VARIANCE OF SAPLING AND ADULT MOUNTAIN BIRCH RESPONSE TO CLIMATE

An Undergraduate Research Scholars Thesis by

JACLYN GUZ

Submitted to the Undergraduate Research Scholars program
Texas A&M University
in partial fulfillment of the requirements for the designation as an

UNDERGRADUATE RESEARCH SCHOLAR

Approved by
Research Advisor: Dr. David Cairns

May 2016

Major: Environmental Studies

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ABSTRACT

Variance of Sapling and Adult Mountain Birch Response to Climate

Jaclyn Guz
Department of Geography
Texas A&M University

Research Advisor: Dr. David Cairns
Department of Geography

Arctic treelines have been used as global indicators of climate change. Study has shown that terrestrial vegetation has migrated up-and-down mountain sides throughout the Holocene. Mountain birch (*Betula pubescens* subsp.*czerepanovii*) is the dominant treeline species in northern Sweden. There has been extensive research on how mature mountain birch responds to change in temperature and precipitation. However, there has not been a comprehensive study on how mountain birch trees respond. This study evaluates the potential changes in the sapling mountain birch trees across the treeline in northern Sweden. Data from mountain birch tree-ring chronologies from sixty-nine field sites in northern Sweden are used to create a tree ring width index, and explores its relationship to climate. Three global climate models are then used to predict future RWI values. Results indicate that sapling trees RWI correlate with summer temperatures, but does not strongly correlate with precipitation. It is predicted that when compared to mature trees, saplings will not have a consistent response in how they are impacted by climate change due to the differences in factors that influence the establishment of trees.

DEDICATION

I dedicate my undergraduate thesis to my grandfather who helped me with my first research project in high school. Without his encouragement I would have never started my journey in research. He was always willing to go out into the field during a Texas summer and spent countless hours teaching me statistics and helping me prepare for oral and poster presentations. I want to thank him for taking me hiking and participating in Indian Princesses. Mostly I want to thank him for moving to Texas and taking an active role in my life.

ACKNOWLEDGMENTS

First, I would like to thank my advisor Dr. David Cairns, for giving me the opportunity to complete this research project. He has been critical during my undergraduate career. He taught the first course I took at Texas A&M University, wrote me countless of letters of recommendation, and gave me critical advise while preparing to apply for gradate school. I would not have been able to have such a wide variety of experiences during these three years without his continued support.

Second, I would like to thank the Texas A&M University LAUNCH office for allowing me to participate in the Undergraduate Research Scholars program. Special acknowledgements to Ms. Annabelle Aymond, Administrative Assistant, Undergraduate Research, LAUNCH for her unwavering patience editing each installment and Dr. Duncan MacKenzie, Associate Director, LAUNCH: Undergraduate Research, for teaching the thesis-writing course and being my Leadership Scholars Advisor.

CHAPTER I

INTRODUCTION

Treeline

Variations in climate are most notable in extreme environments such as high elevation and latitude (Young et al. 2011). Shifts in vegetation distribution are often indicators of climate change. The transition between two vegetation regions is known as an ecotone. Mountain ranges often create ecotones because of their variety of climates across a slope and elevation gradient. An ecotone that is often observed and studied is the treeline. There has been debate about defining and classifying treelines. The term treeline can vary from the physiological species limit (Pederson *et* al 2004), to the boundary between full-sized and dwarf trees (Takahashi *et al*. 2005; Tømmervik *et al*. 2004). This study will use the definition that treeline ecotones are scattered trees between the forest and tundra (Holtmeier 2003; Holtmeier & Broll 2005; Macdonald *et al*. 1993; Smith *et al*. 2003; Sveinbjörnsson 2000; Sveinbjörnsson *et al*. 1996). Trees at their physiological limit are ideal to study because they have a greater radial response to climatic changes than trees at lower elevation and altitudes (Fritts 1976; Helama *et al.* 2004; Kirchhefer 2001). The growth and advancement of saplings of tree species above the present treeline ecotone is one of the best indicators of vegetation susceptibility to climate change (Holtmeier & Broll 2005). Saplings require a larger period of optimum conditions to establish themselves above the treeline (Holtmeier & Broll 2005; Harsch *et* al., 2009).

