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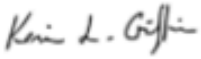
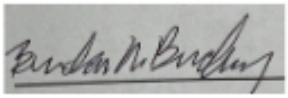
In the City of New York
Department of Ecology, Evolution and Environmental Biology

M.A. Degree Conferral Form

Student Name: Adam Gelfand

Thesis Title: Examining the Interactions Between Oak Loss and Above-Ground Carbon Storage in Northeastern Forests: A Tree Ring Study

This student has completed the M.A. thesis and is recommended for the M.A. degree conferral on May 7, 2024.

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Examining the Interactions Between Oak Loss and Above-Ground Carbon Storage in Northeastern Forests: A Tree Ring Study

Abstract

Forests collectively store 45% of Earth's terrestrial carbon, and as such are an instrumental part of the global carbon cycle. Foundational tree species are abundant and comprise large portions of the aboveground biomass, and therefore serve as the ecological cornerstones of forest ecosystems. Here I focus on the North American foundation tree species red oak (*Quercus rubra*), due to their capacity for biomass accrual and carbon sequestration. North American forests have been impacted by progressive loss of oak due to suppression of both naturally occurring and anthropogenic fire, among other causes and threats. Given the progressive and continued loss of foundational oaks in the eastern US, I conducted a study to assess the interactions between foundation species loss and above ground carbon sequestration in remaining tree species. I hypothesized that following a loss of dominant oak canopy, neighboring species would increase their growth rates, thus sequestering more carbon per year at the individual tree level. I found that following an abrupt loss of oak in a temperate forest, neighboring trees (such as birch, maple, and beech) exhibited increased rates of growth and carbon sequestration. However, the increase was not sustained as most trees decreased or plateaued in growth rate following the release event. Additionally, due to the loss of oak, the overall basal area of the forest is far lower than that of oak dominated plots and it remains to be seen if birch, maple, and beech stands will match the carbon sequestration rates and capacity of oak forests.

Introduction

Foundation species are characterized by their abundance, provision of crucial food sources, and influence on abiotic conditions (Ellison, 2019). They are additionally distinguished by mutualistic relationships with many other organisms, operating at the nexus of trophic flow and habitat structure (Derksen-Hooijberg et al., 2018). Oaks have been described as foundation species in the eastern United States for their abundance (Hanberry et al. 2020), modulation of hydraulics (Chandrathilake et al, 2022), influence on soil composition (Rossetti et al. 2015), and their determination of understory conditions and plant assemblages (Hanberry & Nowacki, 2016). Furthermore, oak trees support abundant biodiversity. They have been found to create islands of soil fertility due to increased soil organic matter and nutrient availability, leading to greater proximal establishment of native grasses (Dahlgren et al., 2003; Roche et al., 2012).

Various oak species also support a diverse array of insects, which then serve as a food source for insectivorous avifauna (Tallamy, 2021). Moreover, oaks also support a wide range of mammals such as bears (Penteriani et al., 2019), small rodents (Villalobos et al., 2020), and squirrels (Steele & Yi, 2020) through provision of acorns as a food source. In addition to their role as foundation species, oaks also sequester significant amounts of above and below ground carbon, making them key players in mitigating climate change (Rossetti et al. 2015, Wotherspoon et al. 2014).

Many oak populations have recently been experiencing significant decreases in size while various *Acer* (maple) species have risen to dominance. It is estimated that in the last 100 years, oak occurrence has decreased by 30% in the Eastern US (Glitzenstein et al, 1990). Numerous studies (*e.g.*, Aldrich et al, 2005; Brose et al, 2013; Abrams et al, 2021) posit that the observed transition from oak- to maple-dominated forests can be attributed to low oak regeneration rates resulting from fire suppression. Oak seedlings require ample sunlight in order to grow and become established (Burns and Honkala, 1990). Additionally, their root systems grow relatively deep early in their life cycles, thus protecting them during above ground disturbances (Abrams, 1992). Young maples on the other hand have shallow root systems, making them vulnerable to certain above ground disturbances (McEwan et al, 2011). In the absence of fire, mesic species such as maples create a dense understory which prevents sunlight from reaching the oaks. In the presence of fire, young oak root systems are protected underground while maple saplings burn, allowing sunlight to filter through. Mature oaks are generally protected from fire by thick bark while maples are prone to damage (Abrams, 1992). Furthermore, the timeline of oak decline roughly correlates to the forced prevention of Indigenous burning and institution of policies that promote fire suppression (Abrams et al. 2021). In addition to fire suppression, oaks are vulnerable to more direct threats. Oak wilt, a deadly pathogen that spreads via beetles, currently ranges from Texas to New York (McLaughlin et al. 2022). Moreover, the spread of introduced species and selective deer browsing have prevented oak seedlings from advancing through canopies (Fei et al, 2011). Furthermore, over the last 100 years eastern forest habitats have become wetter and warmer- conditions which are favored by maples. Various hypotheses have been presented to explain the general mesification of eastern forests. Some posit that this is a result of increased precipitation due to climate change (Rustad et al, 2012) while others suggest that fire suppression itself is responsible for increasingly moist conditions (Paulson et al, 2016).

While loss of oaks is an ecological phenomenon with great ecological implications, it could also lead to a shift in the growth rates- and therefore the carbon sequestration rates- of proximal North American tree species (Sedjo & Sohngen, 2012). This could potentially influence atmospheric carbon levels, thereby enforcing an extant feedback loop wherein mass tree mortality exacerbates climate change, leading to greater and more widespread tree mortality (Vose et al, 2015, Zhou et al, 2020). As oaks decline and climate change intensifies, it becomes imperative to evaluate the capacity of northeastern tree species to sequester carbon and adapt to ecological disturbances.

