Forest Composition and carbon sequestration of urban hardwood, deciduous forest patches in Northfield, Minnesota

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Abstract

Terrestrial ecosystems such as forests act as carbon sinks under current climate conditions. Recent research has indicated that forests have the potential to mitigate the effects of anthropogenic climate change, yet the extent to which forests can mitigate climate change remains unclear. The vulnerability of forest ecosystems to natural disturbances such as fire, disease, weather damage and insect infestations undermine forest carbon mitigation efforts, necessitating an understanding of current forest composition and carbon sequestration potential. The Big Woods region of Minnesota, a temperate hardwood forest, is particularly vulnerable to the emerald ash borer (EAB), an invasive beetle species that has decimated ash tree populations throughout the Midwestern United States. The purpose of this study is to (1) measure how much carbon is sequestered in three urban forest patches in Northfield, Minnesota and (2) compare the abundance and diversity of tree species in each forest patch prior to the arrival of the EAB. The forest patches were sampled by identifying the tree species and measuring diameter at breast height (DBH) to calculate the carbon sequestration of aboveground tree biomass at the individual, plot and site level. I found that between the three urban forest patches there were 16 tree species with the Green Ash (*Fraxinus pennsylvanica*), the only ash species identified in this study as vulnerable to the EAB, comprising 9 percent of the total number of trees measured. Carbon sequestration did not vary between sites but varied between tree species. This study has implications for future urban forest management and provides the basis for future comparisons of forest composition and carbon sequestration given changes in climate and disturbance.

Introduction

Anthropogenic increases in carbon dioxide (CO_2) and greenhouse gas (GHG) emissions caused by the combustion of fossil fuels and changes in land use pose a threat to global climate patterns and ecosystem health. Elevated GHG emissions increase global temperatures, effectively resulting in extreme changes in temperature, precipitation, drought and occurrence of severe weather events. To offset GHG emissions and reduce climate change impacts, researchers and climate activists alike are considering the carbon sequestration potential of trees and forests to mitigate released GHGs into the atmosphere.

Previous research estimates that 45 percent of terrestrial carbon (C) is stored in forests and forest soils, contributing to approximately 50 percent of the total global terrestrial net ecosystem production (Bonan 2008). Like most plants, trees convert atmospheric CO_2 to biomass through photosynthesis, with an estimated 60 percent of the carbon stored in forest ecosystems sequestered in live and dead trees (McKinley et al. 2011) by accumulating aboveground carbon in the form of biomass. Some of the aboveground tree biomass is then converted to soil organic carbon (SOC) through the decomposition of fallen branches, dead roots, and leaf litter, sequestering carbon in the microorganisms, bacteria and fungi within the soil that allows forest soils to act as a carbon sink (Minnesota Board of Soil and Water Resources).

It is unclear the extent to which forest ecosystems will act as a carbon sink for GHG emissions in the United States. Important research and resources are being allocated to better understand the carbon sink potential of forests, specifically through modeling which examines how afforestation, or the planting of trees on land that was not previously forested, supports climate change mitigation. Under current climate conditions, Bastin et al. (2019) estimates that an increase of 25 percent of forest area (an additional 0.9 billion hectares) has the potential to store 25 percent of the current atmospheric carbon pool, supporting afforestation as a solution to the climate change crisis. Such predictions were met with criticism from Veldman et al. (2019), who recognized the model's failure to consider the consequences of afforestation of grasslands, savannas and shrublands that promote biodiversity and sequester carbon without a large abundance of trees. The emphasis on planting more forests as opposed to increasing the carbon sequestration potential of existing forests is contingent on the false assumption that ecosystems with fewer trees are degraded and thus unable to sequester carbon in amounts that are comparable to that of forests. This assumption has led to afforestation in places that were not previously forested, diminishing the ecological value of other ecosystems such as grasslands and constraining the potential productivity of planted forests.

Moreover, afforestation efforts increase the tendency to plant forests for the singular purpose of sequestering carbon within the carbon credit system, creating a separation between those contributing to the increase in atmospheric levels of greenhouse gases and those who are affected by afforestation. This pattern has led to forest plantings in areas that are important to indigenous populations without consideration for the history, culture and ecological knowledge of indigenous communities. Consequently, researchers and land managers have changed their approach to increasing the terrestrial carbon sink by researching the ways in which the carbon sequestration potential of existing forests can be expanded to better mitigate anthropogenic increases in carbon.

Although forest ecosystems mitigate the effects of anthropogenic climate change, the ability to quantify aboveground carbon and estimate forest carbon sequestration is complicated by current and future disturbances. Disturbances such as fire, disease, weather damage and insect infestations disrupt the relationship between biomass production and decomposition, making the prospect of predicting future forest disturbances further complicated by the unpredictable effects of climate change. One of the most common disturbances to forests within the Midwestern United States is the potential for increased insect infestations. When analyzing forest quality in the Midwestern United States, researchers determined that the emerald ash borer (EAB), an invasive beetle species from Asia, killed 99 percent of infested ash trees within six years (Knight et al. 2013). The introduction of such invasive species thereby exemplifies the difficulty of estimating carbon sequestration of forests undergoing substantial disturbances.

Understanding the existing composition and carbon sequestration potential of forests is important for documenting and predicting change. Research has shown that forest ecosystems are particularly vulnerable to climate change in urban environments with a predicted 65 percent of tree species unable to adapt to the exceeding temperature and precipitation conditions caused by climate change (Esperon-Rodriguez et al. 2022, Huang 2022). The Midwestern United States is a region that has undergone significant land use changes since European settlement as prairies and forests were converted to agricultural land. Prior to European settlement, 61 percent of the land cover that constitutes Minnesota was forested (Minnesota DNR). The Big Woods region of Minnesota, a temperate hardwood forest, covered most of central Minnesota and divided the prairies of Western and Southern Minnesota, and the coniferous forests of Northern Minnesota. The Big Woods is of particular interest when considering forest quality, sequestration potential and impending ecological disturbances given its history of clear cutting, agricultural use and recent forest restoration efforts challenged with the impending arrival of the EAB.

In this research, I quantify the current carbon sequestration potential of several aboveground urban forest patches in Northfield, Minnesota by measuring the biomass of live trees. My objectives for this study were to; (1) measure how much carbon is sequestered in three urban forest patches in Northfield, Minnesota and (2) compare the abundance and diversity of tree species in each forest patch prior to the arrival of the EAB. This research supplements our knowledge of the current carbon sequestration potential of existing forest patches and evaluates the effectiveness of forests as a method of climate change mitigation.

Methods

Study Sites

This study was conducted in three city parks in Northfield, Minnesota in fall 2022 on the homelands of the Wahpekute Band of the Dakota Nation. The forest patches, Odd Fellows Park (44.45613, -93.17610), Sechler Park (44.44768, -93.18119) and Hauberg Woods (44.47717, -93.16886), are secondary growth forests owned and maintained by the City of Northfield (Figure 1). The three parks were chosen because the forest patches are large enough to fit three 20m x 20m plots and their proximity to urban infrastructure such as housing developments and fields used for outdoor recreation sports. The study sites receive frequent recreational use and are accessible by walking and mountain biking trails. The trails are maintained by the city or a local mountain biking community organization. Odd Fellows Park, bordered by a retirement home and a highway is considered a non-native forest planting with a stand age estimation of 30-45 years (Gould 2005). Hauberg Woods is located between a housing development and land used for conventional agriculture. Historic air photos indicate that Hauberg Woods was likely more open, with partial logging that occurred approximately 60-75 years ago. Sechler Park borders the Cannon River, a tributary of the Mississippi River, and is located within the river's floodplain. The geographic landforms indicate the forest patch undergoes seasonal flooding and is considered a floodplain forest silver maple subtype. Three 20m x 20m plots were created in each of the three city parks for a total of nine plots within this study. Individual plot locations were chosen based on accessibility, sufficient tree coverage, and adequate size of forested land. All plots were oriented north-south.

Data Collection

All trees within the 20m x 20m plots were surveyed and species identification was recorded in September and October 2022. Tree species were identified using leaves as the main identifying characteristic with the Seek app used for verification. In each plot, every tree with a diameter at breast height (DBH) >2.5 cm was measured approximately 1.35 meters from the ground using a DBH tape. DBH was measured to the nearest millimeter. If a tree had multiple stems, each stem was measured individually to accurately estimate biomass. For example, if a tree had more than one stem with a DBH >2.5 cm, both stems were measured and recorded as "9.1" for the first stem and "9.2" for the second stem of tree 9 of the plot. Using the DBH measurements, I followed the procedure of Sherman (2021) and calculated the potential carbon sequestration of each tree, plot and study site using the equation for aboveground biomass in Jerkins et al. (2003).

$$\text{Biomass} = \text{Exp}(\beta 0 + \beta t \ln [\text{DBH}]) \text{ where } \beta 0 = -2.0127 \text{ and } \beta t = 2.4342$$

After biomass values were calculated, the values were converted into carbon sequestration estimates using the equation for broadleaf deciduous trees (Kuers et al. 2011).

$$\text{Carbon sequestered} = \text{biomass} * 0.45$$

Data Analysis

Statistical analysis was conducted using version 4.1.3 of RStudio including ANOVA tests. Boxplots were created to look at differences in DBH between species and plot sites to detect differences in the carbon sequestration potential between different species and plot locations.

<u>Results</u>

Species Composition

In total, 310 trees were measured and 16 tree species were found within the three urban forest patches with Hauberg Woods having the highest species richness (n=10) of the forest patches sampled in this study and the lowest species richness in Sechler Park (n=7) (Table 1). Calculations of tree species diversity using the Shannon Diversity Index determined that forest patch tree diversity followed the same pattern as species richness with Hauberg Woods having the highest species diversity (1.93) and Sechler Park having the lowest species diversity (1.38) (Table 1).

Basswood (*Tilia americana*) was the most abundant species (n=57) found in only Hauberg Woods and Odd Fellows Park while American Elm (*Ulmus americana*) was the most common species found in all three forest patches (n=31) with the highest proportion in Sechler Park (42%) (Figure 2, Table 1). The least abundant species (n=1) included Alternate Leaf Dogwood (*Cornus alternifolia*) and Sugar Maple (*Acer saccharum*) found only in Odd Fellows Park, American hophornbeam (*Ostrya virginiana*) and Bitternut Hickory (*Carya cordiformis*) found only in Hauberg Woods (Table 1). Bur Oak (*Quercus macrocarpa*) had the highest mean DBH (Figure 3). Green Ash (*Fraxinus pennsylvanica*) constituted 9 percent of the total number of trees measured (Table 1).

Carbon Sequestration

An analysis of variance test found that there was no significant difference between DBH and urban forest patch location (F value=2.221, dfl=2, p value=.11) (Figure 4). However, an ANOVA test determined that there is a significant difference between DBH and tree species (F value=10.56, dfl=15, p value=2e-16), although a subsequent TukeyHSD test showed that not all differences between tree species are significant (Figure 3). Silver Maple (*Acer saccharinum*) sequestered the most carbon of all tree species with an average of 13091.17 tons of carbon between all three forest patches, followed by Black Walnut (*Juglans nigra*) that sequestered an average of 9077.93 tons of carbon in Odd Fellows Park (Table 2). Alternate Leaf Dogwood (*Cornus alternifolia*) (n=1) sequestered the least amount of carbon of 0.87 tons (Table 2). Hauberg Woods sequestered the most carbon (17179.81 tons) followed by Sechler Park (14482.76 tons) and Odd Fellows Park (13962.23 tons) for a total of 45624.80 tons of carbon stored within the three study plots at all forest patches (Table 2).

