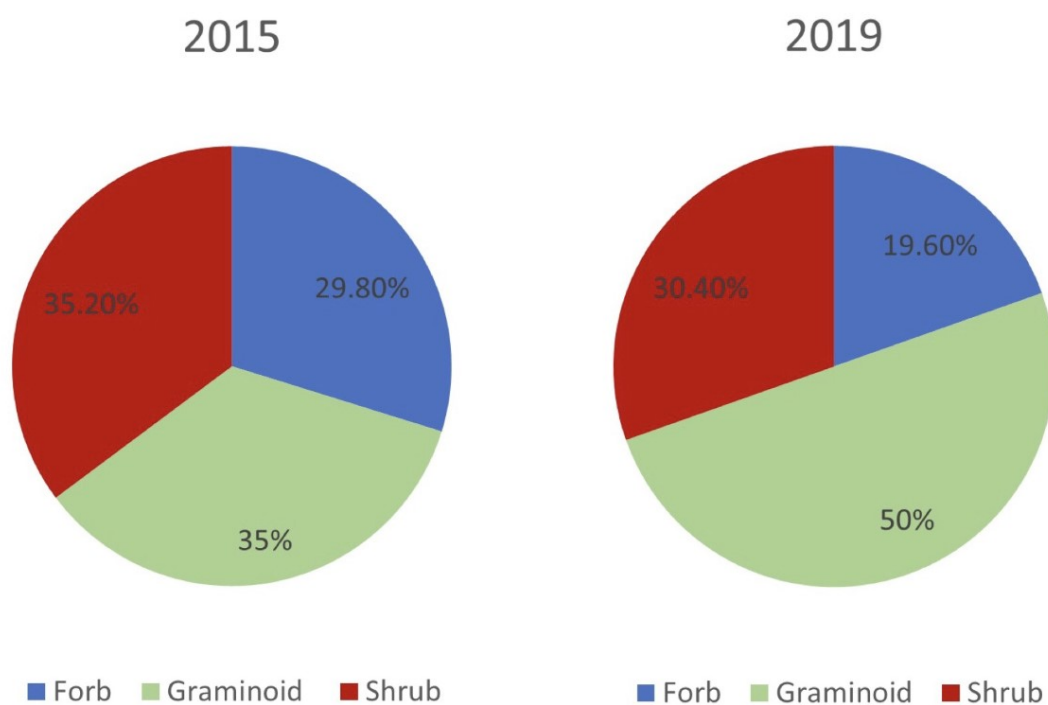
Figure 5. Relative changes in the distribution of plant functional types across all areas, pre and post study.

Forbs also had the smallest population prior to the experiment and was the PFT that had the most plants removed throughout the experiment. Considering the plants that were removed, all three functional types have managed to increase in areas where they were left to grow (Table 2). Forbs have increased with 58 hits in areas where they were not removed, especially *Bistorta vivipara* that increased with 26 hits, and *Silene acualis* which increased with 24 hits. Graminoids as seen have had benefitted the most from the treatment have increased with 307

hits in areas where they were not removed. Shrubs were the PFT that grew the least in areas where they remained untouched with +33 hits in 2019. *Empetrum nigrum* experienced the largest growth with +34 hits, which was not enough for an overall population growth considering the plants that were removed.

Table 2. Total change of plant functional types from 2015 to 2019 considering the removed plants.

	2015 count	Plants removed	2019 count	Total change
Forb	525	310	273	+58
Graminoid	618	229	696	+307
Shrub	620	231	422	+33

