St. Olaf College

Local Ecology Research Papers

Tree diameter, cone production, and seedlings: an analysis of northern conifers in southern Minnesota

Andy Harrison

2021

Tree diameter, cone production, and seedlings: an analysis of northern conifers in southern Minnesota

Andy Harrison
Field Ecology
St. Olaf College
Professor Kathy Shea
1-21-22

Abstract

The St. Olaf College Natural Lands represents an effort to restore agricultural land into native Minnesota biomes. One of the biomes in the Natural Lands is coniferous forest. This forest includes conifers typically found in northern Minnesota and was planted for educational and research purposes. The purpose of this study was to examine the growth and reproduction patterns of different northern conifers planted in a warmer climate, giving insight into the role climate change will play in shaping the northern Minnesota coniferous biome. The goals of this study were to (1) compare mean tree size among species, (2) compare mean cone production among species, and (3) compare seedling establishment among species. To understand if there is a correlation between tree size and cone production, the diameter of 97 trees in the 1993 transects was sampled, followed by examining the trees for cone production. Approximate counts of cones were taken for each cone-producing tree. Additionally, four conifer forest clearings in the 1993 and 1999 plantings were examined for the presence of conifer seedlings. A weak positive correlation was found between the diameter and the number of cones. The presence of seedlings indicated successful reproduction, but there was no significant difference in seedling population density among species. A growth rate of 0.7002 cm/year was determined by comparing the diameters of trees from 2011 to diameter in 2021. The proportion of trees with cones was greater in 2011 than in 2021. These results indicate that the conifers are successfully reproducing in a warmer climate, that they could be past peak cone production at their current age, and that larger trees tend to have more cones than smaller ones.

Introduction

Minnesota is home to three major biomes. The southwest and west side of the state is dominated by prairie grassland, where trees are scarce, and the wind appears to turn the grass into a sea of movement. The southeast is occupied by deciduous forests, whose trees are famous for shedding their leaves each autumn. This biome stretches across the state like a belt into the northwest. Coniferous forests, characterized by their fragrant needle-covered trees, are the third major biome represented in Minnesota.

Conifers are right at home in northern Minnesota, where their cold-weather adaptations allow them to survive and thrive in freezing temperatures, keep their needles anywhere from two to fifteen years, and begin photosynthesizing as soon as winter subsides, and temperatures begin to rise again (MN DNR 2017). While conifers may be cold-adapted, climate change threatens these trees with warmer conditions and changing weather patterns. It is therefore crucial that we understand the effects of a warmer climate on these northern conifers, and what that means for the future of the coniferous forest biome.

One study suggests that there is a tradeoff between freeze tolerance and growth rate, which indicates that while conifers would not necessarily suffer due to high temperatures, they could be outcompeted by species with higher growth rates at their southern range limit (Loehle 1998). Flannigan and Woodward (1994) came to a similar conclusion for their study, stating that competition determines the southern limit of the red pine, and calculated that a doubling of the current concentrations of CO_2 would result in a northeastern shift of the red pine range by 600-800 kilometers. Despland and Houle (1997) concluded that a warmer climate may provide a longer growing and reproduction season for these conifers, which would limit the potential tradeoff between growth and cone production.

Roland et al. (2014) examined white spruce as an example of a mast-seedling conifer and found that there were positive associations between seed fall and increased summer precipitation along with decreased summer warmth for all years save for the year before seed fall. There is evidence of smaller trees investing a high proportion of their resources into reproduction compared to larger trees (Santos-del-Blanco and Climent 2014). Although the conifers in this study are monecious, Rozas et al. (2019) found that sex could play a role in how dioecious conifers respond to climate, with female trees growing more in warmer locations and males growing more in colder ones, with the resource allocation to growth or cone production being dependent on the weather conditions before the growing season.

Collecting data on conifer trees planted in southern Minnesota can help provide an insight into how they grow and reproduce in a warmer climate, and the seven acres of conifer forests in the St. Olaf Natural Lands were planted with the purpose of research such as this (St. Olaf College 2021). The goals of this study were to (1) compare mean tree size among species, (2) compare mean cone production among species, and (3) compare seedling establishment among species.

