A Dendrochronological Analysis of Black Spruce Productivity in Wetlands and Adjacent Uplands of Nova Scotia, Canada

By

Submitted in fulfillment of Honours in

Bachelor of Environmental Studies at

Saint Mary's University Halifax,

Nova Scotia Thursday April 2019

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Dedicated to Isabella Vivian Konstantinidis

ABSTRACT

A Dendrochronological Analysis of Black Spruce Productivity in Nova Scotia Wetlands and Adjacent Uplands

by

Georgia Konstantinidis

Coniferous forest uplands and wetlands are abundant in Nova Scotia. Tree growth in wetlands is known to be stunted compared to uplands. The objective of this study was to compare the growth of black spruce trees in wetlands and uplands of four Nova Scotia sites. Along a transect at each site, tree cores were taken from selected black spruce trees, for which tree height and diameter at breast height (DBH) was also measured. Data on peat moss and soil moisture were collected to determine whether trees were in wetland or upland. Black spruce age and tree ring productivity were assessed by analyzing tree cores with Windendro software. The average width of the outermost ten tree rings of each tree core was used as a measure of recent growth and productivity. Black spruce age and growth were relatively consistent across all habitats. Spruce radial growth was not always greater in upland environments, but trees were taller in uplands than wetlands at two of the study sites. Favourable environmental factors for tree growth often resulted in taller trees in upland habitats because the soils are drier. More recent tree growth appears to be indifferent to soil moisture on forested wetland landscapes; I presume it is because of unmeasured effects such as climate change and competition.

April, 2019

Acknowledgements

I must acknowledge the tremendous help of my supervisor Dr. Karen Harper. Dr. Harper never failed to be helpful. I would like to acknowledge the help of my secondary reader Dr. Jeremy Lundholm. Dr. Karen Harper and Dr. Lundholm never made me feel pressured or rushed. I acknowledge Dr. Philip Giles for introducing me to Dr. Karen Harper because I would have not had her as a supervisor. I must also acknowledge the support from the honours coordinator of the BES program, Dr. Cathy Conrad.

The tremendous help of librarian Sally Wood is acknowledged, Sally helped me with my secondary data collection. I would like to acknowledge the help of Jane Kent of Truro, Nova Scotia who helped me use Windendro software. I would like to thank post-doc Sean Haughian, for lending me books on dendrochronology and helping me analyze my tree cores. I must also acknowledge the great help of Garland Xie who helped me use RStudio to create my graphs in an efficient way. I must acknowledge the work Iain Wilson, Logan Gray, Amanda Ring and Morgan Rice contributed to my data collection. Without them I would not have tree cores from two study sites and I would not have the understory data. I must also show how grateful I am to have had the strong support of my family and friends throughout my research.

My data collection and funding would not be possible without the financial support of Dalhousie University, Saint Mary's University, the Government of Canada and Project Learning Tree Canada. The understorey data collection would not be possible without Nova Scotia Labour and Advanced Co-op Education Incentive Application. For my supervisor's research grant of which I used the data, Natural Sciences and Research Council of Canada (NSERC) is accredited. Financial support was given by the Government of Canada through the Environment and Climate Change Canada and Atlantic Ecosystems Initiative, which funded the project Biodiversity and Ecosystem Functioning of Forested Wetlands Across Atlantic Canada.

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Chapter 1: Introduction

Wetlands are terrestrial areas that are waterlogged with saline or non-saline water all or most of the time (Warner & Rubec, 1997; Province of Nova Scotia, 2018a). There are various types of wetlands, which perform ecosystem services contributing to various species and people (Nova Scotia, 2017). Wetlands can be forested or non-forested, such as forested bogs or open bogs (Nova Scotia, 2011). Wetlands receive their water from various natural sources such as rivers and precipitation, which also impact water movement within wetlands (Nova Scotia, 2017; Goslee, Brooks & Cole, 1997). There is limited understanding of the ecological importance and biodiversity of forested wetlands (Brazner & Achenbach, unpublished) and many endangered, at-risk and undetermined species live in wetlands (Clair, 1998; Province of Nova Scotia, 2018b; Brazner & Achenbach, unpublished; Nova Scotia, 2011). Limited understanding makes it difficult to characterize forested wetlands.

Wetlands host water-tolerant species and provide unique ecosystem services, in comparison to upland services, such as carbon sequestration and erosion prevention (Kuusinen, 1996; Bowering, Wigle, & Padgett et al., 2017; Lane, Mack, Day et al., 2017). Many wetlands contain peat which stores carbon (Nova Scotia, 2011; Yarwood, 2018; Dimitrov, Bhattia & Grant, 2013; Heinselman, 1970). Wetlands of Nova Scotia provide refugia for migratory and nursing birds (Brazner & Achenbach, unpublished). Wetlands also provide a safe place for species such as turtles to breed. Species such as Warbler, *Cardellina Canadensis,* Olive-sided Flycatcher, *Contopus cooperi* and Eastern Wood peewee, *Contopus virens* are part of the conservation value of peatlands and treed swamps in Nova Scotia. (Brazner & Achenbach, unpublished).

There are different types of forested wetland and forested uplands across Nova Scotia. Soils and the water table vary between wetlands and uplands. Soils at higher elevations are usually not as deep, therefore, they are more likely to become saturated by deposited nitrogen in comparison to lowland environments (Cienciala, Doležalb & Kopáčekc et al., 2018; Viereck & Johnston, n.d.; Perrette, 2010). Nitrogen and other nutrients are less available in wetlands because of the acidic and waterlogged conditions caused by waterlogging and anaerobic conditions (Bubier, 1991). In addition, microorganisms and the anaerobic conditions of wetlands make them different from uplands, which contributes to their difference in functioning and ecosystem services (Yarwood, 2018).

Black spruce is the dominant tree in many of Nova Scotia's wetlands because it is able to tolerate stressful, infertile (Perrette, 2010), cold and poorly aerated conditions (Paterson, Guy & Dang, 1996; Haavisto & Jeglum, 1994). Black spruce grows on a variety of soil types including wet organic soils. Black spruce has similar genetics to other spruce, but it has been proven to withstand nutrient poor bogs better than other spruce such as white spruce (Patterson et al.,1996). Black spruce of low productivity are usually found on thick deposits of partially decomposed *Sphagnum* peat (Viereck & Johnston, n.d), which is characteristic of wetland environments. Productive black spruce are usually associated with hardwood species and are found on well drained soils such as tills, and river terraces. The most productive black spruce stands usually have a considerable amount of decayed woody material (Viereck & Johnston, n.d).

