Investigating Growth Rates of Western Hemlock Between Bog and Forest Areas Within Blaauw Eco-forest

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Abstract

Ombrotrophic bogs can act as limiting factors for the growth rates of trees within these unique environments due to the fluctuating water tables, nutrient poor soil, and the high acidity of the soil. Trees, such as the western hemlock, can be found to reside within bog-like ecosystems since they can tolerate poor, acidic soils. However, the growth rates of western hemlock within a bog-like ecosystem is limited due to the water and nutrient availability of the soil. This study will explore the effects of a bog as a limiting factor for western hemlock growth rates and analyze the growth characteristics of western hemlock samples between bog and forest areas to compare growth rates using dendrochronological techniques. Thirty samples were collected from 15 trees within the second growth forest, and twenty samples collected from 20 trees within the bog area in order to estimate radial growth rate trends and develop a crossdated tree-ring chronology that spans 117 years (A.D. 1902-2018). Master-ring width chronologies displayed growth trends for both tree stands, and no significant difference in the growth rates was found over the entire growth period. A significant difference was found in the growth rates of the two distinct stands over the last 25 years (A.D. 1994-2018), displaying growth rate divergence. The results suggested that a bog environment has recently established at Blaauw Eco-forest and that bogs can act as limiting factors for the growth rates of western hemlock.

Introduction

Determining the growth rate of tree rings through dendrochronological techniques can help explain the environmental history of a specific area. Dendrochronology is a discipline that is characterized as the systematic use of tree-ring cross dating procedure that utilizes the variability of ring characteristics in order to date the formation of rings (Fritts and Swetnam, 1989). “Dendro” (δένδρον) comes from the Greek word “tree” and “chronology” (χρόνος, -λογία) which means the study of time (Speer, 2013). Since trees record any environmental factor that acts as a limiting process, the growth of the rings from one season to the next can be affected; this, makes them useful tools for marking events (Speer, 2013). Different records can be gained from a variety of tree species on a site, and this allows dendrochronologists to develop records that can contribute to understanding environmental process such as historical landslides, fires, and temperature records, along with the cultural applications such as solving boundary disputes (Hughes et al., 1982; Frits, 1976; Douglass, 1914). Although many other climatological and environmental dating recording methods exist, such as pollen, ice core, and coral layers; dendrochronology, thanks to cross dating and ring counting techniques, provides the most reliable dating with the highest accuracy when compared to the other paleorecords. The most important principle in the field of dendrochronology is crossdating which was first documented and developed by A. E. Douglass in 1904 (Webb, 1983). However, in order to enhance their understanding, dendrochronologists also use the principles of replication, limiting factors in particular Ombrotrophic bogs, aggregate tree growth model, uniformitarianism, ecological amplitude, and site selection (Fritts and Swetnam, 1989). When combined together, these principles give the ability to dendrochronologists to date tree rings and build their chronologies in order to get an accurate understanding of how environmental factors impact tree growth.

The main principle, crossdating, helps determine the exact year of growth for each annual tree ring. Without crossdating, a ring count would produce dating error due to a false ring or locally absent rings. Crossdating matches the pattern of ring size in a tree to determine the location of ring boundaries and providing a date for a specimen (Frits 1976; Fritts and Swetnam, 1989). Patterns from one tree can then be matched to the patterns of another tree to determine if all the rings are accounted for. This technique helps show if rings are missing, and results in accurate dates for every ring in the tree-ring record (Speer, 2013).

Another important principle that helps strengthen the principle of crossdating is the principle of limiting factors, which is based upon Liebig's law of the minimum. This principle states that the most limiting environmental factor controls the growth of the organism (Speer, 2013). A limiting factor will dominate the growth for each year and will be the main variable recorded in ring width, which creates a series of rings that vary in width from year to year (Conkey, 1986; Kienast and Schweingruber, 1986).

