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Tree age and growth at barrens forest edges in Cape Breton Highlands National Park

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I dedicate this thesis to Caroline Franklin and Christine Angelidis who worked with me collecting data in Cape Breton

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Abstract

Forest encroachment is occurring in non-forested habitats across North America. Barrens are unique non-forested habitats that contain a variety of plant species including rare species. Forest encroachment would lead to a loss of the unique barrens habitat. This study examines the age structure and growth rate of spruce dominated forests adjacent to barrens in Cape Breton Highlands National Park using dendrochronology. If the age of the forest decreases from interior to edge, we assumed that the forest is expanding into the barrens over time. Growth rate was measured to determine if trees at the edge compared to the interior forest were growing faster due to increased access to resources. Difference in growth rate between 1991-2000 and 2001-2010 was calculated to determine if growth was increasing or decreasing over time. Four transects were set up perpendicular to the forest edge with 20m by 5m plots set up every 20m for 80m, starting at the forest edge. Three reference plots of the same size were set up at least 100m away from the forest edge. Within each plot, trees >5cm diameter at breast height were cored. These cores were then examined using a Velmex stage system to estimate age, and to determine growth rate over the past 10 and 20 years. Analysis suggests that some forest areas may be encroaching, while others are stable. This difference may be due to differing microclimates in the area. Growth rate is not correlated with distance from edge, possibly due to increased shelter in the interior forest. Overall, growth is decreasing in this area for reasons that are unclear.

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Introduction

Forest encroachment into non-forested habitats is occurring around the world (Suarez et al., 1999; Coop and Givnish, 2007; Widenmaier and Strong, 2010). Non-forested habitats are being converted through natural succession, changes in management regimes, and changes in climate (Suarez et al., 1999; Copenheaver, et al., 2005; Coop and Givnish, 2007). Succession is a natural process where changes in vegetation occur over time, usually changing from an open space to a forested one. Fires historically maintained many non-forested habitats, and modern fire suppression means that natural succession is able to occur (Coop and Givnish, 2007). Changes in temperature and weather also affect forest encroachment. In Alaska, changes in temperature allowed for increased growth and therefore forest encroachment (Suarez et al., 1999). Similarly, in Virginia, it has been found that climate is related to increases in growth and may lead to encroachment (Copenheaver et al., 2004). Within a specific habitat, some areas of forest may be encroaching, while others may not due to differing microclimates or other factors (Coop and Givnish, 2007). In Virginia, USA, both stable and encroaching forests were found (Copenheaver et al., 2004). Stable forests may be due to climate conditions, soil quality, or elevation (Coop and Givnish, 2007; Walker and Mallik, 2009)

Generally, forest encroachment occurs at forest edges due to mechanisms of dispersal and microclimatic conditions (Coop and Givnish, 2007). If distance of seed dispersal is low, or if the trees have a slow growth rate, encroachment may still occur, but will do so more slowly (Meades, 2002). If encroachment is occurring, loss of these non-forested habitats has implications on the overall ecosystem. Many non-forested areas contain vulnerable species such as endemic species (Copenheaver et al., 2004). In Spain, it was found that the numbers of endemic species found in the non-forested area decreased in the forested areas and were more sensitive to change than the non-endemics (Andrés and Ojeda, 2002). These areas may also

contain tree islands, which create microclimates within non-forest areas, and provide functions such as maintaining soil nutrients, providing shelter or habitats, and increasing diversity (Manning et al., 2006). If forests encroach on these areas, these landscapes would be lost. If this is the case, management of these habitats may be necessary to maintain them (Widenmaier and Strong, 2010). In New Mexico and Alberta, fire has been suggested as a tool to maintain grasslands and other non-forested areas from encroachment (Coop and Givnish, 2007; Widenmaier and Strong, 2010). One study found that in addition to fire, disturbances such as cutting or introducing browser species may also maintain the edge, and that any of these disturbances combined make it less likely that encroachment will occur (Payette and Delwaide, 2003). In combining other disturbances (such as cutting, or introducing browser species) with fire, maintenance may be more successful.

Barrens are non-forested areas within a forested ecosystem with shallow or no soil and low growing shrubs and may also be referred to as heathlands or taiga (Oberndorfer and Lundholm, 2008; Burley et al., 2010). They occur in stressful environments, generally at high elevations and may also be exposed to increased saline conditions due to ocean spray (Latham, 2003). In Spain, it was found that pine forests were encroaching on heathlands (Andrés and Ojeda, 2002). In southwestern Australia, browsers maintain heathlands, but protection of new trees by shrubs means that encroachment is still occurring (Maher et al., 2010). Fire has been suggested as a control for encroachment in southwestern Australia (Maher et al., 2010).

In Nova Scotia, forest encroachment has been found to be occurring in barrens ecosystems (Burley et al., 2010). Barrens across Nova Scotia contain a variety of plant species, including rare species (Oberndorfer and Lundholm, 2008). The barrens also provide a source of food for many species during the summer months and are a breeding ground for bird species

(Parks Canada, 2009a). Aerial photos suggest that there may be encroachment into the barrens by the forest, which would mean a loss of this habitat and its functions (Oberndorfer and Lundholm, 2008).