Alpine and arctic treelines have been used as global climate change indicators (Kupfer & Cairns, 1996; Harsch *et* al., 2009). Mountain birch has been documented to show a greater response to temperature change than other alpine species (Young et al. 2011; Levanic and Eggertsson 2008;

Kirchher 1996; Karlsson et al. 2003). The treeline in Northern Sweden is ideal to study, because it has an abrupt transition between forest and tundra (Cairns & Moen 2004; Moen & Danell 2003).

There are many variables that influence the location of a treeline. Climatic variables include low temperature and precipitation (Smith *et al*. 2003). Temperature does not directly influence the treeline, but it does influence a tree's the ability to acquire enough carbon (Neuvonen *et al.* 2001). Some of the factors that influence temperature are elevation, wind, topography, slope, and albedo of ground cover (Holtmeier & Broll 2005). There has been wide spread acknowledgment that increased temperature leads to the advancement of treelines across the world (Harsch et al. 2009;). Overall research has shown that trees are able to adapt to climatic change (Holtmeier 2003; Kullman 1993).

Northern Sweden treeline

Sweden's northern treeline is primarily composed of mountain birch (*Betula pubecens* ssp. *czerepanovii* (Orlova)) and Scots Pine (*Pinus sylvestris* (L.)). Mountain birch dominates the majority of the treeline (Young et al. 2011). The mountain birch treeline is sensitive to variations in climate variables that include temperature, precipitation, and the North Atlantic Oscillation (NAO).

The North Atlantic Oscillation (NAO) is a fluctuation in atmospheric pressure between Iceland and the Azores Islands. In its positive phase, the pressure difference between Iceland and the Azores is high. This results in a strong polar vortex and fast moving westerly winds blowing from mid-latitude regions to the artic. During this period Northern Europe experiences an increase in temperature and precipitation. A weak polar vortex results in weaker winds and Northern Europe experiencing below average temperatures. NAO phases can last for several years. The most recent negative phase lasted from the 1940's to the 1970's. Since the 1970's NAO has experienced an extended positive phase (Hurrell 1995; Hurrell & Dickson 2003; Rogers 1985). The correlation between NAO, temperature, and precipitation has been well documented (Rogers 1985). NAO accounts for 21 % of temperature variation in Sweden (Chen and Hellstrom 1999), and 31% of winter temperature variation.

In addition, mountain birch are sensitive to non-climatic variables such reindeer (*Rangifer tarandus* (L.)) herbivory and defoliation by cyclical moth outbreaks (*Epirrita autumnata* (Borkhausen). Semi-domesticated reindeer feed on mountain birch leaves. Studies have shown that reindeer graze on seedlings have a negative impact on the regeneration of defoliated mountain birch (Cairns & Moen 2004). Increases in moth outbreaks could harmfully impact mountain birch by leading to a decline in mountain birch annual growth.

Mountain Birch response to climate

There have been a variety of studies addressing climatic influences on mountain birch trees. Studies have shown that trees along the boreal forest ecotone depend largely on the summer growing season temperature to determine the treeline. This is because evidence has shown that in order to experience cambial activity mountain birch requires a minimum of three weeks in which they are not exposed to freezing temperatures (Schmitt et al. 2005). There is debate about when the optimal growth period is for mountain birch trees. Previous study has shown that June

(Kullman 2003) and July (Schmitt et al. 2005) temperatures are most important for annual growth in established mountain birch tree. Studies in northern Norway (Kirchhefer 1996), Sweden (Eckstein *et al* 1991), and Iceland (Levanic & Eggertsson 2008) have found that mountain birch responds to June and July temperatures of the current growing season.