Historically, black spruce has been important to Canada because it has been used as a pulping species in the economy (Munson & Timmer, 1988; Haavisto & Jeglum, 1994) and spruce is able to support species richness and diversity in a forest for small and large species (Kuusinen, 1996; Bowering, Wigle, & Padgett et al., 2017), making it valuable to the Canadian environment as well. Nova Scotia has a long history of deforestation due to the extensive uses of spruce and many other trees in the provinces forestry sector (Robichaud & Laroque, 2008; Bush, 2018). Less than 5% of the Acadian forest exhibits pre-European conditions (Brazner & Achenbach, unpublished). Most black spruce trees in Nova Scotia are not of old growth stands due to deforestation (Robichaud & Laroque, 2008), and black spruce is not considered a species of conservation concern by the province.

Although black spruce can tolerate unfavorable growth conditions, various biological, geophysical and environmental factors, such as climate, influence the timing, duration, physical anatomies and rate of black spruce growth and productivity that drive this species to grow differently when it inhabits different environments (Karam, 2009 & Cienciala, Doležalb & Kopáčekc et al., 2018 & Amoroso, Lori & Baker et al., 2017; Hofgaard, Tardif & Bergeron, 1999; Campbell & Laroque, 2007). It is important to understand how the environment affects black spruce productivity because of how sensitive the species' productivity is to its environment (Amoroso, Lori & Baker et al., 2017; Karam, 2009; Fleming & Mossa, 1995). Tree productivity can be measured by analyzing tree rings using tree core samples and dendrochronological methods (Haygreen & Bowyer, 1996; Cook & Kairiukstis, 1989; Selig, Laroque, & Marsh, 2007; Huang et al., 2010).

Throughout my secondary research I found no studies on black spruce tree growth in wetlands and adjacent uplands using dendrochronological methods in Nova Scotia. My research on black spruce tree growth in wetlands and adjacent uplands of Nova Scotia fills a knowledge gap in dendrochronology of the province. My study contributes to research of wetlands in Nova Scotia as part of a larger study by Dr. Karen Harper on the Biodiversity and Ecosystem Functioning of Forested Wetlands Across Atlantic Canada which aims to classify wetlands. My research question is if black spruce is more productive in wetlands or adjacent uplands. I hypothesize that black spruce is less productive in wetlands due to the unfavorable growing conditions that wetland environments provide, as other studies have shown (Kuusinen, 1996, Perrette, 2010; Viereck & Johnston, n.d.; Wood & Jeglum, 1984; Haavisto & Jeglum 1994).

Chapter 2: Methods

2.1. Study Area

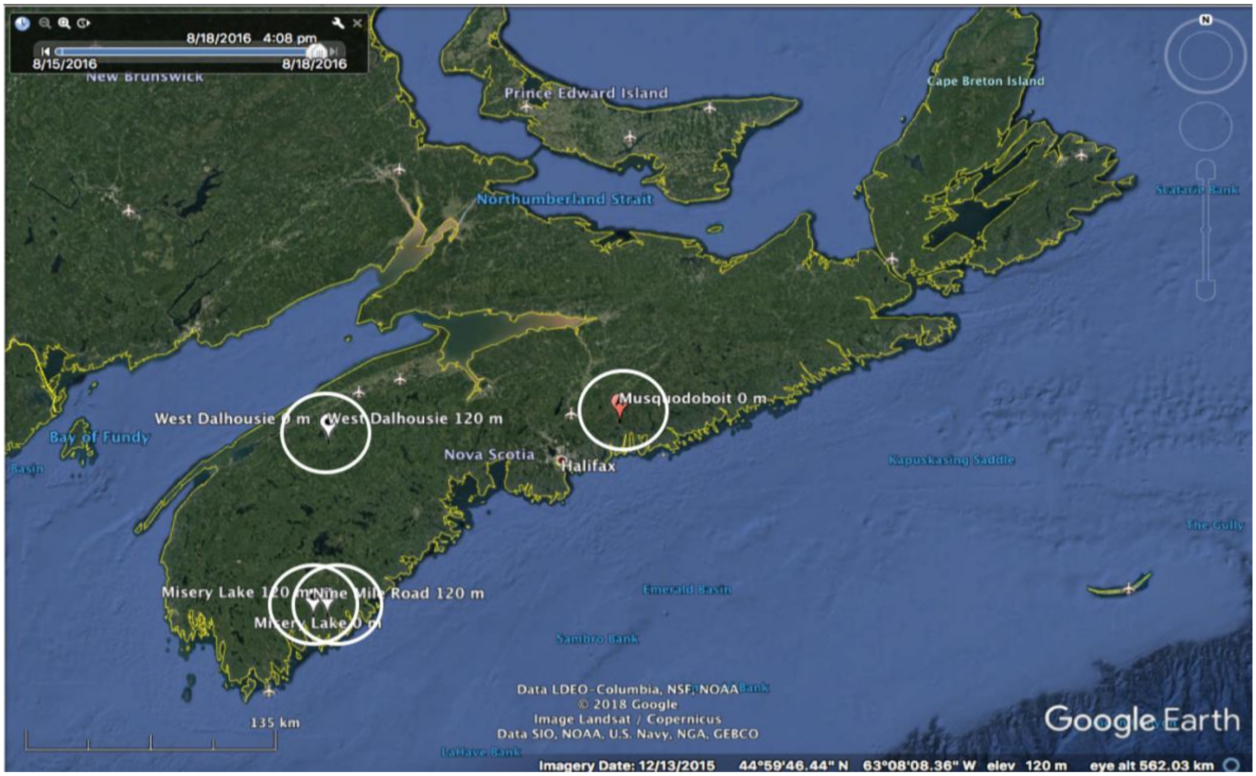

Figure 1. Map of Nova Scotia with four study sites (Musquodoboit, West Dalhousie, Nine Mile Road and Misery Lake) taken from Google Earth.

My study area is located in the southern part of Nova Scotia and consists of coniferous forested wetlands and adjacent coniferous uplands. The study area is characterized as Acadian forest and is dominated primarily by shade tolerant species such as *Picea mariana* (black spruce), *Abies balsamea* (balsam fir), *P. rubens* (red spruce) and spruce hybrids. The study area has a humid continental climate with an average of 1,410 mm of precipitation annually (Ross, 2017). The study area also has a mosaic of different types of forested wetlands and upland forests.

The Musquodoboit study site is located in the southeastern part of the province and it is not part of the greater Musquodoboit salt marsh. The area is not close to much human activity, but it is also not located in a deep forest. Musquodoboit exhibits transitions between open bog, treed bog and a different unclassified forested wetland. By observation it is apparent that the Musquodoboit transect is entirely in forested wetland except for one end of the transect which is in an open bog area containing scattered trees. The Musquodoboit site also contains peat (Wilson, unpublished) making it a peatland ecosystem which contributes to carbon sequestration. The upland of the Musquodoboit study site is significantly higher in elevation in comparison to the uplands of the three other study sites. The Musquodoboit study site has an average high of 23°C in the summer (Environment Canada, 2018).

