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Local Ecology Research Papers

Tree Ring Width Variation in Pinus strobus with Varied Water Availability; The current effects of past ecological footprints

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2006

Tree Ring Width Variation in *Pinus strobus* with Varied Water Availability;
The current effects of past ecological footprints.

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Field Ecology 371
December, 15 2006

Study Site: St. Croix River, Minnesota.

Abstract:

Tree ring patterns provide a reliable estimator of climate from past years in a forests history, water being one of the strongest limiting growth factors creates a variation in tree ring width. The purpose of this study was to determine if there is less variation of tree ring width found in trees growing in close proximity to a water source and to predict if constant water availability provides an advantageous environment for the maximum growth of *Pinus strobus*. Near the St. Croix River by Interstate State Park, Minnesota, diameter base heights were recorded and ten tree core samples were taken from each of the two sample sites, each site had different levels of elevation and soil moisture. Results from analysis of variance tests preformed with STATA illustrate that, trees growing in close proximity to the river had a significantly wider average ring width. A regression graph with diameter base height as a function of tree age showed that tree age is directly proportional to DBH. While there was as a difference in the average age of trees from the two sites, there was not a significant difference in the DBH of tree from the two sites. A composite skeleton plot of tree ring width variation for the two sites illustrated that trees growing further from a constant water source have a greater frequency of narrow rings, than trees growing near the river. This study suggests that trees benefit from growing near a water source and experience a faster growth rate, but growing in a site without constant water availability may contribute to long-term fitness and a longer lifespan of *Pinus strobus*.

Introduction:

By examining tree ring patterns it is possible to explore past climate and growing conditions for a population. The patterns in ring widths provide the most reliable estimator of past variations in moisture and temperature, which may have limited the growth controlling process for trees (Fritts 1966). A growth ring is formed inside the bark by divisions of cambial cells, which produce large, thin walled wood, or xylem cells at the beginning of the growing season, and small thick walled wood cells towards the end of the season. The abrupt change in cell size between the last formed wood of one year and the first formed wood of the next year usually delineated the boundary between annual growth increments (Record 1962). Each successive layer when viewed in a transverse section appears to be a ring; encircling many previously formed concentric rings, whose number increases towards the stem base and each year produces a continuous layer surrounding the previously formed wood where the year's increment becomes the first layer of wood (Fritts 1966).

It is commonly known that the widths of annual rings in trees in semiarid sites correlate with the variations in climate (Douglass 1928 as cited by Fritts 1966). Observations of the tree rings can determine the age of the tree and growing conditions of individual years, wide rings are generally produced by wet years and other factors contributing to the maximum growth of the tree. The primary sequence for formation of narrow rings includes; increased water stress, reduce net photosynthesis and low accumulation of food resulting in reduced rates of cambial activity and the formation of narrow rings (Fritts 1966). Within season growth responses of forest trees are more sensitive to fluctuations in soil moisture than to any other environmental factor (Zahner and Stage 1966).

If water stress plays such a factor in the variation of the widths of tree rings then large, healthy trees found growing near a water source should have constant tree ring widths. However, since large trees can be found at varied distances from water, there is reason to believe that trees growing at a further distance from a water source will compensate for growth during a wet year due to their lack of constant water availability. Some studies have found negative correlations between summer precipitation and radial growth; wet summers tend to be cool and cloudy, conditions unfavorable to rapid growth (Enright 1984). So does the tree ring width of trees growing near water correlate with the general health and size of the trees or is having a constant source of water over years actually a detriment to the trees maximum growth? Do trees adapt to the fluctuation in moisture availability and compensate for loss of growth and a narrow ring in a dry year, by producing wider rings during wet years; moreover do trees adapt their water absorption and retention depending on their growing location? Pervious studies have shown that unusually warm or cold, wet or dry winter conditions influence growth in the following summer by increasing or decreasing desiccation tissue damage and respiration rates (Werren 1981). So how does the average measurement of the rings from trees near water compare to trees sampled further from the water source? Much research has been done in fluctuation of tree ring variability during wet to dry years, but little research has been done to observe the variation of tree rings within a species in relation to the proximity of water source. Since it is important to explore all the possibility that could affect the healthy growth of a tree and the entire health and balance of an ecosystem, my research will attempt to answer some of these important questions.