Overall there has been little evidence over the 20th century to support that mountain birch are sensitive to precipitation variability (Young et al. 2011). In Iceland mountain birch didn't show a significant response to precipitation (Levanic & Eggertsson 2008). There has been a mixed response to precipitation in Norway and Sweden. Two studies showed no response to precipitation (Karlsson *et al.* 2005; Kirchhefer 1996), while a third showed response to the previous year's precipitation (Eckstein *et al* 1991).

The non-growing season can play a significant role for mountain birch annual growth. Snow helps maintain the temperature of soil and provides moisture during the summer. However to much snow can shorten the growing season. Historically, higher temperatures and early snowmelt has reduced seedling mortality and increased annual growth (Kullman, 2002; Barbeito *et* al., 2002.).

Established and sapling Mountain Birch trees

Compared to the early Holocene, modern day climate is in the Scandinavian Mountains consist of warmer, drier summers, and less snow in the winter. An increase in fast-growing saplings can be attributed to a series of warm summers and mild winters (Kullman 2001).

It has been predicted that birch trees will isolate themselves to where snow accumulates. In comparison, earlier snow melting and warmer summers may lead to better conditions for germination and seed establishments.

Many studies have been done on how established mountain birch responds to changes in climatic variables. Established trees are more tolerant to extreme environments than saplings. Established mountain birch trees often have extensive root systems and biomass that makes them more resilient to extreme storms (Smith et al., 2003). Dendroecological research has shown that seedling have a negative response to summer drought due to the inability to tap into deep, moist soil (Kullman 1989).

Dendrochronology research

Dendrochronology is the study of analyzing the patters of tree rings over time. Tree-ring patterns can help improve our understanding of historical and predicted climate. Increased temperature and precipitation will theoretically increase tree growth and potentially raise the tree line.
The location of the mountain birch treeline is economically important for Sami reindeer herding and ecologically important for the stability of the region. There has been debate on the economic value of denrochronological studies performed on mountain birch (Sonesson & Hoogesteger 1983). Some researchers have expressed a variety of obstacles working with mountain birch rings that include: missing rings due to insect outbreak (Hoogesteger & Krlsson 1992), inability to cross-date due to suppressed rings and ring morphology (Levanic and Eggertsson 2008), wood morphology, and decay of dead wood (Kirchhefer 1996). Despite the limitations of dendroclimatic studies, the technique provides valuable understanding about possible future

vegetation changes under adjusted climate. This information could be utilized to understand other forest ecotone dynamics.

In this research, I conduct a regional dendroecological investigation of climate influences on sampling mountain birch at the treeline in Northern Sweden. I use core samples, climate records, and global forcing scenarios to determine how changes in temperature and precipitation will impact the growth of sapling mountain birch trees. I hypothesize that sapling trees will respond most to changes in temperature during the months of June and July, and that there will be variation in response to precipitation. In addition, I hypothesize that that the climate forcing models will result in an increase in annual ring width index.

CHAPTER II

METHODS

Field data collection

Dr. David Cairns collected a large data set in 2012. The site is located on the eastern side of the Scandes Mountains in Northern Sweden. The small tree data was collected in 2012 from sixty-nine field sites that were established within 6 reindeer herding districts. Each site consisted of 10 x 50 plot within the tree line ecotone. Within each site, basal cross-sections were collected for live mountain seedlings and saplings <5m in diameter. Birch tree cross-sections were analyzed and put into databases. I used this mountain birch core database to analyze sapling mountain birch tree by running global climate models and comparing the trees response for precipitation and temperature.

Laboratory methods

Cores were statistically cross-dated using COFECHA (Homes 1986). A 32-year spline with 50% frequency response was used to detect errors in cross-dating (Grissino-Mayer 2001). Cores that had poor correlations were adjusted or deleted if they could not be fit to the master chronology for their region.