3.2 Changes in Plants Based on Mycorrhizal Associations

Plant species with either arbuscular or no mycorrhiza, which are mainly grasses and sedges (graminoids or forbs), are more commonly found over the whole study location compared to plants with ericoid or ectomycorrhiza. These plants have also experienced the largest increases throughout the treatment (Figure 6). Almost all species have more hits in 2019 than in 2015, except for a few species. *F. vivipara* was the most common plant in 2015, found in every treatment area, and remains so even after the treatment. *D. flexuosa* was uncommon prior to the treatment and but have expanded because of the treatment. Species that have experienced the losses have had symbiosis with more than one type of mycorrhiza or no mycorrhiza, such as *B. vivipara* and *D. octapela*. *K. myosuroides*, *P. lapponica*, *C. vaginata* and *A. alpinus*, which can no longer be found in any treatment areas in 2019. Unlike plants with arbuscular and no mycorrhiza, almost no plant populations with ericoid and ectomycorrhiza have not experienced as large increases. Average hit count for plants with ectomycorrhiza have increased more so than those with ericoid mycorrhiza, but none of the two groups have increased close to as much as the two other groups (Figure 6). The most common species in 2015 are still relatively common, meaning that they have increased in some areas where they were not cut off, and in Ctrl areas. *V. myrtillus*, *L. procumbens* and *S. hastata* did not appear in any of the treatment areas after the study whilst one *S. lanata* plant appeared, which was not found in any squares prior to the experiment.
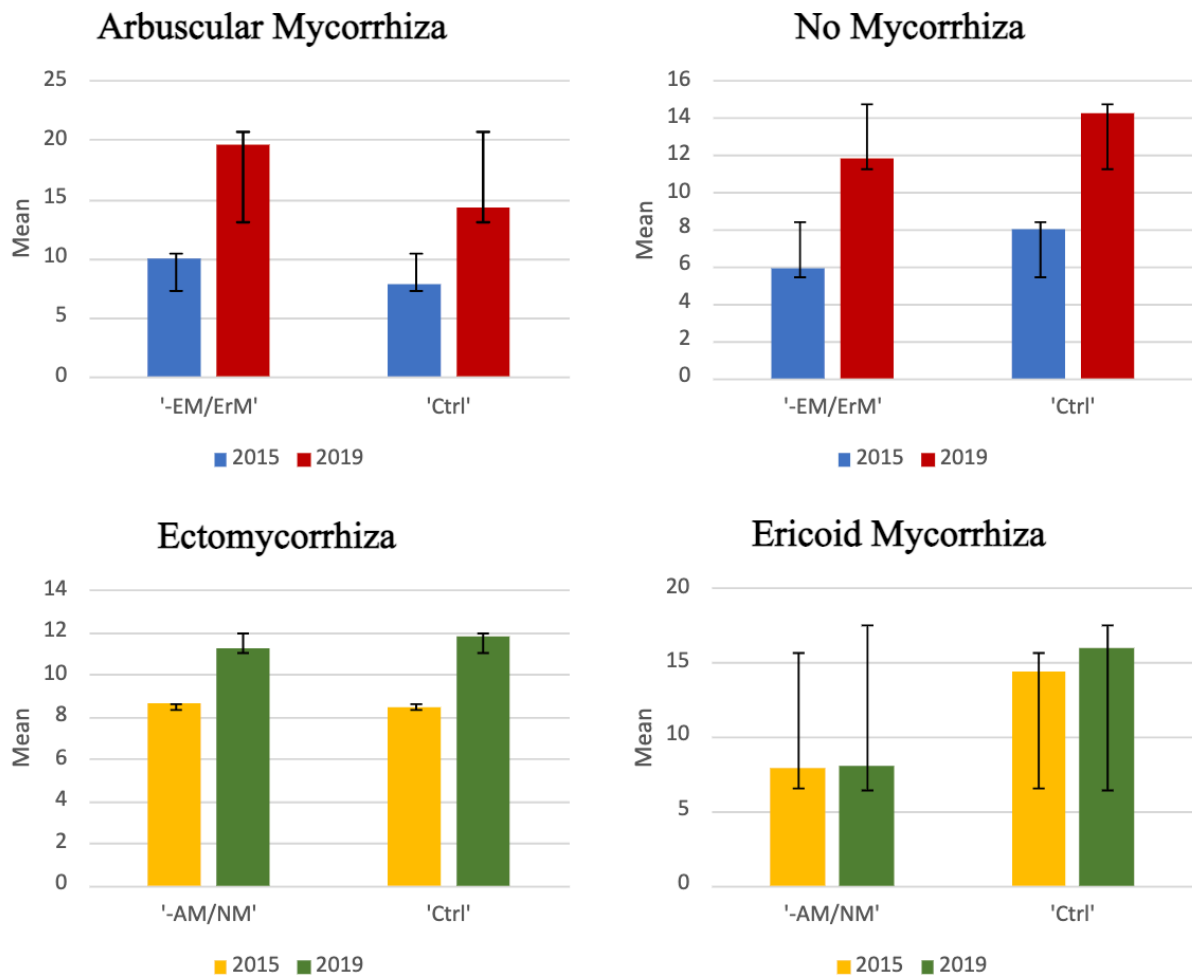
Figure 6. Changes in the mean of all plant hit count according to the plant's mycorrhiza with standard deviation.