The objective of my study was to determine if there is less variation of tree ring width found in trees growing in close proximity to a water source and to predict if constant water availability provides an advantageous environment for the maximum growth of Pinus strobus. Also by comparing the total diameter of tree cores from samples at varied distances from a water source, it may be possible to determine if trees growing further from a source of water maximize their growth in a wet season, by producing wide rings to make up for lack of growth in a dry season. Therefore I hypothesized that *Pinus strobus* found growing near an adequate water source will have less variation in tree ring width that those growing a greater distance from the water source, and the average widths of the past twenty tree rings will reflect equal growth from trees sampled near and far from the water source.

***History of the site*:**

The St. Croix River valley extends from just north of Wild River State Park in Chisago County south to its convergence with the Mississippi River at Point Douglas in Dakota County (Fig 4). This land which was a part of the great northern pine forests was originally occupied by the warring Dakota and Chippewa tribes (McMahon, E., Karamanski, T. 2002). Early white explorers discovered the rich diversity of pelts and timber in the great Minnesota forests and were attracted to the St. Croix River valley because of its promising economic value (Fig 5). The fur trade business flourished along the river from the early 1700’s until 1820 when the beaver population had nearly disappeared (McMahon, E., Karamanski, T. 2002). Soon after pelt stores were depleted, the forest was accessed as the site of an even more lucrative resource. A French scientist named Joseph Nicollet, who journeyed up the river in August 1837 reflected this new interest in the valley’s forest writing “The banks of the St. Croix are still covered with black alder, sumac five or six feet tall, white and red oak, soft maple and some walnut, oil nut or shagnut trees, white pine are mixed with the deciduous forest and there are wild plum trees on the ridges." (McMahon, E., Karamanski, T. 2002). The dominated species in the forest was the white pine (*Pinus strobus*) which had entered Minnesota 7000 years ago, during the Holocene period (Jacobson 1979). The fact that white pine was light, floated well on log drives, yet was strong, durable and resistant to decay, made these trees a particularly valuable timber (Bachmann 1945)**.**

Commercial lumbering began in 1839 with the installation of sawmills in Stillwater and Taylor Falls, for seventy years the St. Croix river was channeled into a disciplined waterway, the once wild free flowing river now existed as a river of pine (Larson 1949). The volume of timber taken out of the St. Croix River valley is astounding, around the 1890's more that 450 million board feet of lumber was harvested per year. The total production between 1840 and 1912 if loaded onto standard log cars would have required 2.2 million rail cars (McMahon, E., Karamanski, T. 2002). The sudden dramatic loss of the valleys forest has not only changed the appearance of the landscape, but the ecological changes caused by the massive logging boom are unrivaled since the last descent of the glaciers (Jacobson 1979). Although efforts have been made to replant the beautiful and valuable woods, the big white pines forest will never be replaced and only remnants of the majestic forests can be found along the banks of the St. Croix River.

Methods:

Using a tree corer, twenty samples were taken from two sample sites by the St. Croix River near Interstate State Park, Minnesota. Site 1 consisted of a grove of white pine within a distance of 20m from the river, this site had a high level of soil moisture an elevation of 687 ft (Fig 6). Site 2 was 70 meters away from the river with an elevation of 834 feet (Fig 7). Tree cores were taken from as low to the base of the tree as possible (<.25 m from the base). The diameter base height of each tree was measured by using a diameter tape. In lab each tree sample was aged, by counting the total number of rings from the center to the outside end of the core. The average tree ring width was then found by measuring the total diameter from the center of the core and dividing it by the number of rings counted on the core. The last twenty years (rings) were counted and measured with a millimeter ruler. Twenty years was chosen as a standard measurement to compare measurable recent tree growth, since the trees were all different sizes and ages, the last twenty years was used as a controlling factor to limit the standard of error. A skeleton plot was draw for each of the samples to determine if there was a greater variation in tree ring widths between sites. This is done by using a strip of fine graph paper to plot a visual measurement for each year of the trees growth (Stokes and Smiley 1968). A line was drawn for a narrow ring, a length of the line represents the narrowness of the ring, a longer line representing a very narrow ring, average rings or wide rings were not marked. A master skeleton plot was finally created for each site as a composite representation of each of the individual plots (Fig 10).