Thirty-six mountain birch chronologies were developed in this study. The chronologies were developed based on herding district. Each of the four districts had nine chronologies based on the three global climate models and three scenarios.

Table 1. Summary statistics for mountain birch (*Betula pubescenes* subsp. Czerepanovii) master chronologies

Herding Districts	Nearest Weather Station	No. of Plots	No. of Trees
Girjas	Abisko	4	22
Laevas	Abisko	11	79
Sorkaitum	Abisko	6	18
Vilhemina	Hemavan	16	65

The monthly climatic influence on an annual ring width was determined using a stepwise linear regression based method on the standardized ring-width chronology. The nearest weather station to each site was used. The monthly precipitation and temperature data from the current and prior year was used as the independent variables in the regression analysis. Individual climatic factors that were significant (alpha =0.05) were kept in the regression model. Regional climate was obtained from the Swedish Meteorological and Hydrological Institute and the Abisko Scientific Research Station. The nearest weather station for Laevas, Sorkaitum, and Girjas districts was Abisko (45-80 km), where the mean daily temperature and precipitation data have been recorded since 1913. The Vasterbotten districts of Vilhelmina borra and Vilhemina sorda were closest to the Hemavan weather station (65 km compared to Abisko 375 km to Abisko), where the mean monthly temperature data was acquired since 1966.

To determine the relationship between growth and regional climate, the residuals for each site were regressed against the mean monthly temperature and precipitation in the current and prior proceeding. This allowed understanding the relationship of the growing year.

The predicted average monthly temperature and precipitation for three global climate models (GCMs) were used to predict future RWI at each site. The GCM data was acquired at the KNMI Website (http://climexp.knmi.nl). The three models include the CGCM3 (Canadian Center for

Climate Modeling and Analysis), ECHAM5 (Max Planck Institute for Meteorology), and the HADCM3 (Hadely Center for Climate Prediction and Research). Three climate-forcing scenarios (A1B, A2, and B1) developed by the Inter-governmental Panel on Climate Change (IPCC) were included. Scenario A1B is a moderate (~2.8 8 °C), scenario A2 represents a future climate that has significantly higher temperature than present time (~3.4 °C), and scenario B1 has the least amount of increase in temperature (~1.8 °C) (Christensen et a. 2007). In Scandinavia, the result of all of these scenarios is warmer and wetter conditions.

Table 2. Beginning and ending years of simulations for three GCMs and scenarios A2, A1B, and B1.

	GCM					
	HADCM3		ECHAM5		CGCM3	
Scenario	Beginning Year	Ending Year	Beginning Year	Ending Year	Beginning Year	Ending Year
A2	2000	2099	2001	2100	2001	2100
A1B	1860	2199	1860	2200	1850	2300
B1	2000	2199	2001	2200	2001	2300

The methodology was modeled after Dr. Cairns' work on the relationship between the mountain birch and Scots pine treeline in northern Sweden and is related to the approach used in MT-CLIM for predicting temperature and precipitation at treeline (e.g., Cairns 2005; Young et. all. 2011; Grafius and Malanson 2009).

CHAPTER III

RESULTS

Seasonal regression

The mountain birch chronologies showed that temperature of the current summer temperatures was significant for radial growth. Three of the four sites indicated positive influence on ring width. Herding sites Sorkaitum and Vilhemina showed a significant positive growth in current June temperatures and Laevas showed growth in July. Sites Laevas and Sorkaitum showed significant growth for previous winter month temperatures. In all cases, the sign of the regression coefficient was positive. This indicates that warmer summer conditions are favorable for increased radial growth and mild winter temperatures may be beneficial as well (Table 3 & 4). There was little consistency for temperature in current or previous years. Sorkaitum and Vilhemina did show a positive response to precipitation in December (Table 3 & 4).