The largest increases of the experiment were found in plants with arbuscular mycorrhiza and no mycorrhiza in areas given the '-EM/ErM' treatment, although only the result for the no mycorrhizal category showed statistically significant. The smallest increases were found in plants with Ericoid mycorrhiza, which almost did not increase at all in either '-AM/NM' or Ctrl areas, but these results were not found statistically significant when a t-test was done. The t-test only showed statistical significance for plants with arbuscular mycorrhiza or no mycorrhiza in Ctrl areas, and plants with no mycorrhiza in '-EM/ErM' areas. Changes in the other groups and areas did show any significance from the t-test (Table 3 & 4).

Table 3. Increase of plants from 2015 to 2019 found in Ctrl areas according to their mycorrhiza, as well as results from the t-test.

Ctrl areas	Increase (%)	t-test	p
Arbuscular Mycorrhiza	83	0.04665	< 0.05
No Mycorrhiza	78	0.02358	< 0.05
Ectomycorrhiza	40	0.26479	> 0.05
Ericoid Mycorrhiza	1.6	0.31029	> 0.05

Table 4. Increase of plants from 2015 to 2019 found in either -AM/NM or -EM/ErM areas according to their mycorrhiza, as well as results from the t-test.

-AM/NM or -EM/ErM areas	Increase (%)	T-test	p
Arbuscular Mycorrhiza	95	0.09786	> 0.05
No Mycorrhiza	101	0.04480	< 0.05
Ectomycorrhiza	30	0.12013	> 0.05
Ericoid Mycorrhiza	1.6	0.39244	> 0.05

3.3 Benefits and Drawbacks

The graminoid *Festuca vivipara's* population grew with 150 hits which is the largest increase found amongst the plants in this study. *C. bigelowii* follows with its population growing with 97 hits in areas where they were left to grow, and then *D. flexuosa* with an increase of 36 hits. These three plants that benefitted the most from across all treatments are in symbiosis with arbuscular mycorrhiza and they have all increased in areas given the -EM/ErM treatment. *Juncus trifidus* with no mycorrhizal associations also grew the most in an -EM/ErM area (Table 3). Most plants that were found to benefit from treatment either have arbuscular or no mycorrhiza, except for *E. nigrum*, *S. polaris* and *C. hypnoides* which have either ericoid or

ectomycorrhiza. *E. nigrum* grew the most in area H2 where the eight most rare species were removed, whilst *S. polaris* grew in area D1 given the -AM/NM treatment, and *C. hypnoides* population expanded in control areas. Several of the plant species increased in control areas over the four years of treatment. *C. nigra*, *B. vivipara*, *S. acualis* and *C. hypnoides* had their largest increases in there, meaning that their populations expanded in an untouched environment. *C. nigra* also expanded its population in area E2 where the eight most common plants were removed. Most plants removed in this area were either forbs or graminoids apart from the shrub *C. hypnoides*. Species with ericoid and ectomycorrhiza do not tend to increase in areas given the -AM/NM treatment but more so in control areas. As seen in Table 5, some species have increased in -AM/NM areas but not in the large amounts that species with arbuscular and no mycorrhiza have expanded in areas given the -EM/ErM treatment.