Statistical analysis:

STATA was used to create regression graphs showing diameter base height as a function of tree age, KelidaGraph was used to display the results in graphic form.

Analysis of variance tests (ANOVA) were preformed to determine if there was a significant difference in the age of the trees between the two sites (Table 2), to determine it there is a significant difference in the width of the last twenty years of tree ring growth and site (Table 3) and to determine if there was a significant difference of the diameter base height between sites (Table 4). A fourth ANOVA was preformed to determine if there was a significant difference in the average tree ring width between sites (Table 5).

Results:

The direct association displayed in the regression graph (Fig 1) shows that the diameter base height of trees (Site 1 and Site 2) as a function of tree age has a direct relationship. The low P value (0.0001) and slope of 0.8608 showed direct association between the DBH and age of trees. This is also show in the site specific regression graphs (Fig 3, Fig 4). The composite skeleton graphs illustrates that there was a much higher frequency of narrow rings occurring in the Site 2, there is also a greater deviation from a consistent pattern of average tree ring widths. Table 2 shows significant variance in the measured ring width over the last 20 years between the two sites. The small P value (0.0209) is significant and allows rejection of the null hypothesis and confirms that there is a significant difference in the length of the last twenty years of tree growth; Site 1 is shown to have a much greater average twenty year width. The average ring width is also show to be significantly high in Site 1 (Table 5), this is confirmed by the low P value of 0.0011 and rejects the null hypothesis and shows that there is a significant size difference in the average ring widths between sites. Table 1, shows that the sizes of an average ring in the Site 1 (6.28mm) was more than twice that of Site 2 (3.11mm). Table 8, shows the variance of the DBH in trees between the two sites, the high P value (0.983), allows acceptance of the null hypothesis, that there was no variation in the average DBH of trees in Site 1 and Site 2. Table 1 displays that the average DBH of a tree in Site 1 was 35cm and average DBH in Site 2 was 47cm. However analyzing the variance between the two different sites and age, (Table 2) allows rejection of the null hypothesis that there is no difference in the age of both sites, because of the significant P value (0.0015). The trees in Site 2 were significantly older; Table 1 shows the average age being 80 years, while the average age of trees in Site 1 was only 33.

Discussion:

The dominance of the water supply factor in determining the relative width of annual rings in conifers has been emphasized by many studies in recent years (Lyon 1943). It must be kept in mind that many factors effect the relative growth rate or trees and the length of the growing season may fluctuate more widely from one year to the next as the tree increased in size (Fritts 1966). However the results of this study seem to clearly show that that availability of water, significantly affects the growth rates of *Pinus Strobus.*

Relationship between Age and DBH.

Figures 1-3 show that there is a direct association between the age of the trees in Site 1 and Site 2 and their corresponding DBH measurements. While at first this seems obvious, this relation is dependent on many other limiting growth factors and species. It is generally know that the there is a close relation between height, diameter, and age but this relationship may not be consistent for individual trees (Morey 1936). An example of how age is not necessarily associated with the size of the tree, is the sequoia (*Sequoia gigantean)* and Bristlecone (*Pinus aristata*) pine species, while sequoia trees are the largest in the world they usually only a couple hundred years old and the small gnarled bristle cones can live to be four thousand years old. However, because this study only involved on species of tree a direct relationship between age and DBH can be drawn.

Skeleton graphs.

By looking at skeleton graphs (Figure 10) it's clear to see that there was much greater frequency of narrow rings occurring in Site 2, there is also a greater yearly variation in the ring widths. This can be defined sensitive growth, which is a variation in ring thickness, due to a variable limiting growth factor (Glock 1937). Complacent rings, which indicate uniformity and show little variation in ring widths from year to year, were found in the trees of Site 1. Studies have confirmed the fact that the constant presence of water does produce the type of growth found in Site 1. Pines growing in very moist climates are less sensitive to climactic factors in swampy areas and therefore have a more even rate of growth (Goldthwait and Lyon 1937)

Ring width comparison.