Table 5: Regression statistics for cliamte - ring width models for mountain birch (*Betual pubescens* subsp. *Czerepanovii)* at all study sites

Site	Adjusted R^2	F	p(>F)
Girjas	0.42	10.6	<0.001
Laevas	0.27	22	<0.001
Sorkaitum	0.51	11.9	<0.001
Vilhemina	0.34	9.46	<0.001

The predictive ability of the climate – ring width regression model varies over a large range. The majority of the models were significant at $\alpha = 0.05$ determined by the F statistic for each model. Adjusted R^2 values varied between 9.46 and 11.9 (Table 5).

Table 3. Significant predictors of ring width for mountain birch (*Betula pubescens* subsp. *Czerepanovii*) by site for current year

	Previous Year											
Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature												
Girjas				+								+
Laevas							+					
Sorkaitum						+						
Vilhelmina						+						
Precipitation												
Girjas										+		
Laevas												+
Sorkaitum												+
Vilhelmina												

Note: Significant variables are indicated by either + or - depending on the direction of their influence on ring width

Table 4. Significant predictors of ring width for mountain birch (*Betula pubescens* subsp. *Czerepanovii*) by site for previous year

	Previous Year											
Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature												
Girjas						+						
Laevas	+										+	
Sorkaitum				+							+	
Vilhelmina												
Precipitation												
Girjas			+			+						
Laevas												
Sorkaitum									+			
Vilhelmina												

Note: Significant variables are indicated by either + or - depending on the direction of their influence on ring width

Relative increase of Mountain Birch ring width index

The predicated RWI at year 2100 differ among models and scenarios tested. Scenario A2 represents the highest temperature than present time showed slight decreases in ring width values in all herding sites accept Girjas (Figure 1). Herding site Laevas continued to show a decrease in ring width value of all other models and scenarios. Girjas and Sorkaitum showed an increase in ring width index for all other models and scenarios (Figure 2).

Figure 1. Measured and predicted ring with index (RWI) value for selected stations and scenarios: (1) Laevas, HADCM3, A2; (2) Girjas, HADCM3, A2; (3) Sorkaitum, ECHAM5, A2.

