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2016

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Field Ecology, Fall 2016
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Abstract

The emerald ash borer (EAB, *Agrilus planipennis*), which has an established population in the Twin Cities metro area, will likely colonize Northfield, MN by 2020 (Kovacs et al. 2011) and could cause the death of all native ash trees in the city (City of Northfield 2016). In this project, data concerning high and low ash density forest plots were collected in the 1990 forest restoration area in the St. Olaf College Natural Lands to understand current forest composition and growth rates as well as predict and manage the effects of the EAB. Utilizing the methods specified in the EREN Permanent Forest Plot Project (Dolan and Kilgore 2013), each mature tree (> 2.5 cm DBH) in four 20 x 20 plots was catalogued and measured in fall 2016 and compared to data from 2015. Data were compiled in stand tables describing species, DBH, basal area, number of individuals; additionally, data were analyzed using ANOVAs and contingency tables. Trees were on average .378 cm wider in 2016 than 2015 ($p < 2.2e-16$). Ash trees did not grow significantly faster than non-ash trees ($p=0.929$), but ash trees were significantly wider than non-ash trees ($p=1.47e-08$), suggesting faster growth in the long term. Low ash density forests were significantly different in composition than high ash density forests ($p=4.409e-14$). Low ash forests had more white oaks, bur oaks, black walnut, and red maple. Thus, the EAB may have the effect of making forest composition in high ash plots more like low ash plots. Precautions should be taken to prevent the growth of invasive trees like the common buckthorn from colonizing areas where ash trees have died. The results of this study combined with future studies of the area should help mitigate impacts of the EAB on forest composition and minimize the costs of an invasion.

Introduction

The emerald ash borer (EAB, *Agrilus planipennis*) is an invasive species from China that currently threatens all native ash tree species (*Fraxinus* spp.) in the United States. First found in Detroit in 2001, the EAB has since spread throughout the Midwest and the Mid-Atlantic (Dolan and Kilgore 2013). As of June 2015, twenty-five states and two Canadian provinces have been infected (Iverson et al. 2016). The EAB primarily spreads via two modes: human-assisted transportation and insect-flight up to 3 km (Kovacs et al. 2011). Minimizing the effects of EAB is dependent on early detection, which allows for insecticide treatment and/or removal of infected trees as well as human-assisted replacement of ash by other tree species (Iverson et al. 2016).

The EAB causes mortality in ash trees during its larval stage when it eats the phloem of the tree, resulting in nutrient starvation of the tree (Dolan and Kilgore 2013). Klooster et al. (2014) noted that the EAB caused 99% mortality in white, green, and black ash species with DBHs above 2.5 cm in Michigan in 2009. Some tree species, like the American elm (*Ulmus americanus*), have been able to persist despite invasions by deadly pests and diseases since they can reproduce before the disease causes mortality. However, ashes are unable to do this as they only reach reproductive maturity around 8 cm DBH, long after they can be colonized and killed by the EAB larvae. Thus, the only generations of ash that survive the EAB tend to be ashes that were seedlings and saplings (< 2.5 cm DBH) at the time of the invasion (Klooster et al. 2014). Additionally, ashes do not have standing seed banks (which usually germinate in 2-3 years), so the number of ash seeds declines sharply after the death of mature ash trees in an infected stand (Klooster et al. 2014). Depending on the ash density of the forest, this could leave wide disturbances for the succession of different trees and shrubs. Native trees like elms (*Ulmus* spp.) and sugar maple (*Acer saccharum*) have been found succeeding ash trees in Michigan (Dolan and Kilgore 2013). It is also expected that invasive buckthorn or prairie grasses could invade stands with dead ash trees (Iverson et al. 2016).

Minnesota specifically is threatened by the EAB because of its high ash populations. Iverson et al. (2016) note that Minnesota had the highest ash biomass of all U.S. states with a total of 36.8 million cubic meters of black ash, green ash, and white ash combined. Not only does this serve as a large carbon sink for the state (9.2% of the state's total aboveground biomass), but it also functions as an important resource for ecological services and human activities (Iverson et al. 2016). Ash trees help regulate nutrient and water flow (Klooster et al. 2014) as well as provide food and shelter for arthropods, birds, and mammals (Klooster et al.

2014, Iverson et al. 2016). Humans often utilize ash in timber and nursery industries (Dolan and Kilgore 2013) and to make pulpwood and other wood products (Iverson et al. 2016). The invasion of the EAB to Minnesota – which will cause widespread ash tree death – thus puts at risk a large portion of the state's forested habitat and the services that come from it.

In Northfield, Minnesota, the EAB has not yet invaded and ash trees make up about 20% of the tree population. In 2009, satellite populations of the EAB were discovered in the Twin Cities metro area (Kovacs et al. 2014), and Kovacs et al. (2011) estimated that even with 75% effective treatment that the EAB will reach Rice County (where Northfield, MN is located) and most other Minnesotan counties by 2020. As of the USDA's November 2016 report, the two counties bordering Rice County are both under state and federal EAB quarantine. The threat of the EAB in Rice County is therefore imminent; studying the potential impacts of the EAB in the area is necessary and of time-sensitive importance so that we can understand what the potential effects on ecological processes and humans will be. Studying potential impacts also will inform how we respond to those impacts with ecological and economic concerns in mind. The more effective EAB elimination programs are, the less costs there are overall for treatment, removal and replacement. For Minnesota alone, Kovacs et al. (2011) estimates that the cost of treatment, removal, and replacement could range from $264 billion (in a 100% effective treatment scenario) to $974 billion (in a base case scenario).

Since the EAB is likely to colonize Northfield, MN, studying forest plots in the area is important as it can help forest managers predict the impacts of the EAB on forest composition and prevent ecosystem destabilization. With this in mind, our study aimed to analyze the species composition (2016) and growth rates (2015-2016) of mature trees in the forest restoration loops in the St. Olaf College Natural Lands, specifically looking at differences between ash and non-ash trees as well as low and high ash density plots. We also aimed to hypothesize the potential impacts of the EAB on the species composition and growth rates, and suggest strategies to manage the EAB invasion in order to maintain a "productive, functioning forest" (Iverson et al. 2016).

Methods

We surveyed mature tree populations in four 20 x 20 meter plots Forest Restoration Loops #1 and #2 in the St. Olaf Natural Lands (see Figure 1) throughout the months of October and November 2016. The four plots were set up in accordance with suggested guidelines in the EREN Permament Forest Plot Project – two with low ash concentrations (Field 1 North and Field 2 North) and two with high ash concentrations (Field 1 South and Field 2 South) (Dolan and Kilgore 2013). We measured and identified mature trees (> 2.5 cm DBH) – recording DBH, stem status (living or dead), stem type (multiple or single), species code, soundness, canopy class, tree damage, and notes. Data were compiled using the EREN Tree Data Entry Form (Kuers 2014). Data from this portion of the study will be submitted in their raw form to the EREN Emerald Ash Borer Impact Study. Additionally, as supplemental data for this project and for the EREN Distribution of Earthworms Project, soil samples from each site were collected and analyzed for mean % organic matter, mean % moisture, mean pH, and litter depth. Earthworms at each site were also collected and identified as anecic, endogeic, or epigeic using the methodology as recommended by the EREN Worm Protocol (McCay 2013).

Data were organized in Excel, and statistical analyses were run in R Studio. A table was compiled for summary purposes, showing the mean DBHs, standard deviations, standard errors, number of stems, number of individuals, and total basal areas of each tree species sorted by plot. Basal areas were calculated by using the formula "basal area (in m) = $0.00007854*DBH^2$"

(Brower et al. 1998) and summed by tree species within each plot to approximate coverage. Next, we used 2015 (collected by John Inglis, a 2016 St. Olaf graduate) and fall 2016 data to calculate growth rates from 2015-2016. We used a one sample t-test to evaluate whether the mean change in DBH from 2015-2016 was significantly greater than zero. We compared changes in DBH between ash trees and non-ash trees as well as between species using a one-way ANOVAs. We also compared changes in DBH between site using a one-way ANOVA. Using just 2016 data, we performed a one-way ANOVA between mean DBHs of ash and non-ash trees. This analysis was continued by running a pairwise multi-way ANOVA between mean DBHs of all tree species found in plots. A multi-way ANOVA was also performed between trees' observed crown class and their 2016 DBH. Finally, we created contingency tables to determine if counts of dominant tree species were significantly different in high and low ash plots as well as each of the four plots individually.

Results

In total, 217 trees were measured and recorded in the four plots, with a total of 327 stems from single-stemmed and multiple-stemmed trees (see Table 1). White ash trees were the most abundant species in total (84 individuals) followed by bur oak (27 individuals), black walnut (22 individuals), white oak (15 individuals), sugar maple (14 individuals), red maple (13 individuals), boxelder (11 individuals), and American elm (9 individuals).

Tree Diameters & Growth:

There was a significant change in mean DBH from 2015-2016, approximately a 0.378 cm increase (95% CI: 0.313 cm $< x <$ 0.443 cm; p-value $< 2.2e-16$). There was not a significant difference between the change in DBH for ashes versus non-ashes ($p < 2.2e-16$) as ashes grew on average 0.381 cm (SD: +/- .543 cm) while non-ashes grew 0.376 cm (SD: +/- .613 cm).

Likewise, there was not a significant difference between species for the change in DBH ($p = 0.0811$). Looking between plots, there was not a significant difference between the four plots for the change in DBH ($p = 0.598$).

Looking at the 2016 data, there was a significant difference mean DBHs for ash and non-ashes ($p = 1.47e-08$; see Figure 2). Ashes had an average mean of 10.055 cm (SD: +/- .4.938 cm; n=128) whereas non-ashes had a mean of 7.070 cm (SD: +/- 4.251 cm; n=199). There were also significant differences between mean DBHs looking between all observed species ($p < 2e-16$; see Figure 3). Ash, specifically, had a significantly higher mean DBH than amur maple, boxelder, red maple, choke cherry, bur oak, and American elm, and a significantly lower mean DBH than white oak. Between plots, there were significantly different mean DBHs as well ($p= 0.00104$; see Figure 4). Looking at the pairwise comparison, Field 2 North had a significantly lower mean DBH (mean = 6.652 +/- 3.474 cm) than both Field 1 North (mean = 8.989 +/- 5.178cm; $p = 0.00971$) and Field 1 South (mean = 9.251 +/- 5.155 cm; $p = 0.00215$). Between observed crown classes (dominant/co-dominant, intermediate, or overtopped), DBH also varied significantly ($p < 2e-16$): dominant/co-dominant averaged 11.712 +/- 4.272 cm, intermediate averaged 5.749 +/- 2.190 cm, and overtopped averaged 4.380 +/- 2.317 cm (see Figure 5). Looking pairwise, all three were significantly different from each other: intermediate to dominant/co-dominant ($p < 0.001$), overtopped to dominant ($p < 0.001$) and overtopped to intermediate ($p = 0.023$).

Forest Composition:

Low ash and high ash plots were significantly different in the composition of dominant species ($p = 4.409e-14$; see Table 2). Low ash plots were dominated by bur oak (28.6%) white oak (15.4%), black walnut (14.3%), and white ash (14.3%) whereas high ash plots were dominated by white ash (68.3%) with smaller numbers of black walnut (8.7%), boxelder (6.7%), and sugar maple (6.7%). All four plots were significantly different in dominant species composition as well ($p < 2.2e-16$; see Table 3). Within low ash plots, Field 1 North was dominated by bur oak (49.1%) and white oak (26.4%) whereas Field 2 North was dominated by black walnut (47.9%), white ash (22.9%), and red maple (18.8%). Within high ash plots, Field 1 South was dominated by white ash (62%, sugar maple (10%), and boxelder (10%) while Field 2 South was dominated by white ash (74.1%) and black walnut (11.1%).

Soil and Earthworm Data:

Mean percent organic matter ranged between 2.56% and 6.25% (see Table 4), with Field 1 plots having lower values than Field 2 plots. Mean percent moisture ranged from 9.46% and 15.75%, again with Field 1 having lower values than Field 2. As seen in Table 4, mean pH was between 5.83 and 6.87 depending on the site, and litter depth for low ash sites was lower (~3 cm) than high ash sites (~5cm). Earthworm biomass was greater in Field 1 sites than Field 2 sites, having greater number of anecic worms (see Figure 6).

Discussion

Forest Characteristics:

Overall, trees grew in 2016, averaging 0.3779 cm greater DBH than 2015 ($p < 2.2e-16$). Although ash trees are known for their fast growth, they did not grow significantly more than non-ash trees, averaging only 0.381 cm growth compared to 0.376 cm for non-ash trees ($p = 0.929$). There are two possible explanations for this: either ash trees had a poor year of growth or only one year of data is not enough to show their faster growth rate. Though ashes did not have a greater change in diameter, ashes did have a significantly larger mean DBH than non-ash trees ($p = 1.47e-08$), with ashes having an average mean of 10.055 cm and non-ashes having a mean of

7.070 cm. Ashes' higher DBH than non-ashes gives support to the hypothesis that a year was not a long enough period to show the speed of their growth. Since the forest was restored in 1990 and most trees were planted at the same time, the higher mean DBH shows that ashes have grown faster on average than other trees in the plots. Additionally, since the ash has continued to grow this year (even if not significantly faster than non-ashes), it is unlikely that the ash borer has unknowingly colonized the area, as colonization would likely slow growth.