The measured ring width over the last twenty years of growth was significantly greater in Site 1, the average ring width in Site 1 was also greater, being twice the size of the average ring width in Site 2 (Table 1). This does relate to the complacent and sensitive growth of the two sites, because not only were the rings more uniform but they were also much bigger in Site 1. Ring size is presumptive evidence for either drought like conditions or a generous supply of water in the growing season in which the ring was formed (Lyon 1943).

Age and DBH variation.

In white pine diameter and height can be correlated but not age (Morey 1936) As shown in Tables 2 and 4, there was a significant difference in age, but no variation in the overall analysis of DBH between sites. When comparatively looking at the age of each site they are very different, but the sizes of the trees are not drastically different. The age of a tree may not have the height or diameter that the given age has attained, and age diameter correlations cannot be used to determine growth (Morey 1936).The average age in Site 2 was 80, while only 33 in Site 1, consequently a tree in Site 2 could be fifty years older than it's same sized tree in Site 1 (Table 1). It must be consider that not age but the quality of the site determines the growth and size during the life cycle of a tree (Morey 1936). Therefore the rate of growth in Site 1 must be much greater that Site 2 to compensate for fewer years of growth.

Growth Conditions:

Growth rate is limited and somewhat governed by water availability in soil (Lyon 1943). While trees growing and a low wet location with a constant supply of water may have benefits of initial fast growth, in the long run this lack of a drying period may not be beneficial to the overall condition of the tree and the complacent growth found in Site 1 could be a potential limiting growth factor. Many of the trees in Site1 were particularly hard to core, the wood being so soft and wet caused many of the cores to fragmented into several pieces upon extraction, it was nearly impossible to extract the core in one continual piece. Trees this wet may have an increase mortality rate due to increased rotting. Soil moisture has to be high enough to promote a flow path for the products of enzyme action, yet low enough to prevent water logging; which produces an anaerobic habitat hostile to the normal wood growth and conducive conditions for wood decay organisms (Levy 1987).

The fallen trees and decaying logs observed in Site 1 may be evidence that the extreme moisture of the soil in Site 1 may cause instability of the rooting system, leading to the increased risk of upheaval from wind or unbalanced mass distribution of the tree. Complete vegetative covering is necessary to ensure full rooting capacity, and the litter mulch gives protection against soil puddling and crusting (Zahner and Stage 1966). This lack of consistent litter coverage may limit the rooting capacity of trees in Site 1. It is commonly known that trees growing in areas with high moisture do not have to establish deep roots in search of moisture when adequate amount of moisture is available on the surface. The fact that dryer soils have increased root depth (Pearson 1930), may be evidence that the trees in Site 2 are more resistant to risk of wind fall or top heavy upheaval. Other studies have confirmed evidence that porous well drained soil is accepted as the best growth condition for white pine (Goldthwait and Lyon 1937).

Age and duration of survival can also be a determining factor for the general health of trees; samples in Site 2 were on average fifty years older than the trees found in

Site 1. The sensitive growth patterns found in the trees in Site 2 show that the trees are more receptive changes in soil moisture than the trees in Site 1; this may actually be advantageous to the general health of the trees. Studies confirm that white pine at high altitudes, rooted in dry soil are very sensitive to moisture variations and atmospheric factors (Goldthwait and Lyon 1937). Not only the level of soil moisture, but also the increased elevation of Site 2 may contribute to the overall longevity and wellbeing of the trees. Rate of growth has been found to be greatest in the presence of extremes mainly high elevation and dry soil situations (Sperry 1934). Examples are found in the fact that some of the strongest and most beautiful conifers exist in areas with extreme variations in moisture levels. Trees growing in the mountains of western U.S. usually experience hot dry summers and seasonal high moisture levels due to the immense levels of snowfall in the winter months. Extreme altitude distribution and deep well drained soil produces massive pine trees growing in the Sierra Nevadas, mainly *Pinus jeffreyi* and *pinus ponderosa* (Oosting and Billings 1943).