Methods

Site Description

The coniferous forest sampled (44.464, -93.194) is a portion of the restored forest in the St. Olaf Natural Lands west of campus in Northfield, Minnesota. The St. Olaf Natural Lands contains 7 acres of restored coniferous forest on land that was formerly farmed for corn. These acres are divided into two plantings, one planted in 1993 and the other planted in 1999. The forest contains two species of conifers that are native to the region, white pine (*Pinus strobus*) and red cedar (*Juniperus virginiana*). Other included conifer species planted in the Natural Lands which are native to northern Minnesota include red pine (*Pinus resinosa*), jack pine (*Pinus banksiana*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), white cedar (*Thuja occidentalis*), and tamarack (*Larix laricina*). The forest is managed by a team of Natural Lands technicians who remove invasive understory species such as buckthorn (*Rhamnus cathartica*) among other management techniques.

Data Collection

To explore how conifers were reproducing in conifer forest clearings, a large clearing was divided into four separate sections to simplify area estimates, followed by the flagging of seedlings present in the clearings. Three out of four of the separate clearings were in the 1999 section of forest, with the fourth being in the 1993 section. The seedlings were identified and recorded with the help of a tree identification guide. The number of seedlings by species was divided by the area of the clearing in which they were found to get the population density. The rough shape of each clearing was assumed to be rectangular, so width and length were measured with a 50-meter measuring tape and multiplied to get the area of the clearings.

Conifers in the 1993 planting were examined to determine information about diameter and cone production. To measure the diameter of the conifers I used a diameter tape and a pole to determine DBH (diameter at breast height) placement. For trees with multiple stems, only the largest stem was recorded to help compare my data to that of previous years and to simplify analysis involving diameter. If applicable, the tree tag information was recorded including species and tree number. For trees without tree tags, a tree identification guide was used to help identify the species. A random number generator was used to select the tree number to be collected, with approximately one red and one white pine collected for each transect as they did not appear to be reproducing. Higher numbers of conifer species were collected if they had evidence of reproduction, with 3 of each species planned to be recorded for each transect. Every species save for red and white pine were treated as if they were reproducing. Due to the lack of certain species depending on the transect and in some cases, difficulty in locating species, less than 3 of each species per transect were collected. Ninety-seven conifers were measured across the ten transects in the 1993 planting. Due to their lack of abundance, I did not collect data on tamaracks. If the entire tree could be seen without obstruction, cones on one side of the tree were counted using binoculars. Since the 1993 planting is not on the edge of the forest, this method was rarely used. For the more common case of the top of the tree being obscured in the canopy, the number of cones on one branch were counted using binoculars and this number was extrapolated to the entire tree by multiplying the number of cones by the number of branches. For jack pine, which has both standard and serotinous cones, the number of closed cones was recorded along with the total number of cones. The data I collected was compared to the tree survey completed in 2011 so that a growth rate could be determined over 10 years along with determining if the proportion of trees with cones was changing. Data were recorded and organized in a Google Sheets datasheet.

Data Analysis

To determine the population density of seedlings for each clearing, the number of seedlings found was divided by the area of the clearing they were located in. As this resulted in four different population densities for each species, and each clearing was only a segment of one larger forest clearing, the population densities were averaged to generate an overall population density for each species. I performed several statistical tests to analyze the data, along with making multiple figures to visualize the results. Simple calculations including population density and average growth rate were calculated using Google Sheets. Additionally, data were organized in the sheet so that it could be easily imported and processed in R Studio. I created a new binary categorical variable to sort trees with and without cones. AOV (Analysis of Variance) was used twice, once to compare the population density of seedlings by species and again to see how diameter differed between trees with and without cones. Boxplots and the 'favstats' function were also used for these two situations to visualize the results along with calculating the mean, standard deviation, and sample size.

Results

Seedlings

The four clearing sizes ranged from approximately 172 square meters to 416 meters, and despite the visual difference of population density, there is not a significant difference between the population density per square meter of any of the four species found in the forest clearings (p-value: 0.0557, Fig. 1). Four different species of conifer seedlings were found in the four clearings including balsam fir, red pine, white cedar, and white spruce.