Table 5. An overview of the 10 plants that have benefitted the most from the treatment in areas where they were not removed.

Name	Mycorrhiza	Increase (hits)	Area of Increase	With Treatment
Festuca vivipara	AM	150	F2, A3, C2	-EM/ErM
Carex bigelowii	AM+NM	97	F2, C2	-EM/ErM
Dechampsia flexuosa	AM	36	H3	-EM/ErM
Carex nigra	NM	34	E2, G3	-Common, Ctrl
Empetrum nigrum	ErM	34	H2	-Rare
Bistorta vivipara	AM+EM+NM	26	D2	Ctrl
Juncus trifidus	NM	25	E4	-EM/ErM
Silene acualis	NM	24	E1	Ctrl
Salix polaris	EM	14	D1	-AM/NM
Cassiope hypnoides	ErM+EM	13	F4	Ctrl

Disregarding the plants that benefitted from the treatment, and excluding the plants that were removed, many of the plant population stayed approximately the same throughout the four

years. Despite this, some species have experienced drawbacks, mainly *S. herbacea*, *A. alpinus*, *S. reticulata* and *V. ulignosum* (Table 6). These are mainly shrubs with either ericoid or ectomycorrhiza, except for *A. alpinus* which is a forb with no mycorrhizal associations. These four species all decreased the most in control areas which means that their populations declined in an environment that remained untouched throughout the four years. Since they did not experience any large increases in any other areas that received treatment, they did not seem benefit from any species being removed from other areas.

Table 6. *An overview of the species that benefited the least from the treatment throughout the four years.*

Name	Mycorrhiza	Decrease (hits)	Area of Decrease	With Treatment
Salix herbacea	EM	-19	E1	Ctrl
Astralgus alpinus	NM	-14	A1	Ctrl
Salix reticulata	ErM	-7	H4	Ctrl
Vaccinium uliginosum	ErM	-7	B1	Ctrl

4. Discussion

4.1 Plant Functional Type Responses

I found that species-species interaction within an arctic tundra ecosystem can change as a consequence of species loss. From the three different functional plant types included in this study, only graminoids benefitted from the treatment. Contrary to the general trend of shrubification and increase in forbs (Bjork & Vowles, 2018; Bjorkman et al., 2018), none of them increased with significance in areas where they were not removed. Shrubs have generally been observed to increase in warmer areas where there is access to more soil moisture. Forbs increases with warmer summer temperatures but only in locations with near surface permafrost (Elmendorf et al., 2012, Bjorkman et al., 2018). Permafrost in Tarfala valley have been found continuous at altitudes above 1561 m a.s.l., discontinuous above 1218 m a.s.l., and sporadic above 875 m a.s.l (Fuchs, 2013). The study area is located at an altitude of 1135 m a.s.l. which

means that permafrost is located sporadically through the landscape. This heterogeneity of the Arctic vegetation and environments is important regulating local responses which varies depending on biotic as well as abiotic factors. Because of the elevation and the somewhat dry soil character of the study location, it is possible that conditions have not been optimal for shrubs, nor forbs, to reproduce.