If hot and dry summer conditions are the most conducive growing conditions for maximizing cambial activity, then having a constant, year-around source of water is actually detrimental to the maximum tree growth and correlates negatively with the general health and size of the tree. Overall results of this study point to the fact that constant moisture ingestion may not be the best method for the resourceful water use of *Pinus strobus.* Simply because there is an overly adequate level of water in an area, does not mean that trees will be able to utilize the excess water to produce beneficial lasting health. Studies have shown that the months which produce the most rainfall are not always directly correlated to maximum cambial growth. Internal moisture tension in the tree may result from soil moisture tension at times when soil is moistened to field capacity (Buckingham and Woods 1969). A much more resourceful method of water utilization is found in trees that have seasonal growth periods which require satiation of moisture needs due to soil dryness. Little effect on growth will result from an inch of rain during the growing season when the soil is already at field capacity from previous rains; however the same inch of rain when the soil is dry will positively correlate with growth (Zahner and Stage 1966).

One of the objectives of this study was to compare the total diameter of tree cores from trees at Site1 and Site 2 to determine if trees growing further from a source of water maximize their growth in a wet season by producing wide rings to make up for lack of growth in a dry season. While the rings in Site 2, were certainly narrower than the rings from Site 1, this is not an accurate assessment of how the trees maximize their growth in times with ample moisture, because size of the average rings by site were not equal. Trees in Site 1 simply had faster growth rates, so direct comparisons could not be made of the ring growth rate between sites. The other objectives of my research were to determine if there was less variation of tree ring width found in trees growing in close proximity to a water source and to predict if constant water availability provides an advantageous environment for the maximum growth of *Pinus strobus*. I found that there was less variation in the tree ring width of trees growing in Site 1 and initially these trees benefit from a faster growth rate due to the constant water source, however trees which do not grow in the presence of a constant water source may have superior fitness and a longer lifespan. Although the portion of my hypothesis that the average widths of the past twenty tree rings will reflect equal growth in trees sampled from Site 1 and Site 2, could not be accessed, because the growth rates of the average rings had such a great variation between sites. The main portion of my hypothesis was supported, because *Pinus strobus* growing near an adequate water source had less variation in tree ring width that those growing a greater distance from the water source.

Conclusion:

This study has shown that trees growing in wet conditions experience fast growth for a relatively short lifespan, and trees growing in dry conditions grow more slowly for a longer time. The big question is do benefits of fast growth outweigh the benefits of the species long-term health? Similar to the story of the tortuous and the hare, in this case slow and steady growth does win the fitness race! It is sometimes necessary to question the results of research, by looking for reasons of the conditions of the study sites. Reasons for the detrimental growing conditions of *Pinus strobus* found in Site 1 may be directly correlated to the history of the site. Not only did the over trapping of the beavers change the geographical design of the local waterways, but the St. Croix River was also vastly changed during the logging frontier. The gated dams left as their legacy by creating a shallow flowing river whose banks were prone to erosion, where the current slackened, the sand and earth suspended in the river settled into bars and shoals (McMahon, E., Karamanski, T. 2002). It is very possible that the conditions of the many trees growing in low wet conditions along the banks of the river were created by the man made alterations of the river.

The St. Croix River today is what remains of an area that has been severely marked by ecological footprints, namely the comprehensible measure of environmental impacts and the on land use required to support the material consumption of a nation (York et al 2003). Human interference can be seen in obvious ways along the St. Croix, the sudden dramatic loss of the valleys forest has changed the appearance of the landscape, by trapping of the beaver, logging of the white pines and the channeling of the river. Less apparent ecological footprints can be found in research which can uncover concealed indications of the how past human interference affects future generations, unfortunately we are still discovering the implications of ecological mistakes today. More extensive research on trees growing in low wet conditions along the banks of the river is necessary to determine the magnitude and the lasting effects of these ecological footprints.

