Climate Resilience of Tulip Poplars in Blind Brook Forest

by

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Abstract

As climate change increases stress on ecosystems, there is greater chance of regime shifts within ecological communities that alters their original function, structure, and identity.

Forests are a particularly vulnerable regime shift; The impacts of climate change are compounded with urbanization which leaves forests at risk of additional stress factors, such as higher chance of invasive species and pathogenic takeover. Research was conducted in Blind Brook Forest of SUNY Purchase Campus to understand how climate change is impacting forests at a local level. Utilizing dendrochronology, Tulip Poplar growth over the past century was analyzed to determine how changes in precipitation levels are impacting tree growth. Research found that Tulip Poplar growth rates have declined over the last fifty years as the Northeast experiences increased precipitation due to climate changes. This data highlights a gap in climate change research regarding the investigation of increased precipitation on tree growth rates in the Northeastern United States. It additionally can inform climate change mitigation strategies within Blind Brook Forest. It suggests that, without intervention, Blind Brook Forest may experience a regime shift specifically in its structure due to the loss of fast-growing Tulip Poplars. To preserve this forest's identity, an overstory species that is resilient to increased precipitation must be introduced.

Introduction

Forest Ecosystems

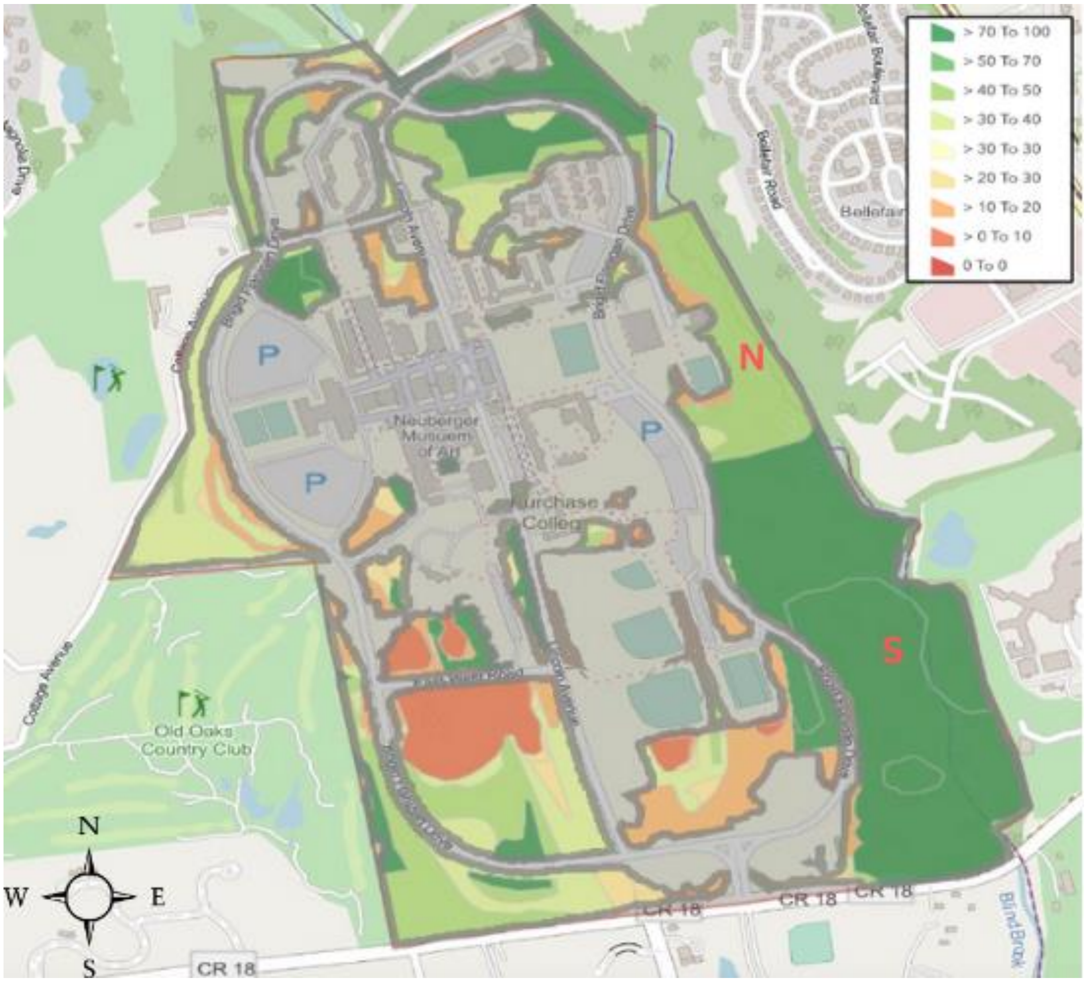
Forest communities across the world help to bolster biodiversity and support ecosystem services that are essential to human survival (Wolff et al. 2021, Zhang et al. 2022). In our increasingly interconnected planet, it is essential that forests and their services are preserved so that they continue to benefit future generations. As sustainable management takes a forefront in addressing both social and ecological issues, it is more important than ever to grasp the importance of forest ecosystems. Forests are important structures that support the larger ecological community in various ways including biomass production, habitat services and water purification (Brockerhoff et al. 2017). Northeastern Hardwood Forests are a particularly important community due to their economic and ecological value, playing a key role in the timber industry and the nitrogen cycle (Rogers et al. 2022). There is limited quantity of old growth, Northeastern Hardwood Forests due to colonial agricultural practices (“Northern Hardwood Forest”). In the fifteenth century, with the arrival of European colonizers, the American landscape was transformed to be used as farmland. These land-altering activities continue to this day, in the form of the timber industry, and thus most of the Northern Hardwood Forests no longer retain their precolonial composition (Thompson et al. 2013). To preserve these forests for the future, it is essential to fully understand their function, structure, identity, and feedback. A thorough comprehension of these variables allows for informed management decisions to be made that benefit both human and ecological welfare.