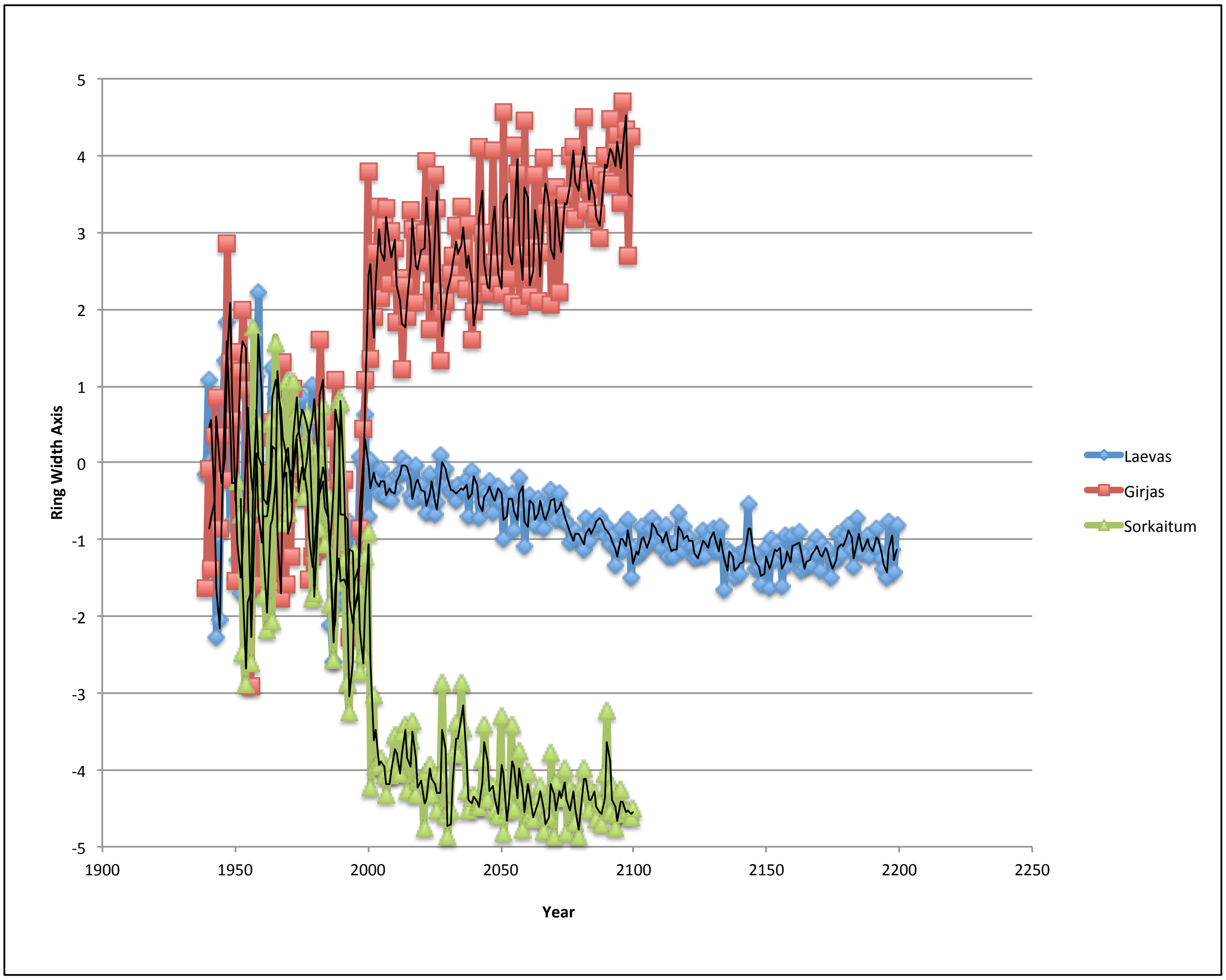
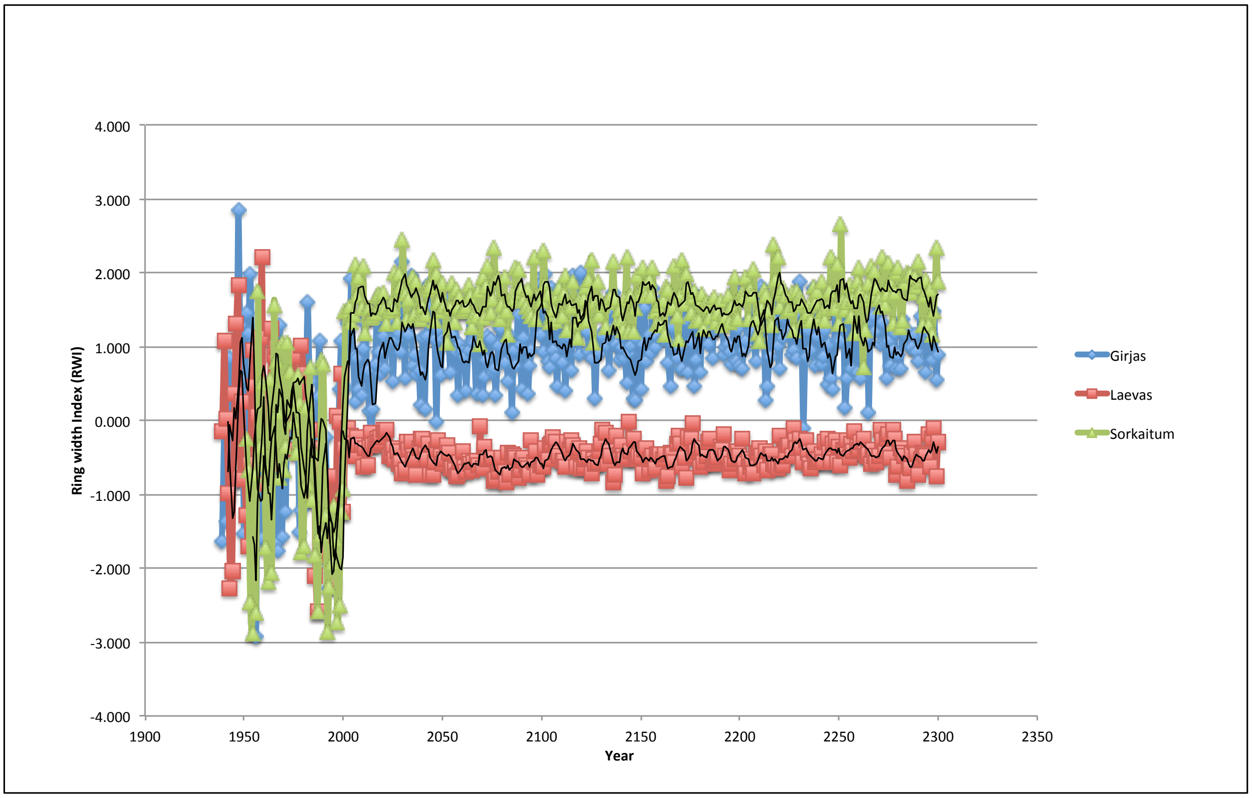