While the costs and benefits of ecological footprints are debatable, the over use of natural resources does have dramatic and lasting effects on an ecosystem. The massive timber harvest benefited the western expansion of the United States and the great white pines still exist today in many homes and buildings across the country. The wide shallow river that exists as the St. Croix today is a wonderful location for state parks and recreational canoeing, swimming and fishing. Utilization of environmental resources while often necessary, need to be carefully considered for future ecological implications and the importance of learning from past history is necessary to better understand the present situation and make wise decisions about the future. Insightful knowledge of the interactions of our ecosystem can hold the key for the future wellbeing of our ecosystems.

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Picture: McMahon, E., Karamanski, T. 2002. TIME AND THE RIVER, A History of the Saint Croix A Historic Resource Study of the Saint Croix National Scenic Riverway. pp 4-35.

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Table 1. Summary of Average Measurements from Site 1 and Site 2.

	Site 1	Site 2
Average DBH	35.04cm	47.31cm
Average Age	33 years	80 years
Average Core Length	191.6 mm	209.5 mm
Average(past 20 year) Length	110.2 mm	74.8 mm
Average Ring Width	6.28 mm	3,11 mm

Table 2. Analysis of Variance test comparing Age (years) between Site 1 and Site 2. (P = 0.0015)

	mean	variance	sd	se(mean)	skewness	kurtosis
Site 1	33.6	140.71	11.86	3.75	.5	2.72
Site 2	80.7	1445.12	38.05	12.02	1.48	3.83
Total	57.15	1334.97	36.54	8.16	1.69	5.72

Table 3. Analysis of Variance test comparing width of last twenty year of growth (mm) between Site 1 and Site 2.
(P = 0.0209)

	mean	variance	sd	se(mean)	skewness	kurtosis
Site 1	110.2	781.95	27.96	8.84	1.01	3.18
Site 2	74.8	1174.17	34.27	10.84	.79	2.96
Total	92.5	1256.27	35.45	7.92	.316	2.76

Table 4. Analysis of Variance test comparing diameter base height (cm) between Site 1 and Site 2.
(P = 0.0983)

	mean	variance	sd	se(mean)	skewness	kurtosis
Site 1	35.04	123.31	11.11	3.51	.75	3.01
Site 2	47.31	371.84	19.29	6.09	1.31	3.74
Total	41.18	274.16	16.56	3.71	1.54	5.41

Table 5. Analysis of Variance test comparing average tree ring width (mm) between Site 1 and Site 2.
(P = 0.0011)

	mean	variance	sd	se(mean)	skewness	kurtosis
Site 1	6.28	6.16	2.5	.78	1.46	4.22
Site 2	3.15	.48	.69	.21	.47	2.05
Total	4.7	5.8	2.4	.54	1.68	5.83

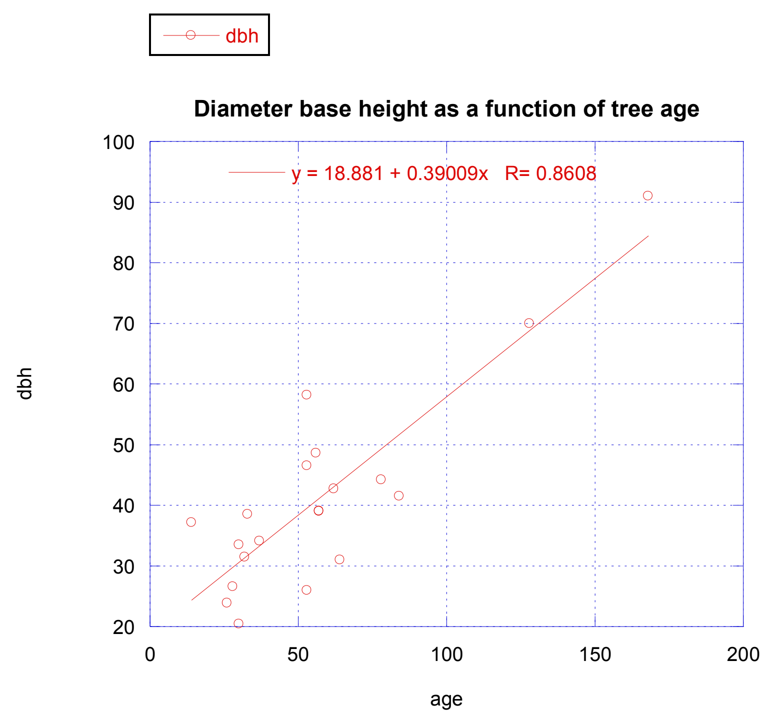

Figure 1. Regression plot of diameter base height in both Site 1 and Site 2 as a function of tree age.
P Value = 0.0001 (dbh of both sites = (cm), age of both sites = years)