The West Dalhousie site has an observable distinct transition between the upland and wetland areas which is also reflected by the presence of *Sphagnum* in the lowland site and the absence of *Sphagnum* in the upland site. The West Dalhousie lowland is adjacent to a harvested edge which indicates recent human activity. The annual average high temperature is -1°C and the annual average low temperature is -8°C (Environment Canada, 2018). The Nine Mile Road and Misery Lake study sites are located in the south shore region of the province. The average high temperature of Misery Lake and Nine Mile Road are 23°C in the summer (Environment Canada, 2018). The Misery Lake site did not exhibit a clear change from wetland to upland environment and it exhibited patches of forested wetland and upland forest. Misery Lake is near lake Misery indicating that its wetland possibly gets its water from that lake.

2.2 Study Site Selection and Tree Core Collection

Four study sites, Musquodoboit, West Dalhousie, Misery Lake and Nine Mile Road, were chosen in Nova Scotia as part of a larger study on the Biodiversity and Ecosystem Functioning of Forested Wetlands Across Atlantic Canada. The transect crosses upland and wetland transition at 70 m in West Dalhousie and the transect of Musquodoboit crosses two types of forested wetland. Nine Mile Road and Misery Lake sites were placed in a heterogeneous forested wetland and upland landscape to cross many transitions. The entire Musquodoboit transect was wetland and I went off of the Musquodoboit transect to sample the upland area.

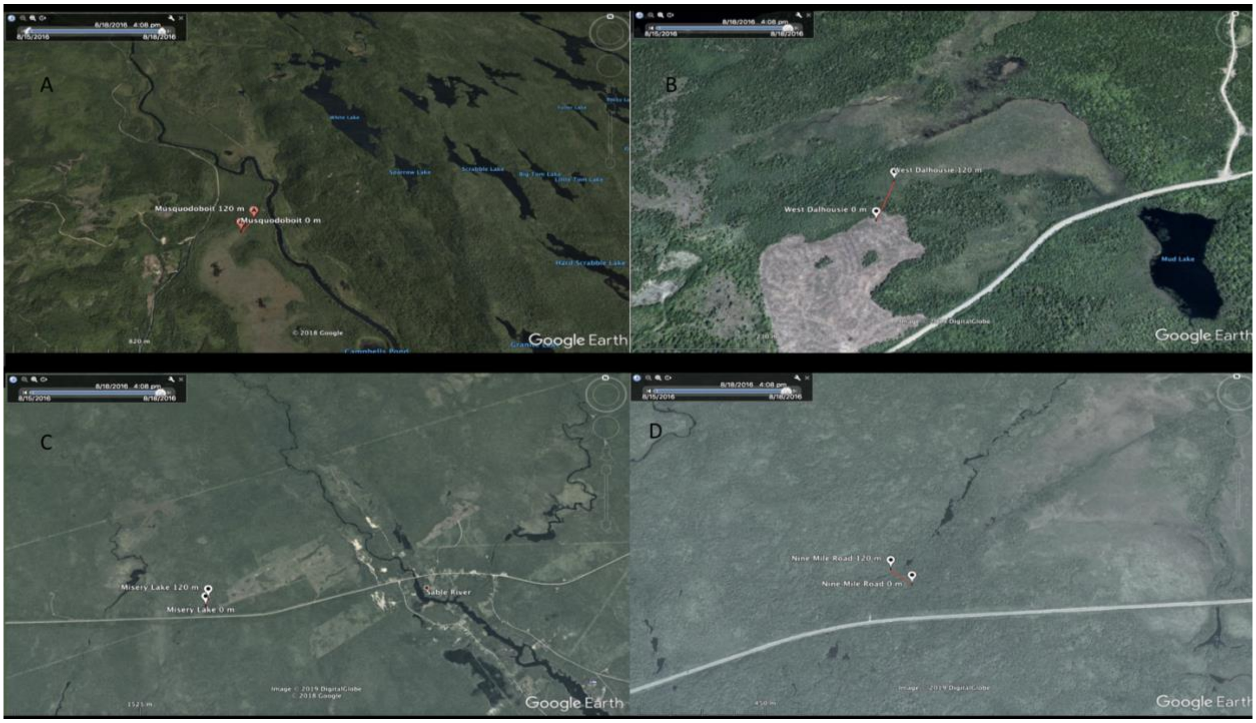

Figure 2. Aerial photos of the study sites: A. Musquodoboit, geographic coordinates: 44.839766N 63.194041W, B. West Dalhousie, geographic coordinates: 44.719083N 65.117572W, C. Misery Lake, geographic coordinates: 43.837519N 65.100920W, D. Nine Mile Road, geographic coordinates 43. 830256N 65.190411W. Images taken from Google Earth Pro V 6.2.2.6613. (March 10, 2019). Nova Scotia, Canada. DigitalGlobe 2018. An area nearby the Musquodoboit transect was sampled as a definite upland approximately 40 m off of the transect and it is labelled 160 m.

Sphagnum cover and soil moisture content were sampled every 1 m in each of the four 120 m transects within 1 x 1 m quadrats. The *Sphagnum* and soil moisture data were used in my study to assess what portions of each transect were wetland and which were upland. In West Dalhousie, Nine Mile Road and Misery Lake, *Sphagnum* percent cover was estimated within the quadrats. In Musquodoboit, *Sphagnum* cover was recorded by presence or absence. *Sphagnum* cover was compared between study sites in graphs created in RStudio by converting the *Sphagnum* content of the Musquodoboit site to frequency within 5 m intervals so that it could be compared to the *Sphagnum* content of the other three study sites that measured *Sphagnum* in percent cover. Soil moisture content was collected using a Lee Valley pH meter. The results of soil moisture were compared between study sites using graphs as well.

Wetland and upland environments were differentiated by on site observation, *Sphagnum* cover and soil moisture. If more than 30 % *Sphagnum* was within a quadrat, it was considered wetland. If more than 40 % soil moisture was within a quadrat, it was considered wetland. If the quadrat had 40 % soil moisture or more and less than 30 % *Sphagnum,* it was still considered a wetland because some wetlands do not have *Sphagnum,* but all wetlands have an abundance of moisture in the soil. In addition, on site observation was also referred to when determining a wetland or upland environment. Individual trees were grouped into upland or wetland categories determined by *Sphagnum* cover, soil moisture content and on-site observation.

Every 20 m along the 120 m transect, diameter at breast height (DBH) was measured approximately 1.4 m from the ground for 1 - 2 black spruce trees before they were sampled because spruce with a DBH less than 5 were not sampled. Black spruce height was measured with a laser range finder and then trees were cored at base height with a Haglof increment borer. Some trees had vegetation obscuring their base which prevented me from coring trees at their true base. In this case, another tree was chosen to core. In some instances, tree cores were rotten and therefore were cored twice if poor quality tree cores were obtained. If the base height was too difficult to access due to ferns or shrubs, trees were cored at breast height. In some instances, not every 20 m of the transect was sampled because there were no trees greater than 5 cm DBH.