This paper uses dendrochronology to determine if spruce dominated forest is expanding into the barrens in Cape Breton Highlands National Park by establishing age across a gradient, and to determine growth rate patterns across gradients and time periods by establishing growth rate. If the forest were expanding over time, we would expect tree age to decrease from the interior forest to the edge (Burley et al., 2010). We may also expect to see a negative correlation between distance to the edge and growth rate, as access to sunlight would be greater at the edge compared to the forest. Difference in growth rate over time will indicate whether or not growth has increased or decreased. Because the barrens are a unique habitat within the Cape Breton Highlands National Park, management may be required to maintain the ecosystem if the age structure of the forest suggests that the forest is expanding.

Methods

Study Area

Within the Cape Breton Highlands Park, there are three main ecotypes: Acadian forest, boreal forest, and taiga forest (Parks Canada, 2009a). The taiga is made up of low growing, scrub like forest, which includes stunted trees called krummholz, wetlands, and, at higher altitudes, barrens (Parks Canada, 2009b). The taiga forest is generally dominated by *Abies balsamea* and *Picea sp.*, with krummholz occurring in transition zones between the barrens and the forest (Parks Canada, 2009b). Within the park, there are 78 rare plant species and 29 rare moss and liverwort species, some of which occur in the barrens (Parks Canada, 2009d). The Park protects almost 75% of northern Cape Breton's barrens ecosystems (Parks Canada, 2009a). The climate

of Northern Cape Breton is characterized as Maritime Boreal, with short summers and cold, long winters (Parks Canada, 2009c). The closest weather station to the sites sampled was in Ingonish Beach which reports a mean January temperature of -5.1°C, a mean July temp of 18.5°, and a mean of 1700mm of annual precipitation (Environment Canada, 2012). However, the high elevations of the study sites mean that temperatures are more varied, there is a shorter growing season, and there is more precipitation compared to at sea level (Parks Canada, 2009c). The high elevations also leave areas exposed to high winds and rain, which combined with shallow soils, contributes to the barrens landscape (Parks Canada, 2009b; Parks Canada, 2009c).

Sampling Design

Potential sites were examined using aerial photographs of the Cape Breton Highlands National Park to determine areas with barrens at least 120m wide and spruce dominated forest at the edges

extending at least 80m away from the forest edge. Two study

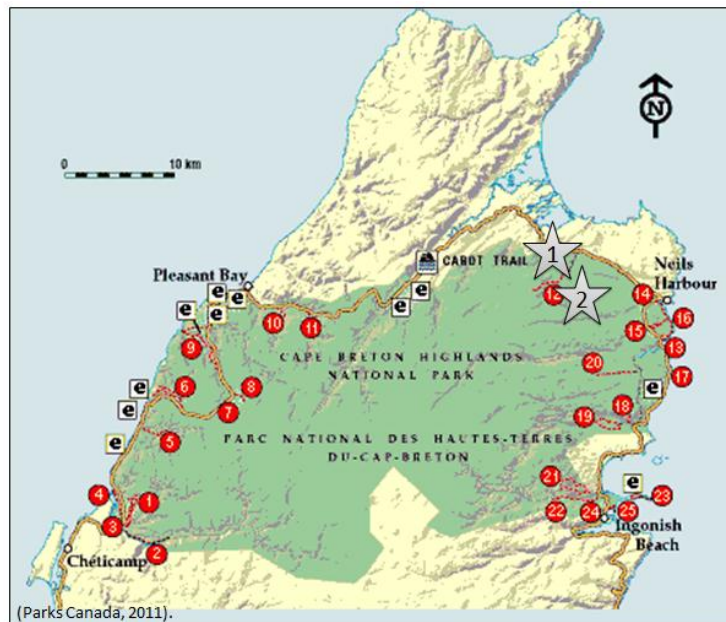
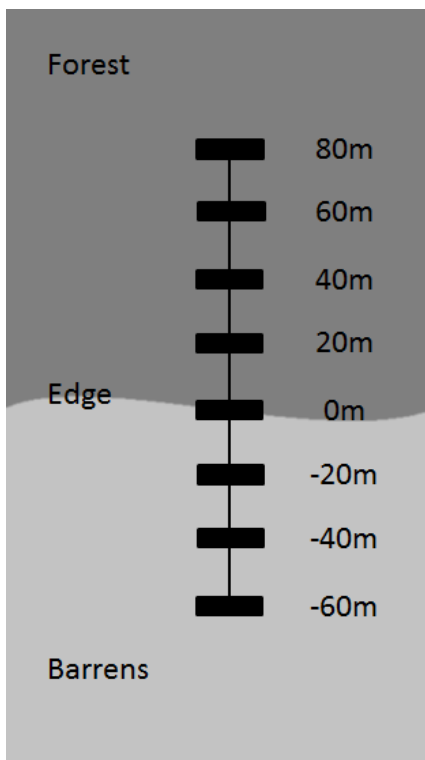


Figure 1: Map of Paquette Lake (1) and Mica Hills (2) in Cape Breton Highlands National Park.

sites were chosen in the barrens of Cape Breton Highlands National Park (Figure 1): Paquette Lake (1) and Mica Hills (2). At each of these sites, two transects were set up: Paquette 1, Paquette 2, Mica 1, and Mica 2 (Table 1). Altitudes at these sites ranged from 286m to 343m (Table 1).

At each of the four sites, a transect was set up perpendicular to the edge. The edge of the forest was considered to be at the limit where shrubs and krummholz gave way to lichen dominated ground cover. The transect extended 80m into the forest, and another 60m into the barrens (Figure 2). The section of the transect extending into the forest was 20m longer than in the barrens to account for a transition zone of shrubs and krummholz between the edge and the forest. Because the krummholz had a very small diameter at breast height (dbh) and had dense branches, they could not be cored. The addition of the transition zone in the forest meant that



more trees could be cored to give a gradient over a longer distance.