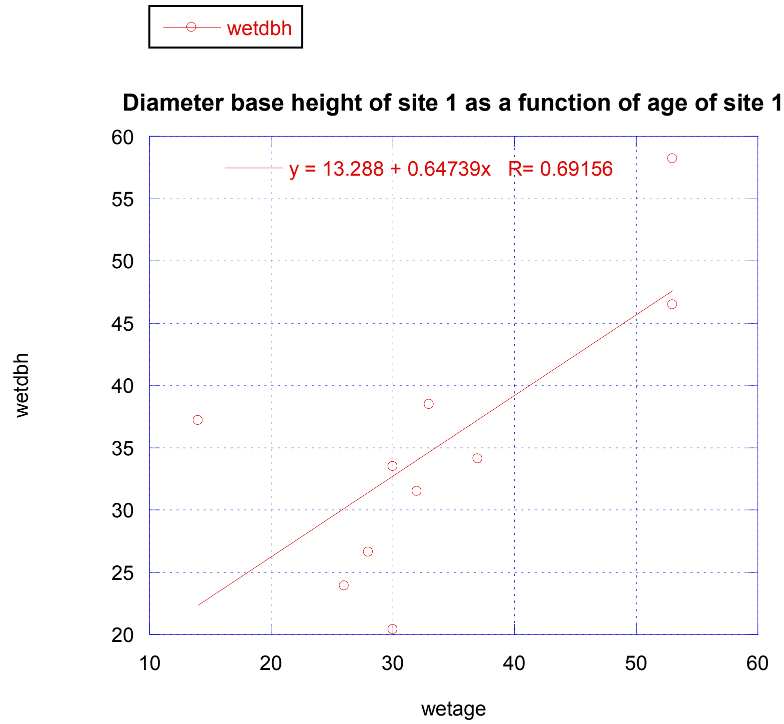

Figure 2. Regression plot of diameter base height in Site 1 as a function of tree age. P Value = 0.0001 (wetdbh = DBH Site 1 (cm), wetage = years in Site 1)

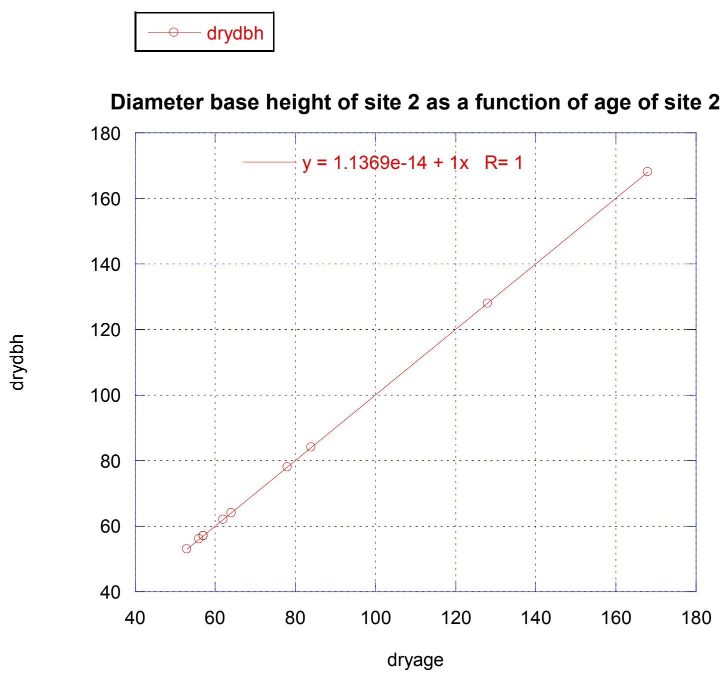

Figure 3. Regression plot of diameter base height in Site 2 as a function of tree age. P Value = 0.0001 (drydbh = DBH Site 2 (cm), dryage =years in Site 2)