Ombrotrophic bogs are areas that can act as limiting factors to the growth of trees. Ombrotrophic bogs are nutrient poor, with fluctuating water levels dependent on precipitation that occurs in the area (Howie and van Meerveld, 2013). Bogs typically have a pH between 3 to 5 due to the H+ ions that are released from the surrounding vegetation of sphagnum moss and ericaceous shrubs (Aerts, 1999; Howie and van Meerveld, 2013). Trees, such as *Tsuga heterophylla*, also commonly known as the Western Hemlock, can be found to reside within bog-like ecosystems since they can tolerate poor, acidic soils (American Forests, 1996). Western Hemlock's reach up to 60 metres in height and have a lifespan of 80-100 years (American Forests, 1996). However, the growth rates of western hemlock within a bog-like ecosystem is limited due to the water and nutrient availability of the soil (Boyd, 1972). In order to generate an output of descriptive statistics that can then be utilized for comparative studies, the growth rates of trees are analyzed through ring width measurements, along with computer interface programs such as COFECHA and ARSTAN (Grissino-Mayer, 2001,).

The objective of this research are to develop a site-specific tree-ring chronology for western hemlock within Blaauw EcoForest, explore the effects of a bog as a limiting factor for western hemlock growth rates, and analyze the growth characteristics of western hemlock samples between bog and forest areas to compare growth rates using dendrochronological (tree-ring) techniques. We expect that determining the exact calendar years of western hemlocks and calculating growth rates will allow us to better characterize site dynamics and explain the environmental history of the research area.

Methods

Study Site

The site of interest is the area known as Blaauw Eco-forest. This forest is located in Glen Valley near the Fraser River and Fort Langley (Ryder and Henderson, 2012). The 25-acre property was donated to Trinity Western University, by the Blaauw family in 2012, in remembrance of Thomas Blaauw. The property was later expanded to 35 acres, in order to provide the public a forever green space. Blaauw Eco-forest is heavily dominated by a western coastal hemlock forest, with a small bog-like, wetland area present in the northeastern corner of the property. The wetland area is characterized by the salmonberry and western hemlock that are present in abundance (Ryder and Henderson, 2012). Furthermore, the wetland area has been found to house sphagnum moss, which is an indicating species of a bog-like environment (Guirr, 2015). Previous studies have also shown that the wetland area has similar resemblance to a bog environment due to the fluctuating water table, the low calcium and magnesium content, along with the acidic soil pH (Cannon, 2017). Data for tree core samples will be collected from the second growth forest, along with the bog-like environment in order to allow for comparison of growth rates.

Field Methods

Specific sites were selected in both the bog, and coastal western hemlock forest area in order target sensitive Western hemlocks. From the targeted area, a 30 meter in diameter plot was created through use of a measuring tape (Figure 1). A 5.1mm Haglaf increment borer was used to extract two core samples from all of the live standing trees within the plot > 10 cm dbh. The GPS coordinates were recorded for each tree that was sampled. The extracted cores were then packaged within plastic straws, and labelled with a site designation, a tree number and a corresponding letter to signify the first or second core taken from a tree. All Western hemlock trees that were canopy/subcanopy dominant, and greater than 20cm diameter at breast height were cored within the plots.