<u>Diameter and Cone Production</u>

There was a weak positive correlation between tree diameter and the number of cones produced (0.315, Fig. 2). The proportion of trees with cones was higher in 2011 (43.82%) than in 2021 (31.46%), with an average growth rate across species of 0.70 cm/year (Table 1). The proportion of trees with cones increased from 2011 to 2021 for some species and decreased for others (Fig. 3 and Fig. 4). The percentage of trees with cones between species was highly variable, with the lowest being 0% (black spruce) and the highest being 100% (balsam fir, Table 2). There is a smaller range of diameters for trees with cones than trees without cones (Fig. 5), and trees with cones have a significantly (p-value: 0.00994) higher mean diameter than trees without (Table 3). The mean diameter of trees by species increased at different rates between 2011 and 2021, and species started and ended within a wide window of mean diameter values (Fig. 6).

Discussion

<u>Seedlings</u>

The presence of seedlings in the conifer forest clearing demonstrates that the trees are successfully reproducing. There were no significant differences between the population densities of the four species found in the clearing. Despite this, it is unique that while six conifer species were documented as having cones this season, only four species were shown to have seedlings in the forest clearing. This is especially interesting considering that jack pine, one of the species that was not represented in the clearings, had the highest percent of trees with cones. One potential cause of this is that jack pine seedlings tend to allocate more energy to belowground biomass compared to other conifer species, which would limit the ability for their seedlings to be found and recorded (Day et al. 2005). Another factor that could influence the lack of jack pine seedlings in the clearing could be the distance to the nearest jack pines. Due to the limited amount of time available for data collection, the trees surrounding the clearing were not documented, therefore this potential hypothesis could not be explored. The mature conifers surrounding the forest clearing would likely be contributing to most seedlings found in the clearing, so their identification would be required to further explore what this data could mean.

Diameter and Cone Production

The mild correlation between tree diameter and cone production indicates that larger trees could have more resources available to dedicate to developing cones. This would be in direct opposition to the findings of Santos-del-Blanco and Climent (2014) who suggested that smaller conifers dedicate more of their resources to cone production. Shea (1987), on the other hand, found that there was a significant correlation between tree size and both female and male cone production. The findings of this study reflect the more common conclusion of higher cone production in trees with larger diameters (Shea 1987). It would be interesting to examine how the number of cones varies per unit increase in diameter to truly determine if larger conifers devote more energy to cone production, or if their larger stores of energy mean that they can produce more cones with smaller proportions of their overall resources.

The decrease in the proportion of conifers with cones from 2011 to the present could be attributed to masting, where conifers, among many other plant groups, can produce large amounts of seeds for one year of seed production and produce little to no seeds during other years. This method of reproduction would explain why such small numbers of red and white pines had cones during this sampling. Roland et al (2014) concluded that climate factors during the year concurrent with seed production such as precipitation could be possible triggers for episodic high seed production, while other climate factors such as drought can decrease reproductive success. This is especially interesting as Minnesota experienced a historic drought during the summer of 2021, which could limit the future reproductive ability of conifers in the state.

Following the trend of larger conifers having more cones, it was statistically significant that trees with cones had higher diameters than those without - the difference between the two averages being over five centimeters. It would be interesting to explore how this trend is altered if data were collected during years when higher proportions of trees were reproducing.

While there are visually different growth rates between the conifer species, this difference was not statistically analyzed to determine significance, which limits what conclusions can be drawn based on the figure. Based solely on the appearance of the figure, white pine had the highest slope and therefore the highest growth rate. It is entirely possible that different species of conifers, which perhaps are more competitive, would be able to compete better in the warmer climate than those that prioritize cold tolerance overgrowth (Flannigan and Woodward 1994). It is also possible that the conifers that demonstrate higher growth rates are more sun tolerant, seeing as this is still a relatively young forest and the canopy has not yet fully closed.