Figure 2. Measured and predicted ring with index (RWI) value for selected stations and scenarios: (1) Girjas, CGCM3 A1B; (2) Laevas, CGCM3, B1; (3) Sorkaitum, ECHAM5, B1.



CHAPTER IV

CONCLUSION

June and July temperatures of the current year appear to be the primary climatic determinant in annual tree ring growth. Precipitation appeared to have little consistency in contributing to annual growth, however it did appear that for two of the four sites had significant winter months. These result coordinate with a variety of previous dendroecological studies of mountain birch. It appears that the current-year summer temperatures have the greatest influence on sapling mountain birch growth. The short growing season has resulted in a consistent relationship between tree growth and mid-summer temperatures. The lack of consistent response in precipitation is expected. Birch has been shown to be resilient to changes in precipitation over the 20th century (Kullman and Kjallgren 2006). The absence of a uniform a response indicates that other variables climatic and non-climatic variable may be critical to sapling mountain birch annual growth.

When calculating predicted change, there is a large amount of uncertaintys in climate modeling that needs to be improved. All of the models assume that a certain amount of warming will occur; the uncertainty lies in how much and how quickly (Raisanen & Joelsson 2001). The models also assumed that mountain birch would be able to adapt to climatic changes. Over thousands of years mountain birch have adapted to a cold climate and frequent summer drought. It is reasonable to predict that accelerated climate changes such as an increase in temperature and precipitation could be potentially harmful to a species that has not been used to this environment. Evidence can be found when looking into other forests response to climate change such as the

Green Mountains of Vermont where abrupt climate change has lead to an increased mortality rate among vegetation (Beckage et al 2008).

Abrupt environmental changes would make it harder for population to adapt and result in uncertain repercussions for the ecosystem. The autumnal moth (*Epirrita autumnata* (Borkhausen) is a species commonly found in Scandinavia that reaches outbreak levels in northern mountains (Bylund 1997). Their eggs hatch in spring when mountain birch bud break occurs to feed at the base of the tree (Tenow 1972). Prolonged outbreaks can reduce radial growth of mountain birch and potentially suppress the treeline (Nuorteva 1963). These outbreaks only occur in Northern Sweden because other patristic ants and wasps cannot survive the colder weather. Potentially warmer weather could allow other species and wasp to expand their range along the mountainside and compete with autumnal moths (Ruohomaki *et al*. 2000; Nuorteva 1963).