At 0m and every 20m into the barrens and forest, a 20m by 5m plot was set up (Figure 2). Three additional 20m by 5m plots were set up in the forest at least 120m from the forest edge, and 40m from each other. These plots were used as reference plots and were considered interior forest. Within each plot, all trees larger than 5cm dbh were cored using an increment borer. Ideally, all trees were cored twice from

Figure 2: The 140m transects were set up perpendicular to the edge of the forest adjacent to the barrens.

opposite sides of the tree at an angle perpendicular to the edge. However, dense branches meant that in some cases, trees were cored twice from the same side of the tree, or at an

angle not perpendicular to the edge. There were also trees >5cm dbh which were not cored at all due to rot inside the tree or because the trunk was inaccessible due to very dense branches (Table 1).

For all transects, there were very few data points at 0m, 20m and 40m. This was due to the fact that the trees present were either < 5cm dbh, or were krummholz and had dense branches making the trunk inaccessible. It was not expected that the barrens would have many trees, but tree islands were cored when they fell across the transect.

Table 1: UTM coordinates, elevation at 0m and 80m, number of trees, number of useable core, and number of cores with more than 21 tree rings for four sites sampled at Paquette Lake and Mica Hills in the Cape Breton National Highlands Park.

	Paquette 1	Paquette 2	Mica Hills 1	Mica Hills 2
UTM Coordinates at 0m	20 T 0695832, 5191186	20T 0695666, 5190987	20T 0695493, 5189286	20T 0695293, 5189186
Elevation at 0m (metres above sea level)	287	290	336	343
Elevation at 80m (metres above sea level)	302	286	336	337
Number of trees (>5cm dbh) along transect	82	62	98	65
Total number of useable cores (max. 2 per tree)	55	54	68	66
Number of useable cores with more than 21 tree rings	51	44	47	59

Data Analysis

Cores that were useable (had not rotted or moulded) were glued to wooden boards using wood glue. The cores were then sanded on varying grades of sandpaper. The cores were examined under a Velmex Stage System at the Mount Allison Dendrochronology Lab for number of tree rings and width of rings. Because the pith of the tree was not included in every core, it was assumed that the number of rings present represented the minimum possible age of the tree. The width between rings was assumed to represent growth rate per year.

It was assumed that the first ring present after the bark represented growth in 2011 (the year the cores were taken) and was measured in microns (0.001mm) per year. The cores were sampled at different times of the year however, so the trees would have been in different stages of growth and the first ring would be inconsistent between the trees. For this reason, the growth in 2011 was not used in calculations.

Data from the barrens was combined into one category due to the fact that very few tree islands were within the transects and date of establishment would not follow the expected pattern on succession, so distance from the edge into the barrens was not important. The forest reference data was also combined due to the fact that the distance from the edge for these plots was the same.

For every transect, maximum age and average growth rate were determined for each distance (barrens data combined, 0m, 20m, 40, 60m, 80m, and the three forest reference data combined). To determine the maximum age, it was assumed that one tree ring on the core represented one year of growth. The core with the most number of rings at any given distance was considered as having the maximum possible age at that distance. For mean growth rate per year, the ring widths were averaged for the past ten years excluding 2011 (2001-2010), and the previous ten years (1991-2000). These values for each core were then averaged over all the trees for each distance along each transect and the standard error was calculated. The growth rate was also averaged across all four transects and the standard error was calculated again.

Differences between growth rates for the past ten years compared to the previous ten years were determined and then linear regressions were performed for maximum age, growth rate, and differences in growth rate. When p values were used to determine the significance of a relationship, a significance level of 0.05 was used. Paired t tests were used to determine if the

difference between growth rates over time was significant. A significance level of 0.05 was used. Because the barren's trees were comprised of tree islands, the establishment date could be much earlier than that of establishment at the edge through natural succession so the barrens data was excluded in some of the analyses.

Results

Most trees cored had their earliest possible date of establishment in the 1980s (Figure 3). Only 21 trees cored had their earliest date of establishment before the 1950s and only four trees cored had their earliest possible date in the 2000s (Figure 3).

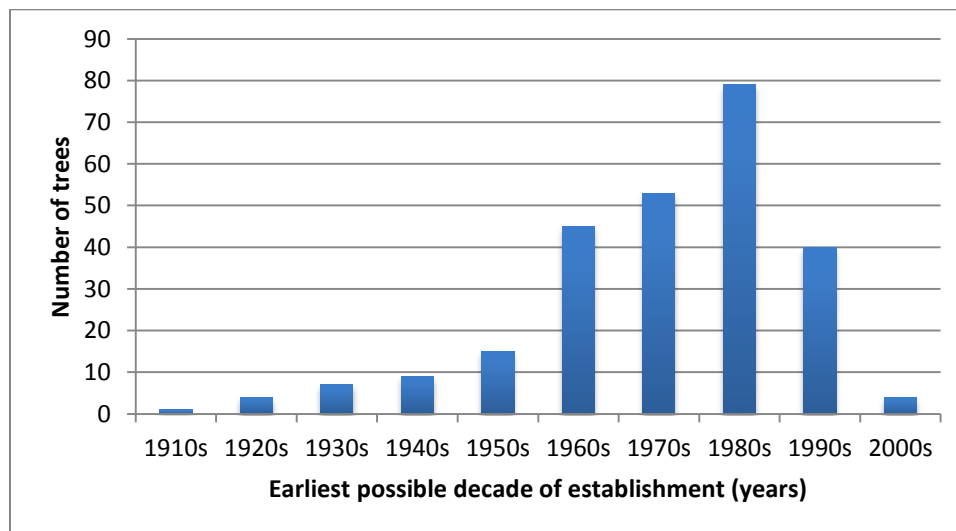


Figure 3: Number of trees for the earliest possible decade of establishment for all trees cored.