Northern Hardwood forests span across Northern United States and Southern Canada, covering around 20 million hectares (Rogers et al. 2022). The vast range of these forests results in variability in composition. These Northern Hardwoods are typically dominated by temperate deciduous species like sugar maple, red maple, yellow birch, and American beech (Pan et al. 2018, Rogers et al. 2022). Furthermore, they support a diverse array of wildlife communities including birds, mammals, insects, and amphibians ("Northern Hardwood Forest"). The Northeastern Hardwoods tend to be mixed-species, containing a diverse array of tree types (Brockerhoff et al. 2017). These mesic forests experience cool, humid climates defined by warm summers and cool winters that support a lush herb layer ("Northern Hardwood Forests"). These forests provide broader ecosystem services including carbon sequestration, climate regulation and pest mitigation (Brockerhoff et al. 2017). In essence, Northern Hardwood forests stand as vital ecosystems, offering not only diversity of flora and fauna but also crucial ecosystem services essential for the well-being of our planet.

There have been anthropogenically-derived shifts in the structure of these Northern Hardwood Forest since early colonization. As much of the original Northeastern American forests had been cleared for agricultural and natural resources harvests, there has been a change in the successional cycle within US forests (Thompson et al. 2013). Specifically, an acceleration in the successional process has been observed, which has resulted in the loss of old growth forests and their associated benefits (Payne and Peet 2023). While ecosystems may successfully adapt to changes in the successional cycle, it does make the system more vulnerable to additional shifts in the environment. Thus, anthropogenic influences that exert pressure on these Northern Hardwood Forests in conjunction with successional changes may have dire consequences on the resiliency of these forest communities. To be specific, as global warming creates a change in climate regime these forests are subjected to increased levels of stress that could induce a change in their structure, function, identity, and feedback.

