St. Olaf College

Local Ecology Research Papers

Early Tree Growth Patterns in a Conifer Restoration

Leigh Cooper
2004

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Abstract

As part of the St. Olaf College natural habitat restoration program, two conifer sites were planted in 1993 and 1999 with two-year-old seedlings to establish areas similar in species composition to northern Minnesota coniferous forests. This project's purpose was to examine early conifer growth patterns and reproductive output to make recommendations for future projects. GPS maps were created to record the conifers' locations. Soil tests for nutrients and moisture showed few significant differences among the conifer sites and local prairie and agricultural plots. Overall, results showed significant differences in tree heights among species. Jack pines had the tallest and balsam firs had the shortest mean heights. The mortality for the 1993 plot was less than ten percent. Growth patterns closely matched the linear pattern predicted by a general linear model based on repeated sampling of marked individuals. Some pines were planted with protective plastic mats or tree tubes, but unless deer herbivory is high, this study suggests the cost of using tree shelters in not justified since conifers with and without shelters showed no significant differences in height. Few viable seeds were produced by the 1993 conifers although there were significant differences in green female cone production among species. The 1993 conifers started to reproduce at the expected average age suggesting healthy growth conditions. In the future, cone production should increase. The conifers' growth rate should increase and then level off with red and white pines dominating the canopy. Continual maintenance will be required to decrease the invasion of hardwood seedlings.

Introduction

Over the past seventy years, humans have become more concerned with their effect on the environment. It has been found that humans have altered up to half of Earth's ice-free surface (Frelich et al. 1999). The idea of restoration has evolved from the hope that humans can reverse or reduce the changes we have made to the Earth. The goal of restoration is to restore an area to a more natural state where plants and animals can live without extensive management. The restoration should be able to survive natural disturbances (Frelich et al. 1999).

This study focuses on the restoration of Minnesota coniferous forests. Coniferous forests have been in the Great Lakes area for the past 7,200 years and, in Minnesota, today, coniferous forest is found in the northeastern part of the state. The forest can be broken down into several different types (Tester 1995). The red and white pines usually grow in dry soil composed largely of gravel while the jack pines grow with an understory of black spruce and shrubs. The forest swings back and forth from mostly spruce and white cedar to white, red, and jack pines throughout its history. There are also black spruce swamps and tamarack bogs in the area. Much of the northern forest in Minnesota is in a pine dominant stage, but small sections of the other vegetative areas continue to exist. Through succession, the transition in species composition of an ecosystem, the dominant species change over time. In a Minnesota coniferous forest, succession is caused by multiple types of disturbances to the forest including windstorms, drought, flooding, fire, insects, mammals, plant diseases, and human disturbance (Heinselman 1996). If a forest is undisturbed and becomes more established, older trees will begin to die off, and young trees will replace them creating a forest with trees of multiple ages.

What makes a forest natural is that disturbances create openings and the stand consists of a variety of tree species of different ages (Frelich 2003). Restoration increases the speed at which succession occurs.

St. Olaf College has 700 acres of natural lands and planners have tried to recreate a variety of Minnesota ecosystems on these lands, including coniferous forests. Although large coniferous forests did not exist in the Northfield area at the time of European settlement, the study site was created to allow students and faculty a chance to learn about the boreal biome and increase biodiversity as part of a greenbelt buffer zone around the St. Olaf campus (Rosenthal 1999).

The specific goals of the conifer studies at St. Olaf in 2003 and 2004 were to (1) Record the heights, diameters and location of the conifers, (2) Measure cone production to determine reproductive success, (3) Create growth curves for individual species, (4) Compare heights among trees grown with and without tree shelters or fabric mats, and (5) Collect and test soil samples to determine if coniferous forests change soil composition over time.

Methods and Materials

The conifer forests on the St. Olaf natural lands were planted in 1993 and 1999 in a field previously used for agriculture as part of the St. Olaf natural habitat restoration project (Figure 1.). In the 1993 site, eight conifer species were planted as listed in Table 1. The site was divided into ten 1 ha. plots. All conifers were tagged for a total of 330 trees. In the 1999 conifer site, six species were planted as listed in Table 1. The site was divided into seven 1 ha. plots. All conifers were tagged for a total of 490 trees.

For both sites, multiple experiments and studies have been conducted over the past few years. Growth was measured in the 1993 field in 1995, 1997, and 1999, and the 1999 field was measured in 2000. Also, soil samples were taken in the 1993 field in 1997 and 1999, and the soil in the 1999 site was tested in 1999. In the summer of 2003 the following measurements were taken: height, diameter, the number of male and female cones, soil samples, and tree cores. The number of male and female cones was again counted in 2004.

Growth and Mortality

In order to record tree mortality, each tree was recorded as either living, dead, or lost. Dead was defined as trees found deceased while lost was defined as those purposefully removed by a chain saw. Data for mortality was only available in the 1993 plot.

The height of each tree was measured with a clinometer. Standing ten meters from the tree and pointing the clinometer at the top of the tree, the instrument calculated the angle and the height of the tree. For the shorter trees a meter stick was used to measure the height. The diameter of the trees was measured at heights of 15 cm and 125 cm (Diameter at breast height or DBH). A diameter tape was used for trees with a diameter over five centimeters, and a caliper was used to measure the diameter of trees less than five centimeters across.