For the maximum of the minimum possible age, there were no significant relationships between age and distance from the edge when barrens were included (Appendix I). Paquette 1, Paquette 2, and Mica 2 were positively correlated, while Mica 1 was negatively correlated with

trees in the interior forest younger than those at the edge or in the barrens (Figure 4). The oldest tree was dated at 99 years of age in the reference plot at Mica 2.

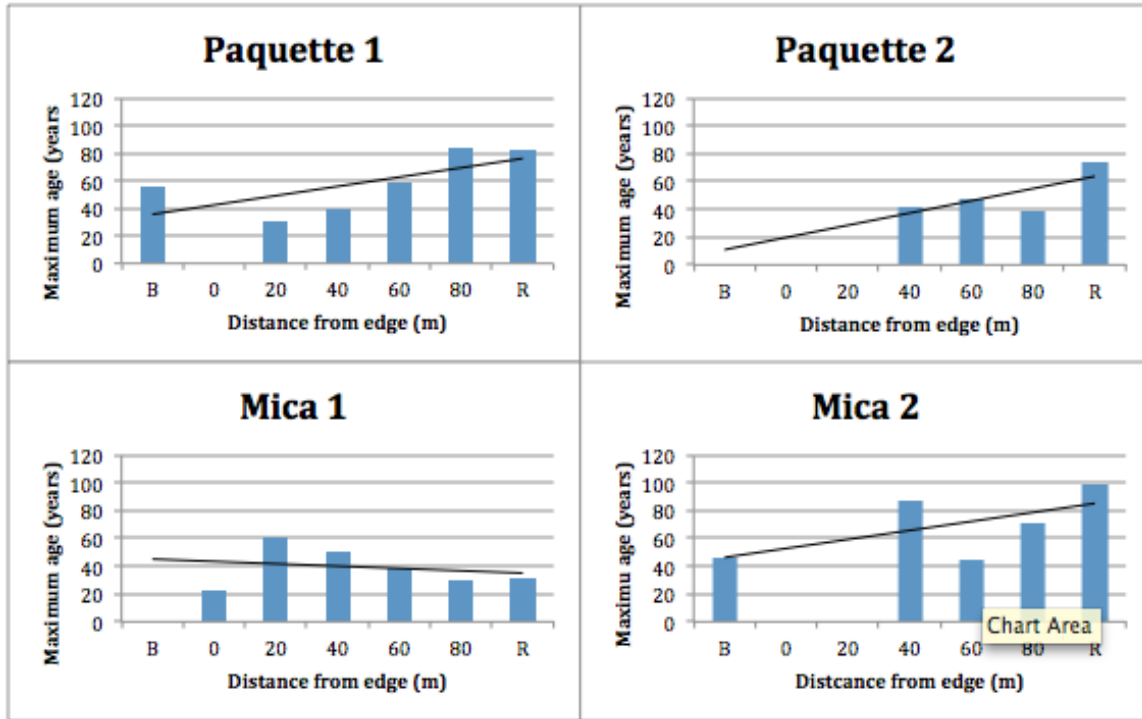


Figure 4: Maximum age at different distances from the forest-barrens edge for Paquette 1, Paquette 2, Mica 1, and Mica 2 with the best-fit linear regression for each of them. None of the linear regressions are significant.

However, when the barrens were not included in analysis, the relationship for Paquette 1 was significant (Appendix I, Figure 5). For Paquette 2, Mica 1, and Mica 2, the relationship was not significant (Figure 5).