Blind Brook - Purchase Colleges' Century Woods

Blind Brook is a 100-acre mixed mesic and hydric, hardwood forest that borders the eastern half of SUNY Purchase. Prior undergraduate research within Blind Brook has illuminated forest age, composition, and structure. A study performed in 2021 used aerial interpretation to determine that the southern forest is more mature than the northern forest. Northern Blind Brook is composed of young trees ranging from 10 to 50 years old, while southern Blind Brook is composed of mature trees ranging from 70 to 100 years old (Starkey2021). The locations of the north and south regions of Blind Brook Forest can be found on the map below.

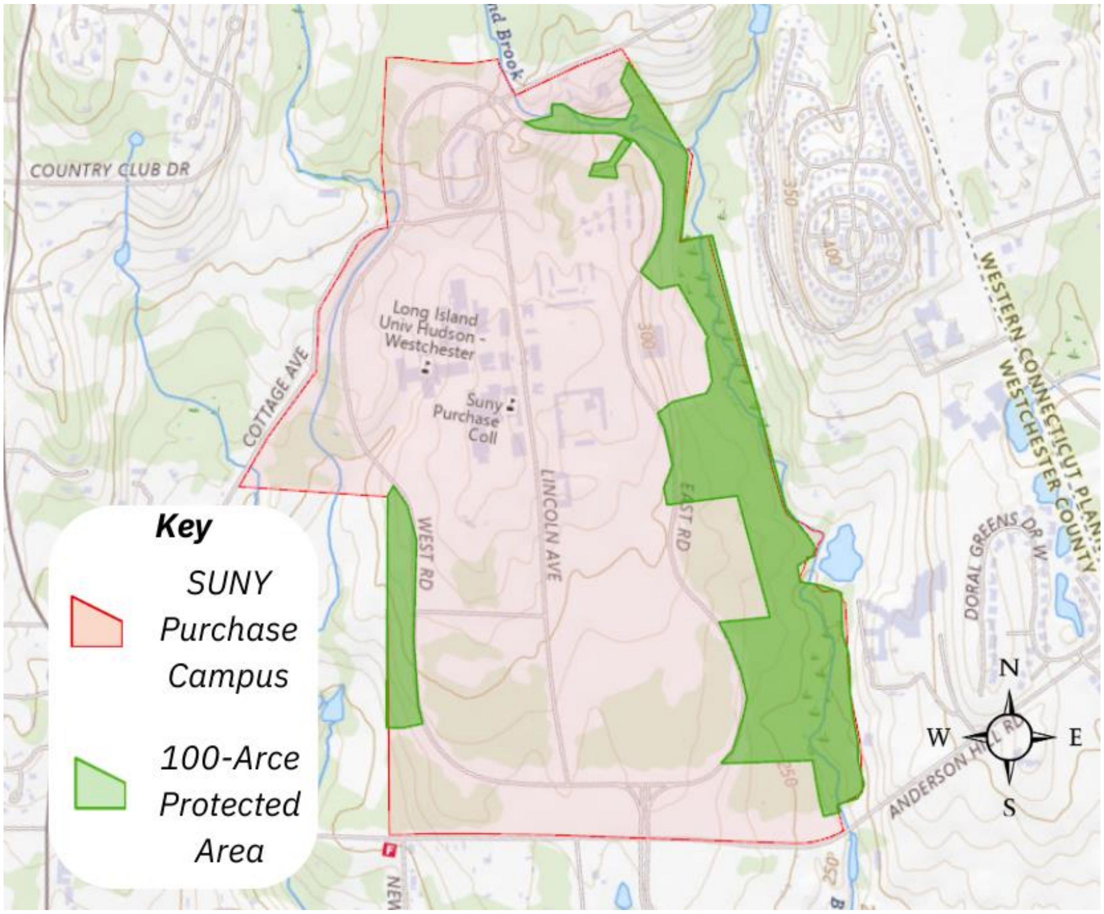


Map 1; *Overview of forest ages within SUNY Purchase Campus. This map was obtained from Starkly 2021. Blind Brook Forest is located on the eastern half of campus. The younger, northern forest is denoted with a red N. The older, southern forest is denoted with a red S. All samples for this study were obtained in the older, southern forest.*