Graminoids were dominating prior to the study, and they remain dominant after the treatment. Thus, they have managed to increase in areas where they were they did not receive treatment. Previous observations have found graminoids to dominate on higher elevations in the Arctic. They tend to have the ability to grow in many different environmental conditions such as various levels soil moistures (Elmendorf et al., 2012). Competitive plant species have been observed to use nutrient availability efficiently in undisturbed environments (Alatalo et al., 2015). Although many locations are facing drastic changes because of global warming, Tarfala valley yet remains relatively undisturbed. However, graminoids and other competitive species are likely to decrease when exposed to stress caused by local changes in abiotic factors (Grime, 2001). Furthermore, graminoids have been observed to be able to take up N from deep, middle, and shallow soil, whilst shrubs use N from only the upper-most layer of the soil in various tundra environments, which makes graminoids more competitive (Wang et al., 2017; Zhu et al., 2016; Oulehle et al., 2016). Therefore, when species are removed and more nutrients become available, graminoids are more efficient at using them. They have been predicted to dominate in areas where permafrost thaws and nutrients deeper down in the soil become available (Wang et al., 2017). While interpreting the results it is important to remember that due to the relatively short duration of the study the results indicate a shift in abundance rather than species turnover (Bjorkman et al., 2018). Further, not all results showed statistical significance when the t-test was performed, and it is therefore also uncertain if the changes that we see based on mycorrhizal associations are of any significance, except for the three changes that were found significant. Thus, it is worth considering prolonging the study further or doing an inventory of larger areas.

4.2 Changes Based on Mycorrhizal Associations

Being statistically significant, I also found that primarily plant species with either arbuscular mycorrhiza or no mycorrhiza have increased in abundance. In this study these plants are mainly graminoids (*f. vivipara, d. flexuosa, c. nigra, c. glacialis, c. bigelowii*). One of the reasons seems to be because of graminoids competitive nature, and due to them already being the dominating

species in the area. Plants with no mycorrhiza (*c. nigra, c. glacialis*) have increased in control areas. The lack of mycorrhiza in these plants' roots is related to cold temperatures, which limits the fungal growth. If soil temperatures are too cold it can limit the physiological abilities or even kill the fungi's hyphae (Kytöviita, 2005). Therefore, mycorrhizal colonization tends to decrease with increasing altitude (Väre et al., 1997). These plants have been able to grow without mycorrhizal associations before and after the treatment. Thus, it could be assumed that if the local climate remains unchanged, they will remain dominant species.

In species with arbuscular mycorrhiza (*f. vivpara, d. flexuosa, c. bigelowii*), the large increases were found in both Ctrl and '-EM/ErM' areas. Still, little knowledge is gathered on the diversity and ecology of Arctic ecosystem arbuscular mycorrhiza (Pietikäinen et al., 2007; Varga et al., 2015). But it has been established that when nutrient availability increases, mycorrhizal plant symbiosis decreases when plants can use the nutrients efficiently enough by direct uptake (Urcelay et al., 2003; Jasper et al., 1979). Arbuscular mycorrhiza has then been estimated to be able to live without a host plant for two years in conditions like those in Tarfala valley (Pietikäinen et al., 2007). This indicates that the mycorrhizal status of the plants does not affect the ability to make use of the newly opened niches and species-species interaction. More so, it seems like the resulting benefits is thanks to the character of the different plant functional types and the extension of their roots. This is further underlined when finding similar number of increases for all mycorrhizal groups in Ctrl as well as '-AM/ErM' and '-EM/ErM' areas. This could be due to the general increase in vascular plants that have been observed across the arctic (Elmendorf et al., 2012). Another possibility is that climatic conditions such as temperature were more optimal for plant growth in 2019 than in 2015, thus it could be interesting to count plant hits again and correlate all current results with temperature and precipitation.

5. Conclusion

This study has found that success of different plant species does not depend on their mycorrhizal symbioses but rather on their competitiveness and stress tolerance and their surrounding biotic and abiotic factors. When these environmental factors are undergoing irreversible changes because of climate change, causing drawbacks or extinctions of plants currently found in the Arctic, it has been found that graminoids are more efficient at using the newly opened niches than forbs and shrubs. Graminoids have been observed being able to take up nutrients from several different soil depths which gives them advantages as permafrost thaws. Shrubs and forbs have been the least able to make use of the new nutrients and space made available for

them throughout the experiment but have still been widely observed to expand all over the arctic. Graminoids were seen expanding the most in areas where shrubs were removed, being the better competitor. Thus, in a local arctic tundra environment undergoing biotic changes, graminoids are the largest benefiters.

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