Tree cores were mounted on dowels with super glue. The cores were then sanded with 150 and 300 grit sandpaper to make the tree rings stand out more and polish was applied to tree cores to make their rings distinctive from the wood and other rings for analysis. Tree age and ring width were analyzed with Windendro technology in Bible Hill Truro, Nova Scotia Perrenia Innovation Centre Lab. Black spruce age was determined by counting individual tree rings of the tree cores. Cores that had missing bark were given an estimated minimum age by counting the total rings on the longer side of the pith. The average widths of last ten tree rings (2009 – 2018) on each tree core were calculated to compare individual tree productivity. Tree ring width, tree height and tree age were graphed on RStudio to compare results.

Chapter 3: Results

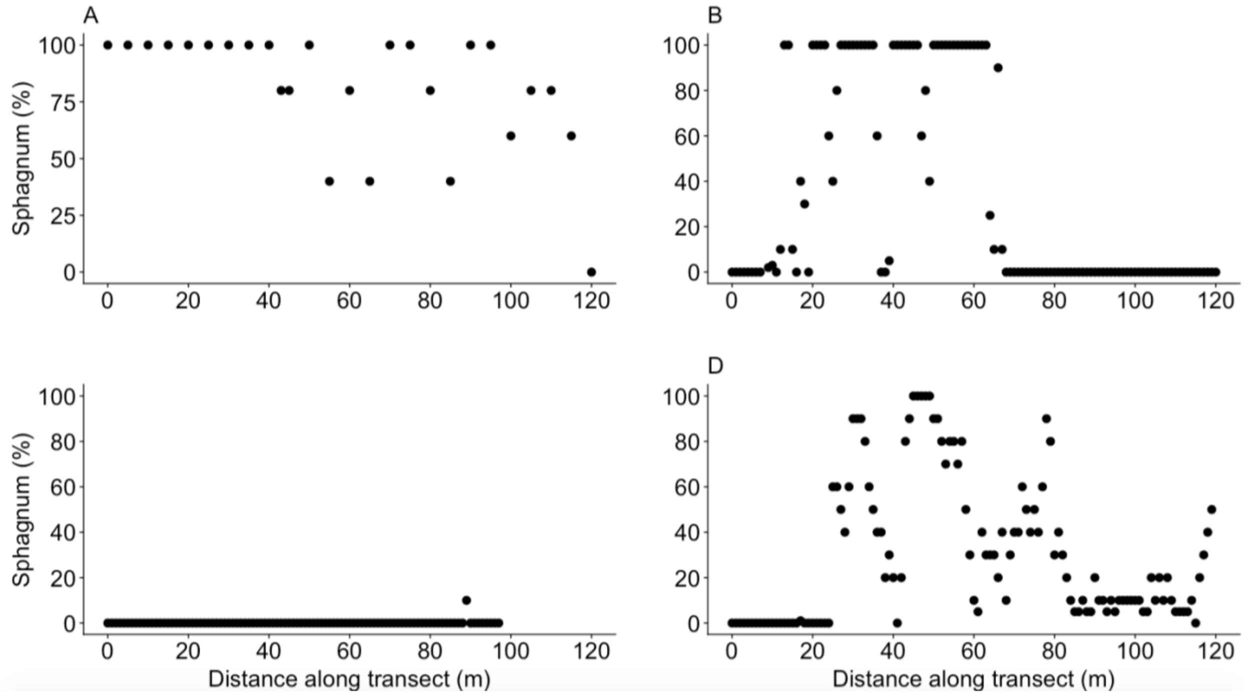

Figure 3. *Sphagnum* abundance at different distances along the transect for four study sites: A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. *Sphagnum* abundance was measured by percentage cover in West Dalhousie, Nine Mile Road and Misery Lake and at Musquodoboit *Sphagnum* abundance was measured by frequency within 5 m.

In Musquodoboit, there was a strong presence of *Sphagnum* until 40 m and then there was a slow drop in *Sphagnum* with fluctuations until the end of the transect where it ended with no *Sphagnum* (Figure 3). Nine Mile Road had the least *Sphagnum* in comparison to the other study sites with only 10% *Sphagnum* at 90 m into the transect. Misery Lake and West Dalhousie had low *Sphagnum* cover at the beginning of their transects. Misery Lake and West Dalhousie both had a sharp increase of *Sphagnum*. The difference between these two sites is that West Dalhousie *Sphagnum* sharply declines around 65 m and then *Sphagnum* abundance remained at 0% and Misery Lake had more fluctuation with less distinction between upland and wetland environment.

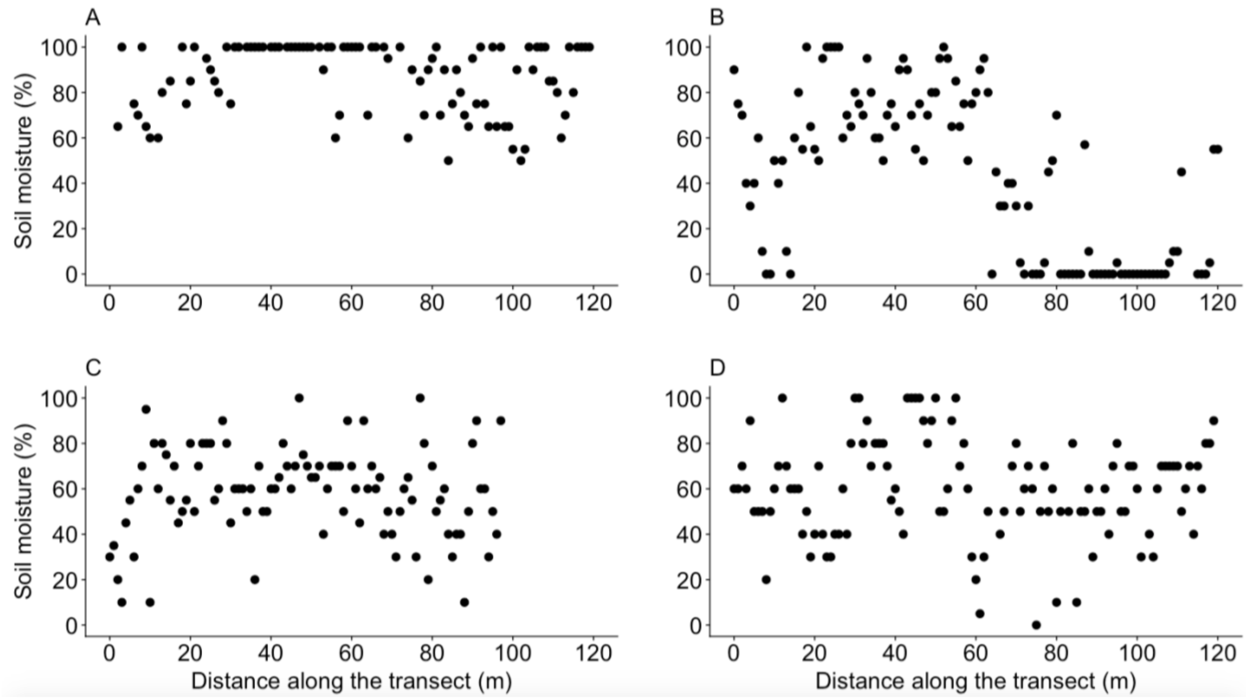

Figure 4. Soil moisture content at A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake.