The status of Blind Brook as a century forest demonstrates its importance in conservation efforts. The division between age structure among the North and South Forest is due to historical land usage, with the northernmost portion of campus being clear cut for the purpose of cattle farming ("20th Century History"). There is variability in tree species composition between forests. Northern Blind Brook is dominated by beech and sugar maple with less frequent occurrences of hickory, red maple, Norway maple, and white birch (Duquesne 2001). Southern Blind Brook is dominated by red maple and pin oak with shagbark hickory, American elm, beech, and tulips occurring less frequently (Pryer 2002). Within the southern forest, high levels of diversity were found among trees, birds and shrub species (Pryer 2002, FitzGerald 1979). Evidently, southern Blind Brook forest serves as a safe-haven of biodiversity from the surrounding urbanized campus.

The characteristics of southern Blind Brook are typical of Northeastern mesic forests. The soils are moist and high in clay content, with past research finding the average soil moisture content to be 62% (DeMarco 1979). The same study found Blind Brook soils to have a low pH with an average value of 5 (DeMarco 1979). Variability in the frequency of water-saturated soils was noted across multiple Blind Brook studies (Duquesne 2001, Pryer 2002, FitzGerald 1979). Blind Brook forest is part of the larger Lower Hudson Valley Watershed, and portions of these woods are within floodplains. In the southernmost region of the forest, there are breaches in the stream that aggregate into pools of standing water (Image 3). Additionally, there is a high to low elevation gradient across the west to east sections of the southern forests. The lowest elevated region is at the eastern end of the forest where the stream is located. This stream is at an elevation of 250 ft, within proximity to the water table. The majority of the forest is elevated from the water table and stream, reaching a height of 280 feet. Utilizing FEMA's National Flood Hazard Layer, the eastern half of Blind Brook in which the river lies can be identified as part of special flood hazard areas. In the southern half of the forest that surrounds the river, there is a minimum regulatory floodway buffer zone of ~40 ft and a maximum of ~250 ft. Furthermore, this buffer zone surrounding southern Blind Brook River is classified as an AE Zone which indicates high risks of flooding. The proximity of Blind Brook Forest to this flood zone impacts the health and composition of the entire ecosystem.