We also used a Trimble GPS (Global Positioning System) Unit to map the locations of each tree to within 1 m accuracy. We then downloaded the GPS points to GPS Pathfinder Office 2.7 and corrected for accuracy. The corrected points were exported to the GIS (Geographic Information System) program ArcView 3.2. In

ArcView, the points were used to make maps for the future or overlaid onto aerial photos (Figure 2.).

The predicted growth curves were determined using a generalized linear model with height as the dependent variable. The covariants in the model were year, a species indicator variable and a year by species interaction term. The model was fit with a robust variance estimator that accounted for the correlation of observations across time.

Reproduction

In 2003, three types of cones were counted: male cones, female cones open from previous years, and closed female cones. The number of cones per tree was individually counted if the number was below 100. If it appeared that the tree contained more than 100 cones, a quarter of the tree was counted. We multiplied this number by four. For trees with over 500 cones, the cone count was recorded as 500. During the second week of September, cones were taken from five trees of three species: *Pinus banksiana*, *Pinus resinosa*, and *Picea glauca*.

In the lab, the cones were allowed to sit for a week so that more of the scales would open. Since the *Pinus banksiana* cones are serotinous, they were put in a drying oven at 104 degrees C until they opened. Cones were measured for diameter and length. Seeds were then shaken out of the cones or extracted with tweezers. Viable seeds and scales were counted.

In 2004 we counted the green female cones, ones that were in their second year of maturation for pines and first year of maturation for spruces, and male cones. We decided to change our cone counting procedure due to the fact that cones will stay on trees several years after releasing their seeds. Green cones are connected to only one year of growth.

Specifically, pines need two summers to produce mature cones. The first year the cones are very small and purple, and the second year, they are green. Spruce only need one summer for their cones to mature so all green cones counted were produced that spring. Although we counted male cones, many of them had already disintegrated during late spring before the counting was accomplished. In 2004 we only counted cones on the three pines and white spruce.

Soil

Soil was collected from the top 16 centimeters from six locations around the St. Olaf campus: the 1999 site, the 1993 site, the Carleton arboretum, an unplanted field, and the St. Olaf prairie. Soil was collected three times: July 30, August 25, and September 13. Six tests were performed on the soil: pH levels, soil moisture, % organic material, nitrates, phosphates, and potassium. Soil pH, soil moisture, and % organic material were analyzed using standard procedure. Nutrients were measured on a spectrophotometer, methods by Hach Company and *Methods for Soil Analysis at St. Olaf College* (Bartz et al. 2003).

Protection

Of the trees in the 1993 site, some of the pines were fitted with tree protection. Seventy-two were fitted with plastic growth tubes and 22 had black plastic mats placed around their bases when they were planted. This was done to see if the tubes or mats would aid in the growth of the trees.

Analysis

All statistical analysis on height, diameter, and cone counts was done with StatView 5.0 (1999). ANOVA tests compared means of the variables measured. Post-hoc tests were also used, specifically pairwise comparisons with the Fisher's PLSD tests. Correlation Z tests were also conducted comparing cone characteristics within species. Growth curves were generated using Stata 8 and Delta Graph 5.

Results

<u>Growth and Mortality</u>

Heights for all species were compared in the 1993 site, and it was found that there were significant differences among heights (P-value<0.0001) (Figure 3a.) The tallest species were jack pines (mean=3.793 m), white pines, (mean=3.507 m), and tamaracks (mean=3.471 m.) Pairwise comparisons with a Fisher's PLSD test showed that jack pines were significantly taller than white pines (P-value=0.0298) but not significantly taller than tamaracks probably because of the smaller tamarack sample size. The shortest species were the more shade tolerant ones, black spruce (mean=1.950 m) and balsam fir (mean=1.897 m). For each species, a correlation was done for diameter and height. The diameters at both 15 cm and 125 cm heights were used for the 1993 site comparison. Most correlations were found to be significant (Table 2a.) Only tamaracks and jack pines showed no significant difference between height and diameter. There was a correlation between the diameter at 15 cm and the diameter at 125 cm for all species.

The heights for all species were also compared in the 1999 site, and it was found that there were significant differences among heights (P-value<0.0001) (Figures 3b.). The tallest species were jack pine (mean=1.778 m) and white pine (mean=1.772 m). The smallest were white spruce (mean=0.841 m) and balsam fir (mean=0.630 m). According to the pairwise comparisons, white spruce and balsam fir were significantly different in height (P-value<0.0001). For each species, a correlation was done for diameter and height. Only the 15 cm height diameter was used in the 1999 site analysis. Significant correlations were found for all species (Table 2b.).

Growth was linear during the eight years of the study. A comparison of the observed and predicted growth curves for each species showed a close fit of the model to the actual growth (Figure 4). The predicted equation was:

$$ht=(Coef.Species1 + 52.318) + [37.372 + (Coef.Species1 \times Year)]Year$$

Jack pine have grown steadily while the red and white pine showed an increase in growth rate since 1999. Balsam fir, black spruce, and white spruce were still growing very slowly.

Reproduction

Using the 2003 data, jack pine had the highest mean number of closed female cones (mean=357.927 cones) while white spruce had the lowest number of closed female cones (mean=6.333). Balsam fir, black spruce, and white pine had no closed female cones. Jack pine had the highest mean number of male cones (mean=358.171 cones) while white pine had the lowest number of male cones (mean=0.058 cones). Balsam fir, black spruce, tamarack, and white cedar had no male cones (Table 3a.). Correlations between the number of female open cones, female closed cones, male cones, height (m), diameter (15 cm), and diameter (125 cm) were examined. For jack pine, only the number of female closed cones and diameter at the height of 15 cm had a significant correlation (P-value=0.0025). For white spruce, the number of male cones correlated with both the number of female open and closed cones (P-values=0.0030 and <0.0001 respectively). The green closed female cones were significantly correlated with the number of female cones that had previously opened (P-value=0.0089). The red pines correlated in multiple areas (Table 4.).

