St. Olaf College

Local Ecology Research Papers

Comparison of forest composition and growth rates in high and low *Fraxinus* spp. density plots in order to predict potential impacts of *Agrilus planipennis* infestation

Clay Wilkens

2021

Comparison of forest composition and growth rates in high and low *Fraxinus spp.* density plots in order to predict potential impacts of *Agrilus planipennis* infestation.

Clay Wilkens
St. Olaf College
Biology 371: Field Ecology Fall 2021
December 16, 2021

Abstract

Forest adaptation to disturbances is an increasingly important topic of study in the era of climate change. This study focuses on predicting the outcomes of emerald ash borer (EAB, *Agrilus planipennis*) infestation on the forest composition of deciduous forests. As part of the Ecological Research as Education Network's EAB impact study, data were collected in the 1990 forest restoration area in the St. Olaf College Natural Lands. The objectives of this study were to compare: (1) 2021 diameter at breast height (DBH) of mature trees between high and low *Fraxinus spp.* (ash) tree density plots (2) growth rates of mature trees after 6 years of growth between high and low ash density plots. Following the protocols laid out by the EREN EAB impact study (Kilgore and Dolan 2013), mature trees (>2.5 DBH) in two high ash dense and two low ash dense 20 by 20 meter plots were measured and recorded in winter 2021 and compared to 2015 data. Mean DBH was 8.23 cm in high density plots and 9.73 cm in low density plots, while mean growth rate was 0.24 cm/year and 0.37 cm/year respectively. There was no significant difference in overall tree growth rate between high or low density ash plots ($p = 0.1825$) or ash compared to not ash trees for all plots combined ($p=0.99$). However mean ash DBH was significantly greater than not ash DBH ($p = 0.003$). If ash is greatly reduced, data from this study suggest replacement species are likely to include *Quercus sp.*, *Juglans nigra and Acer saccharum*. These species may become more important in forest compositions without ash trees. Forest management practices should be utilized in order to mitigate the losses due to EAB and prevent invasive species from dominating the forest.

Introduction

Disturbances are an important part of regulating succession in deciduous forests. In moderation, they can create opportunities for new tree individuals to establish within a canopy by killing or displacing existing individuals (Shea 1993). In addition, disturbances can often be used to explain long-term ecosystem stability (Berland et al. 2011). However, through the introduction of harmful invasive species and dramatic climate variation due to climate change, disturbances are becoming more frequent and more harmful to forests. The frequency and severity of disturbances can impact forest recovery and reduce ecosystem services (Millar and Stephenson 2015). In the era of climate change, it is becoming increasingly important to study these types of disturbances and their effects on forest health and composition. Learning how deciduous forests adapt to climate stressors can inform forest management practices and proactively protect these ecosystems from experiencing significant change as disturbances continue to worsen.

Human activity has been a major disturbance to deciduous forests in the midwestern United States since the arrival of European colonizers. 90% of the pre-colonial "Big Woods" of Minnesota was cut for lumber and agricultural fields, significantly changing the forest composition and leaving small fragments of this once vast forest behind (Shea 1993). In addition, colonizers brought and planted invasive species such as European buckthorn which quickly took over the understory of some of the remaining forest, causing further disturbances (Shea 1993). Currently, human activity, invasive species and pathogens are some of the main disturbances occurring in the remaining fragments of the Big Woods (Shea and Helgeson 2018). These disturbances have changed forest compositions drastically and continue to threaten the remaining forests.

One such disturbance that has been studied with increased intensity is the emerald ash borer (EAB, *Agrilus planipennis*) and how it is affecting ash populations across the midwestern United States. The EAB is an invasive wood boring insect species that was inadvertently introduced in North America in the 1990s and completes most of its life cycle in ash (*Fraxinus spp.*) trees. Tunneling from EAB larvae in the ash cuts off nutrient and water flow between the roots to the top of the tree (Flower et al. 2012). Once a nonnative invasive species such as the EAB becomes established, it can become a permanent resident of the community (MNDNR 2021). From this establishment, the EAB can travel to new communities via its flight range (~32 kilometers/year)(Flower et al. 2021) or the transport of ash wood by humans (MNDNR 2021). Already, the EAB has rapidly killed off millions of ash trees and threatens several billion more. The EAB has no preference on the age or health of ash trees and infects young, old, weak and healthy alike, effectively removing ash species from their native forests. The EAB can kill ash trees in as little as 1-3 years and affected trees usually are not discovered until it is too late (MNDNR 2017, Flower et al. 2021). The impact of the EAB on forest composition is significant. It is a unique infection that is able to target a single genus of tree and completely remove it from a forest within a few years, leading to questions about how forests will respond and adapt to the loss of such a significant species.