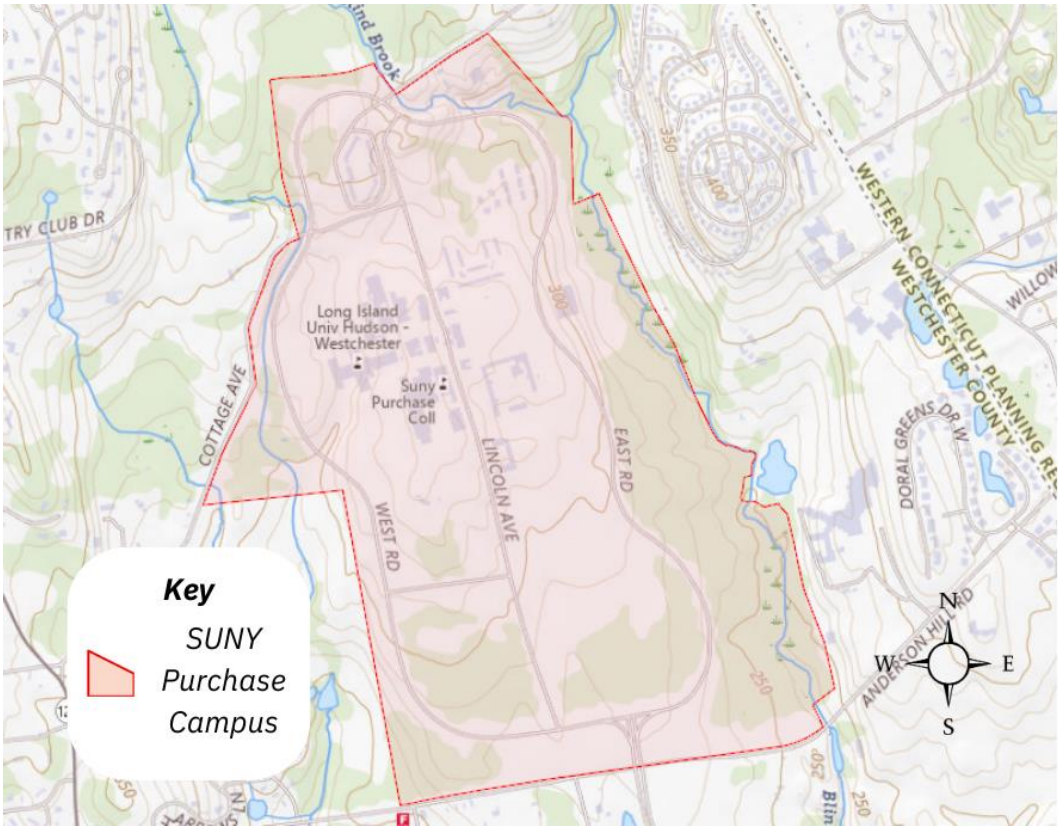
Within this 100-acre forest, 80 acres in the southern half are protected. This protected status is due to the construction of Broadview, a Senior Living Facility, in the western half of campus. While these 80 acres of "forever wild" woods are protected from future construction, the southernmost portion of this forest was clear-cut to connect the sewer system for Broadview. This gap in forest could potentially serve as a corridor for invasive species expansion, and thus puts the ecosystem at risk for degraded health. SUNY Purchase campus is known to harbor invasive and pathogenic species like porcelain berry, knotweed, and beech leaf disease. Therefore, it is important to identify and strengthen the resilience of this forest against the potential challenges it may face.



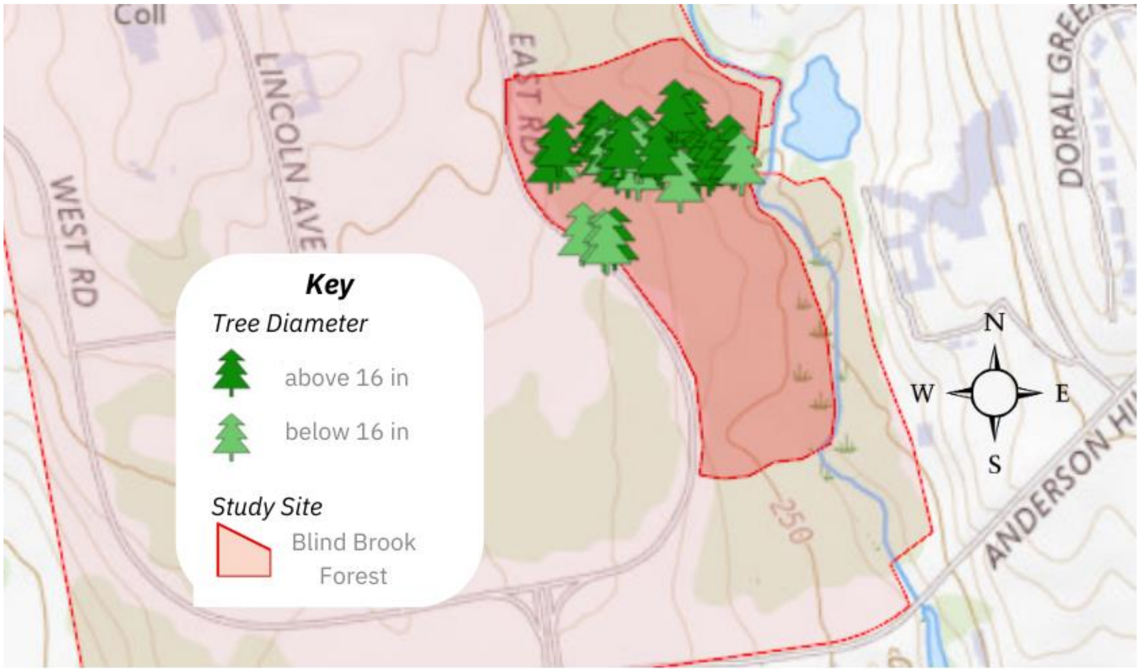
Map 2; *Overview of the 100-arces of protected wood relative to the entire campus. Green polygons denote protected forests.*