There are also multiple areas where errors could have been introduced to the data collection process, which would be inappropriate to ignore. The method for estimating cones by extrapolating the cone number from a single branch could lead to inaccurate estimates, especially considering how this method is reliant on accurately determining the number of branches on the tree. The branches could be miscounted as this method is used for conifers that are partially obscured in the canopy. Data for this study were collected over a period of multiple months, starting in October, and continuing through early December, which could also affect the cone estimates, as the cone number for trees with cones that had fallen before data were fully collected were likely to have been underestimated. Examining only the largest stems of trees, while crucial for the data analysis process and comparison to previous data could also introduce skew. While this method was the same as previous years of data collection, other methods of including the diameter of all stems should be considered, such as taking the square root of the squared sums of all stem diameters. This method would account for the additional stems of a tree and more accurately represent the size. The collection of data by multiple individuals over multiple years can also be a source of error, especially seeing as multiple trees were documented as having higher diameters in 2011 than what was recorded in 2021, which is extremely unlikely to be accurate. Out of the 94 trees that were measured for this data and were also measured in 2011, four trees were recorded as shrinking in diameter, with the recorded diameter decreasing by an average of 0.47 cm. While these measuring errors may be insignificant, they cannot be ignored when it comes to ways that data could contain mistakes.

Conclusions

Conifers with larger diameters tend to have more cones as there was a positive correlation between these two variables. The diameters of conifers with cones were significantly greater than the diameters of those without cones, which reinforces the idea that larger diameter benefits cone production. There does not appear to be a tradeoff between growth and reproduction as previous studies have suggested. The average diameter of all species examined was shown to have increased over the past decade, which is hopeful for the stance of conifers amid climate change and their ability to sequester carbon from the atmosphere. The differences between proportions of conifers with cones over the last decade could be attributed to multiple factors, including seed masting and the consequences of drought. The presence of conifer seedlings indicates that these trees are successfully reproducing despite the warmer climate, which indicates that while climate change could shift the range of conifers into cooler areas, they are not inherently doomed in their existing range.

Acknowledgments

I would like to thank Professor Shea for her guidance in data collection and interpretation of results, as well as previous students who have contributed to the extensive data pool existing on the St. Olaf conifer plantings. I must also thank the biology department, as they provided almost all materials used to collect and analyze data.

Literature Cited

Day, M. E., J. L. Schedlbauer, W. H. Livingston, M. S. Greenwood, A. S. White, and J. C. Brissette. 2005. Influence of seedbed, light environment, and elevated night temperature on growth and carbon allocation in pitch pine (*Pinus rigida*) and jack pine (*Pinus banksiana*) seedlings. Forest Ecology and Management 205:59–71.

Despland, E., and G. Houle. 1997. Climate influences on growth and reproduction of *Pinus banksiana* (*Pinaceae*) at the limit of the species distribution in eastern North America. American Journal of Botany 84:928.

Flannigan, M., and I. Woodward. 1994. Red pine abundance: current climatic control and responses to future warming. Canadian Journal of Forest Research 24:1166–1175.

Loehle, C. 1998. Height growth rate tradeoffs determine northern and southern range limits for trees. Journal of Biogeography 25:735–742.

MN DNR. 2017. Coniferous forest biome. https://www.dnr.state.mn.us/biomes/coniferous.html.

Rozas, V., C. Le Quesne, M. Rojas-Badilla, Á. González-Reyes, S. Donoso, and J. M. Olano. 2019. Climatic cues for secondary growth and cone production are sex-dependent in the long-lived dioecious conifer *Araucaria araucana*. Agricultural and forest meteorology 274:132–143.

Santos-del-Blanco, L., and J. Climent. 2014. Costs of female reproduction in a conifer tree: a whole-tree level assessment. Journal of Ecology 102:1310–1317.

Shea, K. L. 1987. Effects of Population-Structure and Cone Production on Outcrossing Rates in Engelmann Spruce and Sub-Alpine Fir. Evolution 41:124–136.

St. Olaf College. 2021. Coniferous Forest – Natural Lands, https://wp.stolaf.edu/naturallands/forest/coniferous/ accessed December 2021.