Mean cone width, cone length, number of scales, number of calculated seeds (number of scales times two), number of viable seeds found, and seed weight for jack pine, red pine, and white spruce are given in Table 5. Red pine had the widest cones while jack pine had the longest cones. Correlations among cone characteristics showed a significant correlation in red pine between cone width and cone length (P-value=0.0012), cone width and number of scales (P-value=0.0046), and cone length and number of scales (P-value=0.0018). For jack pine the correlation between cone width and cone length was significant (P-value=0.0008). In white spruce a correlation between cone length and number of scales was found (P-value=0.0070). Everything else showed no significant correlation.

With the 2004 data, we did not use the male cone data because rain and wind had disintegrated so many of them. Jack pine had the largest mean number of green female cones (mean=55.150 cones), and white pine had the lowest mean number of green female cones (mean=2.706 cones) per tree (Table 3b.). Female cone production was significantly different among species ($P<0.0001$).

Soil

Soil tests were conducted on five sites including the two conifer plots to compare the effects of conifer trees on soil composition as opposed to other types of vegetation (Table 5.). The only differences were in the percent soil moisture where both St. Olaf conifer sites were higher that the other sites. Between the 1993 and the 1999 sites, all the soil characteristics are higher in the 1993 site than the 1999 except for nitrates. Mean levels of phosphates, potassium, percent organic material, and percent soil moisture were significantly different among sites throughout the test period (P-value=0.0004, 0.0013, 0.0079, and 0.0438 respectively).

The soil characteristics from the 1993 and the 1999 sites were compared with data taken in 1999 from both sites (Tables 6a. and 6b.). The change in the percent of organic material in the soil showed the greatest change over time in both sites (P-values for 1993=0.0013 and 1999=0.0044). For the 1993 site, the percent soil moisture, phosphate, organic material, and pH rose. At this site the percent change in soil moisture (P-value=0.0033), phosphate level (P-value=0.0036), and pH (P-value=0.0246) were also significant. In the 1999 site, the percent soil moisture, percent organic material, and pH rose. None of the other characteristics were significant in the 1999 site.

Protection

It was found that although there were significant differences between tree heights among species that there were no significant differences between the trees with plastic tree mats, trees with tree tubes, or trees without any sort of protection (Figure 5.).

Discussion

Growth and Mortality

Tree mortality was quite low with over 90% survival (Table 7). At the age of roughly twelve-years-old the conifers seemed to be growing satisfactorily. Jack pine, as the tallest tree of the St. Olaf restoration project, is shade intolerant and a pioneer species for boreal forests in North America. It has a shorter lifespan compared to other species and a faster growth rate. The next tallest, white pine and red pine, are more shade intolerant than the spruce and the fir. The young shade tolerant spruce and fir will not put energy into substantial growth until they are shaded. As the white and red pine continue to grow they will produce the canopy needed to spark the growth of the spruce and fir. Tamaracks, another tall species, bud early, and have very long growing seasons. Buschena (1998) showed that evergreen conifers grown in high light grew five times larger than those grown in low light treatments. He stated that conifers have low potential growth rate, an adaptation for survival in low resource environments. As the canopy develops the shade tolerant species will begin to grow at a faster rate. The shade intolerant species will halt their growth first because a culmination of height growth occurs earliest in light-demading trees (Cook 1941). Similar results for conifer growth patterns in St. Olaf natural lands conifers were found in the Rosenthal (1999) and Somers (2000) studies of the conifer plots.

One of the conditions that might affect the growth of the white pines is where the saplings were obtained. One test conducted in Maryland studied six different varieties of white pine at the age of fourteen years of age. They found that white pines from Minnesota were the slowest growing of all the species (Genys 1983). Our trees were bought from the Minnesota DNR and presumably grown from trees originating in Minnesota.

Tests show that heights and diameters strongly correlated in 14-16 year old white pine (Genys 1987). The St. Olaf white pines along with the other species (except the tamaracks and jack pines in the 1993 site) support Genys' findings (Figures 3a. and 3b.). It is unknown why jack pine had a negative correlation between the diameter at 125 cm and height. Height was also found to vary with geography (Genys 1989) and height and diameter correlated inversely with latitude (Genys 1987). St. Olaf's red pines are at the southern end of their range while the white pines are in the middle of their range. This fact could influence not only height and diameter but also reproduction.

In the future, the pines will continue to grow at a rapid pace. We predict that the trees will go through a rapid growth spurt starting with the shade intolerant conifers. These will create a canopy for the shade tolerant species allowing these species to grow at a faster rate. The tamaracks, with their longer growing season, will also continue to rise above the other swamp species.