Much is known about the effects of oak loss on floristic composition and hydraulics (Taylor et al. 2016; Chandrathilake et al. 2022). Far less is known about the growth response of neighboring trees following such an ecological disturbance. While the loss of a forest foundation

species will lead to an immediate loss of aboveground biomass, the resulting increases in sunlight and water availability are likely to impact neighboring trees' growth rates as well. I therefore hypothesize that following the loss of dominant oak species and resulting reduction in canopy, non-oak species will exhibit an increase in basal area increment, above ground biomass, and above ground carbon sequestration rates. I tested this hypothesis at Black Rock Forest, a land preserve in the lower Hudson Valley of New York. Within the preserve is a modestly delineated forest stand where the dominant oaks, comprising about 80% of the canopy, were experimentally girdled in 2008. Many studies have been conducted in this stand to assess the changes in below ground carbon pooling (Levy-Varon, 2012), soil respiration (Levy-Varon et al, 2014), and foliar physiology (Falxa-Raymond et al, 2012), but few include any emphasis on above ground carbon dynamics.

To test the hypothesis, I utilized dendroecology and allometry. Dendroecology involves the identification of intra-annual variability in tree ring widths to make inferences about past ecological conditions. Tree allometry uses mathematical equations to provide the above ground biomass of an individual tree, given the tree's dimensions such as height and/or diameter at breast height (DBH). By subtracting ring widths from the present DBH of each tree, I was able to reconstruct the DBH and basal area of individual trees for each of the past 30 years. I opted to narrow my focus to the past 30 years, as this timeframe aligns well with the experimental oak girdling conducted 15 years ago. Utilizing data spanning 30 years ensures a balanced dataset for the conduction of t-tests. Allometric equations were then applied to reconstructed DBH's to ascertain the shifts in above ground biomass over time. Using this data, I was able to establish how the loss of oak altered the above ground growth and carbon dynamics of remaining tree species.

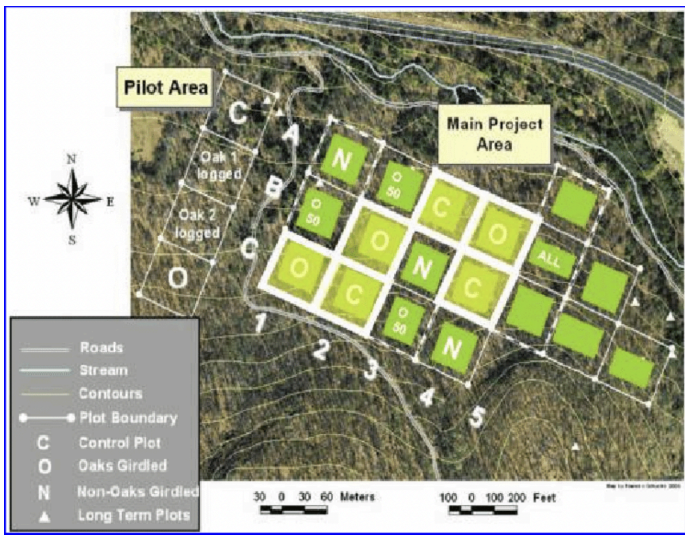


Figure 1: Map of experimental oak removal plots at Black Rock Forest, installed in 2008 and 2010 (Taylor et al, 2016).

Methods

Study Site and Species Selection

The study took place at Black Rock Forest (BRF), a 1550-ha forest preserve located in the lower Hudson Valley of New York State (41.45 °N, 74.01 °W). The area receives a mean annual precipitation of 1.2 meters and the temperature is seasonal with monthly averages fluctuating between –2.7 °C in January to 23.4 °C in July (Turnbull et al. 2001). Significant droughts have occurred recently in the region in 2002 and 2016, with the former being more severe than the latter. The terrain is rough and steep with elevations ranging from 110 to 450 m above sea level and the

soils are mostly rocky loam (Schuster et al, 2008). Within BRF lies the Future of Oaks Experiment, where oaks were removed via girdling in 2008 in order to assess changes in regeneration and nutrient cycling dynamics at the stand level following a canopy disturbance (Taylor et al, 2016). This stand is separated into 12 plots, three of which were left as control plots (C), three of which had all oaks removed (O), three that had 50% of oaks removed (O50), and three that had all non-oaks removed (N) (Figure 1). Plots are 75 by 75 meters in size. Since this study concerned itself strictly with the effects of oak loss on neighboring tree growth, I only collected data in the C and O plots. Since the experiment was implemented 15 years before this study, I selected trees that were at least 30 years old to ensure a consistent sample size of ring widths prior to and following the experiment. The taxonomic composition of this study mirrors that of Black Rock Forest, and more broadly the arboreal composition of montane and riparian northeastern forests. Species present include *Quercus rubra, Betula lenta, Fagus grandifolia, Carya glabra, Picea glauca, Acer saccharum, Acer rubra,* and *Nyssa sylvatica.* All species are naturally occurring except for *Picea glauca,* which had been planted in about 1990 and has now naturally seeded throughout the forest.

Collection

Throughout the summer of 2023, I used standard Hagloff increment borers to extract 5.15 mm diameter cores from 60 trees. Two core samples were taken from cardinal directions from each of at least nine non-oaks in each O and C plot, as well as from three oaks in each C plot, for a total sample size of 120 cores. This was done in order to compare growth rates of tree species across experimental treatments while also assessing the growth of oaks. Once cores were collected, they were placed into labeled straws for transport to the Tree Ring Lab at the Lamont-Doherty Earth Observatory .

Processing

All cores were cataloged, dried, mounted, and surfaced with increasingly fine abrasives (from 200-800 grit), until the cellular structure was clearly visible to distinguish between true ring boundaries and “false” rings and other anatomical structures (Fritts, 1976). Cores were then scanned for image analyses, ring-width and density measurements, and for archival in the International Tree Ring Data Bank.

Crossdating and Statistical Analysis

Cores were dated and ring widths were measured using CooRecorder 9.8.1 software (Cybis Elektronik) and cross dated for accuracy using COFECHA software (Holmes, 1982). Raw ring widths were then transferred to Rstudio 3.3.0 (Posit.co, 2024) where they were used to calculate basal area increment (BAI). In order to assess biomass gain, allometric equations were used to ascertain the kilograms of above ground biomass present in each tree for each year contained in the chronology (Table 1). Carbon was calculated by multiplying biomass by the percentage of carbon content present in the wood of each species (Lamlom and Savidge, 2003) (Table 2). Where proportions were missing, 50% was used to calculate the carbon content (Chave et al, 2009). Time series graphs were created in order to assess the growth trajectories for basal area, above ground biomass, and above ground carbon accrual rates. Each species’ unique characteristics were compared to better understand the species specific growth response to oak girdling.