Figures and Tables

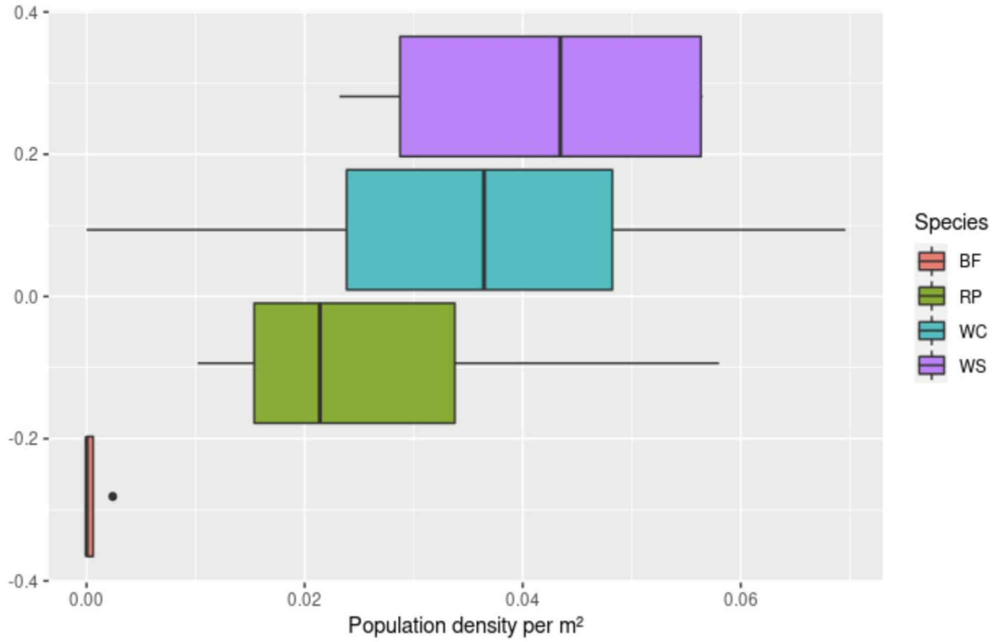

Figure 1: Population density of the four conifer species present in the examined conifer forest clearings (P-value: 0.0557). Tree species are abbreviated to the initials of the common name for this and following applicable figures.

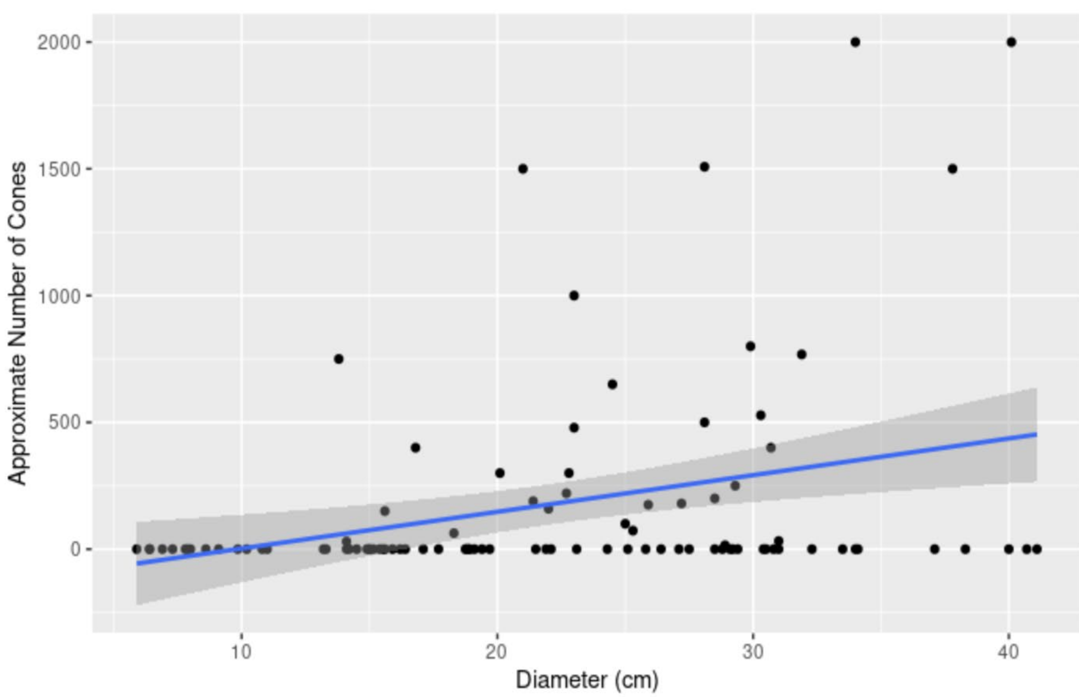

Figure 2: Correlation between tree diameter and the number of cones produced, $r = 0.3154422$, $p = 0.001648$