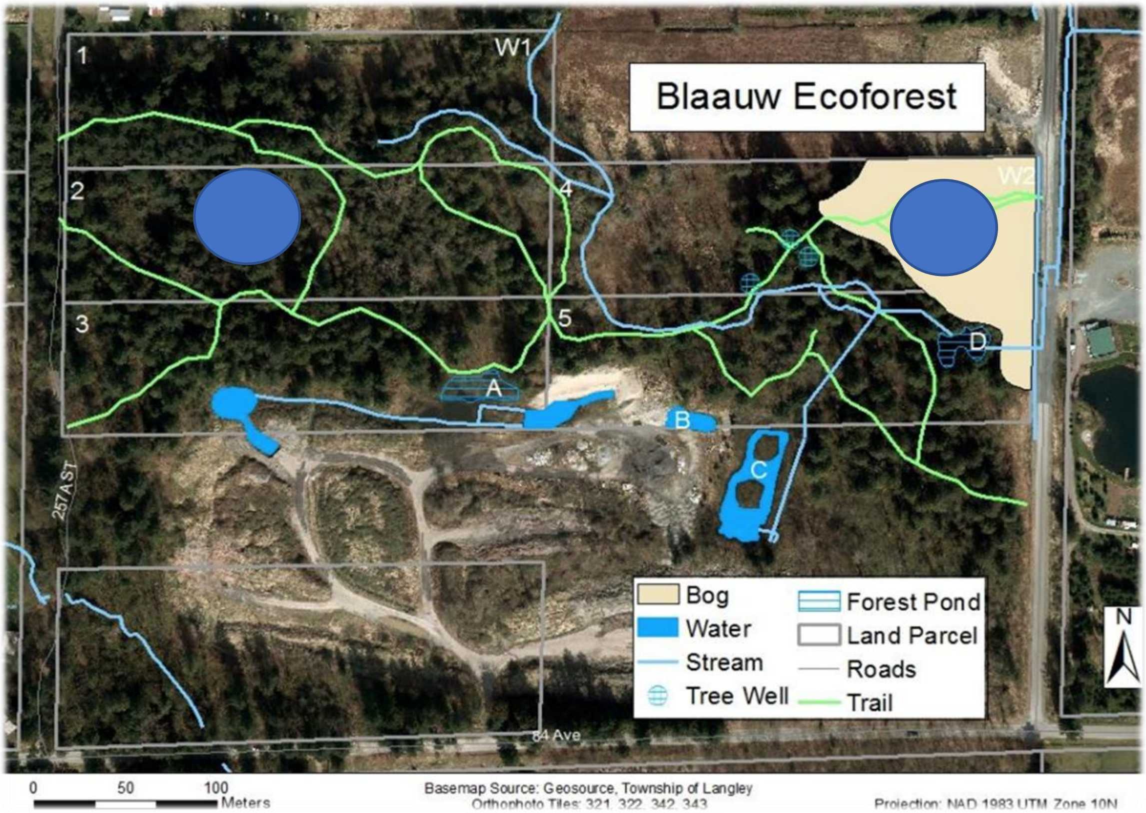

Figure 1: Targeting sampling plots at Blaauw Ecoforest shown by the (blue) circle plots

Lab Methods

The collected cores were first air dried in the lab while still packaged within the straws. Ventilation for the straws was made by poking holes within the ends to allow air to flow through. Once dried, the cores were mounted on a prefabricated wooden core mount. Before mounting the cores, the information from the straw was recorded onto the core mount. A line of glue was then be extruded into the core mount groove, and then the tree core mounted onto the groove, with the cross-sectional view facing up. Masking tape was then utilized to restrain the core as it dried. Once the glue dried the cores were sanded using a belt sander with progressively finer sandpaper from ANSI 80 grit, and 120 grit. Following this, the cores were hand sanded using ANSI 320 grit, and ANSI 400 grit sandpaper.

Analysis

The cores were visually counted assigning calendar dates to each annual ring, starting from the bark-side ring, and working backwards in time towards the pith. One dot is used to mark the decade, two dots for 50-year rings, and three dots for century rings. A list method was then used to crossdate the rings, counting back the rings from the bark to the pith, and noting narrow rings, and finally writing the date of occurrence of the rings in a vertical list (Yamaguchi, 1991). This list then allowed for marker rings to be developed to date other samples. The ring widths between the rings were then measured using a computer interface program called MeasureJ2X, and a Velmex measuring stand interfaced to a PC workstation. An optical linear encoder was used to measure the rings to 0.001mm precision. A check of the visual dating was completed through use of a program called COFECHA. COFECHA statistically matches the segments of cores and creates a master chronology in order to correlate the core samples to signify matches between years. Further a program called ARTSAN was used to build the final stand-level chronologies. ARTSAN also has a broader range of standardization techniques that was used on individual series before creating a master chronology. Chronology data between the forest and bog tree stands were statistically compared through use of a two-way t-test with the program VassarStats.