Northfield, Minnesota is one of few cities in Minnesota that have shown no signs of EAB infections (as of December, 2021). While this is almost certainly a fleeting reality, as many of the cities and counties surrounding Northfield have confirmed EAB presence (MNDNR 2017), the past few decades of EAB free forests have allowed for the study of variable-density ash forests and what impacts they may have on forest composition. The Ecological Research as Education Network (EREN) has developed a Permanent Forest Plot Project (PFPP) which includes an EAB Impacts study as a subproject. The goal of this subproject is to study the loss of ash trees in forest ecosystems, especially due to EAB infestation (Dolan and Kilgore 2013). St. Olaf College participates in the EAB impacts study and has set up plots following the guidelines of the study. These plots provide valuable data in order to study the long term effects of low ash presence in fragmented forests. Additionally, these plots can continue to be studied throughout the infestation of EAB in order to answer questions about forest adaptation to this invasive insect. I studied these plots in order to determine if there are differences in diameter at breast height (DBH) of mature trees and, using past data, growth rates between high and low ash density plots. By comparing the characteristics of each plot and using past data, we can predict how forests with similar compositions can adapt to a disturbance like the EAB and how gaps in the canopy can give rise to other species.

My objectives for this study were to compare; (1) 2021 DBH of mature trees between high and low ash density plots (2) growth rates of mature trees after 6 years of growth between high and low ash density plots and (3) forest composition of high and low plots in order to predict future canopy makeup.

Methods

Site Description

St. Olaf's EREN EAB impact study plots are located in the 1990 Forest Restoration loops one and two in the St. Olaf Natural Lands on the west side of the campus (44° 27' 40.7016", - 93° 11' 25.2672"). There are a total of four, 20 by 20 meter^2 plots, two in each of the forest loops. Additionally, the plots are designated as "high ash", planted with a high density of ash trees and "low ash plots", planted with a low density of ash trees so that each forest loop has one "high ash" plot and one "low ash" plot. The plots were also planted with common deciduous tree species native to the Northfield area. These plots are managed by the St. Olaf Natural Lands technicians and are close to active trails on the campus.

Data Collection

I collected data on all trees within each of the four plots following the specific EREN PFPP protocols that are consistent across all EREN plots. Data were collected in October and November of 2021 and all trees were measured by myself, keeping the measurements consistent. Trees were only measured and recorded if they were equal or greater than 2.5 centimeters at DBH. These plots have been measured before, most recently in 2015, 2016 and 2017, and in order to keep measurements consistent across time, they have been marked with an aluminum number tag. These number tags counted up from 1 and ended when the last tree was tagged.

When new trees are discovered, they are tagged with the number above the last number in the plot. Many of the trees across the plots had multiple stems larger than 2.5 cm at DBH. To account for this, multiple stemmed trees had tags with decimals to indicate which stem was which. For example, if tree number 10 had two stems above 2.5 cm at DBH, the first stem (usually the larger stem) would have a tag reading "10.1" and the second stem would have a tag reading "10.2". This way, the growth of multiple stemmed trees can be determined without having to choose or combine the multiple stems into one calculation. Furthermore, each plot has an accompanying map that has the approximate location of all of the trees within the plots. This map was especially helpful, as some of the trees had died, fallen and decomposed without a trace. New trees discovered above 2.5 cm at DBH were added to the map as well. At each of the trees, I recorded the number of the tag and the DBH in centimeters using a DBH tape for each tree. If I discovered that a tree was dead, I made a note of that in my data sheet. I did not identify the tree based on species as this had been done in previous years. For a more detailed description on the EREN PFPP protocol methods, please refer to "Emerald Ash Borer Impacts Study Protocols" by Dolan and Kilgore.