Table 1: Comparison of the proportion of trees with cones and average diameter of trees from 2011 to 2021, along with the calculated average growth rate

	2011	2021
Proportion of trees with cones	0.4382	0.3146
Average Diameter (cm)	14.96	21.96
Average Growth Rate (cm/year)	0.7001595745	

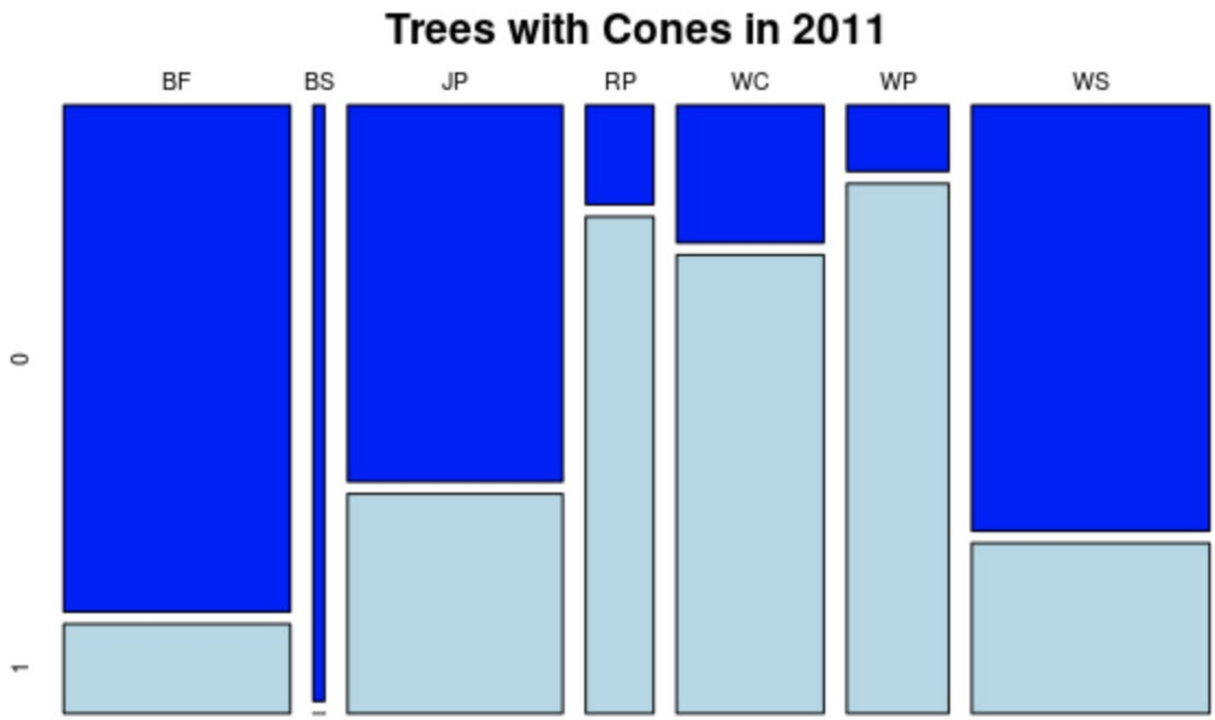

Figure 3: Proportion of trees with cones by species in 2011, where dark blue (0) represents trees without cones and light blue (1) represents the trees with cones.

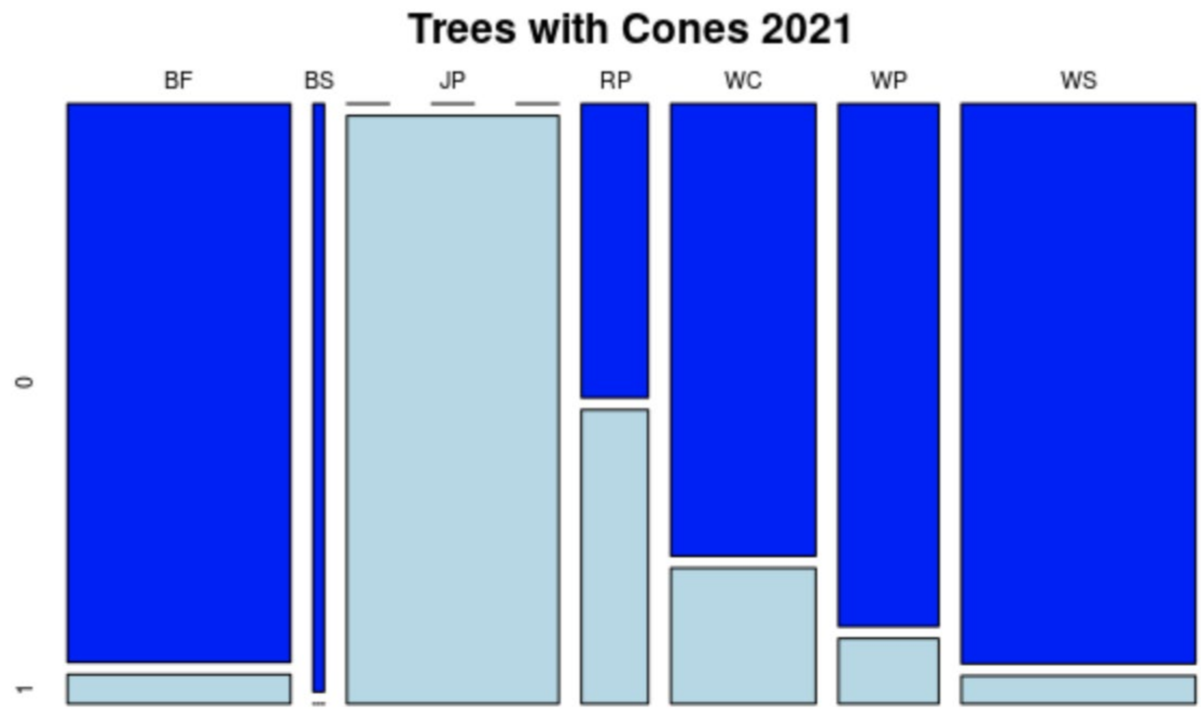

Figure 4: Proportion of trees with cones by species in 2021, where dark blue (0) represents trees without cones and light blue (1) represents the trees with cones.

Table 2: The numerical values for the proportion of trees with cones by species for 2011 and 2021

Species	% with cones (2011)	% with cones (2021)
Balsam fir (BF)	15	5
Black spruce (BS)	0	0
Jack pine (JP)	36.84	100
Red pine (RP)	83.33	50
White cedar (WC)	76.92	23.08
White pine (WP)	88.89	11.11
White spruce (WS)	28.57	4.76