Musquodoboit had consistent high soil moisture from 25 – 75 m along the transect, which then dropped and increased throughout the rest of the transect (Figure 4). West Dalhousie exhibited a sharp decline in soil moisture around 70 m into the transect and remained low until the end of the transect. From 5 – 15 m along the West Dalhousie transect, there were few points that showed a drop in soil moisture, but this is not consistent enough to classify that area as an upland. West Dalhousie had similar trend of soil moisture and *Sphagnum* abundance in approximately 19 – 120 m of the transect and the 70 – 120 m of West Dalhousie; *Sphagnum* and soil moisture were similar because both percentages were either 0% or below 60%. This indicates that the 65 – 120 m part of the West Dalhousie transect is upland. Based on fluctuating soil moisture of Nine Mile Road, it appears to be all or mostly wetland, similar to the fluctuations in Misery Lake. The *Sphagnum* abundance of Misery Lake was minimal, and this indicated that it was a different wetland ecosystem without *Sphagnum*. The soil moisture of Misery Lake fluctuated from 0% - 100% and it remained between 30% - 70% for most of the transect, indicating that Misery Lake is an intermediate ecosystem between wetland and upland.

Considering the soil moisture and *Sphagnum* abundance of all four study sites, West Dalhousie was the only site that had a distinct transition from wetland to upland. The other study sites were either entirely wetland or fragmented wetland. From these results, it appears that all of Musquodoboit's 120 m transect was wetland, West Dalhousie had a distinct change from wetland to upland at approximately 70 m mark and Misery Lake and Nine Mile road were both fragmented wetlands and upon observation the sites appeared as a wetland environment.

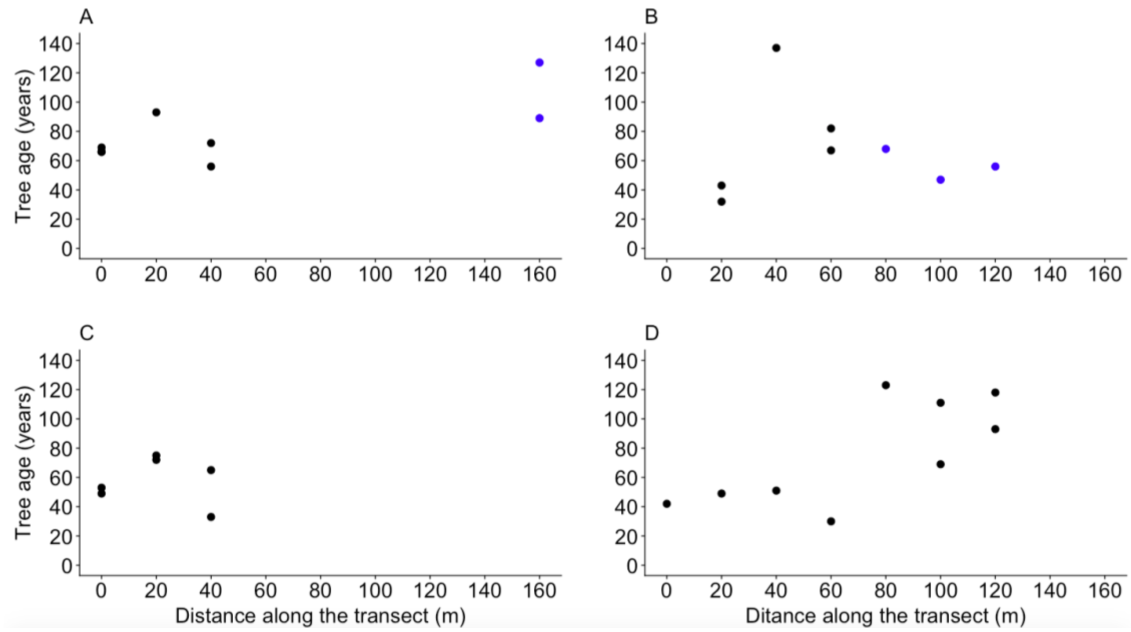

Figure 5. Estimated minimum tree age for A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. One to two trees were cored at every 20 m along the transect. Wetland trees are indicated by black dots and upland trees are indicated by blue dots. Wetland trees of Musquodoboit are between 0 - 140 m of the transect, and upland trees are at 160 m of the transect. Wetland trees of West Dalhousie are at 20 - 60 m of the transect and upland trees are from 80 - 120 m. Nine Mile Road and Misery Lake trees are all wetland.

Tree age appears to have no trend between upland and wetland in all four study sites (Figure 5). Nine Mile Road had similar tree ages for the same quadrats except at 40 m which instead had a large gap between the ages of the two trees and in Nine Mile Road, the oldest tree was 75 years old. There was a distinct increase in tree age at 80 m at Misery Lake and tree age remained larger until the end of the transect; the oldest tree of Misery Lake was 123 years old. The oldest tree of all study sites was found in West Dalhousie and it was 137 years old. West Dalhousie had the most variance of tree age and

Musquodoboit showed no trend. The oldest tree in Musquodoboit was 127 years old and it was found in the upland area of the site. The oldest tree in the lowland site of Musquodoboit was 82 years old.

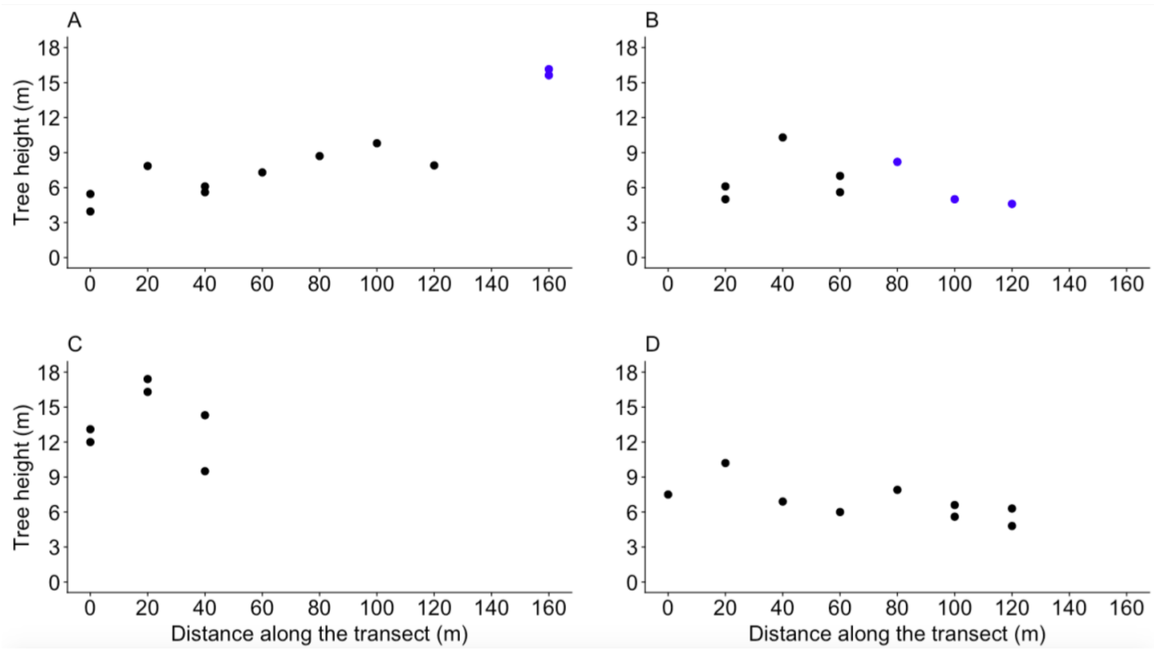

Figure 6. Tree height of A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. Wetland trees are indicated by black dots and upland trees are indicated by blue dots. Wetland trees of Musquodoboit are between 0 - 140 m of the transect, and upland trees are at 160 m of the transect. Wetland trees of West Dalhousie are at 20 - 60 m of the transect and upland trees are from 80 - 120 m. Nine Mile Road and Misery Lake trees are all wetland.

The Musquodoboit upland trees were taller than the wetland trees (Figure 6). There was a steady increase in height along the transect in the direction of the upland in Musquodoboit as expected. The tallest tree at West Dalhousie was found in the wetland portion of the transect and the West Dalhousie site had taller trees in the wetland environments. Nine Mile Road had a trend distinct from the rest of the three study sites because height was consistently tall, and Nine Mile Road had the tallest tree of all of the study sites at 17.4 m tall and Nine Mile Road had no trend. West Dalhousie has an increase in tree height around 40 – 60 m into the transect and then tree height remained high and then decreased after the 40 m mark. In Nine Mile Road, the tree age trend (Figure 5C) looks similar to tree height trend; at 0 m there were medium aged trees and medium height trees and at 20 m the tallest and oldest trees were found.

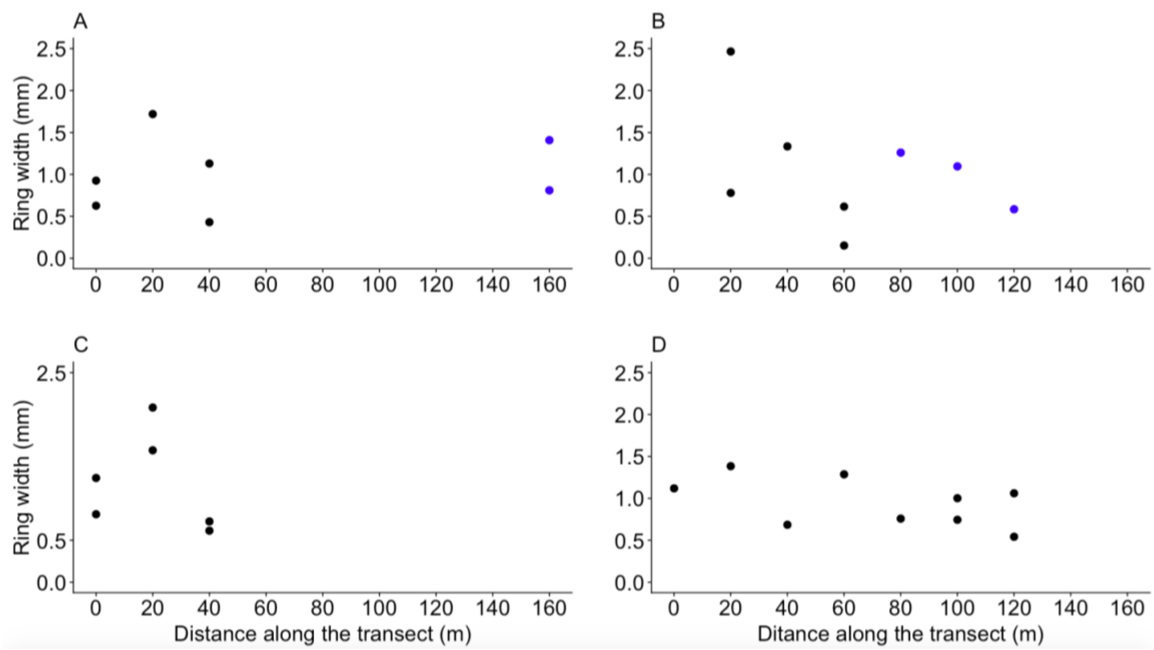

Figure 7. Average ring width of the last ten tree rings of each tree for: A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. Wetland trees are indicated by black dots and upland trees are indicated by blue dots. Wetland trees of Musquodoboit are between 0 - 140 m of the transect, and upland trees are at 160 m of the transect.

Wetland trees of West Dalhousie are at 20 - 60 m of the transect and upland trees are from 80 - 120 m. Nine Mile Road and Misery Lake trees are all wetland.

The upland and wetland trees of Musquodoboit appeared to be growing at a similar rate. West Dalhousie had the most variation of radial growth. In addition, West Dalhousie had its widest tree ring width in the upland area, and this tree ring width is also the largest tree ring width of all of the study sites. West Dalhousie also had the smallest tree ring width at the 60 m mark which is considered to be close to where the wetland environment begins. The upland trees at West Dalhousie were older and taller than the wetland trees and had slower growth rates. At the 40 m mark in Nine Mile Road, the two trees did not have a large difference in ring width average that their height and age had, and the older trees grew wider and taller (Figure 5, 6&7C.). The first 20 m of Misery Lake were considered wetland and the tree ring width at the 20 m quadrat was wider than the rest of the transect. The rest of the Misery Lake tree ring widths had no trend. The trends in ring width average and tree height of Misery Lake look almost identical.

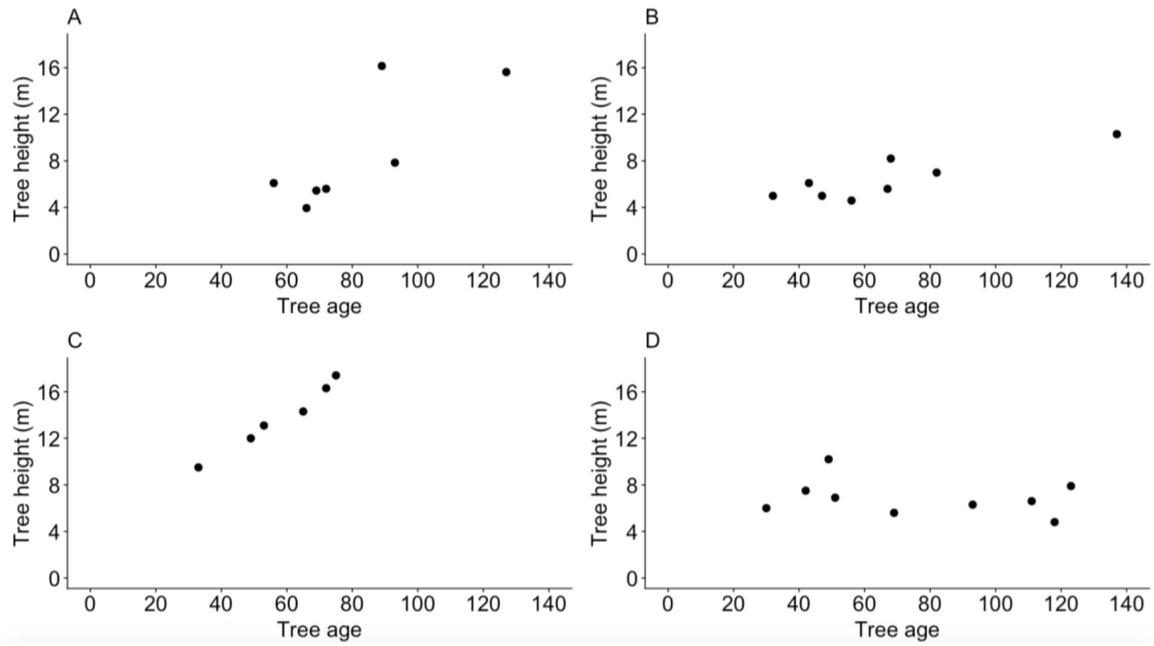

Figure 8. Comparison of tree height in meters and tree age of each tree for: A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. The older trees seem to be taller except for the tallest tree in Misery Lake.

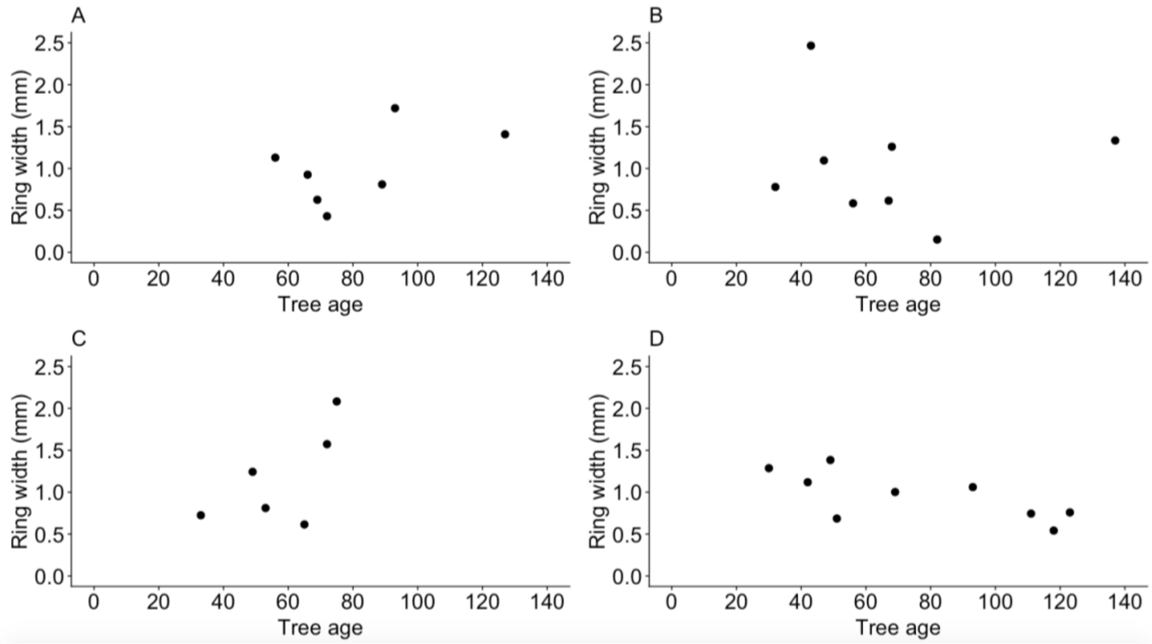

Figure 9. Comparison of ring width in millimeters and tree age of each tree for: A. Musquodoboit B. West Dalhousie C. Nine Mile Road and D. Misery Lake. The older trees in Musquodoboit and in Nine Mile Road have the larger ring widths and in West Dalhousie and Misery Lake some of the older trees have the thinnest ring widths.

Environment	Musquodoboit	West Dalhousie	Nine Mile Road	Misery Lake
Wetland	0 – 120 m	0 – 60 m	0 – 120 m	0 – 120 m
Upland	160 m	60 – 120 m	None	None
Wetland Trees	9	5	6	9
Upland Trees	2	3	0	0

Table 1. The amount of wetland and upland trees in each study site and which portions of each transect are wetland and upland environments.

CHAPTER 4: Discussion

John Brazner's wetland classification system was considered when distinguishing wetland from upland. However, some transect plots that had less than 30% *Sphagnum* cover were still considered wetland because of their high amount of soil moisture and because *Sphagnum* and soil moisture were sampled in a smaller quadrat than the quadrats for the tree coring. This smaller sampling may have missed *Sphagnum* nearby. The soil moisture of Nine Mile Road and Misery Lake resemble a fragmented wetland because there are patches of high and low soil moisture and some parts of the transect are drier than others and some may be dry enough to be considered upland. It was also expected that I would encounter fragmented wetlands within the transects making a definite change in wetlands and uplands difficult to identify. It was anticipated that there could be changes between wetland and upland every few metres of the transect rather than a clear transition. The *Sphagnum* and soil moisture results from the Musquodoboit and West Dalhousie sites are what I expected because by observation the Musquodoboit transect was all wetland and the West Dalhousie transect had a clear wetland and upland transition.

It was expected that all spruce would be taller in the upland environments and spruce were taller in uplands except for the entire Nine Mile Road site. Karam (2009) shows that tree growth in height within a season depends on hereditary factors and immediate past and present environmental conditions, which could explain why the Nine Mile Road spruce were not shorter. Bubier (1991) found that height of spruce was lower in bog but age was not just as my study found for the wetland environment of Musquodoboit. Bubier (1991) also found the oldest trees in the bog area as my study found. In my study I found that trees in bog are shorter, which may be due to slower growth rates due to less water movement in the lowland area (Bubier, 1991) with the exception of Nine Mile Road. Misery Lake had somewhat consistent tree heights throughout the transect which aligns well with the site being considered fragmented wetland. Wood and Jeglum (1984) found that tree competition with other vegetation in the lowlands of their Ontario study in comparison to uplands reduced height growth of black spruce trees they planted. In addition, Pellerina et al., (2009) state that environmental influences on vegetation are not well understood which I presume would also leave knowledge gaps even in the case where vegetative competition is studied. In my study, competition may have been higher in the uplands; perhaps the proximity of trees with each other was an influence on tree productivity. Perhaps some other form of competition inhibited their growth.

Spruce age appeared to be relatively unaffected by the wetland and upland environments. The results of both upland and wetland tree ages of my study are similar to Perrette's (2010) study in the Hudson Bay lowland stretching across Ontario, Manitoba and Quebec. Perrette's (2010) wetland trees had relatively homogenous ages, which is similar to Musquodoboit and Nine Mile Road wetland trees of my study. In contrast, the Musquodoboit and West Dalhousie upland have both young and old trees. Perrette (2010) and Bubier (1991) had similar results; black spruce age is not consistent in uplands. The varying ages of trees in uplands indicate that trees reproduced at different times. In wetlands, it appears trees reproduced at around the same time because the ages are all similar. Trees that are smaller tend to be less productive and, in some instances, smaller trees are older because they have been growing more slowly (Speer, 2010; Husch, Miller & Beers, 1982). In Misery Lake, the distinct increase of tree age at the 80 m mark (Figure 5D) does not match tree height and radial growth trends. This is not unusual because tree height and radial growth are not always expected to be the same as age because not all trees grow the same throughout their lifespan.

The results are unusual and interesting because historically it is known that general tree growth is more productive in uplands and not wetlands (Viereck & Johnston, n.d.; Bubier, 1991; Kuusinen, 1996, Perrette, 2010; Wood & Jeglum, 1984; Haavisto & Jeglum, 1994; Heinselman, 1970). The trees with the highest growth rates were found in uplands, however some high growth rates were found in wetlands as well. In addition, the least productive tree was found in the wetland portion of West Dalhousie at the 60 m mark which is close to where the upland begins. Perhaps this is because forest productivity declines along transition zones (Dimitrov, Bhatti & Grant, 2014). Many biotic and abiotic factors may have also stunted the growth of trees in the upland environment, especially where the West Dalhousie upland environment was harvested. These results are unusual because wetlands do not usually support productive tree growth (Viereck & Johnston, n.d.; Bubier, 1991; Kuusinen, 1996, Perrette, 2010; Wood & Jeglum, 1984; Haavisto & Jeglum, 1994; Heinselman, 1970). Heinselman (1970) found that black spruce is less productive in areas where *Sphagnum* is present and *Sphagnum* presence characterizes wetland environments (Brazner & Achenbach, unpublished). In addition, Wood and Jeglum (1984) found that black spruce growth is better in uplands even in areas that have been clear cut.

Perhaps upland trees exhibited worse tree growth because of exposure to strong winds since the study sites were not located in a deep forest (Amoroso, Daniels & Baker et al., 2017). The uplands of Musquodoboit were of a significantly higher elevation than the uplands of West Dalhousie, which could have impacted tree productivity in the environment because a higher elevation may have given the Musquodoboit upland trees more exposure to wind. Hofgaard et al. (1999) found that climate change influences spatial and temporal growth of black spruce rings in mixed coniferous forests. Huang et al. (2010) also show how black spruce tree rings change with climate change. I did not measure climate in my study, but it could have influenced the unexpected results. Hofgaard et al.(1999) also showed that different tree species react differently to climate change and Karam (2009) stated different tree species can react differently to the same events as Patterson et al. (1996) show in their study on black spruce and white spruce. As an example, if wetlands continue to dry out as a result of climate change, an outcome may be increased growth rates in trees because a drier habitat would resemble an upland area, whereas other tree species may be less productive under these conditions (Treml et al. 2015). Also, different tree species may react to soil conditions differently. Fleming & Mossa (1995) found that soil moisture regime is important to black spruce reproduction success but in comparison to jack pine, black spruce needs less seedbed moisture availability. In addition, Campbell & Laroque (2007) found that the decay of black spruce in two forests, Cape Breton Highlands and Newfoundland, is driven by climate and that the warmer climate had faster decay. Campbell & Laroque (2007) state that many organisms depend on decay for nutrient retention and nutrient cycling in the forest; therefore, decay of coarse woody debris in my study sites may have impacted tree growth. Bubier (1991) suggests that seasonal fluctuations have more of an impact on black spruce growth than water table depth, emphasizing the prominent impacts that weather and climate have on tree growth.

Bubier (1991) found that small variations in water table depth have big outcomes for tree growth in peatlands in boreal ecosystems due to greater amounts of oxygen available to roots. In Bubier (1991) the bog studied was raised which isolated the trees from nutrients other than nutrients from precipitation. This can apply to temperate deciduous forests. Therefore, elevation, water and nutrient sources of the wetlands may have impacted the growth of the black spruce. Water table dynamics depend on regional scale watershed hydrology and lowering the water table of a wetland causes annual tree growth and productivity of black spruce to increase several times (Dimitre, Dimitrov & Jagtar et al., 2013). Therefore, if my wetland sites have different water tables this could have influenced the growth of the tree rings.

Tree roots can grow far distances from where the root origin is. These roots could have come in contact with portions of the transects that were off of the 20 m increments. This would allow these trees to obtain varying soil moistures and contact with potential peat, impacting tree growth. This is why it is important to sample every 1 m of the 120 m transect for *Sphagnum* and soil moisture. In addition, the roots could have come into contact with soils off of the transect as well, which may explain variability in tree growth.

I have not found other studies reflecting the results of my study. It was clear that the trees in wetlands were stunted, shorter, thinner and had fewer needles and cones, giving the wetland trees a bare appearance. Many biotic and abiotic factors may have stunted the growth of trees in the upland environment. Many spruce in Nova Scotia are not in old growth stands due to deforestation (Robichaud & Laroque, 2008), they have the potential to be old growth in the future and to provide unique ecosystem services of their own (Kuusinen, 1996; Mosseler, Lynds & Major, 2003). Ecosystem and habitat specialist John Brazner has stated that trees of forested wetlands are worth coring to discover their age because they may be old growth although they look younger because their productivity is stunted.

Chapter 5: Conclusions and Recommendations

Forested wetlands are understudied and understanding the health indicators and biodiversity of forested wetlands is a goal of the Nova Scotia Natural Resources Strategy. This is why it is important to research further into forested wetlands and to classify them in more detail (Brazner & Achenbach, unpublished; Pellerina, Lagneaua, & Lavoie et al., 2009).

In conclusion, my hypothesis was not met which is unusual in comparison to other studies. Unstudied or unknown factors may answer why I could not prove my hypothesis. There are knowledge gaps in forested wetland research and in spruce tree research which are worth researching to understand the qualities of our ecosystems. The results of my study can be replicated and researched further with additional forested wetland and upland sites, tree core samples and measurements of other influences of productivity such as vegetative competition and soil sampling. Perhaps more accuracy on tree species can also be considered; taking a cone off of each tree cored can be done to keep track of the tree species in case it is misidentified. In addition, more upland sites should be sampled for future studies. It is worth investigating why black spruce tree growth in wetlands and uplands of Nova Scotia did not conform to my hypothesis. Various factors that could not be measured in this study could have influenced the growth trends observed here.

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