Discussion

In total, there were 16 tree species identified within this study. Hauberg Woods had the most species diversity of the three forest patches and the only forest patch with the Bur Oak (*Quercus macrocarpa*), possibly a testament of its history of partial logging as opposed to clearcutting. Of particular interest is one large Silver Maple (*Acer saccharinum*) located in Hauberg Woods that sequestered 3335.22 tons of carbon alone. Odd Fellows Park was the only forest patch with the Black Walnut (*Juglans nigra*) and the Norway Maple (*Acer platanoides*), a non-native maple species often used in landscaping, possibly located within the forest patch given its close proximity to residential neighborhoods. Sechler Park had the lowest species diversity with an abundance of the Eastern Cottonwood (*Populus deltoides*) and Silver Maple (*Acer saccharinum*), likely due to its location within the floodplains of the Cannon River. The Eastern Cottonwood and Silver Maple are two tree species known to be adapted to seasonal flooding and environments with high moisture levels. A possible limitation of the species diversity and composition of this study is that the three plots within each urban forest patch may not have been representative of the entire urban forest patch.

There is a significant difference in DBH and therefore carbon sequestration between different species. Although there are differences between species, a TukeyHSD test determined that there are only significant differences between some species compared to others, positing that the variation in carbon sequestration between species is affected by other differences than just species identification. It is likely that other factors such as tree size and abundance also influence the differences in carbon sequestration between species. The measurements and data collection also revealed that there is no significant difference between DBH and the urban forest patch location. This finding exhibits no difference in live aboveground carbon accumulation based on the location of the urban forest patches, although further research should be conducted to estimate the belowground carbon sequestration of each forest patch as soil carbon is the longest enduring terrestrial carbon sink (Keenan and Williams 2018).

Green Ash (*Fraxinus pennsylvanica*), the only species affected by the invasive EAB found in the forest patches, was located in each forest patch and comprised 9 percent of the total number of trees measured in this study. While the Green Ash constitutes only a small percentage of the trees included in this study, Minnesota forests are home to approximately 1 billion ash trees with 15,000 to 50,000 individuals located within Rice County (Minnesota Department of Natural Resources). The impending invasion of the EAB therefore will be considerable in changing species composition and forest structure by altering successional trajectories of understory and overstory species. Ash mortality has been shown to benefit oak (*Quercus*), maple (*Acer*) and Basswood (*Tilia*) through the release of competition in the short term but such changes will irreversibly alter the structure of the forest (Smith et al. 2014). Furthermore, the opening of the forest canopy from ash mortality may facilitate the spread of invasive species due to increased light ability and affect the life cycle of insects and animals that host on ash trees. Future research should consider the ecosystem structure and species interactions of the urban forest patches prior to and after the arrival of the EAB to inform researchers on the changes in forest composition and disturbances when tree species are eliminated.

To summarize, it is important to understand the species composition and the carbon sequestration potential of existing urban forest patches to document and predict change under disturbance vulnerability and climate change conditions. In this study, I found that there was no significant difference in carbon sequestration based upon the location of three urban forest patches in Northfield, Minnesota. Moreover, 16 tree species were identified with the Green Ash (*Fraxinus pennsylvanica*) as the only ash species identified in this study as vulnerable to the EAB, comprising 9 percent of the total number of trees measured. This research supplements the existing scientific literature supporting urban forest management and encourages land management that considers the vulnerability and adaptability of urban forests to future climate change and disturbance conditions.

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Land Acknowledgement

I stand on the homelands of the Wahpekute Band of the Dakota Nation and other tribal nations that have stewarded this space. I express gratitude to the people who have stewarded the land, acknowledging the genocide, forced removal and ongoing injustices that have been committed against the indigenous people that call this space home. I acknowledge their ongoing contributions to this region and wish to interrupt the injustices that have been committed against them, beginning with listening, acts of healing and honest storytelling about this place.

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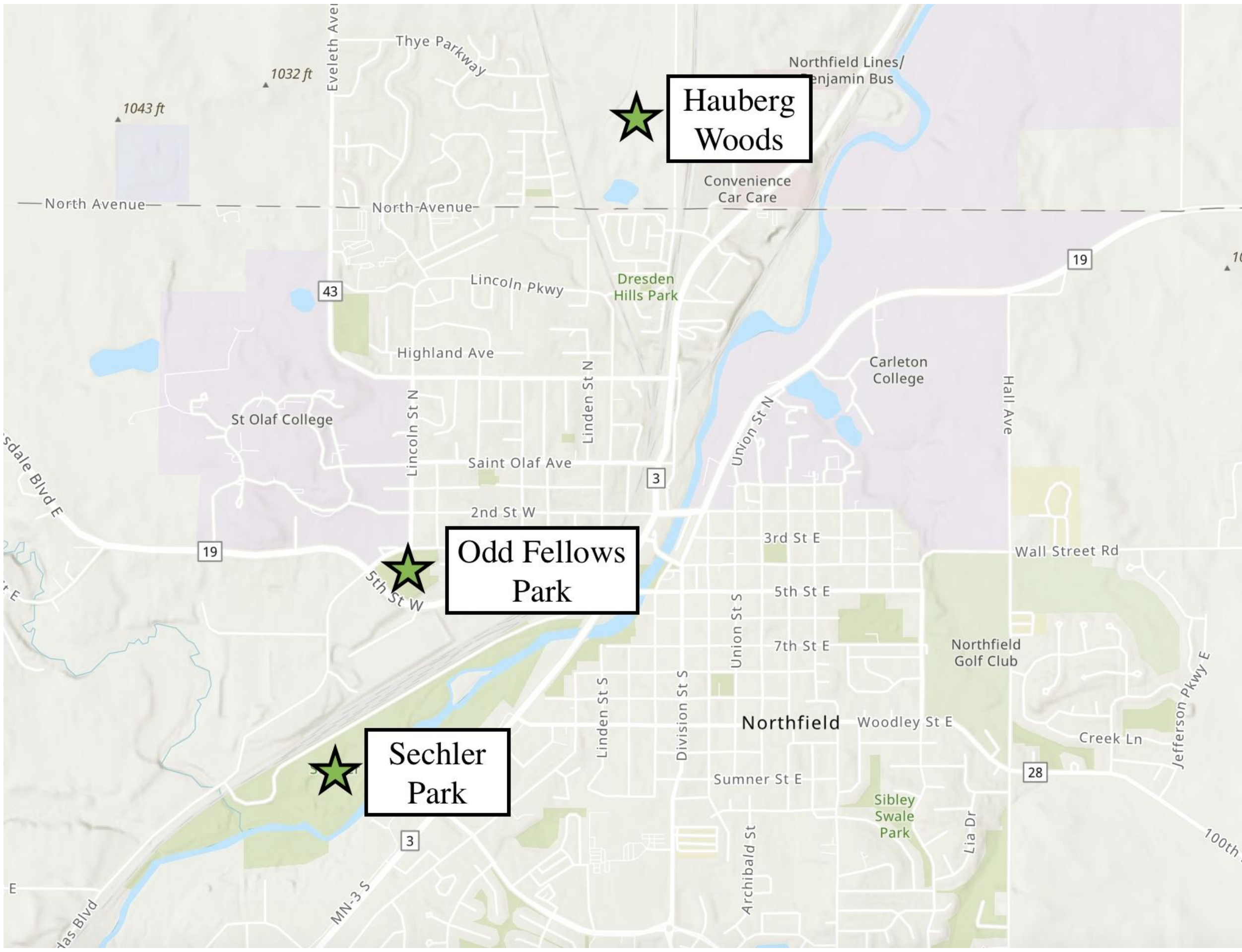

Figure 1. Forest patches in Northfield, Minnesota used for tree sampling of urban forest patches. Green stars are the approximate locations of the three urban forest patches: Hauberg Woods, Odd Fellows Park and Sechler Park.

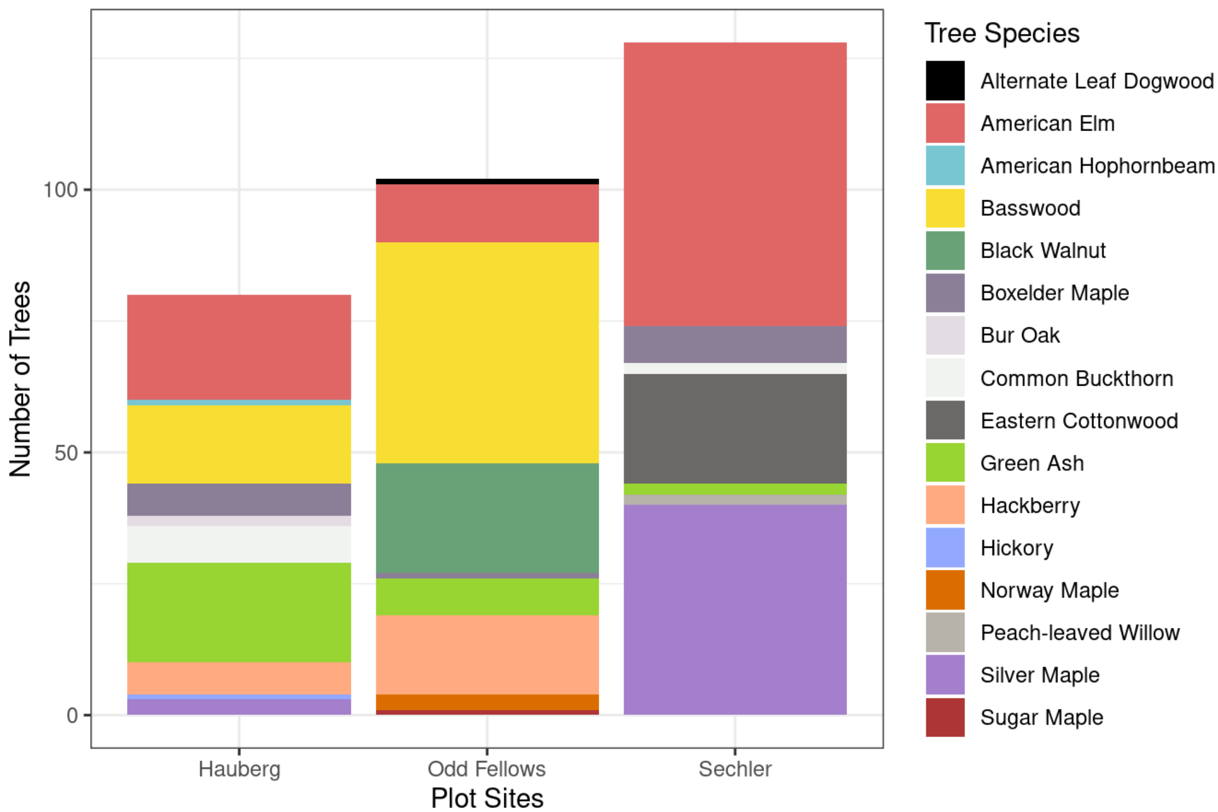

Figure 2. Distribution of tree species sampled in three urban forest patches located in Northfield, Minnesota (n=310).

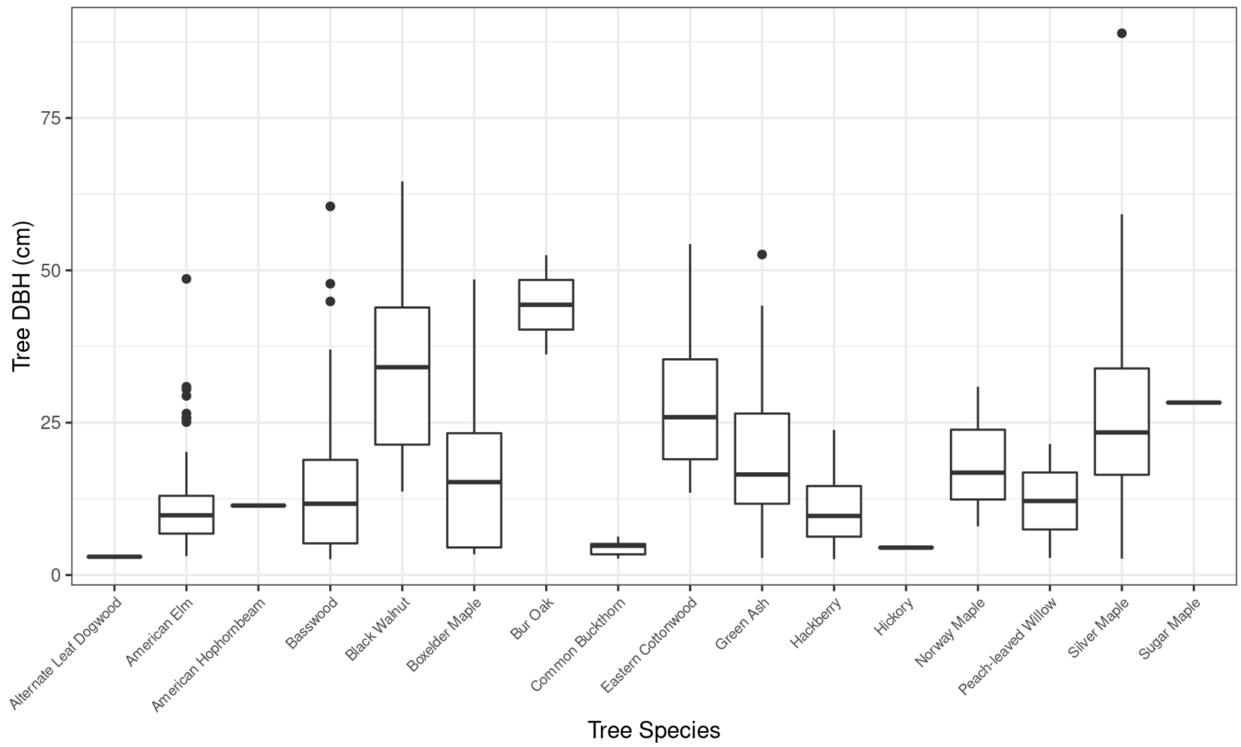

Figure 3. Comparison of DBH (cm) of species identified within all urban forest patches. ANOVA test determined that there is significant difference between DBH measurements and species (F value=10.56, dfl=15, p value=2e-16). Straight black lines within the boxplot indicate species where only one individual was identified.

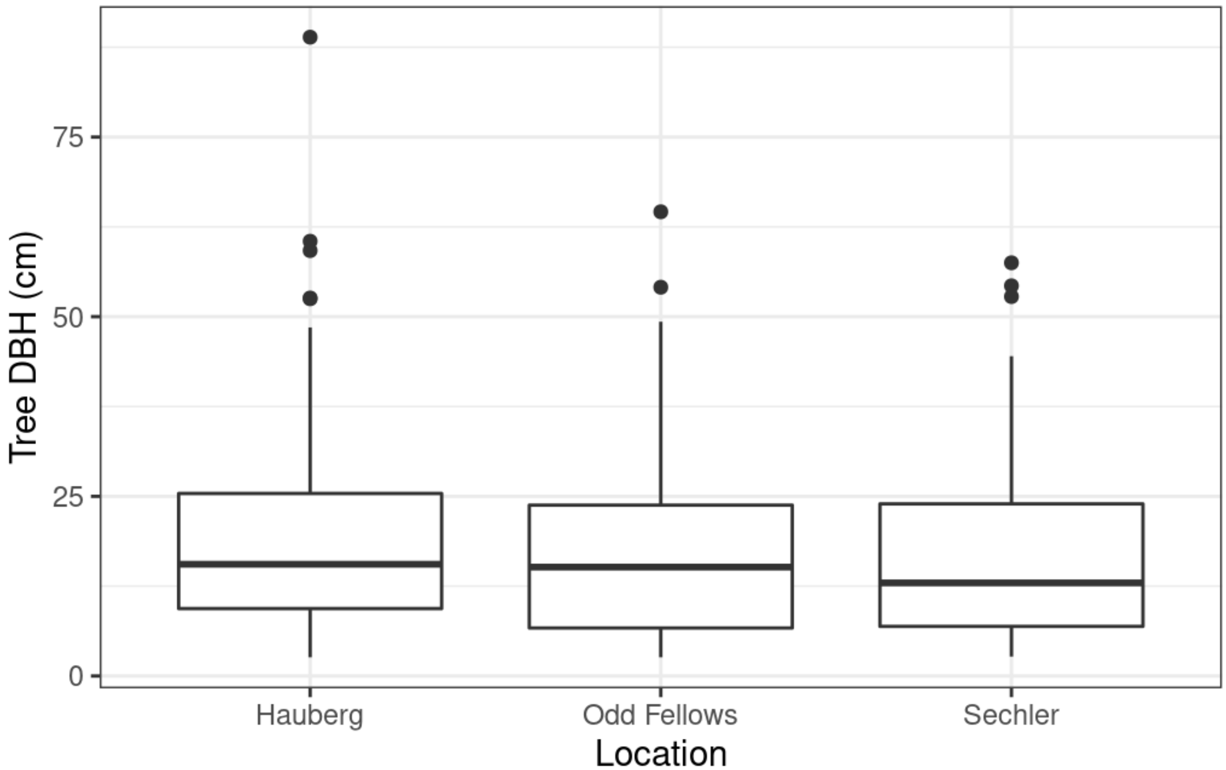

Figure 4. Comparison of DBH between forest patches in city parks in Northfield, Minnesota. There was no significant difference between DBH measurements between urban forest patch locations (F value=2.221, dfl=2, p value=.11).

Table 1. Distribution of tree species in all 3 plots at each urban forest patch (n=310). Individual stems are counted towards the total number of trees. Shannon Diversity Index calculations determined that Hauberg Woods has the most tree species diversity of the three forest patches.

Species Common Name	Hauberg	Odd Fellows	Sechler	Total
Alternate Leaf Dogwood	N/A	1	N/A	1
American Elm	20	11	54	31
American hophornbeam	1	N/A	N/A	1
Basswood	15	42	N/A	57
Black Walnut	N/A	21	N/A	21
Boxelder Maple	6	1	7	14
Bur Oak	2	N/A	N/A	2
Common Buckthorn	7	N/A	2	9
Eastern Cottonwood	N/A	N/A	21	21
Green Ash	19	7	2	28
Hackberry	6	15	N/A	21
Hickory	1	N/A	N/A	1
Norway Maple	N/A	3	N/A	3
Peach-leaved Willow	N/A	N/A	2	2
Silver Maple	3	N/A	40	43
Sugar Maple	N/A	1	N/A	1
Grand Total	80	102	128	310
Shannon Diversity Index	1.93	1.64	1.38	2.24

Table 2. Carbon sequestration sum (tons) by tree species and plot location total=45624.799 tons). Hauberg Woods sequestered the most carbon of the three urban forest patches (total=17179.8112 tons) and the Silver Maple (*Acer saccharinum*) (total=13091.1678 tons).

Species Common Name	Hauberg	Odd Fellows	Sechler	Total
Alternate Leaf Dogwood	N/A	0.87	N/A	0.87
American Elm	916.20	1700.98	930.01	3547.20
American hophornbeam	22.48	N/A	N/A	22.48
Basswood	3927.94	1379.54	N/A	5307.48
Black Walnut	N/A	9077.93	N/A	9077.93
Boxelder Maple	1309.31	371.87	52.33	1733.51
Bur Oak	1299.76	N/A	N/A	1299.76
Common Buckthorn	20.03	N/A	3.01	23.04
Eastern Cottonwood	N/A	N/A	5602.31	5602.31
Green Ash	4167.87	427.78	20.51	4616.16
Hackberry	191.22	475.71	N/A	666.93
Hickory	2.34	N/A	N/A	2.34
Norway Maple	N/A	321.93	N/A	321.93
Peach-leaved Willow	N/A	N/A	106.06	106.06
Silver Maple	5322.66	N/A	7768.51	13091.17
Sugar Maple	N/A	205.61	N/A	205.61
Grand Total	17179.81	13962.23	14482.76	45624.80