In terms of forest composition, white ash dominated the high ash plots whereas a mix of bur oak, white oak, black walnut, and white ash dominated low ash plots (see Table 1 and 2). High ash plots (Field 1 South and Field 2 South) were similar in that white ash was the most dominant species for both; however, the two low ash plots did not share any dominant species (see Table 2). Bur oak and white oak dominated in Field 1 North, and in Field 2 North, black walnut, white ash, and red maple dominated (see Table 3). Indeed, when the mean DBH between the four forests sites were compared, Field 2 North (low ash density) had a significantly lower mean DBH than Field 1 North ($p = 0.00971$) and Field 1 South ($p = 0.00215$). Different mean DBH values – which were significantly correlated with tree species ($p < 2e-16$; see Figure 3) – could thus reflect the differences in species composition of the four sites (and especially Field 2 North from the two Field 1 sites). Of the four highest mean diameter species – basswood, northern red oak, white oak, and white ash – Field 2 North only had white ash (11 individuals) and northern red oak (1 individual), explaining its lower mean DBH.

Differences between species composition and mean DBHs of sites could also be explained by soil and earthworm characteristics. Field 1 plots had lower mean percent organic matter and percent moisture than Field 2 plots (see Table 4). Thus, large diameter trees might be using nutrients and moisture in Field 1 plots, preventing younger trees from getting necessary below-ground nutrients thus skewing the mean DBH. On the other hand, Field 1 also had a larger average biomass of earthworms and more anecic earthworms, and they, not the larger trees, could be preventing younger trees from growing successfully. Not all soil characteristics indicate differences between Field 1 and Field 2 as opposed to low ash and high ash plots, though. Litter depth seems to correlate more closely with low or high ash density rather than field location, as low ash plots had litter depths around ~3 cm and high ash plots had litter depths around ~5cm.

Future Forest:

It is likely that future years will see large changes in forest composition from 2015 and 2016 measurements due to the imminent invasion of the emerald ash borer. High ash mortality should be expected, up to 99% in ash trees with DBHs over 2.5 cm (Klooster et al. 2014). This could cause large changes in species composition in high ash plots, which were solely dominated by white ash trees. Over time, this could cause them to look more like the low ash concentration plots, with an increase of white oak, bur oak, black walnut, and red maple (see Table 2). However, it also could facilitate the invasion of non-native species, like common buckthorn. Although common buckthorn was only found at low abundance in one site (Field 1 South – high ash), it has a significant presence in the Northfield area and is likely to spread to areas where ash trees have died because of its ability to monopolize nutrients (Minnesota DNR 2016). Indeed, the buckthorns that were identified in November in Field 1 South still had green leaves, while almost all other trees had lost their leaves – illustrating buckthorn's ability to outcompete other species.

Other less harmful species that can be expected to retake the forest area after the ash borer invasion are sugar maples and boxelder (Helgeson 2015). As Bray (1956) illustrates in his article "Gap phase replacement in a maple-basswood forest," maples are adept colonizers after small scale disturbances like the falling of a dead tree. Maples reproduce at high rates and are shade tolerant, therefore easily take advantage of a gap in the canopy to outcompete other species. It is possible, that without management, that high ash plots could start to look like the maple-dominated Norway Valley. Another species that may invade post-ash borer is boxelder, a fast-growing colonizer that often grows in abandoned fields or vacant lots (Zuzek and Koetter 2016). If large enough areas are left without trees, it is likely that boxelder could find suitable habitat to colonize as well.

Management Considerations:

To prevent complete takeover of high ash areas by competitive colonizers like common buckthorn, sugar maple, and boxelder, management should consider seeding with shade-intolerant species. Oak species are prime candidates for seeding because they favor sun and are more drought resistant than other species (Helgeson 2015). Especially with warming temperatures in mind, species that can withstand upcoming changes in climate, like oaks, should be seeded in high ash areas so that the forest can thrive through these changes. Bur and white oak are already successful in Field 1 North; thus, it is reasonable to expect that they might be successful in other areas as well. Once oak seeds are planted and beginning to thrive, seeds of species shade-tolerant species like maple can be planted (Helgeson 2015). Together, these efforts can help preserve the diversity and resilience of the forest. However, special care should be taken to make sure invasive buckthorn are not outcompeting trees. Manually removing buckthorn trees from the immediate area before the invasion and as it takes place should help curb its colonization.

Importantly, forest managers should be in contact with local, county, and regional governments as the EAB moves into Rice County and St. Olaf property, as top-down control of responses to the ash borer has the potential to lower costs and decrease the severity of the invasion (Kovacs et al. 2013). On a local scale, frequent checks for D-shaped holes in trees as well as late winter checks for increased woodpecker activity on ash trees can help indicate the presence of the ash borer, and thus speed responses to its presence (Minnesota DNR 2016).

Conclusions:

Altogether, we find that mature trees in the 1990 forest restoration plots have grown an average of .3779 cm DBH in the past year and that ash growth continues to outpace the growth of non-ash species (though not detectably on a year-to-year basis). The forest composition of high and low ash plots is significantly different – low ash plots being dominated by oaks and black walnut, and high ash plots being dominated by white ash. However, soil and earthworm variations may contribute to differences in forest composition as much or more than ash trees, as all four plots had significantly different forest compositions. Future studies should continue to investigate the interacting effects of soil characteristics, earthworm presence, and ash presence on forest composition. Additionally, better predictions for successional changes in the forest could be made by extending growth and composition analysis to seedlings and saplings. Altogether, a successful transition from pre-emerald ash borer conditions to post-emerald ash borer conditions depends on early detection, cooperation between forest management and local government, as well as a human-assisted transition of the forest to prevent colonization by invasive species and ensure forest diversity.

Figures and Tables

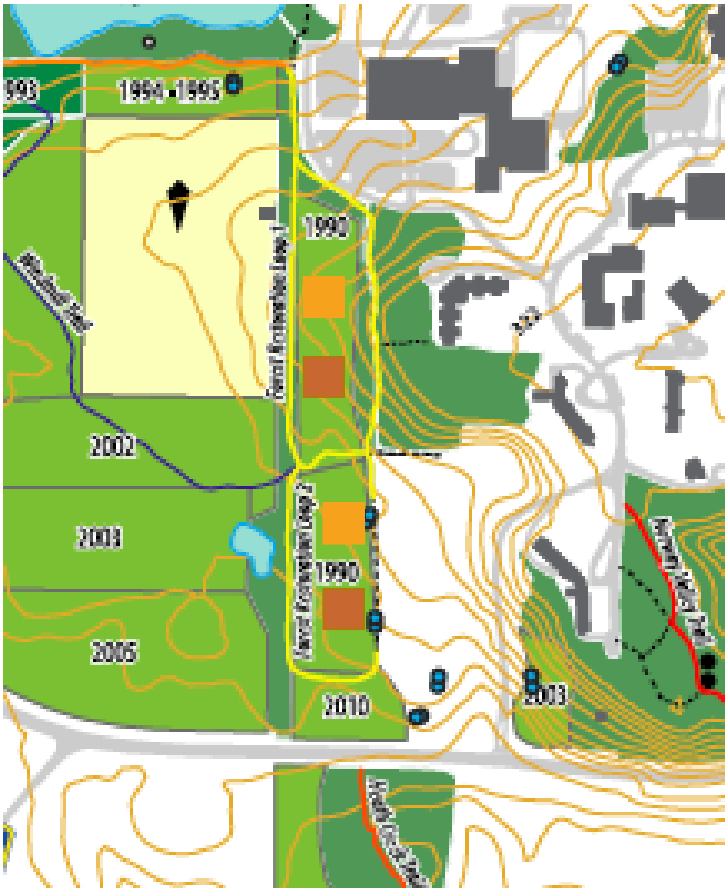

***Figure 1.* Map of the St. Olaf Natural Lands.** Orange boxes indicate low-ash 20x20m plots (Field 1 North and Field 2 North) and red boxes indicate high-ash 20x20m plots (Field 1 South and Field 2 South). **Note: boxes are not to scale. Image courtesy of St. Olaf College; see http://wp.stolaf.edu/naturallands/files/2016/04/Natural-Lands-SmallBrochure-Map-v7-MASTER-wContours-CLIP-1-1.pdf*

***Table 1.* Summary table by forest plot and tree species with mean diameters, standard deviations, number of stems, number of individuals, and total basal area**

Site	Common Name	Scientific Name	Mean Diameter (cm)	Standard Deviation	# Stems	# Individuals	Total Basal Area (m^2)
Field 1 North (Low Ash)							
	Sugar Maple	*Acer saccharum*	7.722	5.346	9	6	0.062
	Bitternut Hickory	*Carya cordiformis*	3.900	0	1	1	0.001
	White Ash	*Fraxinus americana*	11.900	4.668	3	2	0.038
	Bigtooth Aspen	*Populus grandidentata*	5.500	0	1	1	0.002
	Black Cherry	*Prunus serotina*	3.200	0	1	1	0.001
	Chokecherry	*Prunus virginiana*	3.063	0.316	8	2	0.006
	White Oak	*Quercus alba*	13.670	3.236	20	14	0.310
	Bur Oak	*Quercus macrocarpa*	7.063	3.016	30	26	0.139
	Northern Red Oak	*Quercus alba*	18.450	1.950	2	2	0.054
	Basswood	*Tilia americana*	14.350	1.335	4	1	0.065
	American Elm	*Ulmus americana*	6.640	5.324	5	5	0.028
		TOTAL	8.989	5.147	84	61	0.708
Field 1 South (High Ash)							
	Boxelder	*Acer negundo*	4.922	2.358	9	5	0.021
	Sugar Maple	*Acer saccharum*	5.829	1.567	7	5	0.020
	White Ash	*Fraxinus americana*	11.555	4.753	60	31	0.736
	Black Walnut	*Juglans nigra*	6.800	4.167	3	3	0.015
	Ironwood	*Ostrya virginiana*	6.920	2.870	5	1	0.022
	Black Cherry	*Prunus serotina*	5.200	0	1	1	0.002
	Chokecherry	*Prunus virginiana*	3.000	0	1	1	0.001
	White Oak	*Quercus alba*	16.700	0	1	1	0.022
	Bur Oak	*Quercus macrocarpa*	7.000	0	1	1	0.004
	Common Buckthorn	*Rhamnus cathartica*	4.133	0.386	3	2	0.004
	American Elm	*Ulmus americana*	3.050	1.579	4	4	0.004
	Unknown		3.700	0	2	2	0.002
		TOTAL	9.251	5.128	97	57	0.852
Field 2 North (Low Ash)							
	Amur Maple	*Acer ginnala*	3.971	1.063	7	3	0.009
	Boxelder	*Acer negundo*	4.250	1.059	4	4	0.006
	Red Maple	*Acer rubrum*	5.736	2.313	28	9	0.084
	Sugar Maple	*Acer saccharum*	4.800	0	1	1	0.002
	White Ash	*Fraxinus americana*	10.500	3.929	18	11	0.178
	Black Walnut	*Juglans nigra*	6.064	1.935	14	13	0.045
	Northern Red Oak	*Quercus rubra*	5.400	0	1	1	0.002
	Unknown		2.750	0	1	1	0.001
		TOTAL	6.652	3.450	74	43	0.326
Field 2 South (High Ash)							
	Amur Maple	*Acer ginnala*	3.567	0.170	3	3	0.003
	Boxelder	*Acer negundo*	6.100	3.200	2	2	0.007
	Red Maple	*Acer rubrum*	7.390	2.789	10	4	0.049
	Sugar Maple	*Acer saccharum*	4.450	0.650	2	2	0.003
	White Ash	*Fraxinus americana*	7.851	4.661	47	40	0.308
	Black Walnut	*Juglans nigra*	10.171	3.601	7	6	0.064
	Unknown		3.400	0	1	1	0.001
		TOTAL	7.689	4.333	72	58	0.435
TOTAL					327	219	2.322

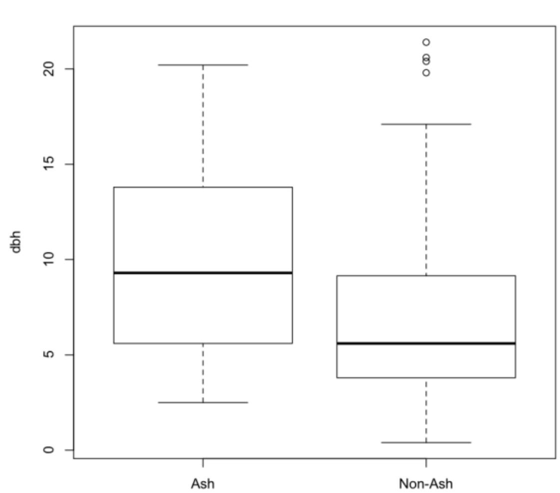

***Figure 2.* Box-plot of DBH (cm) for ash and non-ash trees.** The mean DBH for ash trees was 10.055 cm (SD: +/- .4.938 cm; n=128) and was significantly higher than the mean DBH for non-ash trees 7.070 cm (SD: +/- 4.251 cm; n=199; p = 1.47e-08).

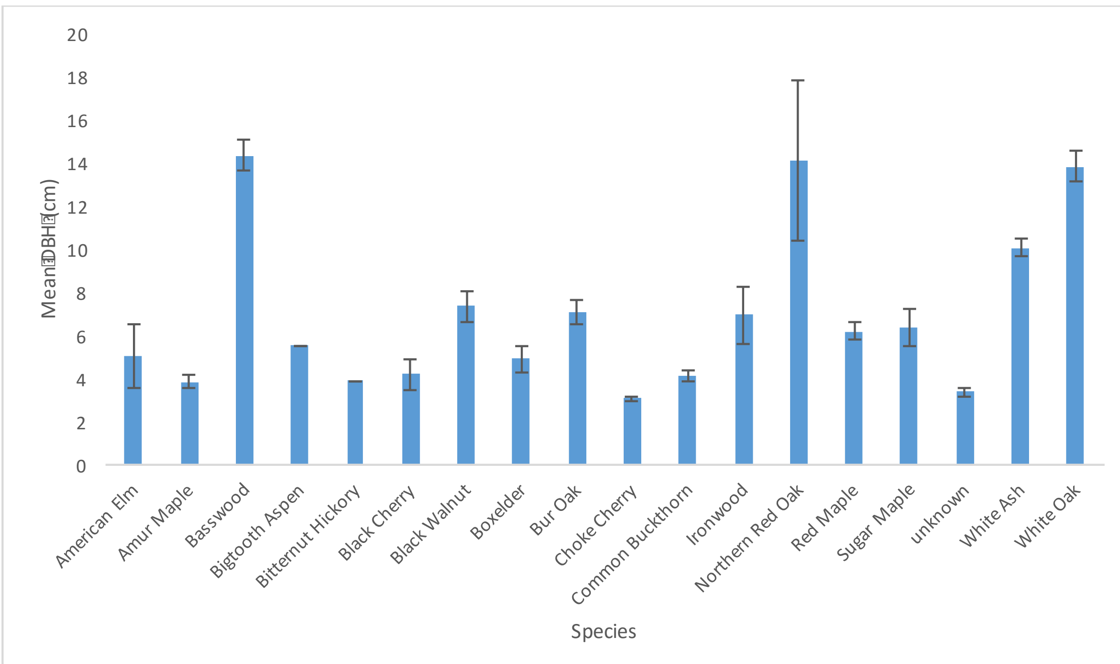

***Figure 3.* Mean DBH (cm) with standard errors of all observed tree species in plots.** There were significant differences between mean DBHs looking between all observed species (p < 2e-16). White ash had significantly higher DBHs than the American elm, amur maple, boxelder, bur oak, choke cherry, and red maple, and had a significantly lower DBH than white oak.

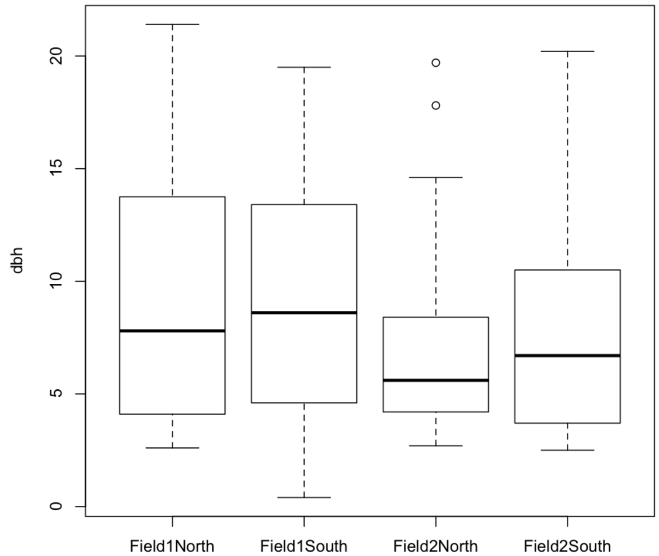

Figure 4. **Box-plot of DBH (cm) for trees in four 20x20m forest restoration plots.** The mean DBH for each of the four plots vary significantly (p= 0.00104). Field 2 North had significantly smaller DBHs (mean = 6.652 +/- 3.474 cm) than both Field 1 North (mean = 8.989 +/- 5.178cm; p = 0.00971) and Field 1 South (mean = 9.251 +/- 5.155 cm; p = 0.00215). Field 2 South averaged 7.629 +/- 4.363 cm.

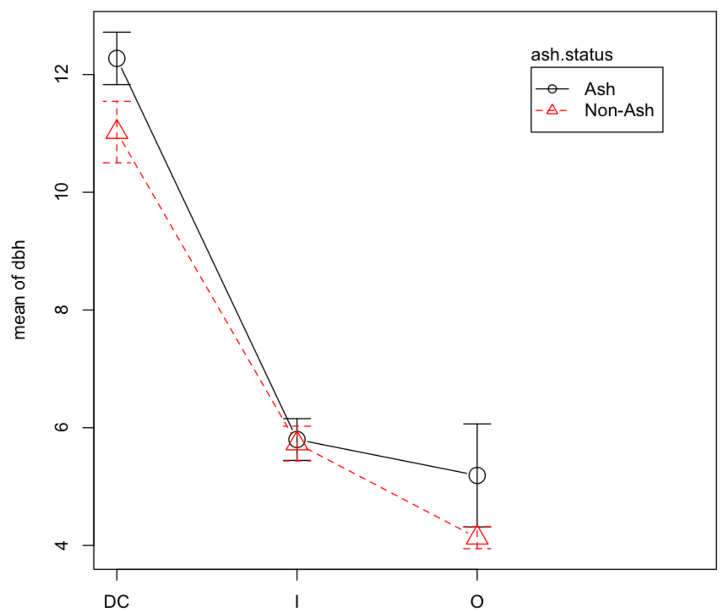

Figure 5. **Comparison of means showing differences in mean DBH by canopy class and ash status (ash or non-ash).** DBH varied significantly (p < 2e-16) between canopy class: dominant/co-dominant averaged 11.712 +/- 4.272 cm, intermediate averaged 5.749 +/- 2.190 cm, and overtopped averaged 4.380 +/- 2.317 cm (see Figure 5). All three were significantly different from each other: intermediate to dominant/co-dominant (p < 0.001), overtopped to dominant (p < 0.001) and overtopped to intermediate (p = 0.023). **Note: DC, I, and O stand, respectively, for dominant/co-dominant, intermediate, and overtopped trees.*

Table 2. **Contingency table showing the percent composition of low and high ash plots by dominant species (p = 4.409e-14)**

Species	Low Ash	High Ash
Sugar Maple	7.7	6.7
White Ash	14.3	68.3
White Oak	15.4	1
Bur Oak	28.6	1
American Elm	5.5	3.8
Boxelder	4.4	6.7
Black Walnut	14.3	8.7
Red Maple	9.9	3.8
Total	100.1	100
Count	91	104

Table 3. **Contingency table showing the percent composition of four restoration plots by dominant species (p < 2.2e-16)**

Species	Field 1 North (Low Ash)	Field 1 South (High Ash)	Field 2 North (Low Ash)	Field 2 South (High Ash)
Sugar Maple	11.3	10	2.1	3.7
White Ash	3.8	62	22.9	74.1
White Oak	26.4	2	0	0
Bur Oak	49.1	2	0	0
American Elm	9.4	8	0	0
Boxelder	0	10	8.3	3.7
Black Walnut	0	6	47.9	11.1
Red Maple	0	0	18.8	7.4
Total	100	100	100	100
Count	53	50	48	54

Table 4. **Soil data showing mean % organic matter, mean % moisture, mean pH, and litter depth (cm) for low and high ash sites**

	Field 1 North (Low Ash)	Field 1 South (High Ash)	Field 2 North (Low Ash)	Field 2 South (High Ash)
Mean % Organic	2.56	4.34	5.61	6.25
Mean % Moisture	9.46	12.82	13.80	15.75
Mean pH	6.48	6.87	5.83	6.47
Litter Depth	3	5	3.73	5.1

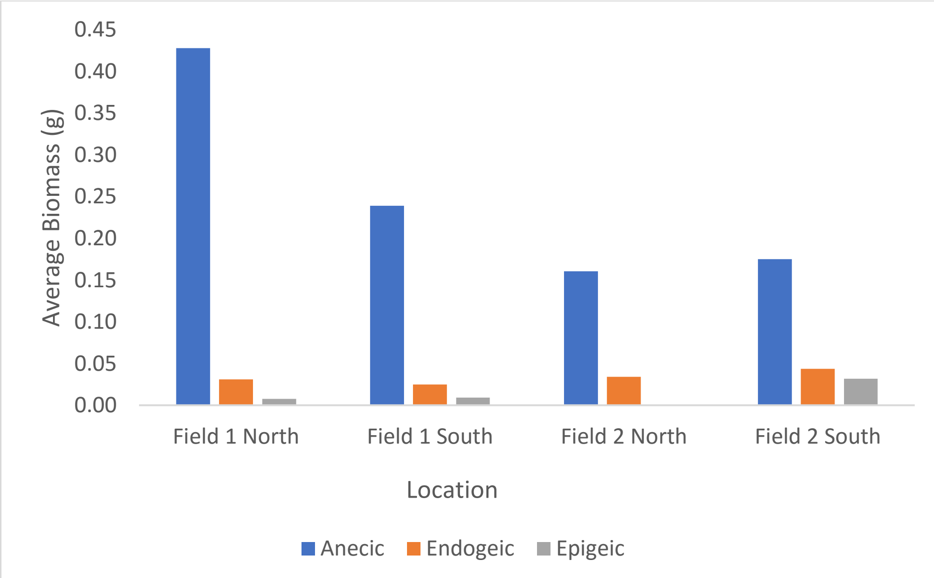

Figure 6. **Average earthworm (anecic, endogeic, and epigeic) biomass for low and high ash plots**

Acknowledgments

Sincere thanks to Prof. Kathy Shea for her guidance throughout this project as well as Connor Phelan and members of the fall 2016 Field Ecology class for their assistance in collecting data. I would also like to acknowledge the work of John Inglis and Sonja Helgeson, as their past data collection and efforts in understanding the forest characteristics of the 1990 restoration loops informed the direction and results of my project.

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