Reproduction

Generally, plants must reach a certain size before they can reproduce. Cone data are used to study the robustness of the conifer trees. The number of seeds and the percentage of seeds that are viable give an idea of how well a plant is reproducing and provide an estimate of fitness. According to Heinselman (1996), red pines reproduce between the ages of twenty to twenty-five years, jack pines from the ages of three to fifteen, and white spruces at the age of thirty. On the other hand, white pines tend to reproduce at the age of five to ten years. Jack pine in this study reproduce at the same age as seen in other studies, but red pine and white spruce were early and white pine were late. In one study of white pines on the Maryland Piedmont Plateau, the native conifers grew to be fourteen years old and none of the trees had cones on them but were growing satisfactorily (Genys 1980). Also, high cone production and seed viability can usually be associated with warm and dry summers (Despland et al. 1997). In other tests, the mean weight of mature seed cones from red pines varied appreciably. Cone volume, the number of full seeds per cone, and the number of seeds per cone were positively correlated for at least red pines, but the number of scales and the number of seeds per cones were not as well correlated (Dickmann 1971). The size of the cones varied with exposure, placement, nutrition, and tree vigor. The potential for cone growth differs under environmental conditions, so everything from weather, geographic location in relation to site or origin, soil composition, and shade could be influencing the reproductive trends of the St. Olaf conifers.

One can also study the differences between the conifers' reproductive habits, including seed weight, which influences seed dispersal ranges (Eichhorn 1999). The cone data were difficult to gather because many of the seeds were undersized or, the seeds were, although full sized, empty. This was especially true in the red pine seeds. It was also hard to judge how many viable seeds the cone truly carried because a fair number of seeds had been lost before the cones were collected. To discover the true number of viable seeds, the cones will need to be gathered earlier in September (Dickmann 1969). The trees were in their first years of reproduction, and there were not many correlations between cone data and growth patterns. As stated before, conifers begin to reproduce over a number of years and it will probably take a number of years before the St. Olaf conifers begin to reproduce steadily. Perhaps in a few years when the trees are more mature the correlations between cone characteristics and growth will show more conclusive trends.

<u>Soil</u>

The conifer site was expected to become more acidic over time. The pH increases significantly in the 1993 site (P-value=0.0246), but not significantly in the 1999 site. The rise was not expected since as conifers add their needles to the soil, the acidity generally increases. If the level of a soil characteristic rose in one site, it also rose in the other (except for phosphate). Concerning the percent organic matter, which showed the greatest change over time, this could be caused by the change from a farming field to a conifer site. With farming, the organic material is harvested and removed from the site. On the conifer restoration site, the organic matter dies, is left to decompose, and becomes part of the litter layer.

Protection

Although it was found in the past that protection positively affected the growth patterns of the conifers, at this point in time there are no significant differences between the heights of the trees with either type of protection and those without protection. Mats, which probably decreased the level of competition for sunlight for the young trees, helped in the past, but now that the pines are taller than the grasses and other species surrounding them, they are not helpful. Perhaps where deer grazing is very high, the tubes might still be helpful in promoting initial growth, but without a high level of deer grazing, the protection is a waste of money and time in setting up and maintaining the tree shelters.

Future Direction

The conifer trees of St. Olaf campus need continual maintenance to represent a true Northern Boreal Forest like those seen in Minnesota's Boundary Waters. St. Olaf needs to protect against shade intolerant angiosperms like *Populus spp., Betula spp.,* and *Acer negundo.* They have higher relative growth rates than *Pinus spp., Picea spp., Larix spp,* and *Thuja spp,* because plants with leaves with high surface areas can take up more light and CO_2. Many southern boreal forests are gone because, after farmers and loggers disturbed them, aspen forests have taken them over (Cronon 1991, Reich 1998).

Maintenance crews have done a good job of taking out the box elder that grow profusely in the St. Olaf conifer sites.

There is one other problem that needs to be looked at before it becomes a problem. Most conifer forests burn regularly every 50 years. The trees need fire to survive. For example, jack pines and black spruce have serotinous cones, and these need to be heated by fire so that they will open and release the seeds. The seeds will then germinate in roughly one month. Also, red pines and white pines have very thick bark to protect them against fire. Once the ground cover is burned, their seeds can sprout without any competition. They cannot sprout under the shade of competing trees present before the fire swept through the forest (Heinselman 1996).

Fire changes the composition of the area it passes through. In Northern Minnesota, two burns in a short period of time will kill young conifers, and the aspen will succeed the conifer forest. If a forest, like that of the St. Olaf campus, does not receive a burning, the shade tolerant trees like black spruce and balsam fir, which are planted underneath the pines, will overgrow the pines (Frelich 2003). St. Olaf will have to make sure that the red and white pines are not succeeded by the more shade intolerant species by controlled fires or the creation of sunny gaps where young pines can grow without the competition of the other conifers. If controlled burns are too dangerous, maintenance crews will need to plant young pines in sunny areas or make sure that spruce and balsam fir do not take over by thinning. At one point it will also be necessary to add an understory layer to the site since every forest ecosystem has its own specific understory, not the Timothy grass and thistles that are growing in the site right now (Tester 1995).

Conclusion

The St. Olaf conifers are continuing to grow healthily in both the 1993 and the 1999 site. It was found that jack pine is the tallest conifer followed by white pine and tamarack. The shortest trees were black spruce and balsam fir. The shade intolerant trees are expected to soon enter a stage of rapid growth creating a canopy, which will facilitate the growth of the shade tolerant species. The cone data was not conclusive but will probably become a better characteristic of the robustness of the St. Olaf conifers when the conifers are more mature. When looking at soil samples, it was found that the greatest change came in the percent organic matter, which rose significantly in both sites and suggests that the littler layer is increasing and becoming more like what would be found in a boreal forest. Finally the trees, which had been assisted by plastic tree tubes or mats in the past, are now not significantly taller than those that were planted without tree protection. In time maintenance crews will need to either conduct a controlled burn or thin the sites so that the red and white pines can reproduce.