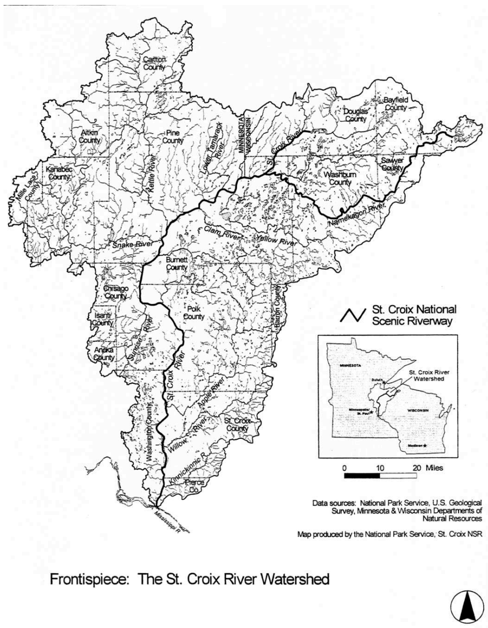

Figure 1. Map of the St. Croix River Valley.

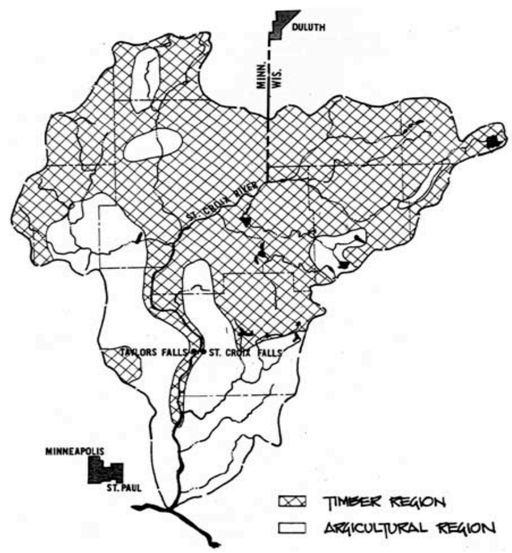

Figure 2. Timber resource map of the St. Croix River Valley.

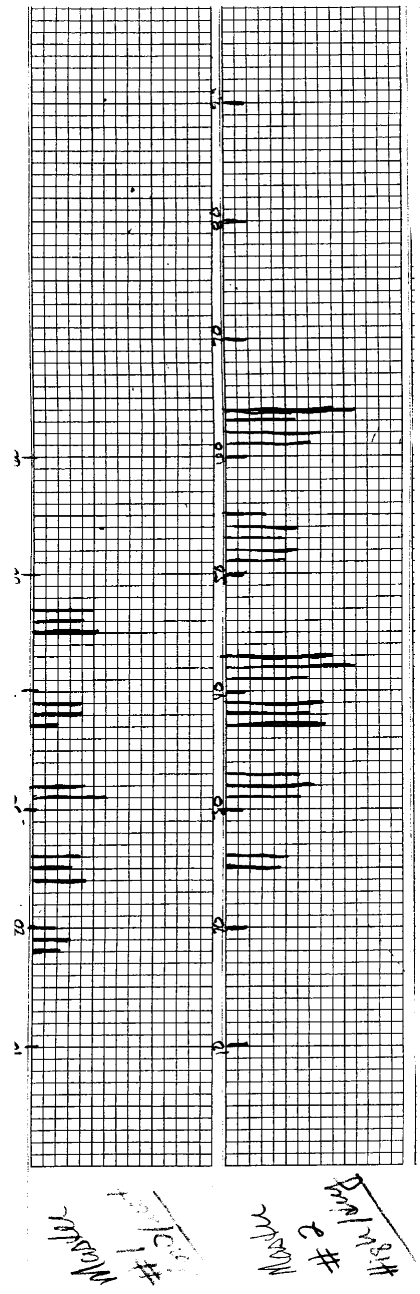

Figure 10. Composite Skeleton graph of Site 1 and Site 2.