Outside of residential construction, Blind Brook has also been a potential site for flood mitigation infrastructure. The forest was first identified as a potential location for a control dam site in 1975. This was met with backlash from staff and students. With a grant from the National Science Foundation, 13 environmental science students conducted research in Blind Brook Forest with the objective of obtaining data to be used in an environmental impact statement (Normandia 1978). This dam proposal never saw fruition, in part due to the work performed by the undergraduate students. As the severity of storms and flood events increased over the years, another flood infrastructure proposal was made in 2022. This infrastructure plan involved the construction of five berms: three to be located directly on campus behind the gym, and two to be located on a downstream property. These berms would reduce flood water levels for the surrounding neighborhoods but would require removal of 50-100 ft of forest for construction and maintenance. Furthermore, these berms would alter the existing ecosystems within SUNY Purchase campus by causing long-term flooding in the proposed areas. Protests from students and staff, as well as the protected status of Blind Brook, were successful in preventing this project. The frequent infrastructure proposals in these forests illustrate the importance of understanding and communicating the function that these ecosystems provide.

The fact that Blind Brook Forest has been presented as a flood mitigation site multiple times throughout SUNY Purchase's history demonstrates the lack of cohesion between social and ecological problem solving. It illustrates that problem-solving management typically only accounts for the social and economic sphere and fails to consider the ecological component – even in cases where the issue has environmental origins. Constructing a dam within the Blind Brook floodplains forest would reduce the woods inherent flood-mitigating properties. This forest's status as a floodplains aid in alleviating flood impacts because it functions to store excess flood-waters. A more sustainable approach to mitigating flood damages would involve a socio-ecological strategy which aims to improve the storage capacity of the existing floodplain forests. This would be a more robust, long-term solution that would provide ecosystem services such as improving water quality and creating additional habitat (Opperman et al. 2013). This strategy would provide greater flexibility to climate regime changes than infrastructure projects like dams or levees, while also providing broader socio-ecological benefits (Serra-Llobet et al. 2022) . The creation of a dam to prevent flood damages would result in a less resilient ecosystem, as the saturation of forest soils results in the loss of floodplain ecosystem services. Furthermore, the dams would likely cause a shift in landscape from forest to wetlands ecosystem which may have broader environmental consequences. A more sustainable approach to addressing issues of flooding must provide both ecological and social benefits.



Map 3; *This map provides an overview of the study area. The red polygon indicates the location of SUNY Purchase College, in which Blind Brook forest resides. Blind Brook forest is on the eastern half of campus; the study site is located at the lower right-hand corner of the map, adjacent from the East road.*



Map 4; *This map provides an overview of the protected 80 acres of Blind Brook Forest. Additionally, it provides locations of all Tulip Poplar samples categorized by DBH size class.*