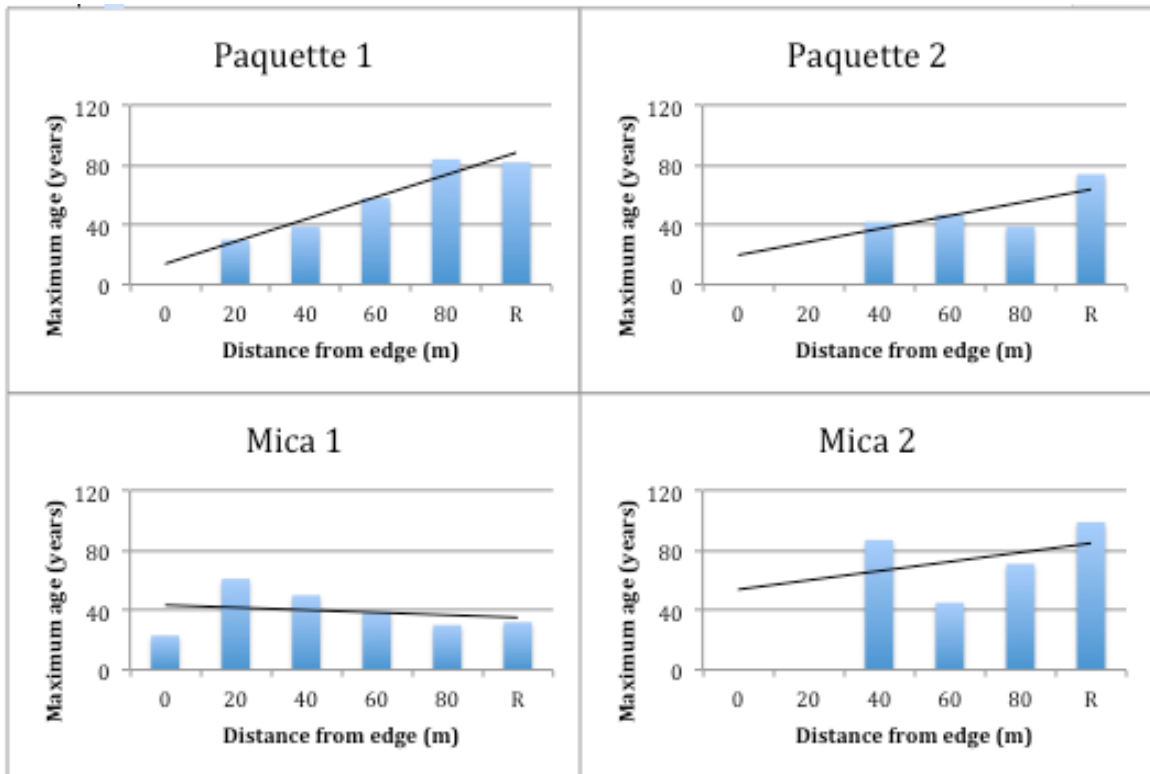


Figure 5: Maximum age at different distances not including barrens for Paquette 1, Paquette 2, Mica 1, and Mica 2 showing a linear regression for each of them. For Paquette 1, $p < 0.05$ with an R^2 value of 0.9269. For Paquette 2, Mica 1, and Mica 2 the regression was not significant.

Between 1991-2000, there was no significant relationship between distance from edge and growth rate (Appendix I). Between 2001-2010, Paquette 1, Paquette 2, and Mica 1, had no significant relationship between distance from edge and growth rate (Figure 6). For Mica 2 there was a significant positive relationship between distance from edge and growth rate. Average growth rate between the years of 1991-2000 and 2001-2010 (Figure 7) had no significant relationship (Appendix I). When barrens were excluded from the analysis, there was no significant relationship between distance from edge during either time frame at any of the transects.

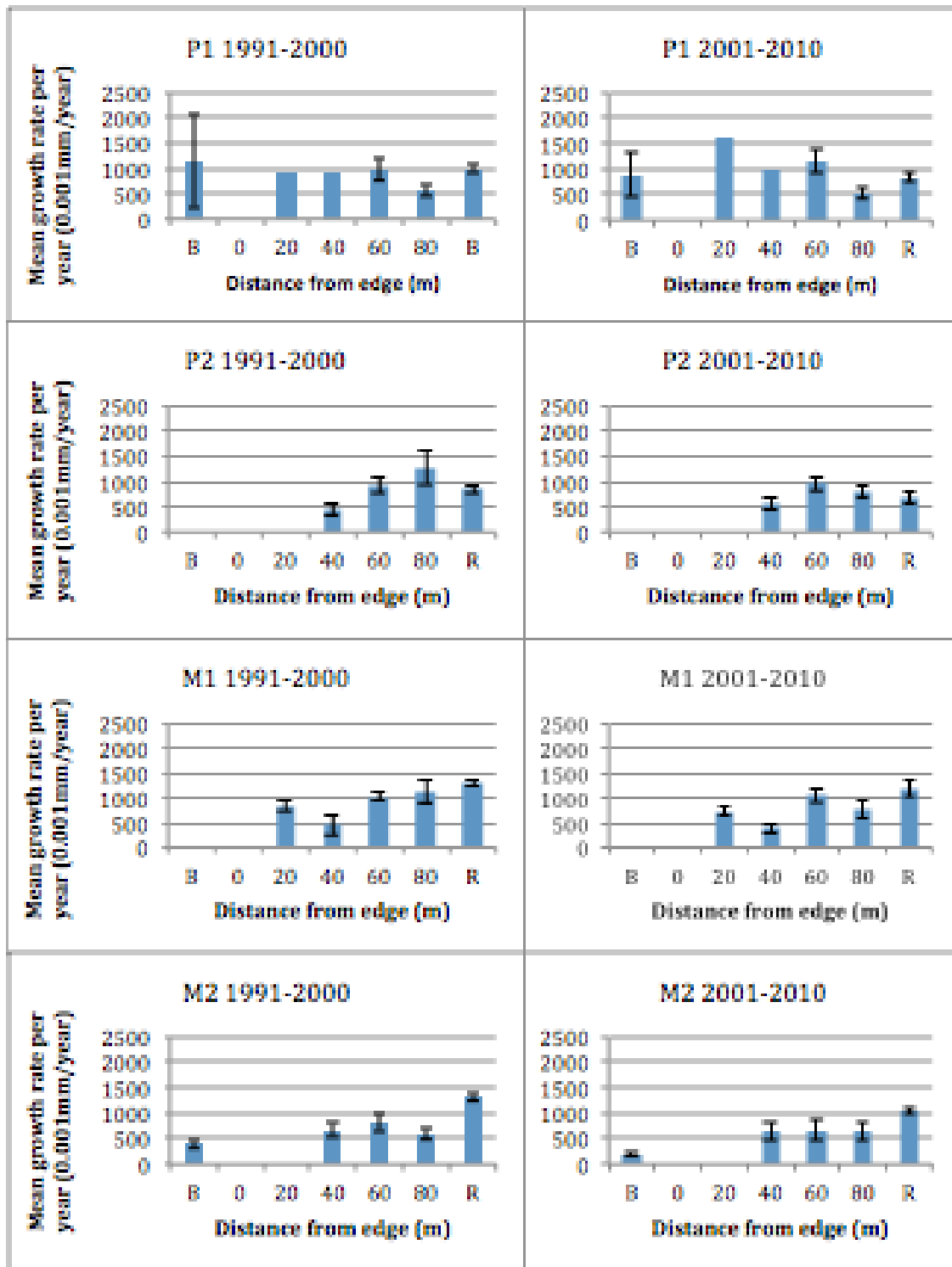


Figure 6: Mean growth rate for Paquette 1 (P1), Paquette 2 (P2), Mica 1 (M1), and Mica 2 (M2) for the years of 1991-2000 and 2001-2010 with standard error bars. Linear regressions were not significant except for Mica 2 2001-2010, where $p < 0.05$ with an R^2 value of 0.8594. Standard error was not calculated for distances where $n=1$.

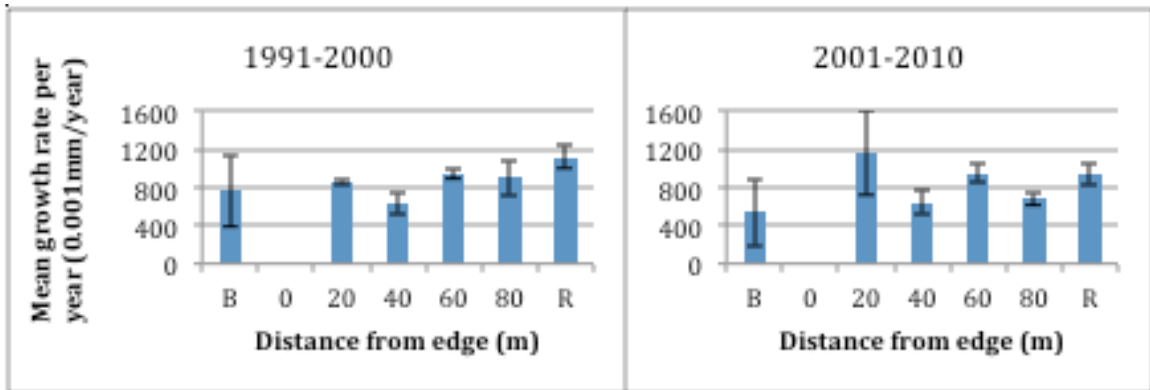


Figure 7: Mean growth rate for all four transects combined 1991-2000 and 2001-2010 with standard error bars. Linear regressions were both not significant.

Mean difference between growth rate during 2001-2010 compared to 1991-2000 (Figures 8, Figure 9) had no significant linear relationships for each transect separately or for all four combine (Appendix I & II).

For Paquette 1, overall growth increased with a positive average growth rate across all distances (Appendix II). For Paquette 2, Mica 1, and Mica 2, overall growth decreased from 1991-2000 to 2001-2010 with negative average growth rates across all distances (Appendix II). Across all four transects, growth has on average decreased from 1991-2000 to 2001-2010 (Appendix II). For all of the transects and for the average, the difference is not significant when tested with a paired t test (Appendix II).

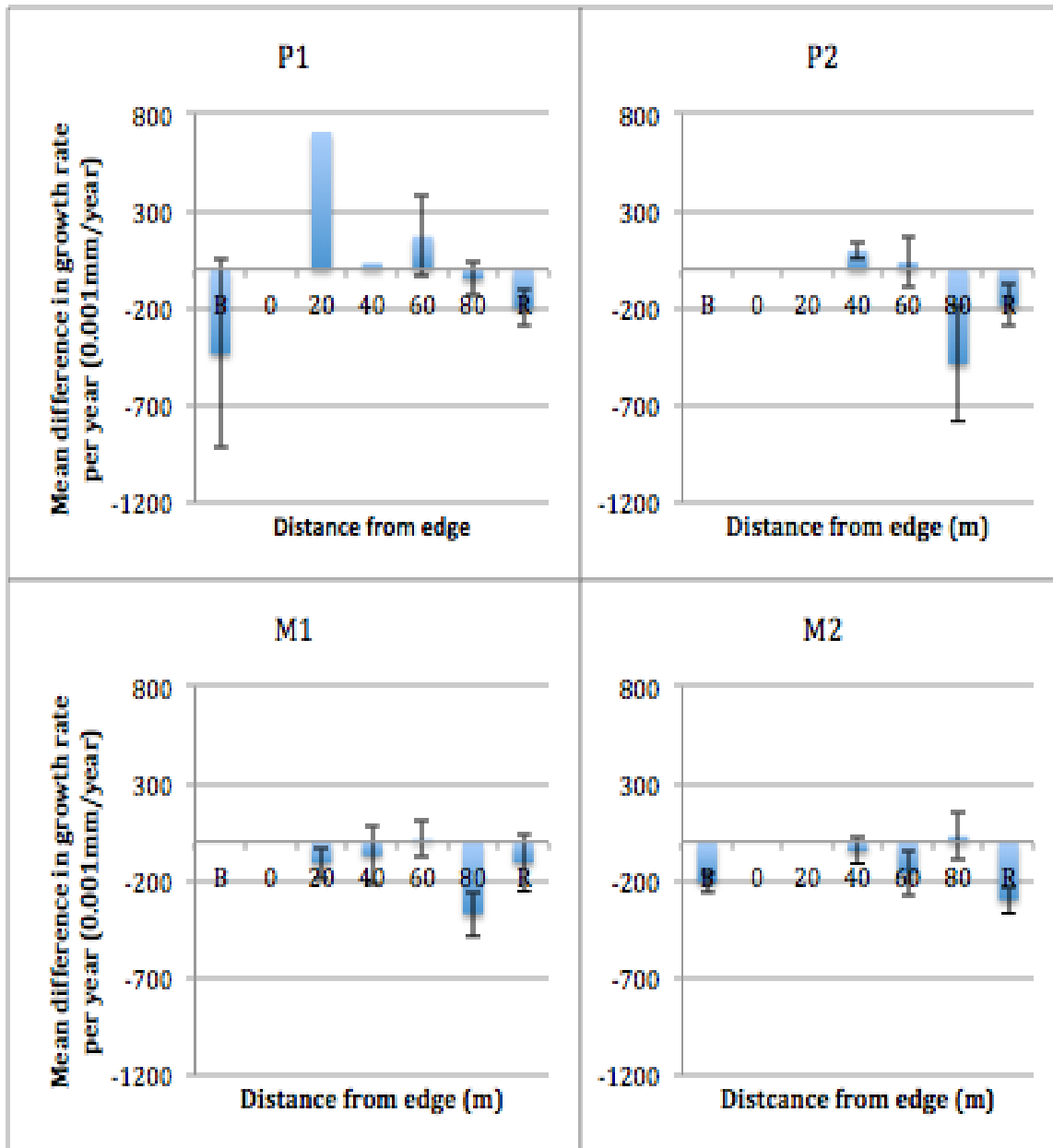


Figure 8: Mean difference between the last ten years of growth (2001-2010) compared to the previous ten years growth (1991-2000) for Paquette 1 (a), Paquette 2 (b), Mica 1 (c), and Mica 2 (d) with standard error. Standard error was not calculated for distances where n=1.

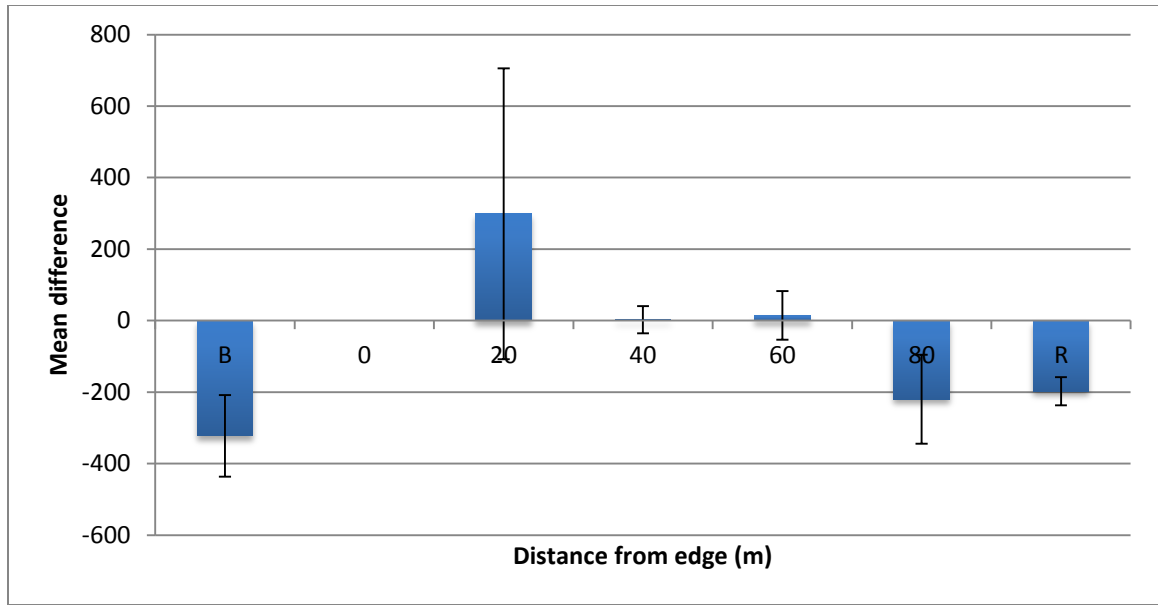


Figure 9: Mean difference between the last ten years of growth (2001-2010) compared to the previous ten years growth (1991-2000) averaged across four transects (Paquette 1, Paquette 2, Mica 1, and Mica 2) with standard error.

Discussion

When the earliest possible date of establishment was determined for all of the trees cored, it showed that the highest number of trees established themselves in the 1980s. There is no evidence of disturbance during this time, so establishment may be due to natural succession. The number of trees established more recently (2000s) may be so few because the dbh of the trees was <5cm and they were not cored.

The lack of any significant relationship between distance and age across any of the transects when barrens were included suggests that the tree islands could have had an earlier establishment date and are more permanent features of the landscape, not related to natural succession of encroachment on the barrens.

The tree islands in the barrens act as a microclimate within the landscape and likely provide ecosystem functions as other scattered trees do in other ecosystems (Manning et al.,

2006). If succession is occurring, as it may be at Paquette 1, the landscape will lose the tree islands to encroachment and they will no longer provide potentially essential functions to the environment.

If tree islands are a natural part of this ecosystem and succession or encroachment has occurred around these tree islands in the past, the trees with >5cm dbh that were cored at the edges of the forest may have once been tree islands. This would skew the data because the maximum possible age would be much earlier than if succession or encroachment was occurring alone. These areas that may once have been tree islands would be considered forest because of the ground cover and species present, but would not follow the expected trend of younger trees at the edge compared to the interior forest.

To determine if these areas once been had tree islands, with younger trees encroaching on the barrens around the tree islands, a photo analysis would have to be done, but historical photos of the area are in black and white and do not give a clear representation of the landscape.

When the barrens were excluded, the significant relationship between distance from edge and maximum possible age at Paquette 1 suggests that the forest may be expanding, as the trees at the edge are younger than those in the interior. However, for Paquette 2, Mica 1, and Mica 2, there was no significant relationship suggesting that while some areas of forest may be encroaching on the barrens, others may not be, due to differing microclimates or differences in soil quality or elevation (Coop and Givnish, 2007; Walker and Mallik, 2009). In Cape Breton, higher elevations have a more extreme climate because they are more exposed to weather events and there is greater variance in temperature and higher precipitation (Parks Canada, 2009b; Parks Canada, 2009c). These areas also have shallow soils, which does not easily allow

for growth (Parks Canada, 2009b). These harsh growing conditions may also be inhibiting encroachment of the forest on the barrens.

Mica 2 appears to have higher growth per year in the interior forest than at the edge between 2001-2010, while all other transects, including the average, showed no difference between growth rate at the edge compared to the interior. It was expected that if there were going to be a relationship, it would be negatively correlated, due to the fact that trees at the edge would have greater access to sunlight and space and would therefore be able to have a higher growth rate than those trees in the interior forest. Because of the harsh climate and shallow soils at higher elevations (Parks Canada, 2009b; Parks Canada, 2009c), higher growth rate in the interior forest may be because these areas are more sheltered from the elements surrounded by other trees.

Difference in growth rate had no significant difference across the transects. This could be because the weather and shallow soil in the barrens inhibits growth enough already in the interior forest and at the edge, so there is very little change over time (Parks Canada, 2009b; Parks Canada, 2009c). Overall, there was a decrease in growth, but this was not a significant finding. This may also be explained by the climate in the barrens inhibiting growth (Parks Canada, 2009b; Parks Canada, 2009c).

This change in growth may not be significant because it is not over a long enough time period. Another study using growth data from time periods further apart coupled with climate data would give a better idea of growth rate patterns over time. While it might be expected that an increase in growing season due to climate change might increase growth, the increase in extreme weather events that are suggested to go along with climate change (Emanuel, 2005),

which the barrens are particularly prone to, may further inhibit growth in an already harsh climate (Parks Canada, 2009c).

In other areas of Nova Scotia, it was found that forests were expanding into the barrens (Burley et al., 2010). In Cape Breton, this was not found and is likely due to differences in climate between barrens in Nova Scotia. In Cape Breton, the higher latitude and elevations create an environment that inhibits growth in addition to the shallow soil, which all barrens have to deal with (Oberndorfer and Lundholm, 2008; Parks Canada, 2009c).

This study shows that at one transect encroachment may be occurring for trees, but not at others. Overall, growth rate and difference in growth rate showed very little trends for trees, and overall growth is decreasing. This study was limited due to the fact that only trees >5cm dbh could be cored and analyzed. While it does not seem that management of the forests >5cm dbh is needed, more studies should be done on smaller trees and krummholz to determine what other changes in the landscape may be occurring.

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Appendix I

P values for Paquette 1, Paquette 2, Mica 1, Mica 2, and the average across all four transects for distance compared to maximum age, average growth rate between 1991-2000 and 2001-2010, and difference between growth between 1991-2000 and 2001-2010 in a linear regression with a confidence interval of 95%. * Indicates a significant value

	Paquette 1	Paquette 2	Mica 1	Mica 2	Average
Maximum age including barrens	0.14858	0.29041	0.66958	0.26742	N/A
Maximum age not including barrens	0.00858*	0.29041	0.66958	0.65714	N/A
Average growth rate 1991-2000	0.28878	0.40843	0.10895	0.12099	0.13790
Average growth rate 2001-2010	0.11435	0.85856	0.21173	0.02340*	0.59373
Difference in growth rate between 1991-2000 and 2001-2010	0.99797	0.33045	0.59138	0.95996	0.87170

Appendix II

Mean difference in growth rate (0.001mm/year) and t critical values and p values for a one tail paired t test for mean growth rate per year between 1991-2000 compared to 2001-2010 with a significance level of 0.05 for Paquette 1, Paquette 2, Mica 1, Mica 2, and averaged across all four transects.

	Paquette 1	Paquette 2	Mica 1	Mica 2	All 4 transects
Mean difference in growth rate across all distances (0.001mm/year)	37	-134	-128	-137	-70
T critical value	2.13	2.35	2.13	2.35	2.01
P value	0.43	0.19	0.06	0.09	0.28