An additional side affect to increased summer temperatures is autumnal moth hatching earlier and before bud burst, resulting in lack of mountain birch spring leaves (Bylund 1997; Rouhomaki *et al.* 2000). Egg mortality may also decrease due to an increase in winter temperatures (Klemola *et al* 2006). The lack of a winter freeze would allow more moths to survive and feed to the mountain birch. This could negative effects on mountain birch annual growth.

An ecosystem that has experienced a similar scenario in increased temperature is Northern Michigan and the bean leaf beetle and corn flea beetle. Milder winter temperatures have put less stress on insects and have resulted in an increase in survival to spring. The bean leaf population spreads the pod mottle virus to early emerging soybean plants (Johnson et al. 2009; Stehr 1970). The increased corn flea beetle has lead to a spread of bacteria, Stewart's wilt that is harmful to seed corn production. Both species of beetles are harmful to the vegetation and lead to a decrease in crop yield (Johnson et al. 2009).

Mountain birch trees are accustomed to snow in the winters and frequent summer drought. It should be noted that the Abisko site is one driest locations in the region studied (Young et al. 2011). It was assumed that the birch trees would be able to adapt at a rate fast enough to respond to climate change. However, a rapid increase in precipitation may not give time for the species to adapt. An example of how increased precipitation could potential be detrimental to species adapted to season drought is the Texas Mountain Loral (*sophora secundiglora)* The Texas plant is used to annual droughts and does not do well if it remains wet to long. They have adapted to dry conditions (Streets 1937). When heavy rain occurs and they are in an area with poor drainage their roots decay. The plant then loses its capacity to take up water because its roots are damaged. The loss of root mass leads to an inability to take up water in future drought and the plant often dies (Cook et al.1972; Streets 1937). Sapling mountain birch trees that are not adapted to an increased amount of precipitation in summer months may experience similar root decay.

A potential reason to the inconsistency in response is the result of microsite patterns that include microclimate, soil conditions, and duration of winter snowpack (Holtmeier et al. 2003).

Snowpack has been shown to be crucial indicator of mountain birch regeneration (Kullman 1983; Holtmeier et al. 2003).

Study has shown that deflation sites result in extremely poor germination of birch and lack of seedlings. However, it has been noted that young mountain birch grow around the edges of deflation area. The edge effect and frequently exposed roots indicate that the saplings were established before the peak of deflation. It has been predicted that the deflation peak occurred simultaneously with the peak of the reindeer population in the 1970s. The reindeer grazing caused erosion and exposed topography that resulted in creating gaps in between the sapling trees and deflation sites. These caps were beneficial for young birch trees because of the reduced competition for resources, soil temperature increase, and nitrogen mineralization (Broll 2000; Karlsson et al, 2005).

In general Northern Europe is expected to have an increase in temperature and precipitation. The resulting non- climatic changes in soil moisture, snow distribution, and autumnal moth outbreaks will likely have adverse effects on sapling mountain birch.

Future research

Further research should be done on the non-climatic variables that influence sapling mountain birch trees. Variables should include: soil nutrient, rooting depth and root/shoot ratios, and reindeer grazing.

In the future the difference between seedling and sprouted mounted birch annual growth should be studied. This could lead to a greater understanding of the change of mountain ecotones. The sprouts could have the advantage of extra resources, but would open themselves up to disease spread by beetles and other insects. In addition, other factors such as reindeer and insects should be studied to analyze the impact they have sapling mountain birch. This would give an insight on how large of a role climate and non-climatic variable influence the treeline.

In addition, more research should be done on what is the optimal increase in temperature and precipitation for mountain birch. There should models do to determine the potential maximum climatic rate of change mountain birch can withstand. This research could result in understanding Northern Sweden's ecosystem will be able to adapt to predicted changes in temperature and precipitation

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