Climate Change

Urbanization compounded with climate change has resulted in the loss of biodiversity on a global scale (Nowak and Walton 2005). Human behavior, particularly with reference to industrialization, has altered the global ecosystem and climate. Since the 1850s, accumulation of carbon dioxide and other fossil-fuel derived pollutants has caused an increase in world temperature (Jones et al. 2023). This shift in climate regime has consequences in social, economic, and ecological sectors. The extreme weather associated with climate change will result in natural disasters occurring at higher rates, accelerated adaptation by pathogenic species, and disruptions in food supply chains (Abbass et al. 2022). Furthermore, the impacts of climate change will be greater in low-income countries that don't have the resources to offset social impacts (Islam and Winkel 2017). It is essential that we preserve our current ecosystem's health and understand the extent of climate change impacts on a local level. This may require a shift in how global resources are managed to emphasize the interconnection between social and ecological problems. As the science of sustainability has matured, there is an emphasis on conceptualizing the world through a socio-ecological framework. This framework aims to foster sustainability in socio-ecological systems through reduction of vulnerability, enhancement of adaptive capacity, enhancement of resilience, and enhancement of transformability (Chapin et al. 2009). As anthropogenic actions alter land-cover, global climate, and resource availability it becomes more pertinent to modify human behavior to cultivate a resilient world.

Climate change manifests differently around the world. In the Northeastern United States, in which Blind Brook Forest is located, climate change is predicted to cause increased precipitation levels. These impacts are already manifesting, with the Northeast experiencing a 60% increase in the number of days of extreme precipitation (“Climate Change Impacts in the Northeast”). In terms of temperature change, the Northeast is expected to experience a warmer climate. Specifically, this region is likely to experience an increase in temperature up to 5.2° Fahrenheit by the end of the century (Rustad et al. 2012). Furthermore, there is an increase in sea levels associated with the elevated temperature. These changes will impact the welfare of wildlife and humans alike. One way change in the climate regime will impact the region is through range shifts among flora and fauna (Rubenstein et al. 2023). As the Northeast becomes warmer and wetter, species may migrate towards preferential climates. This change in climate will also impact human welfare; as the Northeast experiences a higher frequency and severity of storms, there is increased emphasis on flood mitigation strategies and storm resilience (Abbass et al. 2022, Xu et al. 2022). This can cause a financial strain on communities and exacerbate the stress on surrounding ecosystems as their landscape is altered. Therefore, there should be efforts made to build up the resilience of communities and their surrounding ecosystems in the face of the changing climate. With a focus on protecting socio-ecological health, humans and wildlife alike will be more prepared to adapt to climate change.

Climate Responsive Tree Species

To gain insight into forest health, many researchers use dendrochronology to determine trees' age and growth patterns. This technique was first developed in the twentieth century by Andrew Ellicott Douglas who utilized this process to extend our records of climate data (“About Tree Rings”). The climatic conditions under which a tree grew can be determined through analyzing differences in tree ring width. For example, a year characterized by below-average rainfall typically results in a smaller early-growth ring (Gauli et al. 2022). By using tree ring widths as a proxy record for climate trends, dendrochronology deepens our understanding of climatological preferences of tree species and can identify what species may be more resilient to the impacts of climate change (Williams et al. 2010, Chhin et al. 2018). We can obtain dendrochronological records from a variety of species; different species are sensitive to specific conditions, which allows us to select a tree that will react predictably to relevant climate trends.

Species that are used frequently in dendrochronological research include oaks, pines, and maples (Fekedulegn et al. 2003, Prolic and Goldblum 2016, Au et al. 2020, Canning et al. 2023). These species are known to respond to climate variables in a consistent manner. In general, oak species are drought-tolerant and respond most prominently to temperature variables (Prolic and Goldblum 2016). Specifically, prior studies have found white oak to respond negatively to late summer droughts despite consistent growth during spring droughts (Au and Maxwell 2022).

Pines are a temperature-sensitive, drought-intolerant species. Dendrochronological studies that use pines tend to explore the relationship between growth and low temperatures (Wang et al. 2016). Furthermore, they are also studied in conjunction with oaks when researching the relationship between growth across isohydric vs anisohydric species (Asbjornsen et al. 2021). Lastly, maples are a temperature-sensitive species that has been found to respond negatively to an increased number of thaw-freeze events (Moreau et al. 2020). Additionally, maple growth is negatively impacted by periods of drought (Au et al. 2020). Generally, the species selected in dendrochronological research corresponds with the climate variable being studied.