I separated the BAI, volumetric increase, and carbon increase data into two categories: annual growth prior to the experiment (i.e., disturbance initiated by the removal of oak spp., going back 15 years), and annual growth following the experiment (i.e. 15 years after oak girdling, ending in 2023). Using RStudio, means were found for both data categories and compared using a paired t-test. Allometric equations were also used to determine the amount of biomass accumulated in 15 years prior to the experiment and 15 years after the experiment.

Table 1: Allometric equations for all species present in the study (Monteith, 1979; Brenneman, 1983; O'Dell, 2020)

Tree Species	**Allometric Equation**	**Citation**
Acer rubrum	6.1147-(0.3598*DBH*10)+(0.006344*DBH*DBH*10*10)	Monteith, 1979
Acer saccharum	5.248-(0.3661*DBH*10)+(0.007605*DBH*DBH*10*10)	Monteith, 1979
Betula lenta	EXP(-2.6859+(2.5927*LN(DBH)))	O'Dell, 2020
Picea glauca	4.5966-(0.2364*DBH*10)+(0.00411*DBH*DBH*10*10)	Monteith, 1979
Nyssa sylvatica	5.5247-(0.3352*DBH*10)+(0.006551*DBH*DBH*10*10)	Monteith, 1979
Carya glabra	(2.034*(POWER(DBH/2.54,2.6349)))/2.205	Brenneman, 1983
Fagus grandifolia	5.3373-(0.3257*DBH*10)+(0.007173*DBH*DBH*10*10)	Monteith, 1979
Quercus rubra	EXP(-2.2763+(2.523*LN(DBH)))	O'Dell, 2020

Table 2: Percentage of carbon content based on species (Lamlom and Savidge, 2003; Chave et al. 2009)

Tree Species	**% Carbon Content**
Acer rubrum	48.64
Acer saccharum	49.32
Betula lenta	50.00
Picea glauca	50.39
Nyssa sylvatica	50.00
Carya glabra	48.47
Fagus grandifolia	46.60
Quercus rubra	49.63

Results

Six red maples, seven sugar maples, 20 black birches, nine white spruces, four tupelo, three pignut hickory, three American beech, and eight red oak trees were sampled for a total of 120 cores from 60 trees. Among trees sampled in the experimental plots, average rates of growth for basal area and volumetric growth in the 15 years prior to and following the oak removal experiment differed significantly (Figure 2). Among *Acer rubrum,* group averages of growth rates reflected a difference of 961.5 mm^2 in basal area, 12.9 kg of volumetric growth, and 6.3 kg of carbon increase per year based on time period. Similarly, *Acer saccharum* demonstrates group mean differences of 1712.4 mm^2, 26.5 kg in biomass, and 13.1 kg in carbon. *Betula lenta* trees displayed a mean difference of 948.1 mm^2, 11.2 kg in biomass, and 5.6 kg in carbon per year. *Carya glabra* displayed mean differences of 1457.1 mm^2, 55.5 kg in biomass, and 26.9 kg in carbon based on treatment per year. Between 1993 and 2008, *Picea glauca* demonstrated mean differences of 1052.0 mm^2, 6.0 kg in biomass, and 3.1 kg of carbon increase per year. Finally, *Nyssa sylvatica* demonstrated mean differences of 453.0 mm^2, 6.5 kg in biomass, and 3.3 kg in carbon per year (Table 3). Overall, trees grew 7.1 times quicker in basal area, 4.2 times quicker in volume, and 4.2 times quicker in above ground carbon following the loss of dominant oak canopy.

In order to ensure the shift in growth rates was not due to climate or some other factor, t-tests were conducted to compare average growth rates of species found in both C and O plots from 2008-2022. My results indicate that there is a significant difference between growth rates in the C and O plots following oak removal (Figure 3).

Among trees sampled in control and experiment plots, average rates of BAI and volume increase between 2008 and 2023 differed greatly based on plot (Figure 3). On average, *Acer*

Species	Growth Rate, 1993-2008 (BAI, mm2)	Growth Rate, 2008-2023 (BAI, mm2)	Growth Rate, 1993-2008 (Biomass, kg)	Growth Rate, 2008-2023 (Biomass, kg)	Growth rate, 1993-2008 (Carbon, kg)	Growth rate, 2008-2023 (Carbon, kg)	N
Acer rubra	73.1	1034.6	1.6	14.5	0.7	7.0	3
Acer saccharum	89.5	1801.9	2.9	29.4	1.4	14.5	3
Betula lenta	204.6	1152.7	2.5	13.7	1.3	6.9	9
Carya glabra	263.7	1720.8	22.5	78.0	10.9	37.8	3
Picea glauca	449.1	1501.1	3.0	9.0	1.5	4.6	6
Nyssa sylvatica	157.7	610.6	4.2	10.7	2.1	5.4	4

Table 3: Average annual growth rates of individual trees by species and time period, sampled from experiment plot.