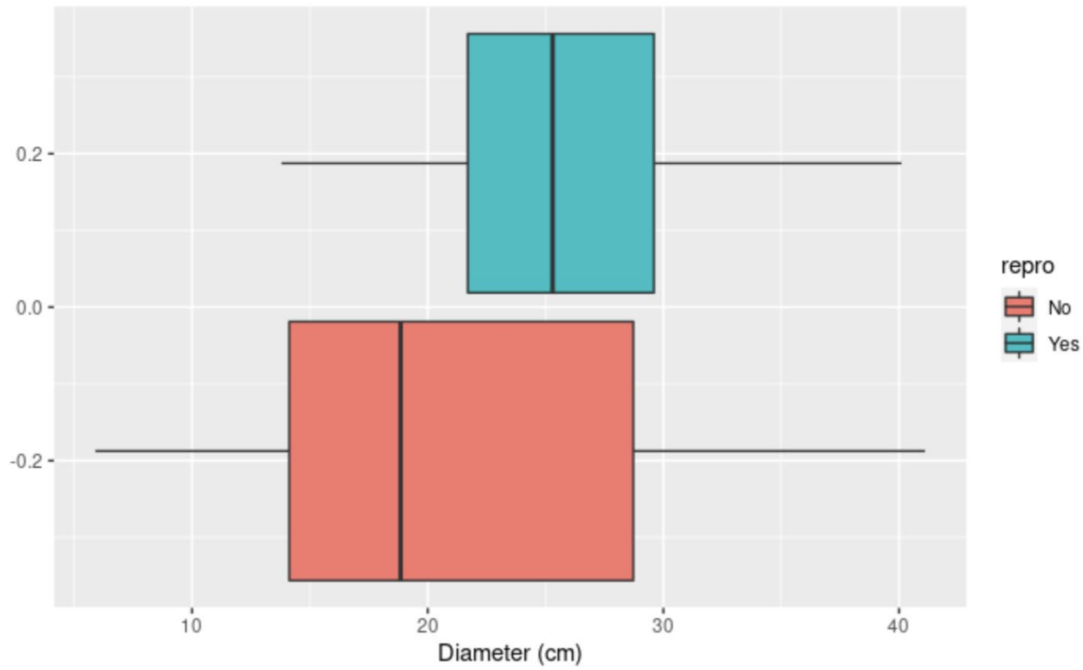

Figure 5: Comparison of the diameters of trees with and without cones where red represents trees without cones and blue represents trees with cones

Table 3: Comparison of the diameters of trees with and without cones including sample size, standard deviation, and the mean diameter

Cones present?	Mean Diameter (cm)	Standard deviation	N (sample size)
Yes	25.52	6.40	31
No	20.49	9.68	66

F-value: 6.921, P-value: 0.00994

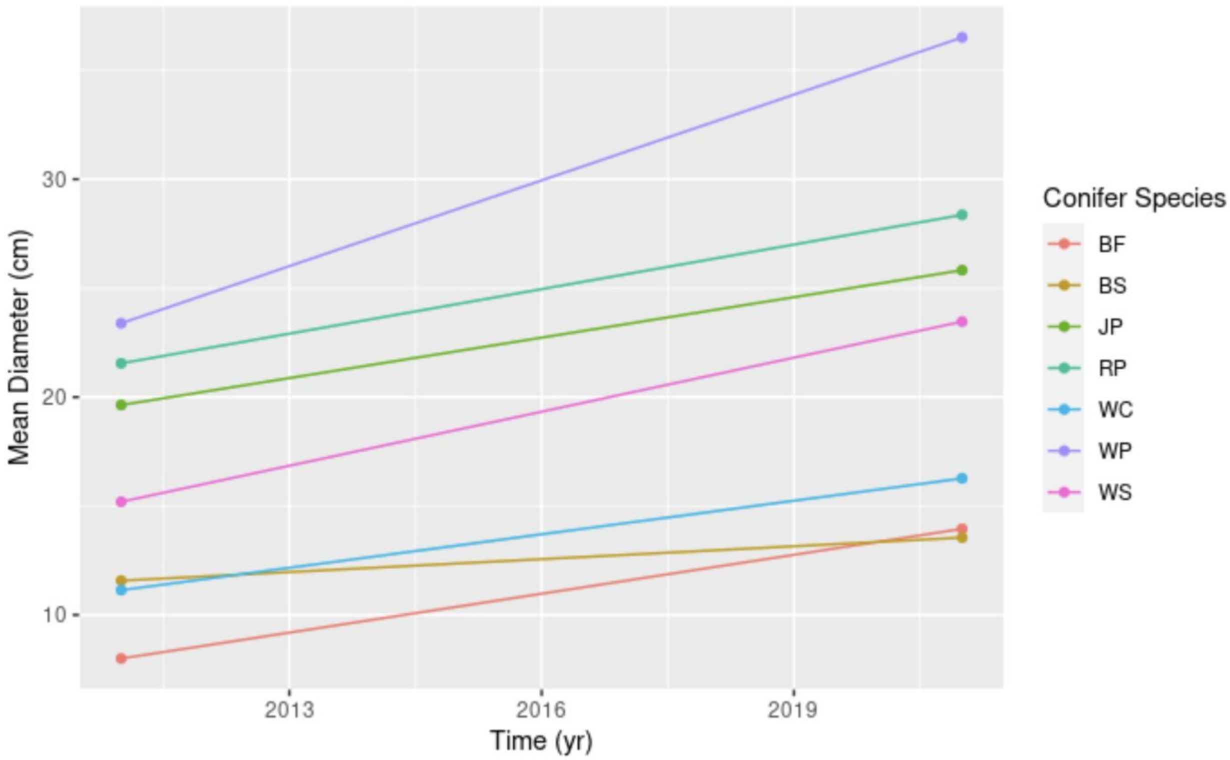

Figure 6: Comparison of the mean diameter of individual tree species between 2011 and 2021