Special Thanks

I would like to thank the following people for there assistance in my research:

AmberBeth VanNingen for her help in data collection,
Jared Walker Smith for field assistance,
Dr. Kathleen Shea for her direction and the creation of the growth curves,
Judy Legler (Sc. D.) for her help with Stata and Delta Graph,
Gene Bakko for his guidance,
St. Olaf's Biology department for their support, and
Howard Hues Medical Institute for their financial contribution.

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Tables and Figures

Table 1. Number of each species planted in the two conifer plots.

Scientific Name	Common Name	Number in 1993 Plot	Number in 1999 Plot	Total Number
Pinus strobus	White Pine	124	94	218
Pinus resinosa	Red Pine	40	98	138
Pinus banksiana	Jack Pine	47	148	195
Picea glauca	White Spruce	47	51	98
Picea mariana	Black Spruce	6	0	6
Abies balsamea	Balsam Fir	36	42	78
Larix laricina	Tamarack	7	0	7
Thuja occidentalis	White Cedar	23	57	80
	TOTAL	**330**	**490**	**820**

Table 2a. Correlation in 2003 between diameter (15 cm), diameter (125 cm), and height (m) for all the species in the 1993 site with their p-values.

	Dia. 15cm vs. Dia. 125cm		**Dia. 15 cm vs. Ht (m) 03**		**Dia. 125 cm vs. Ht (m) 03**	
Species	**Correlation**	**P-values**	**Correlation**	**P-values**	**Correlation**	**P-values**
Black Spruce	0.953	0.0013	0.99	<0.0001	0.956	0.001
White Spruce	0.693	<0.0001	0.703	<0.0001	0.601	<0.0001
Red Pine	0.809	<0.0001	0.616	<0.0001	0.584	<0.0001
White Pine	0.807	<0.0001	0.623	<0.0001	0.597	<0.0001
White Cedar	0.72	0.0003	0.666	0.0009	0.68	0.0009
Jack Pine	0.401	0.0098	0.553	0.0001	neg0.242	0.1325
Balsam Fir	0.844	<0.0001	0.899	<0.0001	0.849	<0.0001
Tamarack	0.999	<0.0001	0.687	0.0924	0.674	0.1015

Table 2b. Correlation in 2003 between diameter (15 cm) and height (m) for all the species in the 1999 site with their p-values.

Species	**Correlation**	**P-value**
White Spruce	0.351	0.0011
Red Pine	0.641	<0.0001
White Pine	0.497	<0.0001
White Cedar	0.733	<0.0001
Jack Pine	0.743	<0.0001
Balsam Fir	0.632	<0.0001

Table 3a. A comparison of the mean (± s.e.) number of closed female cones and male cones per tree in the 1993 plot during 2003. Female closed cone production was significantly different among species ($P<0.0001$). Male cone production was significantly different among species ($P<0.0001$)

Species	Mean # of male cones	Std. Err.	Mean # of closed female cones	Std. Err.
JP	358.171	30.862	357.927	26.722
RP	78.462	18.004	13.256	3.672
WP	0.058	0.058	79.450	38.002
WS	0.949	0.508	6.333	3.189
T	0.000	0.000	9.143	3.210

Table 3b. A comparison of the mean (± s.e.) number of green female cones per tree in the 1993 plot during 2004. Female cone production was significantly different among species ($P<0.0001$).

Species	Mean # of green female cones	Std. Err.
JP	55.15	7.348
RP	31.205	6.472
WP	8.028	0.736
WS	12.411	1.987

Table 4. A comparison using a Correlation Z Test between cone characteristics for *Pinus resinosa* in 2003.

	Correlation	Count	Z-Value	P-Value	95% Lower	95% Upper
Dia @15 cm, Dia @ 125 cm	.809	39	6.745	<.0001	.663	.896
Dia @15 cm, M Cones	.783	39	6.318	<.0001	.621	.881
Dia @15 cm, FO Cones	.427	39	2.736	.0062	.129	.654
Dia @15 cm, FC Cones	.420	39	2.683	.0073	.120	.649
Dia @15 cm, Ht (m) 03	.616	39	4.307	<.0001	.372	.780
Dia @ 125 cm, M Cones	.614	39	4.289	<.0001	.370	.779
Dia @ 125 cm, FO Cones	.411	39	2.622	.0087	.110	.643
Dia @ 125 cm, FC Cones	.428	39	2.747	.0060	.130	.655
Dia @ 125 cm, Ht (m) 03	.584	39	4.010	<.0001	.329	.759
M Cones, FO Cones	.458	39	2.966	.0030	.166	.676
M Cones, FC Cones	.318	39	1.977	.0481	.003	.576
M Cones, Ht (m) 03	.549	39	3.700	.0002	.282	.737
FO Cones, FC Cones	.735	39	5.634	<.0001	.546	.853
FO Cones, Ht (m) 03	.161	39	.977	.3285	-.162	.454
FC Cones, Ht (m) 03	.249	39	1.529	.1264	-.072	.524

Table 5. Mean characteristics of female cones for three species in the 1993 site in 2003.

Tree Species	# of cones tested	Width (mm)	Length (mm)	# of scales	Calculated # seeds	# Viable seeds seen	Seed Weight
Jack Pine	12	35.02	44.87	70.00	140.00	22.00	0.00468
Red Pine	10	37.83	40.44	43.80	87.60	1.10	0.00942
White Spruce	17	22.60	41.07	48.94	97.88	7.00	0.00162

Table 5. An ANOVA was used to compare the mean (± s. e.) soil characteristics in conifers, prairies, and unplanted sites in 2003. Results of ANOVA tests are given as p-values.

Site	Nitrates	Phosphates	Potassium	pH	% Organic Material	% Soil Moisture
1993 conifers	0.969 ± 0.365	18.901 ± 3.380	106.168 ± 3.710	6.653 ± 0.118	5.553 ± 0.586	19.4 ± 0.698
1999 conifers	1.133 ± 0.181	7.824 ± 1.881	105.116 ± 8.722	6.540 ± 0.181	4.230 ± 0.587	18.8 ± 1.255
Mature conifers	0.899 ± 0.093	18.843 ± 0.448	68.306 ± 3.453	6.380 ± 0.312	4.490 ± 0.097	13.4 ± 1.770
Prairie	1.039 ± 0.186	28.255 ± 2.320	124.748 ± 9.295	6.710 ± 0.101	4.773 ± 0.219	17.6 ± 1.291
Unplanted field	0.747 ± 0.062	13.454 ± 0.503	105.116 ± 3.558	6.887 ± 0.189	2.753 ± .0268	17.1 ± 0.751
P-Value	0.7375	0.0004	0.0013	0.4788	0.0079	0.0438

Table 6a. A comparison using an ANOVA test of 1999 and 2003 mean nutrient values in the 1993 site sampled at three different dates.

Test	1999	2003	P-Value
Nitrate (ppm)	3.379	0.969	0.0746
% Soil Moisture	14.19	19.367	0.0033
Phosphate (ppm)	7.928	18.901	0.0036
Potassium (ppm)	119.392	106.168	0.4489
% Organic Material	0.797	5.553	0.0013
pH	5.787	6.653	0.0246

Table 6b. A comparison using an ANOVA test of 1999 and 2003 mean nutrient values in the 1999 site sampled at three different dates.

Test	**1999**	**2003**	**P-Value**
Nitrate (ppm)	1.935	1.133	0.2701
% Soil Moisture	15.123	18.833	0.1406
Phosphate (ppm)	10.14	7.824	0.4688
Potassium (ppm)	109.725	105.116	0.8068
% Organic Material	0.777	4.23	0.0044
pH	5.357	6.54	0.1012

Table 7. Percent of trees that died or were lost since 1995, the year of the original count.

Species	**Original Count**	**2003 count**	**% Dead**	**% Lost**
White Pine	124	120	0.00	3.23
Red Pine	40	39	0.00	2.50
Jack Pine	47	41	8.51	4.26
White Spruce	47	39	0.00	17.02
Black Spruce	5	6	0.00	0.00
Balsam Fir	36	36	0.00	0.00
Tamarack	3	7	0.00	0.00
White Cedar	22	21	0.00	9.09
Total	**324**	**309**	**1.23**	**5.25**
% Dead/Lost				
With shelters	1.59/0.00			
Without shelters	1.42/3.31			

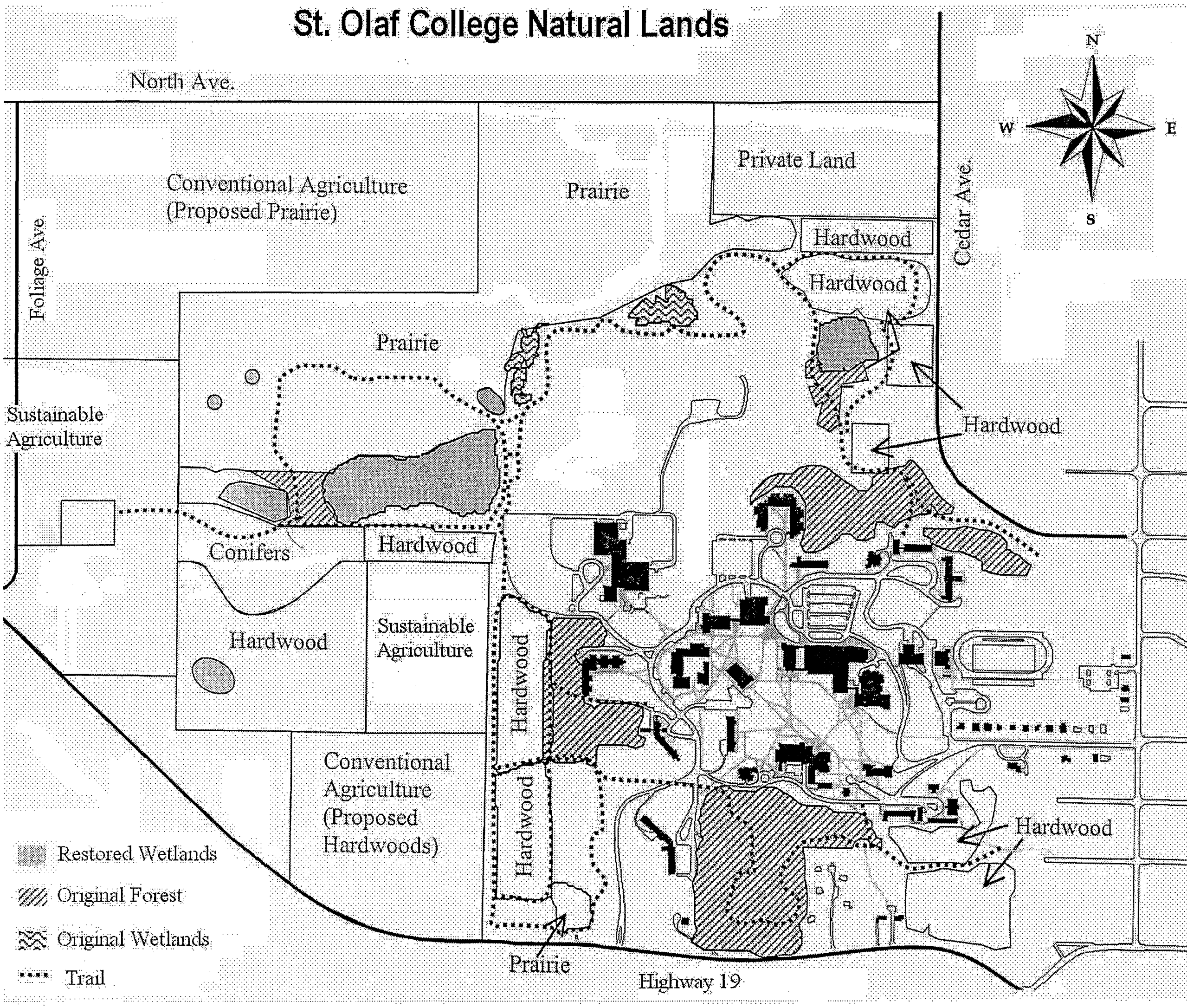

Figure 1. Map of the St. Olaf natural lands. The 1993 site is the northern part of the conifer site and the 1999 site is the southern bulge.

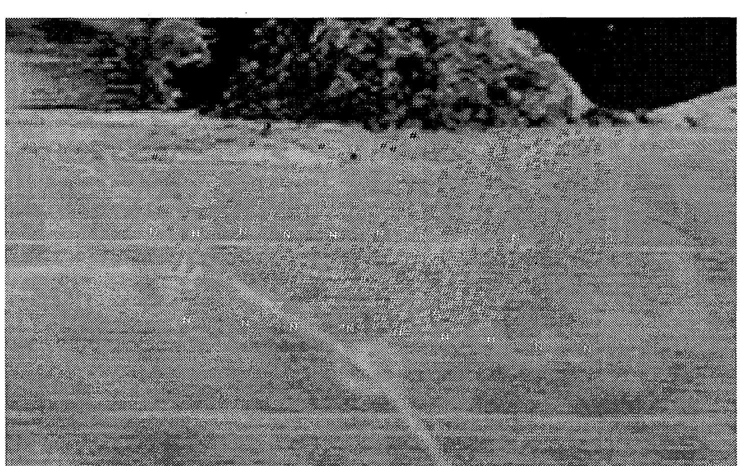

Figure 2. GIS map of our field site. Each color represents a species.

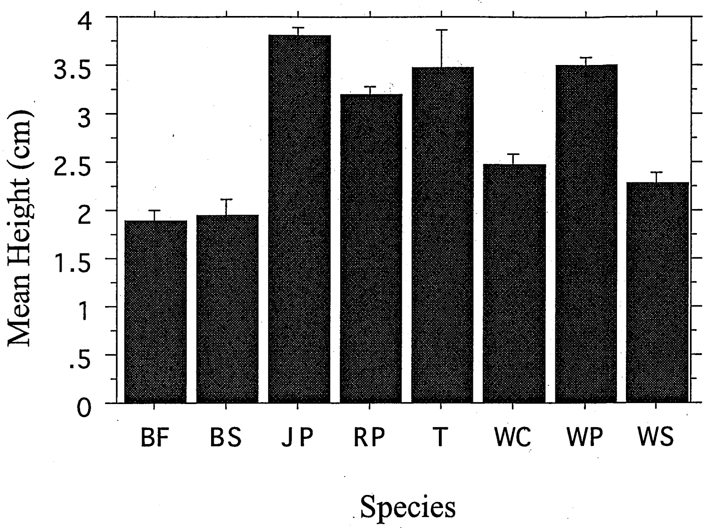

Figure 3a. A comparison of mean (± s. e.) tree heights in the 1993 plot. Heights were significantly different among species (P=0.0001).

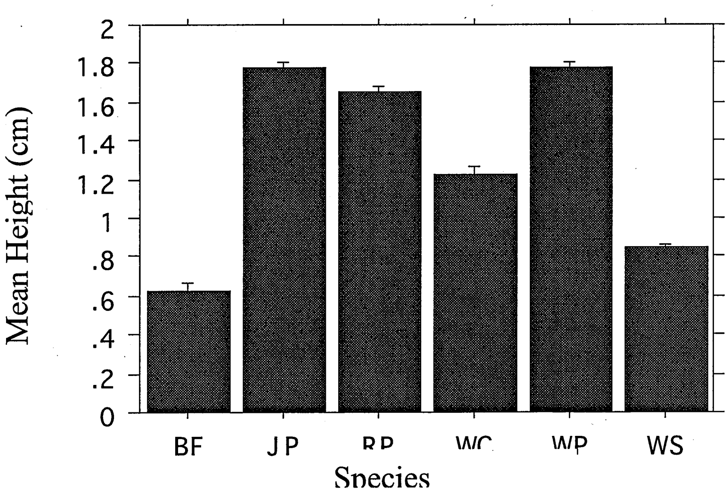

Figure 3b. A comparison of mean (± s. e.) tree heights in the 1999 plot. Heights were significantly different among species (P=0.001).