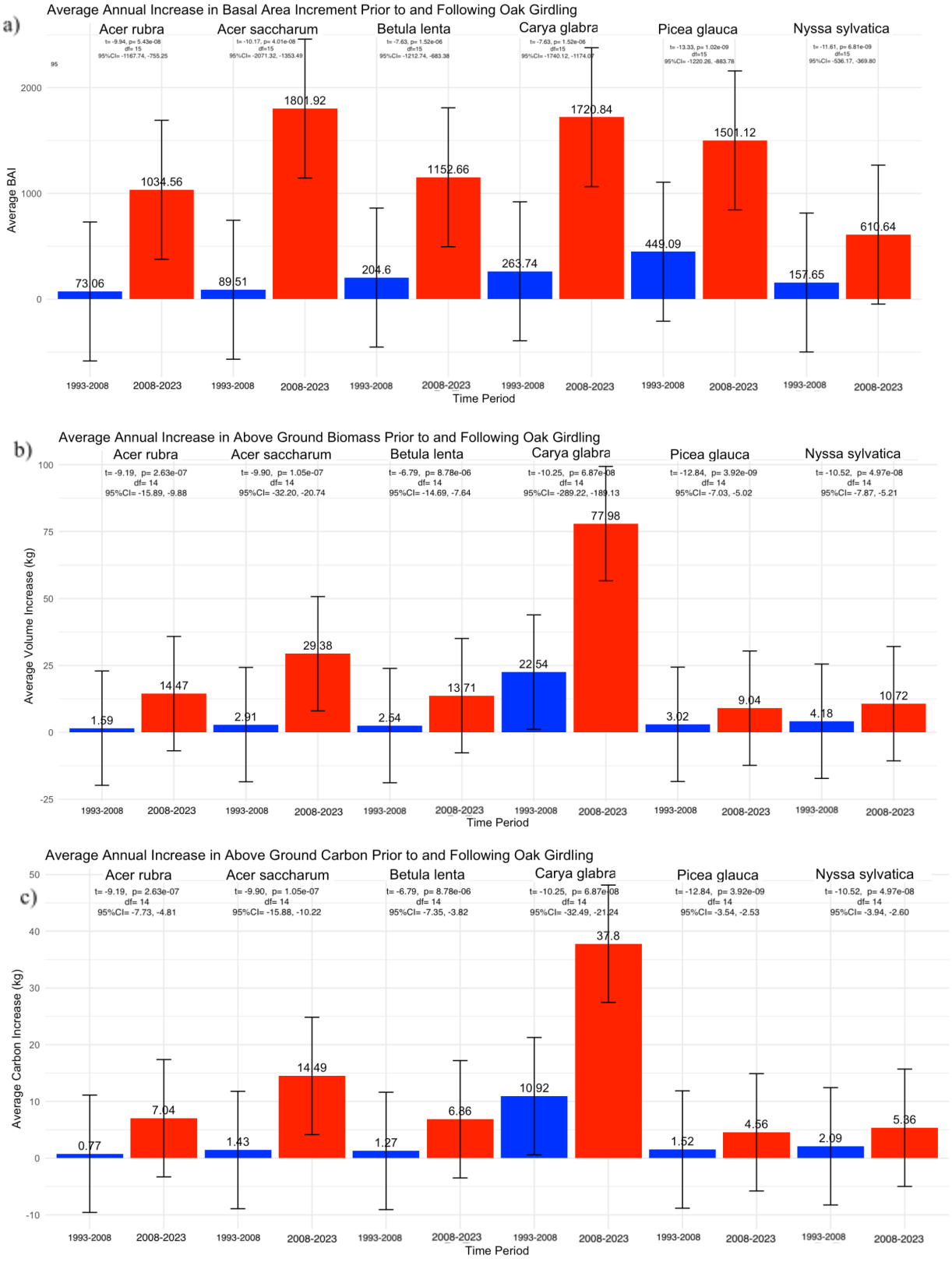


Figure 2: Bar graphs displaying the difference between average annual growth rates of a)basal area increment, b) above ground biomass increase, and c) carbon gain for each species prior to oak girdling (1993-2008) and following oak girdling (2008-2024) in experiment plots within Black Rock Forest

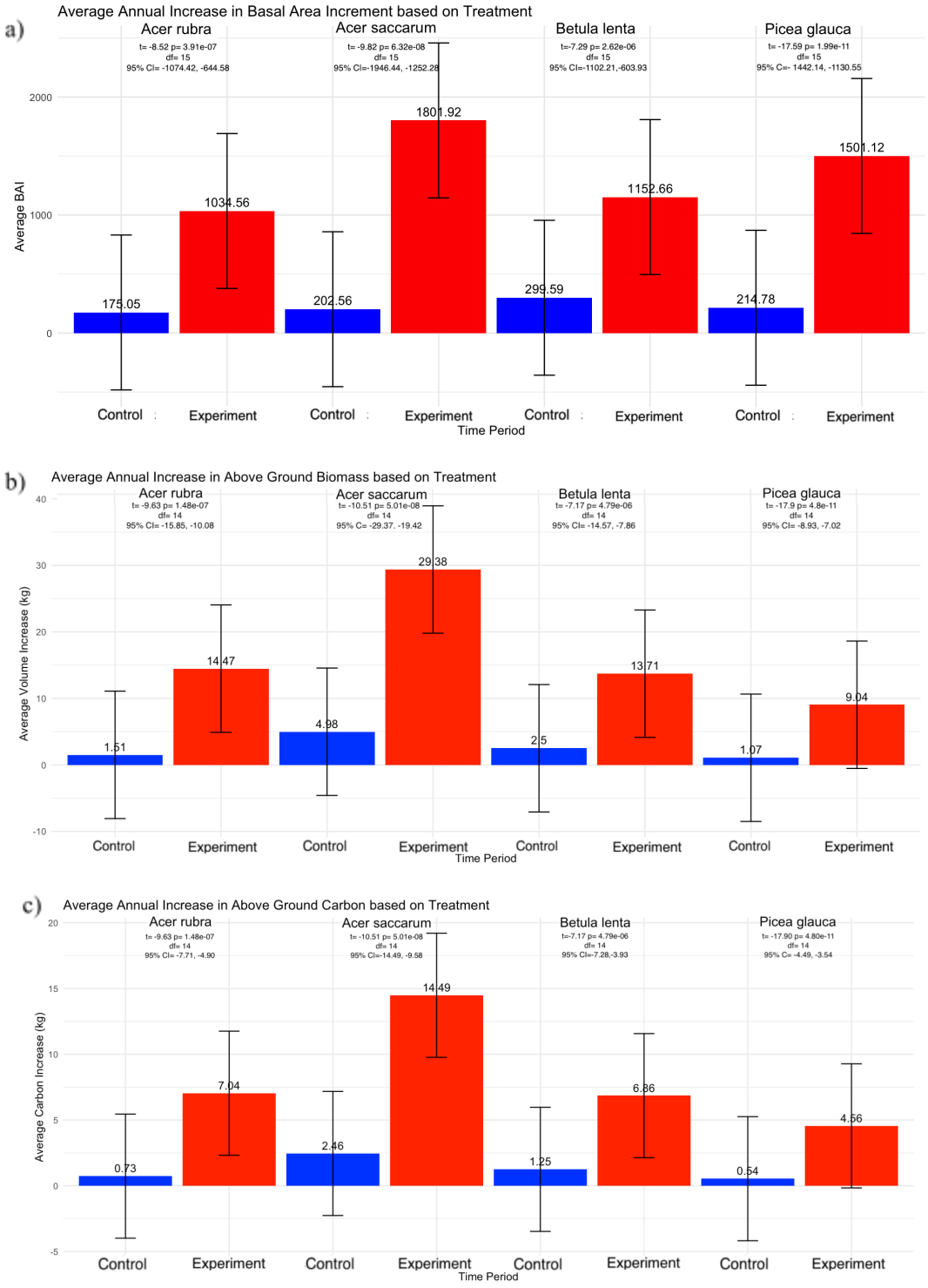


Figure 3: Bar graphs displaying the difference between average growth rate of a) basal area, b) above ground biomass, and c) above ground carbon between 2008 and 2022 for all species sampled from control and experimental oak removal plots, where oaks were girdled in 2008

rubrum demonstrated a mean difference of 859.5 mm^2 in basal area, 13.0 kg in biomass, and 6.3 kg in carbon per year. Similarly, *Acer saccharum* demonstrated a mean difference of 1599.4 mm^2 in basal area, 24.5 kg of biomass, and 12.0 kg of carbon per year. *Betula lenta* demonstrated a difference of 853.1 mm^2 in basal area, 11.2 kg of biomass, and 5.6 kg of carbon per year. Finally, *Picea glauca* demonstrated an annual mean difference of 1286.3 mm^2 in basal area, 7.9 kg in biomass, and 4.1 kg in carbon growth per year based on treatment plot (Table 4). Overall, trees in experimental oak removal plots increased 1.8 times quicker in basal area, 2.2 times quicker in volume and 2.2 times quicker in above ground carbon than trees in control plots.

Examination of graphs plotting annual increase in BAI, volume, and carbon all suggest that following oak removal in the O plots, growth rates in *A. rubra, A. saccharum, B. lenta, C. glabra, P. glauca,* and *N. sylvatica* increased significantly (Figure 4). While all species display increased growth rates following the oak removal, *A. rubra*, *A. saccharum, B. lenta,* and *C. glabra* show an ensuing slow down in growth in the five years prior to data collection. In addition, *P. glauca* and *N. sylvatica* reach a plateau of growth following the release event (Figures 5 & 6).

Species	**Growth Rate, BAI, Control (mm2)**	**Growth Rate, BAI, Experiment (mm2)**	**Growth Rate, Biomass, Control (kg)**	**Growth Rate, Biomass, Experiment (kg)**	**Growth Rate, Carbon, Control (kg)**	**Growth Rate, Carbon, Experiment (kg)**	**N Ctr**	**N Exp**
Acer rubra	175.1	1034.6	1.5	14.5	0.7	7.0	3	3
Acer saccharum	202.6	1801.9	4.9	29.4	2.5	14.5	4	3
Betula lenta	299.6	1152.7	2.5	13.7	1.3	6.9	11	9
Picea glauca	214.8	1501.1	1.1	9.0	0.5	4.6	3	6

Table 4: Average annual growth rates of tree species in experimental oak removal plots and control plots between 2008 and 2023.

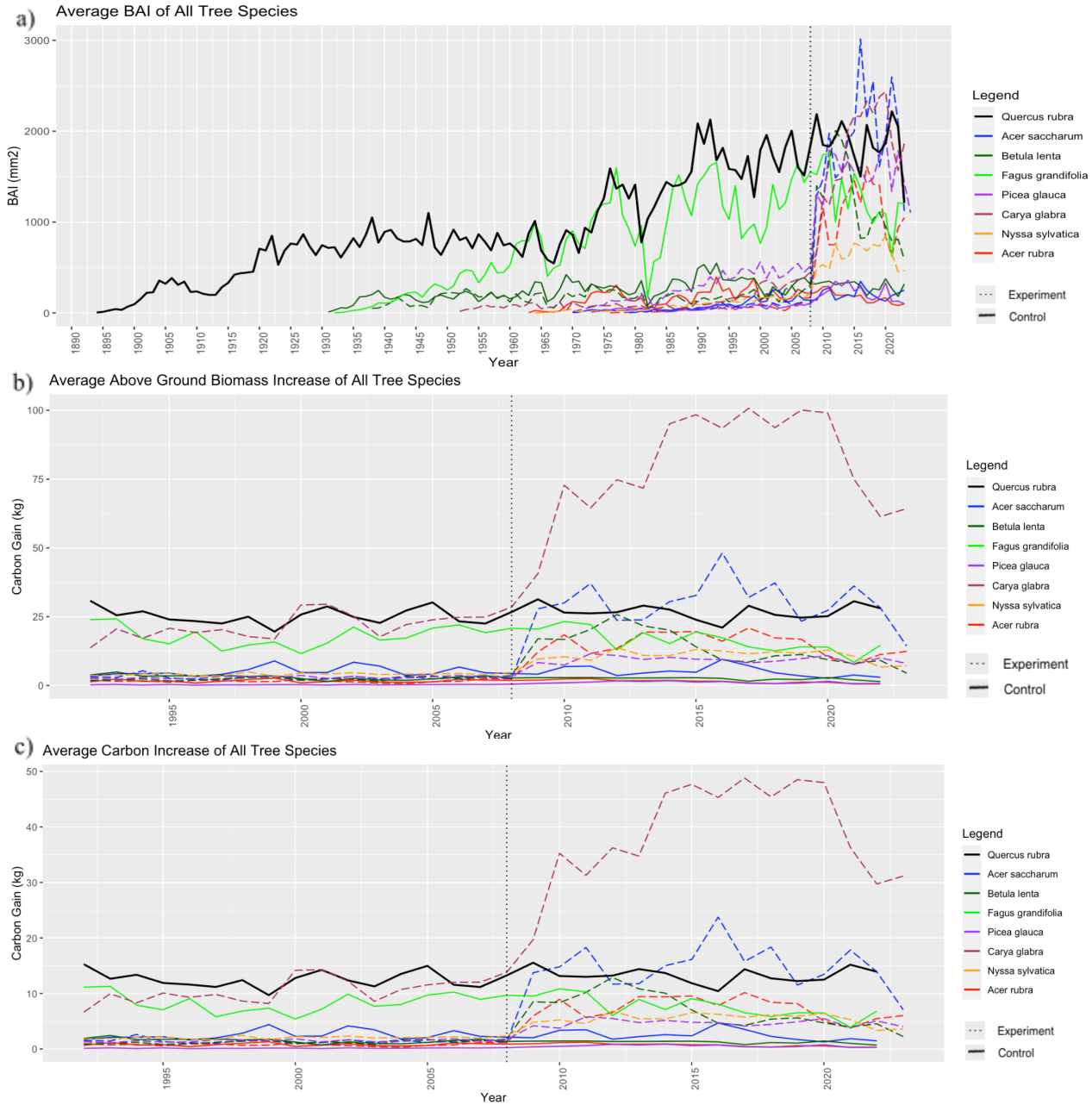


Figure 4: Line graphs of each species' average annual growth in a) basal area increment (entire time series, b) volume (1993-2023, and c) carbon (1993-2023)

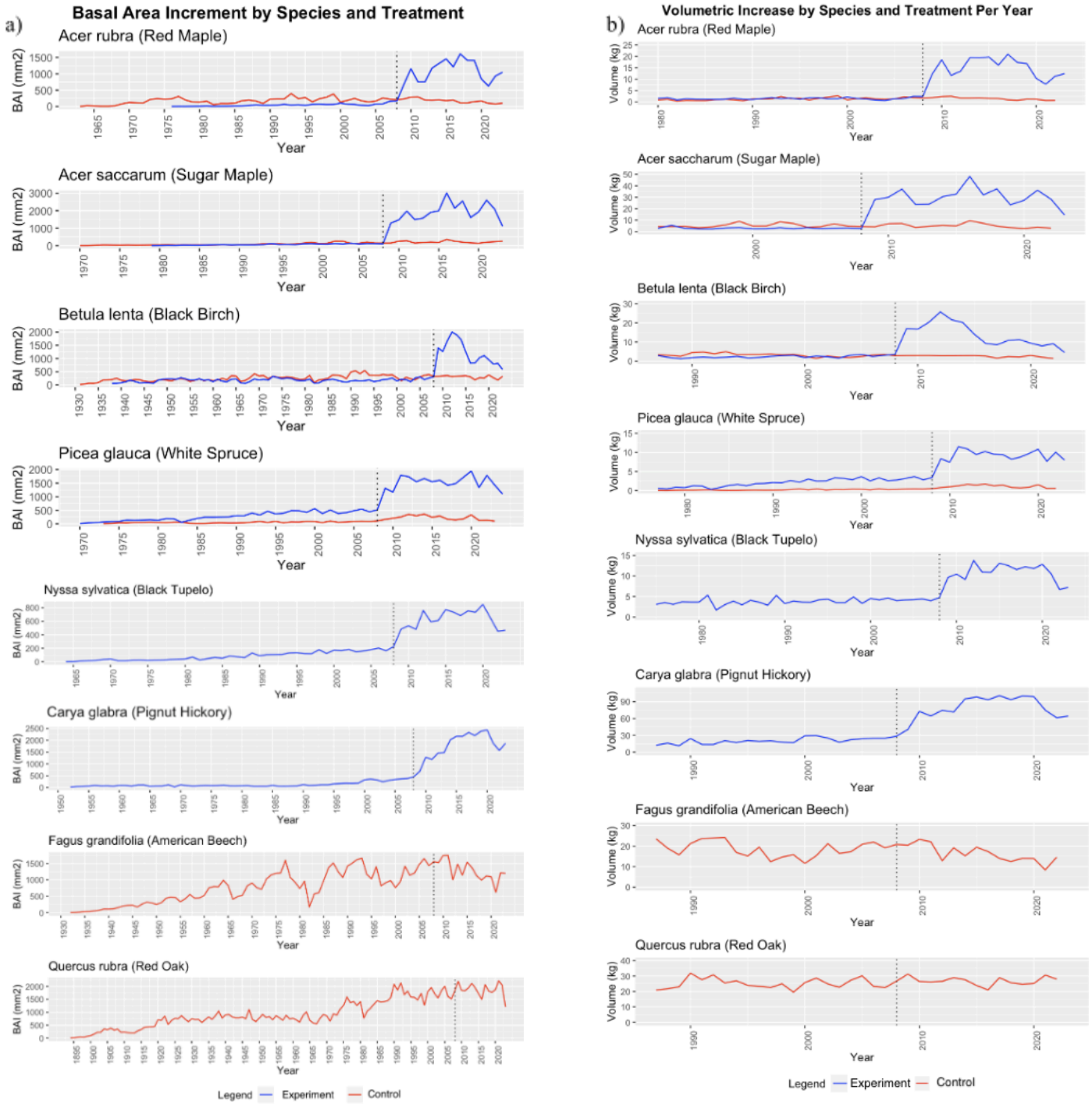


Figure 5- a) a series of line graphs displaying the relationship between basal area increment and time, separated by species and plot treatment; b) a series of similarly organized line graphs displaying the relationship between above-ground biomass and time. Red lines indicate control plots, while blue lines indicate experiment plots.

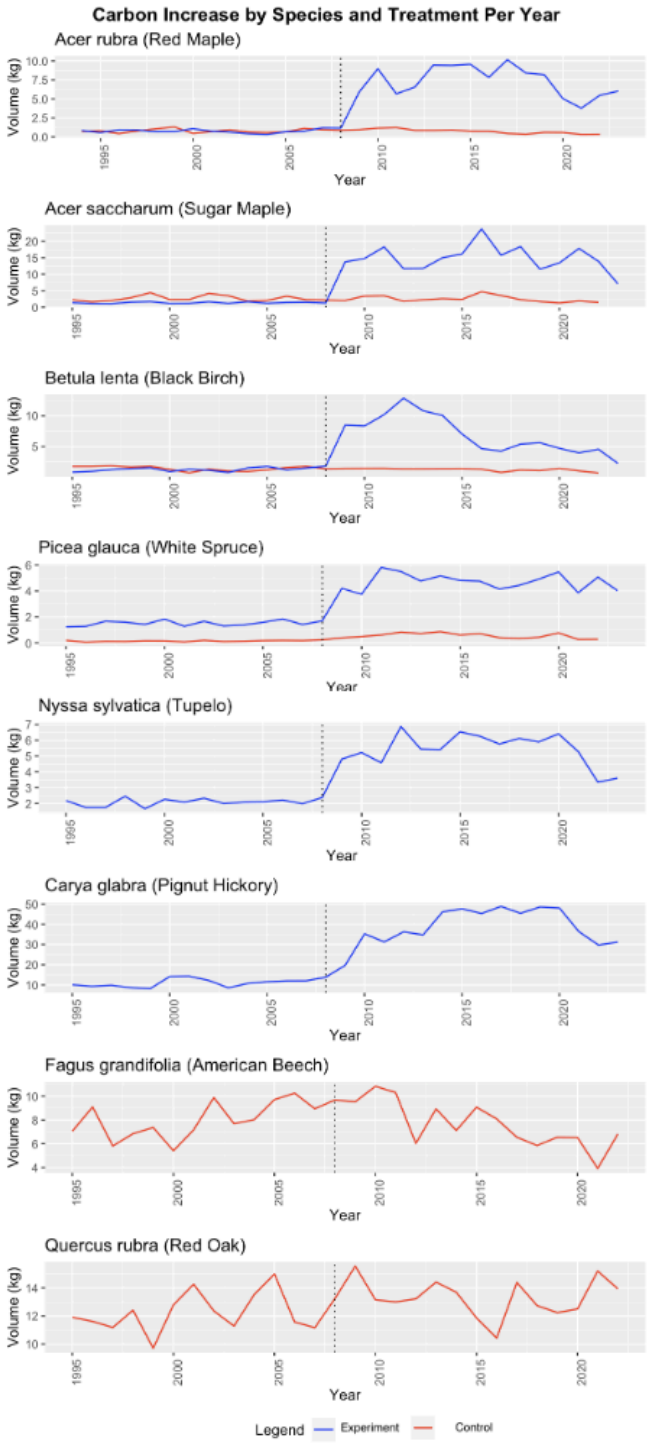


Figure 6- Average rates of carbon growth based on tree and plot. Red lines represent control plots and blue lines represent experiment plots.

Discussion

While climate change is having strong effects on ecological processes, the shifting ecology of the northeast is sure to have an effect on global climate as well. Ecological changes that impact climate are based on the breakdown of habitats that sequester high amounts of atmospheric carbon such as forests. As foundational oak species are at risk of decline due to fire suppression, pathogens, deer browse, and general mesiphication, it is imperative that studies are conducted to assess the carbon sequestration functionality of alternative northeastern tree species. Once these questions are answered, we will have a broader understanding of the growth behaviors of different tree species and can prioritize their conservation accordingly. This study provides valuable insight by assessing the growth rates of different tree species following a loss of canopy oaks.

All tree species in the experimental plots showed an increase of growth rate following the oak removal in 2008. However, *Acer rubrum, Acer saccharum, Betula lenta,* and *Carya glabra* demonstrated a subsequent decrease in growth rate following the release event. Since ring widths increased following a loss of canopy, the decrease in growth is likely due to a natural restoration of canopy. Additionally, despite the increase in growth rate following oak loss, oaks in control plots exhibited greater annual increase in above ground biomass and carbon than all species except *Acer saccharum* (which also demonstrated a decrease in growth rate following the release event) and *Carya glabra*. *Carya glabra* (pignut hickory) exhibits an enormous increase in growth rate in comparison to other species. This disproportionate response is likely due to the highly flexible physiology of the *Carya* genus (Knapp et al. 2021). While hickories tend to be less abundant than oaks where they co-occur, they demonstrate low levels of sapling mortality with certain species surviving for up to 42 years as seedlings, and high levels of recruitment to the overstory following disturbances (Lefland et al. 2018). Furthermore,

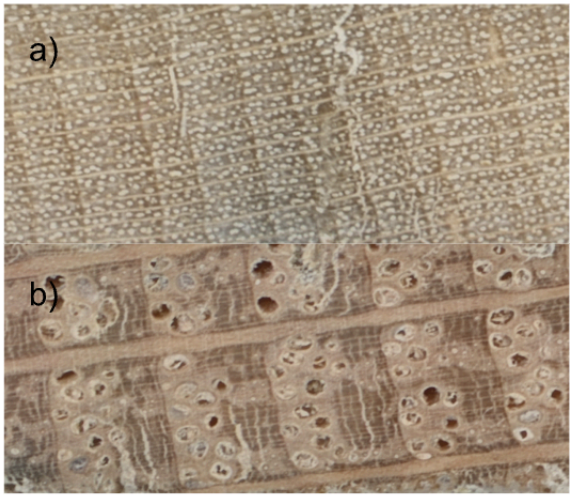


Figure 7: a) Diffuse porous structure of wood anatomy (Acer rubra) and b) ring porous structure of wood anatomy (Quercus rubra). The latter rely on each year's porous ring for nutrient transport, without which they would not be able to foliate. Diffuse porous trees are able to foliate regardless of whether or not they grow a ring.

hickory species exhibit high levels of continued physiological plasticity- an important evolutionary strategy many trees employ when faced with varied resource availability (Knapp et al. 2021). In addition, hickory tree rings (as well as oak tree rings) are porous, meaning a new ring each year is necessary for transporting nutrients in order for the tree to develop leaves in the spring (B. Buckley, Personal Communication, March 3 2024). Conversely, rings of other genera such as *Acer* have a diffuse porous structure (Figure 7). This structure allows such trees to skip rings and sometimes cease growth altogether for years at a time (Koerth, 2012). I noticed this trend in my own samples, with one sugar maple ceasing growth for nine years following the introduction of the spongy moth in 1981. This morphological difference results in a relatively stable growth pattern in ring porous species such as oaks and hickories when compared to diffuse porous species such as maples.

While the results are quite conclusive, it is possible that the outcome was skewed due to varying amounts of data present for each tree. Sample sizes varied by species because we selectively sought out non-oaks that were at least 30 years old. Seeing as how the forest in question is either dominated by oak (control plots) or was dominated by oak 15 years ago (experiment plots), non-oaks were rare and non-oaks older than 30 years were rarer still. To account for this, multiple cores were taken from each tree to create robust average time series for each individual and species. Issues of dependence were resolved by ensuring that the distributions of differences between control and experiment data were normal. Additionally, while the varying amounts of data collected for each tree is inconvenient, it does not disprove the finding that non-oak species exhibited an increase and subsequent plateau or decrease in growth rate following oak removal, or that oak growth rates exhibit greater stability than mesic, diffuse porous species in this particular stand.

Previous research suggests that old growth forests may not sequester carbon as effectively as forests dominated by younger trees (Binkley et al, 2002). This assertion is based on the observation that young trees typically exhibit wide growth rings compared to older trees. Foundation species loss simulates a similar phenomena; the removal of oak trees eliminates competition for essential resources such as sunlight, water, and nutrients, leading to a predictable increase in ring widths among neighboring trees which surpasses that of old growth oaks. While my findings confirm an increase in ring widths following foundation species loss, they also provide support for the notion that although older trees (oaks in this case) tend to have narrower

growth rings, their larger diameter results in a greater surface area, enabling each year's growth to cover the tree with an equal or greater amount of wood (Xu et al, 2012). In other words, the larger a tree is, the more wood it takes to grow a ring around it. Therefore, while ring width decreases over the lifespan of a tree, the rate of basal area, above ground biomass, and above ground carbon increase does not. On average, rates of annual carbon sequestration in non-oaks increased by 420% following the loss of oak. Despite this drastic increase, on average, most of the species present in the study never reach the same annual volumetric growth rate as oaks. Additionally, following a mass die-off of old growth trees, substantial amounts of carbon dioxide are released into the atmosphere through decompositional respiration, resulting in a net decrease in carbon sequestered (Harmon et al., 1990). Therefore, while non-oak ring widths immediately following oak removal were notably wider than those observed prior to removal and wider than the ring widths of mature oak trees themselves, the rate of above ground biomass increase in old growth oaks demonstrates greater stability compared to the fluctuating basal area and volumetric increments observed in oak removal plots. This means that even though younger understory diversity is important to the carbon dynamics and regeneration of disturbed forests, old growth species sequester more carbon over time and are better suited for long-term climate change mitigation.

These findings provide a novel contribution to the fields of ecology, dendrochronology, and climatology. While similar studies of foundation tree species removal have been conducted (Taylor et al, 2016; Chandrathilake et al, 2022), none have focused on the growth response of neighboring trees. In addition, while dendrochronology most commonly focuses on regional climate patterns, dendroecology is a young and burgeoning effort (Manzanedo and Pederson, 2019). Dendroecology provides valuable tools, such as those generated in this study, for comprehensively understanding the compounding impacts of climate change and ecological disturbance on ecosystem health. The data, code, and literature produced in this study facilitate an integrated approach to dendroecology, foundation species ecology, and carbon assessment. This interdisciplinary framework offers a comprehensive understanding of the current state of many disturbed forests worldwide. Finally, while many climate studies focus on how climate change impacts biodiversity, it is rare that we witness localized ecological phenomena that could scale up to have major climatological impacts on a global scale. The results of my study provide insight into the intersection of foundation species ecology and carbon sequestration. The study

also shares a potential framework for answering similar questions in regard to other declining foundation species such as *Tsuga canadensis* (Orwig et al, 2003) and *Fraxinus* spp. (Herms and McCullough, 2014). In addition, the data generated by my study provides context for forest carbon flux models that center ecological disturbances. Finally and perhaps most importantly, the results point towards *Carya glabra* and *Acer saccharum* as potential alternative species to focus restoration efforts on in the event of oak loss in Eastern US forests.

At the beginning of the study, I hypothesized that after the loss of dominant oak species and the subsequent reduction in canopy cover, non-oak species would demonstrate an increase in basal area increment, aboveground biomass, and aboveground carbon sequestration rates. While my analysis confirms the hypothesis, it opens up more questions as well. Through this study, we now understand the 15-year trajectory of growth and carbon sequestration rates for various understory tree species following the loss of oak. However, it is unclear how the rates of growth will continue to shift in the coming decades. This experiment can continue to provide valuable information by following the long term response of growth rates to foundation species loss. Additionally, in order to mitigate climate change and preserve the ecology of eastern US forest ecosystems, action must be taken by policy makers, land managers, and academic institutions to protect and do further research on oaks. These actions might include proactive understory management, prescribed burning (Brose et al. 2013), deer exclosures (Yuska et al. 2008), reduction of oak-based firewood trade (Gibbs, 1980), and further studies. Furthermore, in order to restore beneficial socioecological relationships that have previously supported oak forests, land must be actively managed in collaboration with Indigenous communities (Kimmerer and Lake, 2001).

In conclusion, trees exhibit increased growth rates following a loss of foundation species as predicted. While the initial hypothesis regarding increased growth rates following the loss of dominant oak species was confirmed, the subsequent trajectory of growth rates poses new questions for future research. Additionally, old growth oaks display stable increases in above ground carbon while alternate species in experimental plots show a high variability that rarely meets or exceeds the carbon sequestration rate of oaks. While some might argue that the increase in growth rate following oak loss is indicative of an opportunity for increased carbon capture at the stand level, the results of my study demonstrate that old growth oaks are better suited for long term mitigation of climate change due to their size, physiological growth habits, and steady

rates of volumetric increase. Furthermore, the findings underscore the critical role of old growth oaks in long-term climate change mitigation, highlighting the importance of sustainable forest management practices to the preservation of ecosystem health and resilience.

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