<u>Data Analysis</u>

I compiled all of my data into Google Sheets, performed statistical analysis in version 3.6.0 of RStudio and calculated contingency tables in RCommander. I obtained data from 2015, 2016 and 2017 and matched up my 2021 data to past data using tree numbers. I took note of trees that had died from 2015 to 2021 and new trees that I discovered. Because of the complications of calculating growth rate from dead or new trees, I decided to just analyze trees that had measurements from 2015 and 2021. In Google sheets, I calculated the growth rate in cm per year for each stem by subtracting the 2015 DBH from the 2021 DBH and dividing by 6. After inputting my data into R, I computed summary statistics, made boxplots and calculated t tests and ANOVA tests.

Results

Field 1 North had the highest number of trees (58) and Field 2 North had the lowest number of trees (36) (Table 1). In the high ash dense plots, white ash trees were the most prevalent species in Field 1 South (27) and Field 2 South (39) making up 71 percent of the canopy of high ash dense plots (Table 1, Table 2). In the low ash dense plots, bur oak was most prevalent in Field 1 North (26) and black walnut was most prevalent in Field 2 North (Table 1). Bur oak (28.9%), white oak (15.6%), black walnut (14.4%) and white ash (13.3%) trees made up most of the canopy in low ash plots (Table 2). A Chi square test confirmed that the species composition was significantly different with a p value of less than 0.005 ($X^2 = 79.766$, df = 9). Surprisingly, both high and low ash dense plots had a similar number of individual trees (95 in high, 94 in low) and stems measured (136 in high, 134 in low) (Table 3). High ash plots had an average 2021 DBH of 8.23 cm and low ash plots had an average 2021 DBH of 9.73 cm (Table 3). Additionally, high ash plots had an average growth rate of 0.24 cm/year and low ash plots had an average growth rate of 0.329 cm/year (Table 3). An ANOVA (df1 = 3, df2 = 356, F value = 3.712, P value = 0.012) and subsequent TukeyHSD test showed that there was a significant difference in 2021 DBH between Field 1 South and Field 2 North (p value = 0.041) and Field 1 South and Field 2 South (p value = 0.034)(Figure 1). An ANOVA (df1 = 3, df2 = 266, F value = 2.144) of growth rates between plots was not statistically significant, with a p value of 0.095). A t test was conducted and showed that there was no significant difference between 2021 DBH and high/low ash plots (t = 0.59575, df = 267.92, p-value = 0.5518)(Figure 2). There was no significant difference between growth rate and high/low ash plots (t = -1.3366, df = 264.6, p-value = 0.1825)(Figure 3) and no significant difference between growth rates of ash and non-ash trees (t = -0.0051513, df = 252.4, p-value = 0.9959)(Figure 4). There was a significant difference between the 2021 DBH of ash trees and not ash trees (t = 3.6413, df = 244.81, p-value = 0.0003309) (Figure 5).

Discussion

Growth Trends

All of my plots were very similar in terms of 2021 DBH and growth rate. There was no significant difference between the growth rates of the four plots, which means that the plot environments are similar and can act as a control if and when EAB infestation occurs. Field 1 South showed a slightly higher DBH on average, resulting in a statistically significant difference between this field and Field 2 South and Field 1 North. This result is puzzling, especially the difference between the two southern, high ash plots. It would make sense that a high ash plot has a higher DBH than the other plots because ash trees are a faster growing tree species and that would reflect in the plots. However, Field 2 South has a lower mean 2021 DBH than the low ash plots (and a smaller standard deviation too) which indicates that the difference in the plots can only be attributed to some untested factor. Ash trees were not shown to have a significantly higher growth rate than non ash trees, a result consistent with Burck 2016. Additionally, Burck 2016 concluded that ash trees had a significantly higher mean DBH than non ash trees, a result that I found as well. These results should mean that Field 2 South is consistent with Field 1 South (the other high ash plot, with the highest mean DBH) but it is not. I assume that because the growth rates of all plots are similar and that the growth rates of ash trees and non ash trees are similar, the plot had a disturbance early in its life causing it to briefly stop growing at the rate of the other plots. It may also be due to intraspecific competition between ash trees in Field 2

South, as found by Braker 2017. This field had 12 more ash trees than Field 1 South so it's possible that this difference in ash tree density was enough to cause a noticeable slowing in growth.

Forest Composition

Although they were intended to have different densities of ash trees, there is a significant difference between the composition of low and high ash plots. However, understanding the difference in composition between high and low ash plots is crucial in predicting canopy composition in an EAB future. In the event of EAB infestation, our high dense plots will lose 71 percent of the canopy. This likely will reflect in the real world, as purer ash stands will suffer the most for EAB infestation. However, ash trees are still 13 percent of the low ash canopy which means that even forests with a lower density of ash trees will be affected by EAB. The low ash plots are mostly made up of oak trees, 28 percent of which are bur oak and 14 percent of which are white oak, and black walnut trees. These tree species will likely be given the opportunity to thrive in the absence of ash trees in the canopy due to their already established presence in these areas. Additionally, it is also likely that sugar maples fill in the canopy gaps as well due to their established presence in the area, shade tolerance and seed output (Baker 1949, Shea 1993). Furthermore, good forest management practices are required in order to prevent aggressive invasive species such as buckthorn or black locust from overcoming these plots.

The EREN EAB impacts study plots give us a unique opportunity to study the before and during effects of a likely EAB infestation. While I did not come across any infested ash trees in the plots, it is likely that an EAB infestation will happen in the near future. The Minnesota DNR has closely monitored established EAB populations and have identified EABs within 3 km of Northfield, MN (MNDNR 2021). The EAB will continue to make its way across the central midwest, threatening the estimated one billion ash trees in Minnesota. However, there does appear to be some good news in ash replacement. A study done by Kashian and Witter 2011 concluded that there is evidence of ash replacement post EAB infestation. This is largely attributed to the established seed population in upland forests and assuming that some of these ash seedlings reach reproductive age, ash trees will persist post EAB infestation. In wetland forests, however, ash trees are more threatened. The seed population is less established in these areas due to constant flooding and the nature of the wetlands and ash replacement is unclear. (Kashian and Witter 2011). This is distressing, as much of the estimated one billion ash trees in Minnesota are pure, wetland stands of black ash trees. In all cases, the loss of so many trees opens the door to aggressive invasives that may cause further damage to the forest ecosystem. Dolan and Kilgore 2018 concluded that invasive shrubs increased with ash tree mortality, especially the more shade tolerant species. This again highlights the need for effective forest management in order to prevent takeovers from shade tolerant shrub species.

Conclusions

The EAB is a significant threat to ash populations and it's important to understand the effects of the loss of ash trees in order to plan for the future. In my study, I found that there was no significant difference in growth or DBH between high and low ash dense plots, but the composition of these plots was more significant than growth trends. High ash dense plots (and forests) could quickly be overtaken by invasive or shade tolerant species that will exacerbate the negative effects of losing an important canopy species like the ash. This study adds to the scientific literature urging and supporting effective forest management practices. Without assisted ash recovery or reforesting, forest ecosystems could drastically change. In the future, I hope that these EREN EAB impact plots can be used to understand more about the behavior of forest composition with EAB infestation.

Acknowledgements

I would like to thank Professor Kathy Shea for her guidance with this study. I would also like to thank my mother, Pam Wilkens, for her help in the data collection.

Literature Cited

Baker, F.S. 1949. A revised tolerance table. Journal of Forestry 47: 179–181.

Berland, A., B. Shuman and S.M. Manson. 2011. Simulated importance of dispersal, disturbance, and landscape history in long-term ecosystem change in the Big Woods of Minnesota. Ecosystems 14: 398-414.

Braker, W. 2017. Tree diameter and growth rate comparisons of southern MN trees in density-variable *Fraxinus sp* deciduous forest plots. Local Ecology Research Papers. St. Olaf College, Northfield, MN. https://wp.stolaf.edu/naturallands/files/2018/05/Braker_2017.pdf

Burck, E. 2016. Potential impacts of the emerald ash borer (*Agrilus planipennis*) on ash trees (*Fraxinus spp.*) and forest composition in the St. Olaf College natural lands (Northfield, Minnesota). Local Ecology Research Papers. St. Olaf College, Northfield, MN. https://wp.stolaf.edu/naturallands/files/2017/03/Burck_2016_Forest.pdf

Dolan, B., and J. Kilgore. 2018. Forest Regeneration Following Emerald Ash Borer (*Agrilus planipennis* Fairemaire) Enhances Mesophication in Eastern Hardwood Forests. Forests 9:353.

Dolan, B., and J. Kilgore. 2013. Emerald ash borer impacts study. EREN: 2-16. URL http://erenweb.org/wp-content/uploads/2014/08/ERENPFPPEABImpactsStudy7Aug2014.pdf

Flower, C. E., K. S. Knight, and M. A. Gonzalez-Meler. 2013. Impacts of the emerald ash borer (*Agrilus planipennis* Fairmaire) induced ash (*Fraxinus spp.)* mortality on forest carbon cycling and successional dynamics in the eastern United States. Biological Invasions 15:931–944.

Kashian, D. M., and J. A. Witter. 2011. Assessing the potential for ash canopy tree replacement via current regeneration following emerald ash borer-caused mortality on southeastern Michigan landscapes. Forest Ecology and Management 261:480–488.

Millar, C. I., and N. L. Stephenson. 2015. Temperate forest health in an era of emerging megadisturbance. Science 349:823–826.

MNDNR. 2021. Emerald ash borer (EAB) . https://www.dnr.state.mn.us/invasives/terrestrialanimals/eab/index.html.

Shea, K. L., and S. R. Helgeson. 2018. Tree Growth Patterns, Mortality, and Colonization in a Restored Maple-Basswood Forest. Ecological Restoration 36:295–305.

Shea, K.L. 1993. Forest ecology. In P. Gruchow and G. Deason (eds.), The Cannon River Valley,
unpublished. St. Olaf College, Northfield, MN.

Tables and Figures

Table 1: Tree count per species per plot only including tree individuals and not stems

Tree count per species per plot					
Common Name	Field 1 North (Low Ash)	Field 1 South (High Ash)	Field 2 North (Low Ash)	Field 2 South (High Ash)	Total
Amur Maple	0	0	1	0	1
Boxelder	0	1	1	1	3
Red Maple	0	0	8	2	10
Sugar Maple	6	4	1	3	14
Bitternut Hickory	1	0	0	0	1
White Ash	2	27	10	39	78
Black Walnut	0	3	13	6	22
Eastern Hophornbeam	0	1	0	0	1
Bigtooth Aspen	1	0	0	0	1
Black Cherry	1	1	1	0	3
Chokecherry	0	1	0	0	1
White Oak	14	1	0	0	15
Bur Oak	26	1	0	0	27
Northern Red Oak	2	0	1	0	3
American Basswood	1	0	0	0	1
American Elm	4	4	0	0	8
Total	58	44	36	51	189

Table 2: Contingency table with species percentage in high and low ash dense plots. Only species with 2 or more individuals in at least one plot are included. $Chi^2 = 79.766$, df = 9, p-value = 1.799e-13

Contingency table of high and low ash plot composition		
Species	Percent in high ash dense plots	Percent in low ash dense plots
Boxelder	2.2	1.1
Red Maple	2.2	8.9
Sugar Maple	7.5	7.8
White Ash	71	13.3
Black Walnut	9.7	14.4
Black Cherry	1.1	2.2
White Oak	1.1	15.6
Bur Oak	1.1	28.9
Northern Red Oak	0	3.3
American Elm	4.3	4.4
Total	100.2	99.9
Count	93	90
$Chi^2 = 79.766$, df = 9, p-value = 1.799e-13		

Table 3: Summary table of high and low ash plots with number of individuals, number of stems, mean DBH, standard deviation of DBH, mean growth rate and standard deviation of growth rate

Plot	Tree Common Name	Tree Species ID Code	Number of Individuals	Number of Stems	Mean DBH	Standard Deviation of DBH	Mean Growth Rate	Standard Deviation of Growth Rate
High								
	Boxelder	ACENEG	2	2	3.2	0.28	0.067	0.04714045
	Red Maple	ACERUB	2	5	9.02	2.23	0.24	0.28556717
	Sugar Maple	ACESAC	7	8	7.15	1.7	0.323	0.10115896
	White Ash	FRAAME	66	98	11.61	5.92	0.28	0.35593582
	Black Walnut	JUGNIG	9	10	11.55	5.45	0.476	0.2684101
	Eastern Hophornbeam	OSTVIR	1	5	7.06	2.97	0.06	0.06302557
	Black Cherry	PRUSER	1	1	5.5	0	0.13	0
	Chokecherry	PRUVIR	1	1	3.9	0	0.183	0
	White Oak	QUEALB	1	1	19.8	0	0.6167	0
	Bur Oak	QUEMAC	1	1	7.2	0	0.083	0
	American Elm	ULMAME	4	4	4.55	0.73	0.1875	0.0550673
		Total	95	136	8.230909091	2.754285714	0.240563636	0.168043624
Low								
	Amur Maple	ACEGIN	1	1	8.3	0	0.467	0
	Boxelder	ACENEG	1	1	5.4	0	0.0167	0
	Red Maple	ACERUB	8	24	7.9	3.2	0.464	0.33253055
	Sugar Maple	ACESAC	7	10	9.13	7.002	0.35	0.29918098
	Bitternut Hickory	CARCOR	1	1	3.7	0	-0.03	0
	White Ash	FRAAME	12	20	13.28	4.9	0.45	0.23037401
	Black Walnut	JUGNIG	13	14	7.5	2.49	0.275	0.13516372
	Bigtooth Aspen	POPGRA	1	1	6.6	0	0.267	0

	Black Cherry	PRUSER	2	1	3.5	0	0.083	0
	White Oak	QUEALB	14	20	14.97	3.758	0.3	0.12921264
	Bur Oak	QUEMAC	26	29	7.38	3.35	0.067	0.14424273
	Northern Red Oak	QUERUB	3	3	19.17	8.75	1.02	0.25837813
	American Basswood	TILAME	1	4	21.65	8.17	1.179	1.11549482
	American Elm	ULMAME	4	5	7.76	7.15	0.27	0.31828534
		Total	94	134	9.731428571	5.418888889	0.369907142	0.3292069911

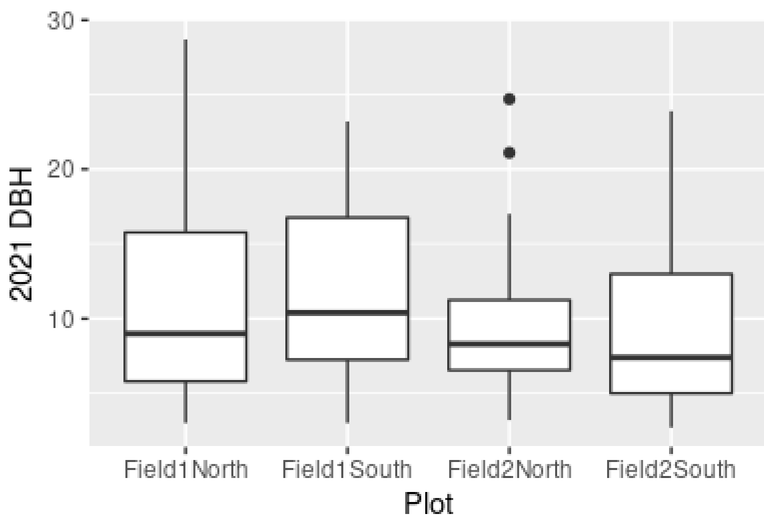

Figure 1: ANOVA for plot compared to 2021 DBH df1= 3, df2 = 266, F value = 3.712 p value = 0.012. TukeyHSD = Field 2 North - Field 1 South = 0.0411093 Field 2 South - Field 1 South = 0.0347936

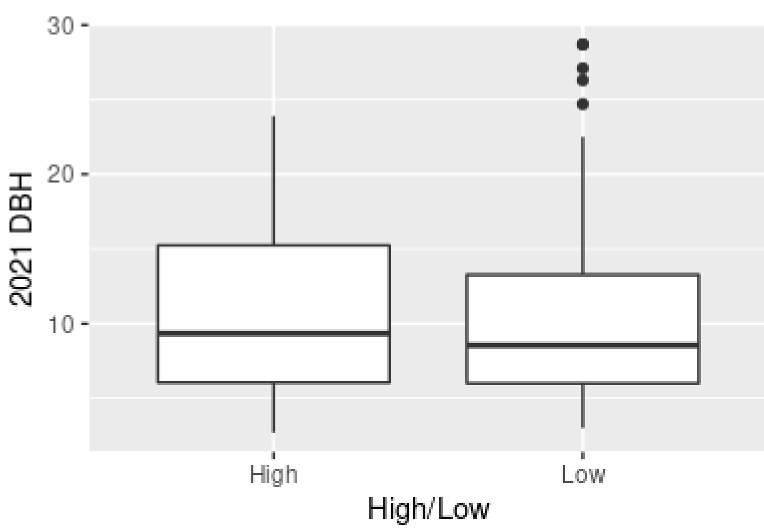

Figure 2: A comparison of mean DBH in 2021 in high and low ash density plots showed no significant difference in DBH. t = 0.59575, df = 267.92, p-value = 0.5518

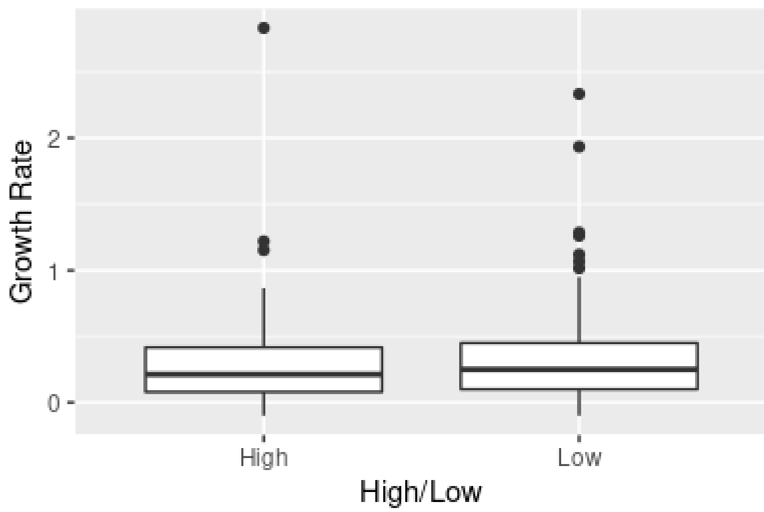

Figure 3: T test of growth rate compared to high and low ash density plots. t = -1.3366, df = 264.6, p-value = 0.1825

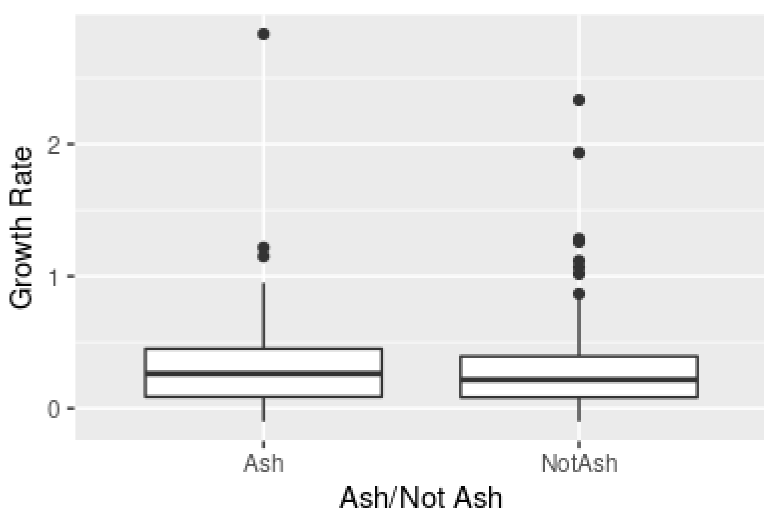

Figure 4: T test of growth rate compared to ash and non ash trees. t = -0.0051513, df = 252.4, p-value = 0.9959

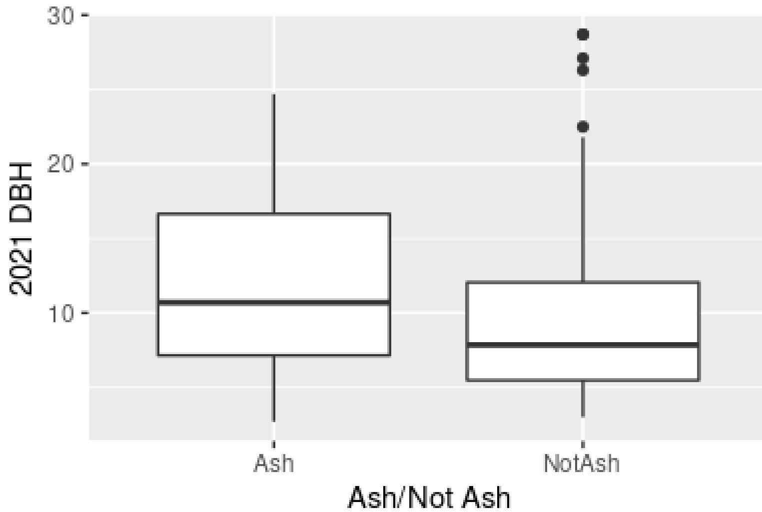

Figure 5: T test of DBH compared to ash and non ash trees. t = 3.6413, df = 244.81, p-value = 0.0003309