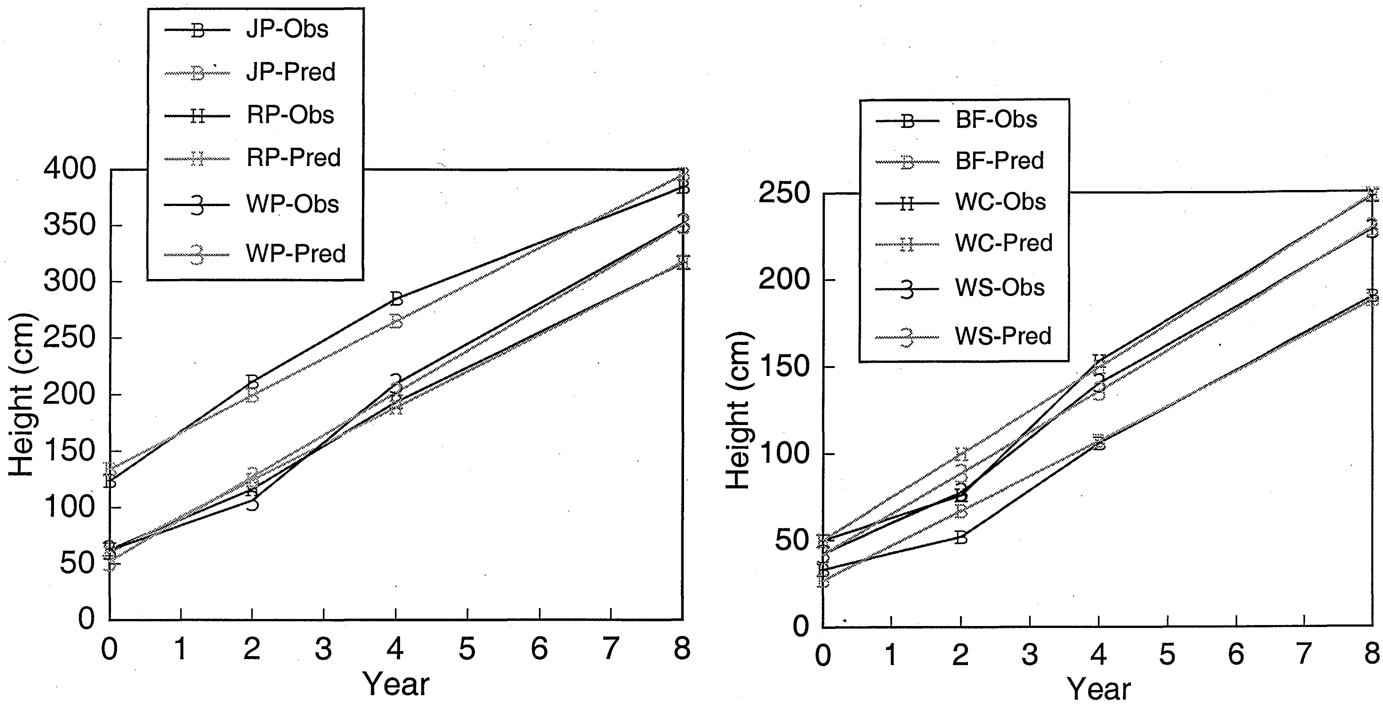

Figure 4. A comparison of observed (Obs) and predicted (Pred) early growth patterns for six conifer species (see Table 1) over an eight year period based on a generalized linear model with height as the dependent variable.

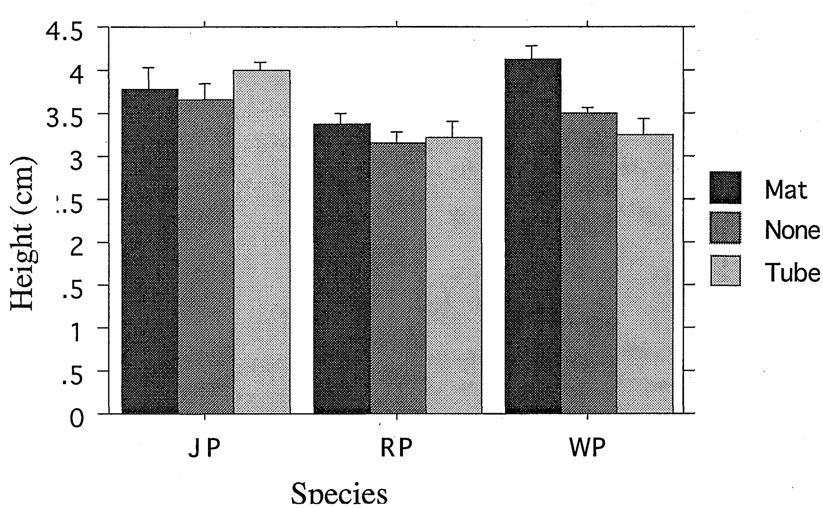

Figure 5. A two-way ANOVA showed significant differences in tree height among species (P=0.0332), but not among types of tree protection.