The Tulip Poplar was selected in this study due to its sensitivity to precipitation (LeBlanc et al. 2020). This species was chosen because it is found frequently in the woods surrounding campus (Duquesne 2001, Pryer 2002) and its rapid growth (Keyser and Brown 2014). These hardwoods are native to the Eastern United States, experiencing the most growth from April through October (Lauritzen and J.E. 2023). They grow at optimal conditions in mesic climates with well drained, loose textured acidic soils (Lauritzen and J.E. 2023). On average, they grow 80 to 120 feet in height, obtain a 4 to 6 ft DBH and reach sexual maturity after 20 years of growth ("Liriodendron tulipifera"). As a pioneer species, they are frequently located in the overstory of forest and tend to persist into mid to late succession (LeBlanc et al. 2020).

Tulip poplars have been the subject of past dendrochronological studies, often being used in conjunction with analysis of increased levels of drought (Hanson et al. 2001, Fekedulegn et al. 2003, Keyser and Brown 2014, D'Orangeville et al. 2018, LeBlanc et al. 2020, Jang et al. 2023). Past research has shown that Tulips are sensitive to soil moisture content, specifically they have been observed to experience slower growth under periods of high temperature and low precipitation (Fekedulegn et al. 2003, Keyser and Brown 2014, LeBlanc et al. 2020, Jang et al. 2023). These studies tend to focus on increased levels of evapotranspiration and drought in relation to Tulip health and climate change. Generally, research has found that Tulip Poplar growth is very sensitive to site water balance (LeBlanc et al. 2020), thus it's expected this species will react to changes in precipitation within the Northeastern United States. Nonetheless, there is a lack of research regarding how increased flood events are impacting Tulip growth on the East coast. As the Northeast will experience an increasingly wet climate, we need more research into how Tulip Poplars and other precipitation-sensitive species respond to this shift in weather patterns.

Methods

Field Work

Tulip Poplars were identified during the fall of 2023, specifically on November 4th and November 15th. Species were identified by leaf shape using binoculars, tagged, labeled numerically, and diameter measured using DBH tape (Image 1). This data was collected using ArcGIS's Survey123, which also notated the location of each tagged tree. Data collection found the largest Tulips at a high point of the forest next to a ropes course on campus. There was a decrease in size of Tulips across the north to south gradient. Furthermore, across the north-south gradient a decline in tree size and health was observed – Northernmost trees had large DBH and with less abnormalities in bark compared to the southernmost trees that had small DBH and prominent abnormalities.

Coring took place after leave fall during the first weeks of December. Two incremental borers were utilized in obtaining core samples: for trees less than 16 inches in circumference, a 16-inch Haglof incremental borer was used; for trees greater than 16 inches in circumference, a 32-inch Haglof incremental borer was used (Image 2). Core samples were taken using standard practices, the measurement taken at breast height and at a 90-degree angle (Stokes and Smiley 1968). Adjustments were made for trees growing at varying angles (UWICER 2017). Beeswax was applied before each sample was taken to reduce friction during core extraction (UWICER 2017). Two samples, A and B, were taken from each tree in opposite directions to strengthen confidence in our data (Stokes and Smiley 1968). Once samples were extracted, they were put into pre-labeled core straw that corresponded with the tree label. All samples were taken to the lab after fieldwork to be stored.

Image 1; *Obtaining DBH of one of the largest Tulip Poplar samples.*

Image 2; Obtaining core sample using 32-inch Haglof Incremental Borer. Note the scarring on the right side of the tree.

Image 3; *Samples sites in Blind Brook. The image on the left is of northern forests. The image on the right is of southern forests where there is a greater quantity of standing water.*

Lab Work

Lab work began at the end of January and continued to the end of February. Samples were glued, mounted, and labeled according to the core straw. The cores were oriented with the fibers running vertically to the mount as with standard practices (Stokes and Smiley 1968). