Light availability affects growth more than browsing from reindeer in Scots pine saplings from Northern Sweden

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Abstract

In Northern Sweden, reindeers (*Rangifer tarandus*) feed on Scots pine (*Pinus sylvestris*) saplings, impacting their growth. In the open areas (clearcuts or sites that have experienced stand replacing fires), pine saplings experience improved light conditions but also higher levels of browsing. The relative importance of these two factors remains poorly quantified. I hypothesized that the growth of pine saplings remains primarily controlled by the light conditions, with the intensity of browsing playing a secondary role. To test this hypothesis, I studied the growth of 350 pine saplings, for which stem growth dynamics were modelled as a function of browsing damages and light conditions. Samples originated from multiple locations in Swedish Lapland, from Jokkmokk and Arjeplog municipalities. From the samples gathered, a statistical analysis was supervised to produce data. The data shows that light dominated over reindeer browsing affecting growth of pine saplings in the study area and may therefore provide a proxy for light conditions. Capitalizing on this finding, I reconstructed the light conditions in the area located in the municipalities of Arjeplog and Jokkmokk. I used a written RStudio script from my supervisor to reconstruct and statistically analyze these results from volume growths correlation to light, browsing and the correlation between both.

Keywords: Light availability, browsing, Scots pine, Northern Sweden

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Abbreviations

Abbreviation	Description
DIFN	Diffuse non-interceptance, Differing light conditions
GAM	General Additive model
LIA	Little Ice Age
MWP	Medieval Warm Period

1. Introduction

Scots pine (*Pinus sylvestris*) is one of the dominant tree species in Northern Fennoscandia. It is a light demanding species and generally does not regenerate under closed canopies and in the absence of exposed mineral soil (Forest research, 2025). As a result, pine regeneration depends strongly on natural and human-mediated disturbances. After being established, pine saplings are subject to browsing by different ungulates, such as moose or deer. In Northern Fennoscandia, reindeer (*Rangifer tarandus*) is the most prominent browser that can limit pine regeneration, especially in the areas used for reindeer herding (Edenius, Danell, Nyquist, 1995). Browsing of pine is a serious concern for Swedish forestry as it affects naturally generated and planted pines and particularly so, on clearcuts.

Light availability is one of the many factors affecting growth of trees (Junttila et al., 1993; Basler et al., 2019). High light availability in Scots pine is more favored compared to other species, like Norway spruce (*Picea abies*) who favor lower light availability. This is because Norway spruce is a second-generation species, that correlates to being more shade tolerant where it manages to survive in the understory to later replace the upper canopy. Therefore, coming in after pioneer species, like Scots pine, that thrives in light (Riikonen et al., 2016).

Ungulate browsing is another affecter of growth, for Scots pine correlates to lessened growth since their browsing focuses on new shoots. In the Mediterranean environments, sources show that when Scots pine shoots are heavily browsed by goats, it leads to a decrease in growth (Zamora et al., 2001). Sources from Sweden support these results, where it mentions the ungulate damages from moose also show similar negative effects in growth on seedlings of native species throughout their early life and effects their survival in the long run, either leading to mortality or reduced growth (Edenius, Danell, Nyquist, 1995). The pine family (*Pinaceae*) is a family of trees known for their serotiny, i.e. adaptation to fire. Thick bark and lack of lateral fuels in mature trees of different pine species are features that help pines survive low intensity surface fires (Wang et al., 2024).

Currently, there are concerns in forestry about the effects of reindeer browsing and other ungulates that damage regeneration and increase mortality rates of seedlings. The browsing also negatively affects the quality of timber through promoting forks and reducing straightness of the stems (Zamora et al., 2001).

The herding of reindeer (*Rangifer tarandus*) is only handled by multiple small groups of communities of Sami people. There are around 50 different communities spread throughout the northern half of Sweden and multiple more from northern Scandinavian countries (Käyhkö, Horstkotte, 2017). There are currently cooperations and negotiations in effect with large forestry industries to harvest accordingly to still have favorable conditions for herding and browsing with reindeer plus giving production companies their yield of investments back (SCA, 2025; Sami council, 2025). The reindeer herding and the Sami people have a long and rich history, starting from hunting reindeers for survival and later adapting to herd them seasonally throughout northern Europe. Sami communities migrate with their reindeer seasonally. They move from the coastline of the Bothnia gulf in winter season, then eastward toward the borders of Sweden and Norway for summer browsing, before returning to the coast and repeating the cycle (Käyhkö, Horstkotte, 2017). The herding means for forest owners in the northern part of Sweden a re-occurring seasonal visit of reindeer husbandry on a private forestry owners land. The reason for this is since that is part of Sami people rights. So, to see how much this affects the Scots pine growth could be important (Kupferschmid, Greilsamer, et al., 2022; Edenius, Danell, Nyquist, 1995; Heikkilä, Härkönen, 1996).

Growth of trees under closed forest canopies can be a proxy of light conditions (Fraver, White, 2005). The study of growth releases resulting from abrupt increases in light conditions can shed light upon the history of forest stands. In Northern Sweden, the relative importance of light environment and browsing in controlling the growth of pine saplings remains poorly quantified. This is where studies of growth releases from sudden increases in light would help answer the questions of historical forest stands.

The study will focus on answering one question:

(1) what is the relative importance of reindeer browsing and differentiating light conditions which affect the growth of Scots pine in the northern climate of Lapland, Sweden?

For this study, which focuses on the effects of differentiating light conditions and the effects of reindeer browsing in Scots pine annual growth trends, looking at previous studies which brought this problem to light of the lacking knowledge within the field. There are differences in growth from both browsing pressure and light conditions. Lower light conditions with Scots pine does affect its growth negatively compared to similarly situated samples but more light reaching the samples have greater growth, which is what this study will analyze to see these factors effects on Scots pine samples. Similarly, sources confirm similar effects from browsing on Scots pine in terms of annual growth (Edenius, Danell, Nyquist, 1995).

From the objectives of this study, I hypothesize light availability plays a larger role compared to browsing damages in terms of volume growth. Where light availability and browsing plays important roles, however, light availability ranks higher in terms of growth.

This report will be a quantitative study; by answering questions of how much does differing light conditions affect Scots pine in northern Sweden, and how much effect do reindeer browsing have on Scots pine from the same stands. Another comparison of both of these effects and their effects on trees growth is also overviewed.

Figure 1. Shows picture of a young Scots pine (Pinus sylvestris) from one of the sample sites in northern Sweden. The picture shows some browsing damage from reindeer.

2. Methods

2.1 Study area

The study of the sample plots of Scots pine are located in the northern part of Sweden, above the arctic circle outside the town of Jokkmokk, with sites both north and south of it (Figure 2.). The climate in northern Sweden, specifically above the arctic circle it alternates between summer days with 20+ hours of daylight and winter day with only a few hours of daylight. This climate makes for unique growing conditions in plants and trees alike (Polcirkeln.nu, 2025).

Identifying the classification of climate using the Köppen climate classification (Arnfield, 2025; Britannica, 2016), the sample site is subarctic or boreal, which means it has long, cold winters ranging from –10 to –30 degrees Celsius. Additionally, shorter, mild summer periods of 15 to 25 degrees Celsius. The biome in northern Sweden is taiga, consisting of a large, coniferous landscape with species composition of mainly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). This biome is also one of the biggest biomes by area globally, covering about 17 percent of the global landmass (Helmfrid et al., 2025) and a multitude of peat/ wetlands where large amounts of carbon are stored. Although the taiga biome is large in size, the annual growth of forestry is slow. However, the sheer size of area of growth counteracts slow growth (Hayes et al., 2022). Due to the climate in the taiga biome, it is commonly a place for natural disturbances to occur, an example being forest fires on multiple scales and frequencies (Hayes et al., 2022).

The browsing from reindeer in the area come from Sami communities herding the reindeer seasonally through Sweden, Norway and Finland. The reindeer browsing and herding do pass through the area of collected sample areas which are also seen on the browsed Scots pine seedlings.

The sites vary in multiple ways. In size, from 3 to 5 hectares, biological diversity and its reindeer browsing damage. The sites are previously undisturbed with natural regeneration. From the pictures gathered on site, it shows similar biological and diversity traits that are associated with the Taiga biome, where sites consist of three to four main species. Species like, Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*) and either Silver birch (*Betula pendula*) or Downy birch (*Betula pubescens*) (Figure 1.; Appendix 3).

All sites old wood samples have been in a fire during their lifetime, giving all of them either a scar of surviving a forest fire, being close to one or its death shown by black scorch marks in the tree's outmost layers.

2.2 Data collection and laboratory analysis

From the fieldwork, two different types of samples were collected from Lapland in a total period of four years (2020-2023). The collection method, two types of sample collection methods were used depending on what type of sample. We employed destructive sampling for the young pine samples at all sites, where the sample trees were permanently removed from the collection areas. For example, by uprooting young Scots pine seedlings and using chainsaws to cut 2-3 samples from each pine. The second sample collection method was focused on old woodfire scarred samples, where 2-3 plates or cookies were collected from each tree. The collection of old wood samples was either from deadwood or live trees. The reason for collecting at least two samples from each tree was to build an accurate depiction of the volume of growth, since a tree is not perfectly cylindrical. Where one sample was from the base, another in the upper, middle part and a last one above the middle.

When the samples arrive at the laboratory, a couple of rounds of sanding the samples are in action to give a smooth and accurate surface to measure.

The collected data (Scots pine samples) from Lapland are used to quantify the relative role of local light conditions, browsing damages and its effects on growth in Scots pine. To split the workload, the samples are split between two people. Firstly, the young Scots pine samples, which a fellow student handles to date and measure. And secondly, the old fire scarred Scots pine data, collected from felled trees and a small number of standing trees by me.

The process of measuring the young samples differs from the old samples' way of measurements where they are gathered and measured by a microscope and a computer measuring device called Coorecorder. The reason for using a computer measuring device is to get accurate results because of difficulties in visually seeing and measuring the radial growth with small distances.

In total, there are 42 sample areas for the old wood fire scarred samples, spanning over 3 years, 2020-2022. From each sample tree, 2-3 samples from each tree were collected to give an accurate volume reading. 33 of the sample sites are from the period 2020-2021 which were already processed for this study and only the 2022 sites samples (Appendix 1). There are nine sample sites in total from 2022. One of these sites from 2022 is not included, the Tjegälväss point. The reason for its removal is because no samples were measured from it, leaving 8 sample sites to process and compare with the young Scots pine sample data collected. To create a calculation of growths, which then can be used on the old samples to create data of annual volume growth (Figure 2.) (Google earth, 2025).

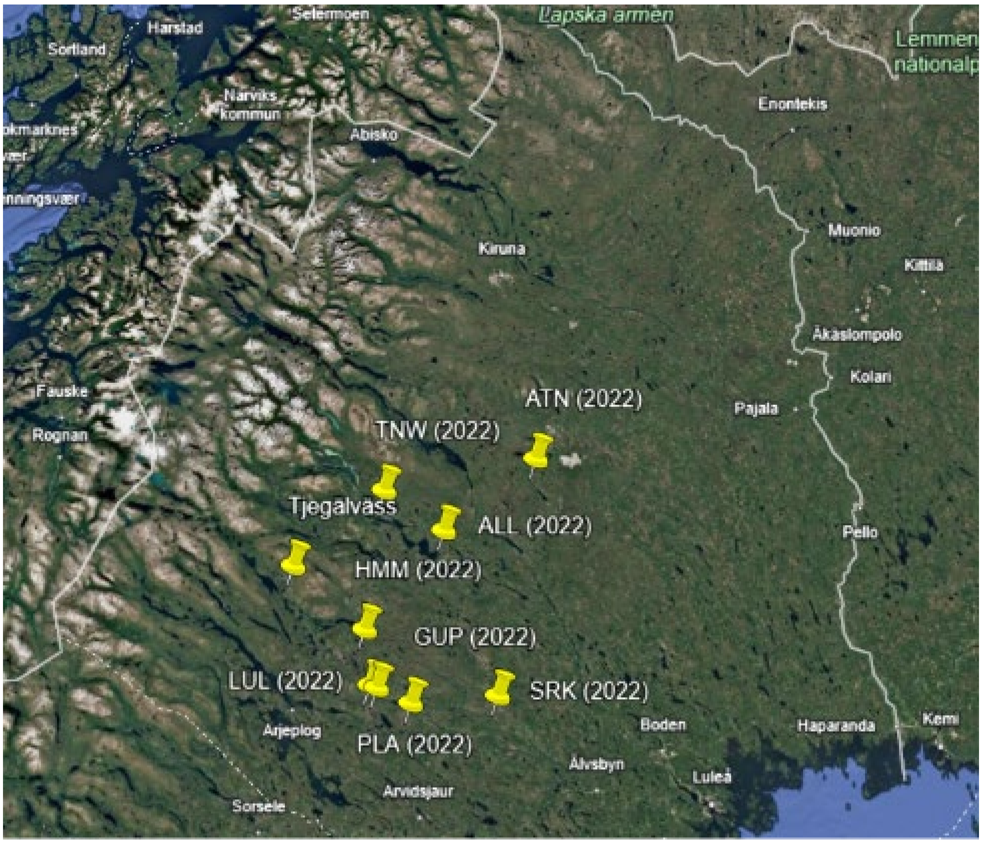

Figure 2. The coordinate placement of the 8 different sites of collecting samples in Lapland from 2022 which I personally handled. There is multiple more points from previous years, including pic in the appendix (Google Earth, 2025).

Additionally, since their old age, the samples are in varying degrees of quality for example, some are missing the pith making them unusable for the data I collect, to measure radially from the center of pith to the age of 50 in rings.

The gathered samples are then dated from the pith (the center piece of wood) to its death in later years and measured from the center of the sample to sum up into five measurements per sample, starting from the 10-year mark, 20-year, 30-year and the 50-year mark plus the year of mentioned fire scar and the measurement from the pith. The reason behind the five measurements and not including more is the time limit of collecting data which makes it difficult to perform yearly measurements of all samples in varying quality. These sample measurements are then manually inputted into an existing excel-program to give each piece a unique number or name to make the samples in the excel program compatible with the made R Studio- statistical analysis script.

These old age fire scarred samples are then ready to be compared with previous data collections of Scots pine from the same sites in Lapland but with younger seedlings instead. The measurements are used to make a stem analysis, where the

2-3 data samples from each Scots pine are used to get an accurate depiction of the annual volume growth.

2.3 Statistical analysis

The project featured laboratory work in the Dendrochronological lab (Dendrochronology, 2025), working with an existing R script to carry out statistical analyses, and thus writing this project report.

The statistical analysis from the young and old wood Scots pine samples will show data from multiple comparisons, in total 5 analyses of light and browsing damages. One will show differing light conditions compared to volume growth, where light was measured in the field with a monochromatic lens to capture how much light gets through the canopy. Plus, in tree rings and the other browsing damages in scale of severity compared to volume, where severity was measured in field by ranking how severe browsing was. Plus, an additional analysis of both light and browsing together and how it correlates with growth in volume, where both the previous methods were used in the statistical analysis to measure.