Results and Discussion

After statistically verifying the visual crossdating through program COFECHA, only 35 of the 40 original cores (87.5%) were retained for creating the master chronology for the western hemlock bog plot stand. The cores BW18401A/B, BW18409B, BW18413A, and BW18443B, were discarded from further study due to the significant negative effect on the overall inter-series correlation. Furthermore, cores BW18433A/B were cut at the calendar year 1970, in order to utilize the cores for the master chronology. One missing ring was found in series BW18425A, and it was found to occur on the year 2004. Significant marker rings that were observed on nearly all the cores included 1974, 1989, 1991, and 2009 (Table 1). The raw age of the oldest tree was found to be 107 years old. The western hemlock chronology had an overall series intercorrelation of 0.413 (n=35, p<0.001), with the individual series correlations ranging from a low of r=0.262 (BW18429A) and a high of r= 0.664 (BW18421B). The strength of these correlation values indicates that the Western hemlock trees at this site are responding to common stand-level signals.

Table 1: Dendrochronological characteristics for tree ring chronology for Western hemlock cores collected at Blaauw Eco-forest from wetland bog environment

Number of trees sampled	20
Number of cores	40
Number of cores retained after cross-dating	35 (87.5%)
Segments flagged	14 (10A, 4B)
Interval	AD 1925-2018
Interval with 2 or more cores	AD 1925-2018

Mean length of series	60.7
Years with narrow marker rings	(1951, 1952, 1974, 1989, 1991, 2009)
Years with wide marker rings	(1940, 1941, 1954, 1955, 1976, 1977, 2012, 2013)
Total locally absent rings in all series	1 (0.047%)
Number of series with absent rings	1
Standard deviation	1.254
Mean sensitivity	0.275
Mean ring width	2.35 mm
Autocorrelation	-0.34
Series intercorrelation (Pearson's R-value)	0.413

After the visual crossdating was statistically verified through the computer program COFECHA, 23 of the 30 original cores (76.7%) were retained for creating the master chronology for the western hemlock sampled within the second growth forest. The cores BW19407A/B, BW19408A/B, BW19413A/B, and BW19415A, were discarded from further study due to the significant negative effect on the overall inter-series correlation, that was unable to be corrected. Significant marker rings that were observed on nearly all the cores included 1950, 1968, 1990, 1992, 2006, 2014 and 2015 (Table 1). The raw age of the oldest tree was found to be 117 years old. The western hemlock chronology had an overall series intercorrelation of 0.415 (n=23, p<0.001), with the individual series correlations ranging from a low of r=0.250 (BW19419A) and a high of r= 0.640 (BW19401B). The strength of these correlation values indicates that the Western hemlock trees at this site are responding to common stand-level signals.

Table 2: Dendrochronological characteristics for tree ring chronology for Western hemlock cores collected at Blaauw Eco-forest within second growth forest

Number of trees sampled	15
Number of cores	30
Number of cores retained after cross-dating	23 (76.7%)
Segments flagged	14 (10A, 4B)
Interval	AD 1902-2018
Interval with 2 or more cores	AD 1905-2018
Mean length of series	100.5
Years with narrow marker rings	(1950, 1968, 1990, 1992, 2006, 2014, 2015)
Years with wide marker rings	(1961, 1962, 1996, 2010, 2011)
Total locally absent rings in all series	15 (0.649%)
Number of series with absent rings	8
Standard deviation	1.183
Mean sensitivity	0.330
Mean ring width	1.75 mm
Autocorrelation	-0.33
Series intercorrelation (Pearson’s R-value)	0.415

The ARSTAN standardization program allowed for the creation of a master ring-width chronology to represent the growth trends of the western hemlock tree stand (Figure 4). Periods of enhanced radial growth are represented during the time spans of 1939-1950, 1974-1987, 1995-1998, and 2012-2015. These periods of pronounced growth may have resulted from the removal of competing vegetation on the site through logging during the early 1900s, along with favoured climatic trends that led to enhanced growth rates. Significant periods of suppression occur in the years, 1958, 1966, 1974, 1989, 1991, and the early 2000s. These are represented by the dipping trends, below 1.0, which is the statistically standardized standard deviation representing average growth rates for the stand. All the ring width growth rates are plotted against sample depth to represent the statistical significance of the collected data.

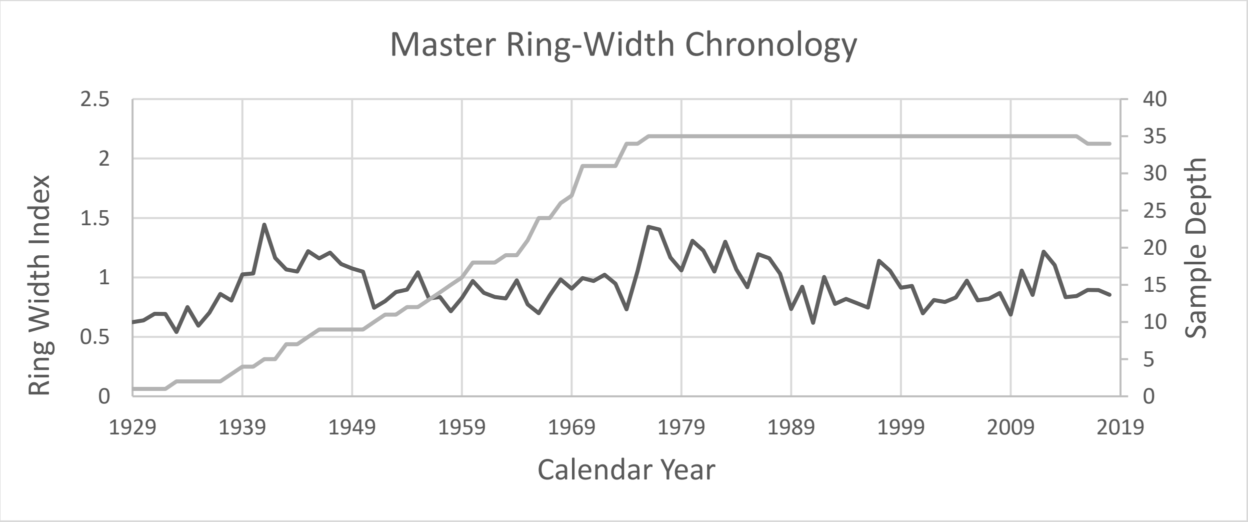

Figure 2: Master ring-width chronology of western hemlock trees within wetland bog environment at Blaauw Eco-forest. Plotting ring-width index for each calendar year (left y-axis) along with sample depth (right y-axis).

Through use of the ARSTAN standardization a master ring-width chronology was created to represent the ring width growth trends of the western hemlock within the second growth forest (Figure 4). Periods of enhanced radial growth are represented during the time spans of 1905-1911, 1940-1942, and 1958-1961. Evidence gathered around the site indicates that these periods of pronounced growth have resulted from the removal of competing vegetation, most likely douglas fir on the site through logging during the early 1900s, along with favoured climatic trends that led to enhanced growth rates. Significant periods of suppression occur in the years, 1937, 1968, 1984-1991, and the early 2000s. These below average growth periods are displayed by the dipping trends, below 1.0. All the ring width growth rates are plotted against sample depth to represent the statistical significance of the collected data.

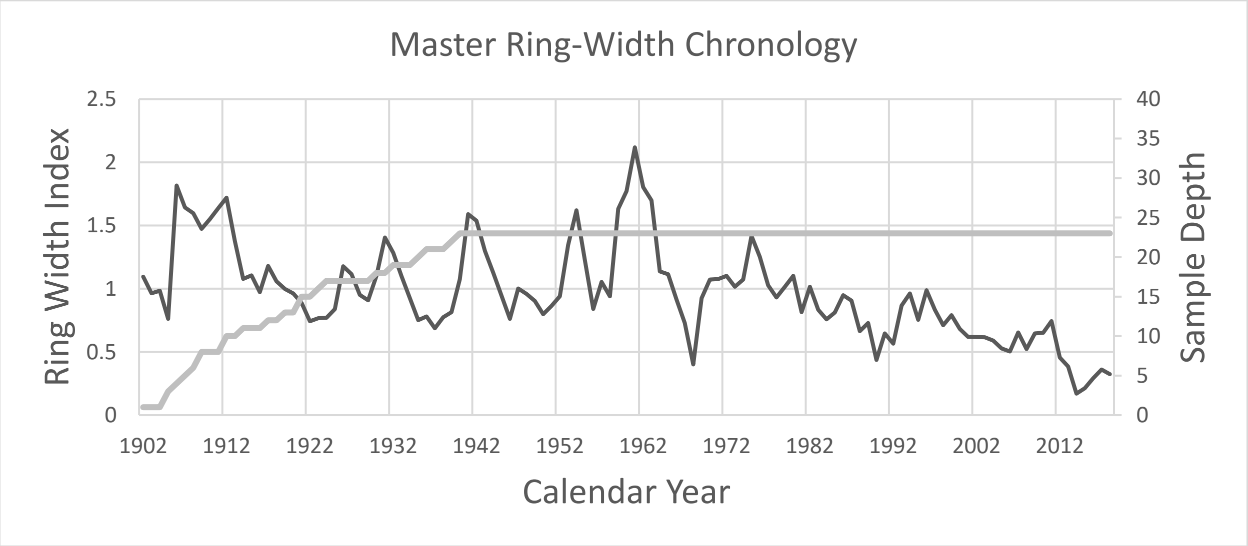

Figure 3: Master ring-width chronology of western hemlock trees within second growth forest at Blaauw Eco forest. Plotting ring-width index for each calendar year (left y-axis) along with sample depth (right y-axis).

In order to compare the growth rates of the western hemlock in the bog environment against the western hemlock within the second growth forest, the ARSTAN master ring-width chronologies were combined together as shown below in Figure 4, to show areas of overlap and years where there are significant differences. As seen in the growth trends, the tree ring widths for the forest are observably more variable, whereas the growth rates for the western hemlock in the bog seem to be more consistent. A significant difference is seen between the growth rates of the two stands within the years 1958-1965, where the second growth forest trees experience a major increase in growth, while the bog remains consistent with average growth. Differences are also seen near the early 2000s, where the second growth forest trees experience a significant suppression in ring growth.

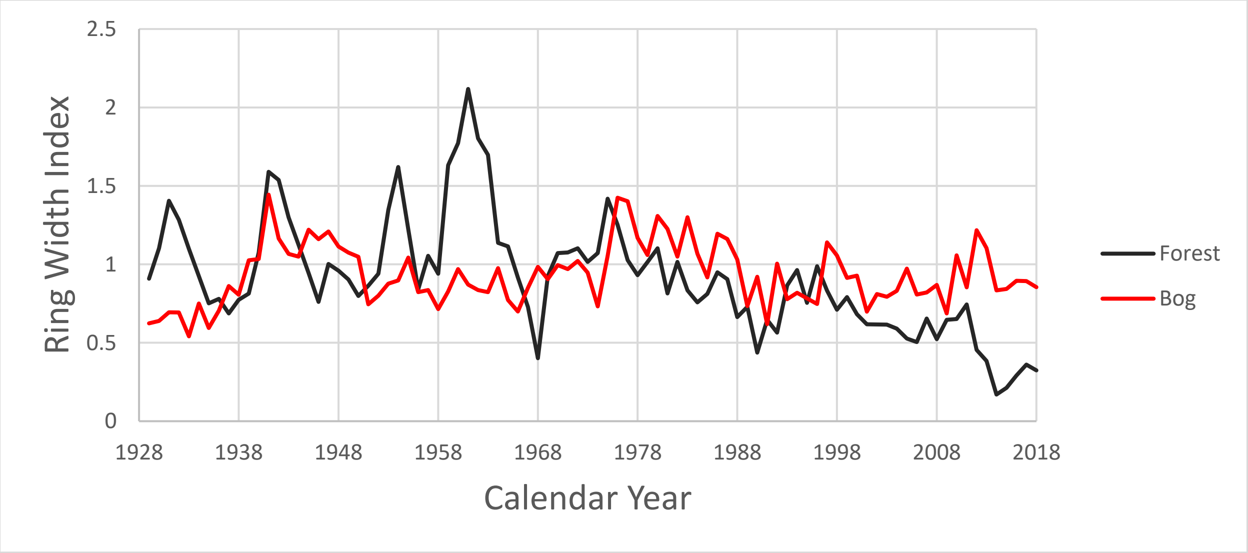

Figure 4: Master ring-width chronology comparison of western hemlock tree ring growth rates within the second growth forest and the wetland bog environment

To statistically compare the growth rates for the second growth forest stand and the western hemlock stand within the bog environment, descriptive statistics were utilized, and a t-test was conducted. Over the whole record, based on the standardized tree ring growth rates retrieved from the program ARSTAN (Appendix Table A1), the mean ring width was found to be 0.97mm for the second growth forest, and 0.93mm for the bog environment, with standard deviations of 0.37 and 0.19 respectively. The t-test calculated a p-value of 0.2, which was greater than the p-critical value, indicating that there is no statistically significant difference between the growth rates of western hemlock between the second growth forest and the bog over the entire record.

Table 3: Descriptive statistics for tree ring growth rates of two western hemlock stands over the entire growth period

	Forest	**Bog**
Mean Ring Width (mm)	0.97	0.93
Standard Deviation	0.37	0.19
Coefficient of Variation (%)	38.2	20.8
P-value	0.2	
P-critical	0.05	
		P Value > P Crit ∴ no statistical difference

In order to further compare the two distinct western hemlock stands, descriptive statistics were conducted in order to analyze the last 25 years of growth rate. The mean ring width for the second growth forest western hemlocks was found to be 0.60mm, while the bog environment western hemlocks had a mean ring width of 0.88mm. A t-test represented a p-value of <0.0001, which was less than the p-critical value, indicating that the average growth rates of the two stands is significantly different. This means that within Blaauw eco-forest, within the two different microclimates, the western hemlocks are subject to different environmental pressures that are creating a growth divergence. The results suggest that the radial growth within the second growth forest is most likely limited by precipitation and moisture availability. While the growth rates of the western hemlock located within the bog environment are likely limited due to the water and nutrient availability of the soil (Boyd, 1972).

Table 4: Descriptive statistics for tree ring growth rates of two distinct western hemlock stands from 1994-2018

	Forest	**Bog**
Mean Ring Width (mm)	0.60	0.88
P-value	<0.0001	
P-critical	0.05	
		P-value < P-crit ∴ statistically significant

Over the entire growth period of the western hemlocks between the two compared environments of the second growth forest, and the wetland bog, the radial growth rates of western hemlock were not found to be significantly different. However, upon analysis of the last 25 years of radial growth, a significant difference was found between the growth rates of western hemlock. The western hemlock situated within the forest contained more variable radial growth trends as shown in Figure 4, compared to the western hemlock situated within the wetland bog. The difference that is visualized between the growth rates can be attributed to the different factors that limit the growth of the western hemlock within each environment. Within the second growth forest the water table is not fluctuating, and the western hemlock growth is limited due to precipitation and availability of moisture. However, bog like environments have fluctuating water tables, and also have low soil pH levels that can contribute to limiting the growth of western hemlocks (Howie and van Meerveld, 2013). However, this difference in growth rates only diverges within the past 25 years and was not seen over the entire 113-year growth record. This may be attributed to the fact that the wetland bog ecosystem has only recently emerged within Blaauw Ecoforest, and that a wetland bog has not always been present within the property. As prior to the last 25 years growth of the western hemlocks were similar, however, the last 25 years contain different growth rates.

Overall, this study has shown that bog environments can act as limiting factors to the growth rates of western hemlocks, and further, this study has produced a site-specific ring width-chronology for the western hemlock situated within Blaauw Ecoforest. This study has extended the tree-ring age chronology of Blaauw Ecoforest, and also has helped to characterize that indeed the wetland environment is a bog, due to the fact that it has limited the growth of the western hemlock for the last 25 years. Furthermore, this study has helped explain the environmental history of Blaauw, and in turn more informed management decisions can be made to restore and maintain the wetland bog ecosystem. However, we do recognize that the environmental-growth relationships that are illustrated in this study are tentative until further research of western hemlock growth trends within bog environments is conducted.

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Appendix

Table A1: ARSTAN standardized western hemlock growth rates

Forest growth rates		Bog growth rates	
Calendar year	Ring width (mm)	Calendar year	Ring width (mm)
1902	1.095		
1903	0.964		
1904	0.984		
1905	0.762		
1906	1.816		
1907	1.643		
1908	1.597		
1909	1.473		
1910	1.551		
1911	1.637		
1912	1.72		
1913	1.377		
1914	1.078		
1915	1.105		
1916	0.972		
1917	1.18		
1918	1.059		
1919	0.998		
1920	0.963		
1921	0.888		
1922	0.742		
1923	0.767		
1924	0.77		
1925	0.838		
1926	1.178		
1927	1.116		
1928	0.951		
1929	0.908	1929	0.624
1930	1.102	1930	0.639
1931	1.405	1931	0.694
1932	1.284	1932	0.693
1933	1.098	1933	0.541
1934	0.925	1934	0.75
1935	0.751	1935	0.594
1936	0.78	1936	0.704

1937	0.687	1937	0.861
1938	0.774	1938	0.806
1939	0.814	1939	1.026
1940	1.075	1940	1.034
1941	1.59	1941	1.444
1942	1.538	1942	1.164
1943	1.299	1943	1.067
1944	1.125	1944	1.049
1945	0.944	1945	1.221
1946	0.761	1946	1.16
1947	1.002	1947	1.209
1948	0.959	1948	1.113
1949	0.903	1949	1.075
1950	0.798	1950	1.048
1951	0.864	1951	0.745
1952	0.94	1952	0.8
1953	1.346	1953	0.877
1954	1.62	1954	0.897
1955	1.223	1955	1.043
1956	0.84	1956	0.823
1957	1.054	1957	0.836
1958	0.94	1958	0.715
1959	1.632	1959	0.827
1960	1.772	1960	0.97
1961	2.118	1961	0.871
1962	1.803	1962	0.836
1963	1.698	1963	0.823
1964	1.137	1964	0.976
1965	1.114	1965	0.773
1966	0.916	1966	0.699
1967	0.728	1967	0.85
1968	0.401	1968	0.984
1969	0.925	1969	0.905
1970	1.072	1970	0.995
1971	1.076	1971	0.97
1972	1.102	1972	1.022
1973	1.016	1973	0.947
1974	1.072	1974	0.732
1975	1.418	1975	1.054
1976	1.252	1976	1.425

1977	1.027	1977	1.402
1978	0.931	1978	1.168
1979	1.014	1979	1.059
1980	1.102	1980	1.308
1981	0.815	1981	1.226
1982	1.016	1982	1.049
1983	0.834	1983	1.3
1984	0.757	1984	1.068
1985	0.812	1985	0.917
1986	0.949	1986	1.195
1987	0.905	1987	1.161
1988	0.664	1988	1.031
1989	0.729	1989	0.734
1990	0.437	1990	0.921
1991	0.646	1991	0.619
1992	0.565	1992	1.004
1993	0.866	1993	0.778
1994	0.963	1994	0.819
1995	0.754	1995	0.783
1996	0.988	1996	0.747
1997	0.833	1997	1.14
1998	0.711	1998	1.056
1999	0.791	1999	0.913
2000	0.682	2000	0.928
2001	0.618	2001	0.698
2002	0.617	2002	0.81
2003	0.616	2003	0.793
2004	0.59	2004	0.831
2005	0.527	2005	0.973
2006	0.504	2006	0.807
2007	0.654	2007	0.821
2008	0.523	2008	0.869
2009	0.646	2009	0.687
2010	0.651	2010	1.057
2011	0.744	2011	0.853
2012	0.455	2012	1.217
2013	0.384	2013	1.103
2014	0.17	2014	0.834
2015	0.213	2015	0.843
2016	0.291	2016	0.895

2017	0.361	2017	0.893
2018	0.324	2018	0.854