The severity of browsing from 5 different stages on Scots pine and its effect on volume growth. The 5 stages are the severity from 1, where there is no browsing damage at all, to 5 with heavy browsing damage on Scots pine. The establishment of each stage of browsing damage was done on each sample on site of collection. From these two effects, one more graph will show the correlation between light conditions, the severity of browsing damage and its volume growth from it.

The analysis also shows the number of fires and their years of fire breakout from the scars, the growth rate from each pith to a certain year, and a generative additive model (GAM).

The GAM will be able to show from the samples collected, where Scots pine shows the most volume growth rate compared to light and browsing damages. The analysis of GAM was built by taking Scots pine volume growth as a response to 2 effects, the light availability and the browsing. The reason for using this complex analysis was to see the non-linear relationship between light availability and browsing damages.

And lastly, from the results, it should show how much light conditions actually affect the annual growth in Scots pine plus the effects of reindeer browsing on shoots of trees from the collected and measured samples of old and young trees. I used Treeglia, a library in RStudio (Bascietto, 2007), to carry out stem analysis on destructively sampled pine samplings.

3. Results

The five measurements from each of the samples totaled 205 samples from the old wood fire scarred plus the 150 samples of young Scots pine saplings, The results from over 350 Scots pine samples were positive toward the hypothesis looking at the graphical analysis from R (Figure 3. to 8.).

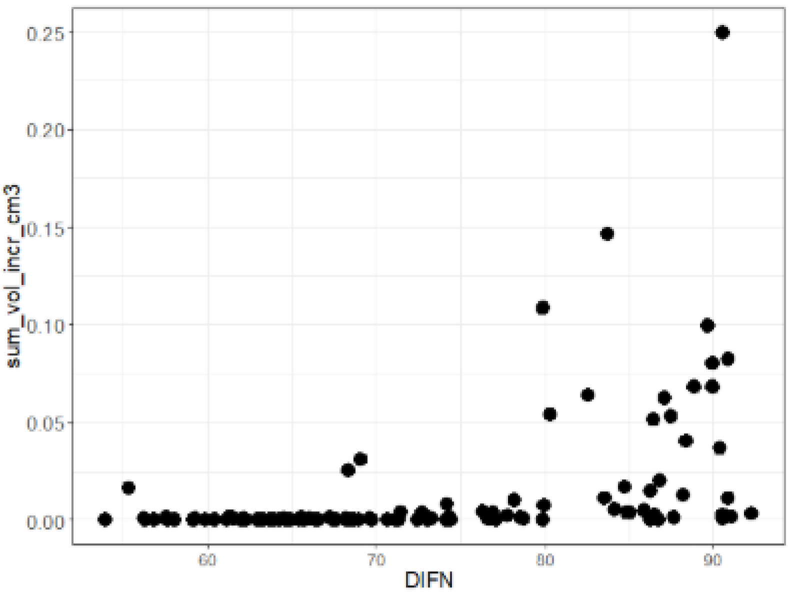

Figure 3. Volume increment versus openness.

From the graphs of light availability/ openness, there are signs of Scots pine growing better in volume from more open sites with available light. The X axis explains the DIFN (Diffuse non-interceptance)/the light availability from the tree ring samples and the Y axis explains the sum of volume growth from the rings. Each dot explains one sample. From the dot positions, between 50-80 no type of difference in growth is seen with only 3 outliers. Beyond the light availability of 80+ a shift is seen with more growth on average, where the growth releases show significant effects from increased light conditions.

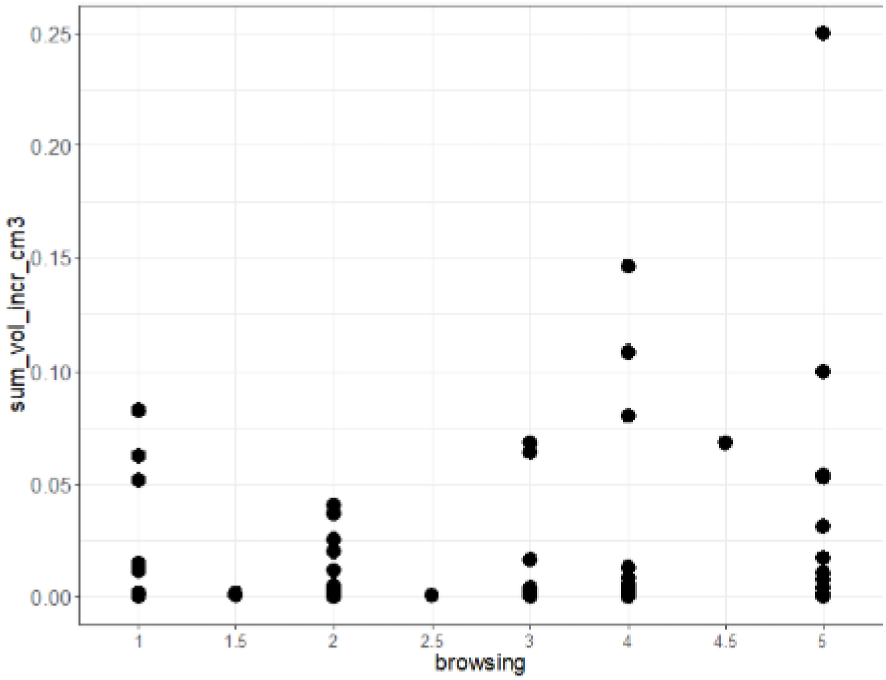

Figure 4. Volume increment versus browsing.

The graph shows the correlation between the volume growth from samples and reindeer browsing in different rankings ranging in severity. The different severities are ranked from level 1 to 5, where level 1 is no browsing at all, to 5 with heavy browsing damages on the samples collected. The correlation between volume growth and browsing shows no clear pattern of where there is less growth with heavier browsing damages compared to no browsing at all.

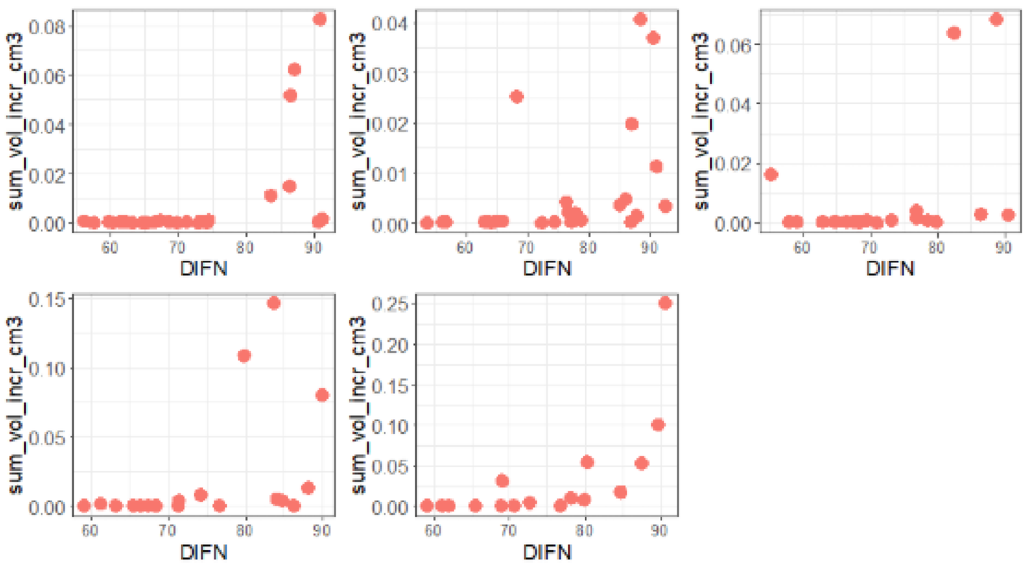

Figure 5. Effects of light effects within different browsing classes,

From one on the top left to five on the bottom right. The results show the correlation between growth from the severity of damage from browsing (In a scale from one, the top left, to five the bottom right), the light availability on the X axis and volume growth on the Y axis. These results show the effects on Scots pine from different light conditions, giving increased growth in all five levels of browsing damage. From the graphs shown, the best growth in volume is in the highest light availability from the sites, where neither low nor high browsing pressure influences the volume growth.

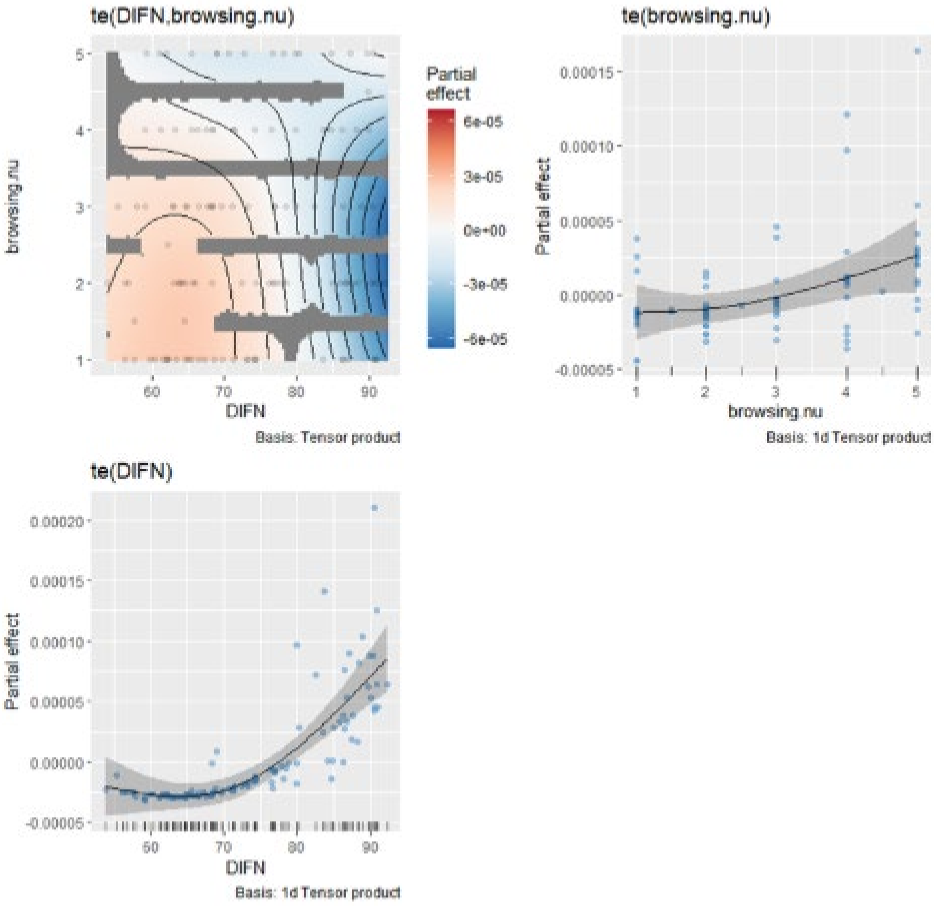

Figure 6. GAM analysis.

GAM analysis shows 3 different graphs; the top left shows the effect of each predictor, between the light availability on the X axis and the 5 levels of browsing damage on the Y axis in terms of volume growth for Scots pine growth. The effect of the predictors shows significant results to the effects of light and browsing in Scots pine. The partial effect (Volume growth), red to blue colors to see where the volume growth was higher to lower. From the graph, it shows greater volume growth in increasing light available. However, the increased effect of browsing in higher light conditions is significant. This means if a sample is from an open area of 90+ DIFN, the sample loses more potential growth if it is browsed compared to a sample within a shaded area of 60-70 DIFN, where less potential growth is achievable. This means too much light for Scots pine gives increased effect to browsing where more growth would be lost.

The rightmost graph shows correlation between browsing levels and the partial effect (volume growth) where the average follows a linear line, here you can also see from the linear line a relationship or correlation between light availability and browsing. The light importance still gives more growth from Scots pine in heavily browsed saplings. The bottom graph shows the correlation between Partial effect and DIFN. Where the results show the same effect of increased growth in volume with increasing light available, just as Figure 3.

4. Discussion

The goal of this study was to answer what the relative importance of light versus browsing damages are for Scots pine in Northern Sweden. We hypothesized that light would show greater importance in terms of volume growth compared to browsing damage, which acts as a secondary effect.

These findings also agree to prove previous studies correct where light is of great importance to Scots pine growth (Junttila et al., 1993; Basler et al., 2019) compared to reindeer browsing. From the results shown by the statistical analysis, the current hypothesis was correct of light availability showing acting a dominant role compared to browsing damages in terms of volume growth for Scots pine. Comparing figure 3, figure 4 and figure 5, a clear pattern of light available enhances volume growth; browsing damages shows little to no pattern in terms of growth. Even in higher browsing damages, light still showed greater growth/ importance where more volume growth was shown to exist in heavy browsing. The data could help provide more knowledge to forest owners with a production focused Scots pine forest and the effects of browsing on pine does not show as large effects on growth compared to high light conditions.

Although browsing was less important compared to light availability, it does not mean it should be excluded from factors that affect growth. This remark has limitations, where this is one case from samples in Northern Lapland, which only represent one land type and species in Sweden.

Canopy openness controlled the growth of Scots pine saplings, where the browsing also shows a consistent impact upon the growth because of the relationship between the growth affectors. The results of GAM (Figure 6.)/ Light and browsing correlation (Figure 5.) indicated significant interaction between light conditions (openness) and browsing, the more open areas exhibiting high levels of browsing damages. The pattern suggested that reindeer and moose feed largely in open areas, which apparently provide more abundant and more nutrient-rich fodder, as compared to more closed-canopy environments. However, the fact that I observed a significant increase in growth with increasing browsing pressure indicates that the browsing effect was clearly overridden by the effect of light environments. The result also implied that GAM might fail to separate effectively the unique contributions of two factors.

Similar significant effects from browsing correlation to volume growth alone are not seen (Figure 4.). Where isolation of the importance/ effects is misinterpreted by the importance of light and its effect on volume growth even in high light environments, where more serious browsing damages are noted. From these results, we could see that light availability/ openness acts as a proxy for growth in the volume of Scots pines.

I noted that even with the effect of light being highly significant and the GAM model explaining 46% of total variability in the dataset, the graphical representation of the growth-openness relationship suggested considerable variability in growth under a given level of openness. There are some reasons behind this variability; two of them are that the climate and soil factors from each sample differ, leading to variability in volume growth in each sample. This would also include differing climate and soil variability from each of the 8 sites. A secondary reason is variability in each sample's genetics and therefore their growth, depending on when each individual sample starts their growth in spring to when going dormant for winter. Lastly, other negative effects not included can have affected their growth and given variability in the results. For example, these could be fungal attacks, snow damage, trampling, or other parasitic insects.

Unfortunately, since relying on existing samples and not collected personally, it has therefore been a difficult process to further explain the multiple site variabilities. These variabilities range from climate of the sites, the site conditions, climate at the time of collection, the detailed number of reindeer browsing in the saplings, and the data collected from the browsed seedling samples. Because of this, the sites will be explained from pictures gathered during the destructive sample collection and discussions from my supervisor to source and explain the browsing damages and climate. Since the old wood samples were gathered for forest fire research, not for light availability and reindeer browsing. This could have had an effect on growth which was not tested; therefore, our data could prove to also show an effect on Scots pine volume growth.

The future research and development from this study should help to show the complex system of the relationship between Scots pine multiple growth affecters and the difficulties to show one singular affect by itself, but also the importance of light to Scots pine growth.

5. Conclusion

This study asked the question of how light conditions and reindeer browsing pressure affect Scots pine in northern Sweden and the hypothesis was the effect of light will show greater difference in growth compared to reindeer browsing pressure. To test this, samples previously collected from areas around Jokkmokk and Arjeplog, northern Sweden. The results agree with the hypothesis that light availability has a higher effect on Scots pine compared to reindeer browsing. Where this also agrees with previous data supporting the effects of light availability on Scots pine however, in this scenario, browsing from reindeer in Northern Sweden show to be of less importance to volume growth. Although these results show differences in Scots pine growth from light availability differences and having more effect than browsing, more studies are needed to further staple this as something true.

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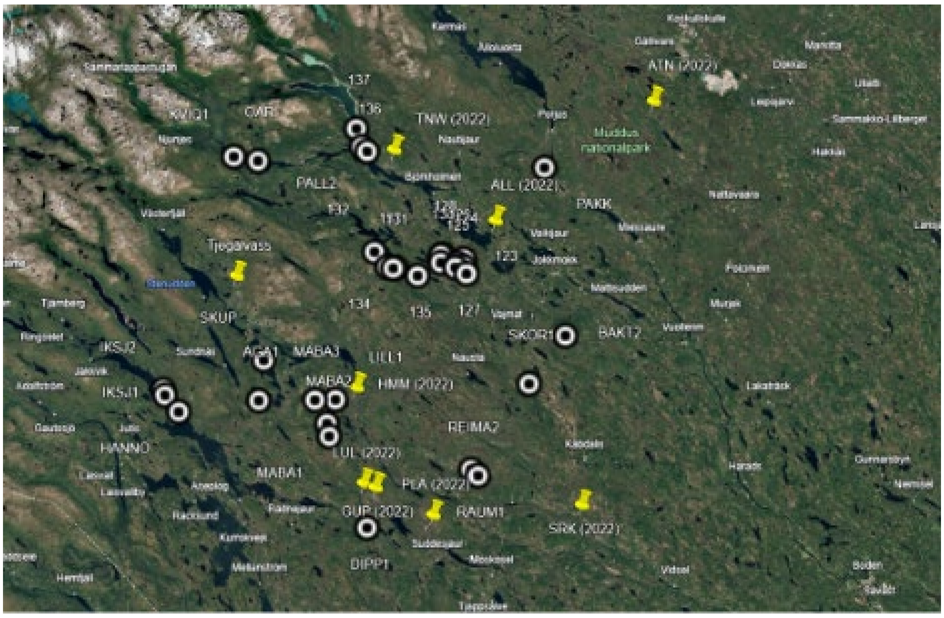
Appendix 1

Coordinates of 2022 sample areas:
ATN: 66°59'45"N 20°26'13"E
TNW: 66°53'02"N 18°48'24"E
ALL: 66°42'33"N 19°26'03"E
HMM: 66°18'06"N 18°34'45"E
LUL: 66°04'01"N 18°37'32"E
GUP: 66°03'23"N 18°41'47"E
SRK: 66°00'33"N 19°56'33"E
PLA: 65°59'20"N 19°02'44"E

Appendix 2

The total number of areas from the 4-year collection period, from 2020 to 2023.



Appendix 3

One of samples collected with browsing damages. Some species are also seen in the background of pines or other evergreen species.

One of samples collected with browsing damages. Some species are also seen in the background of birches.

Appendix 4

The transition from the Medieval Warm Period towards the Little Ice Age was characterized by an increased growth of pine saplings. These dynamics occurred in parallel with the increase in fire activity observed in independently developed fire history reconstruction. I speculate that the increase in fires, most of which were likely not stand replacing, resulted in more open forest conditions promoting early growth and overriding effect of generally colder conditions during LIA. The results support the view of disturbance histories as important controls of biomass accumulation rates in forest ecosystems and call for caution in interpreting tree growth patterns as immediate proxies of climate variability.

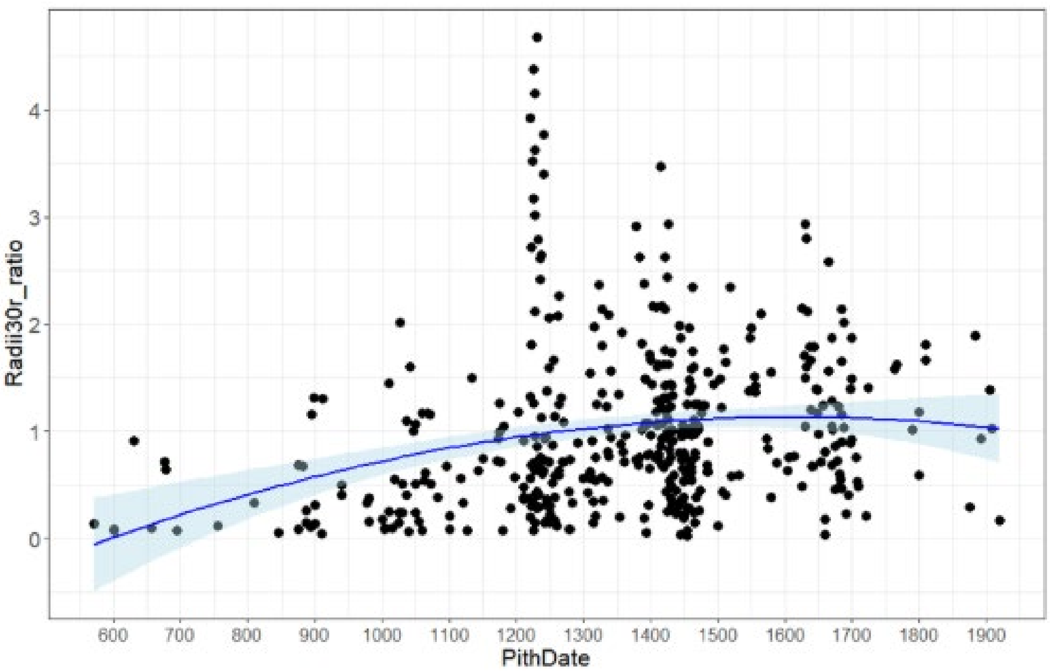


Figure 7. Growth at pith, a proxy of light conditions over 1000 years in Lapland.

X axis shows pith date and Y axis – the cumulative 30-year increment at the pith. There are two well-sampled periods - between the year 1200 and 1500 and one from 1650 to 1700. The blue line shows the average growth rate from the sample plots where the average growth increases to its peak in 1500-1600.

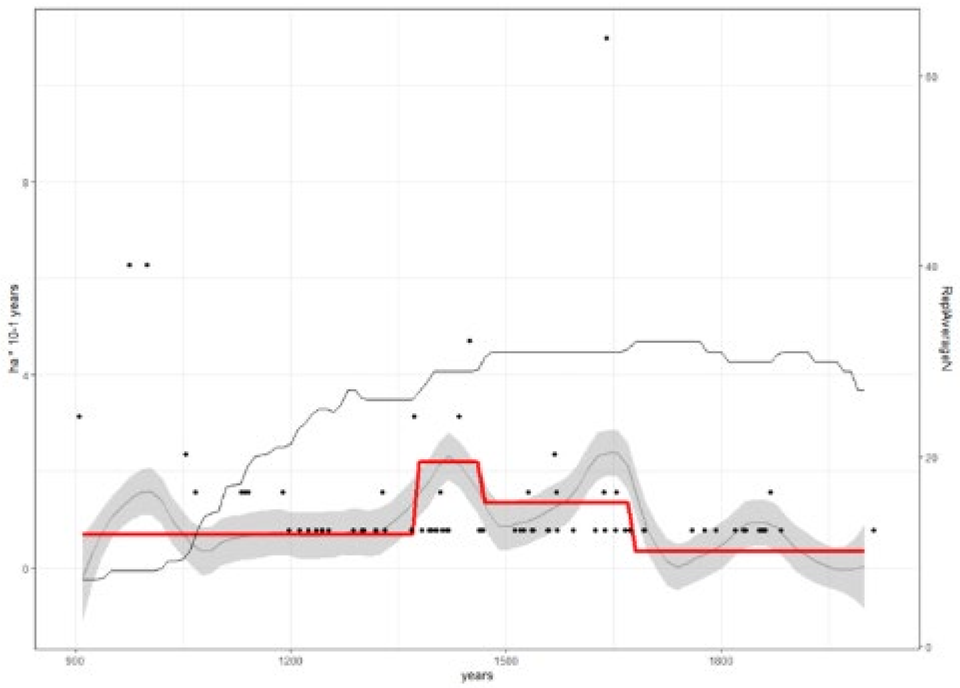


Figure 8. Reconstruction of fire activity in the studied region over 1000 years.

From the figure a hotspot of fires is seen around 1400 and 1700, seen from the collected scar data and its year of scar-forming within the ring in Lapland affecting the land. The average intensity of forest fires is low with four high intensities spanning over a large period of time.

Capitalizing on the observation that pine growth was largely controlled by light conditions, I reconstructed openness of the forests in the studied sites over the last 1000 years. Transition from MWP to LIA was associated with an increase in pine growth. The results suggest that growth of pines was positively correlated with the levels of fire activity, the LIA (Little Ice Age) period exhibiting better pine growth than MWA (Medieval Warm Anomaly) period. This could mean drier climate in LIA compared to MWA and therefore having higher chances of forest fires. The forest fires then give large openings in the canopy letting in more light to the understory. However, the forest fires in this period were not of the highest intensity where it was standing replacing. The fires are rather taking out single trees, opening up spaces of replacement understory.

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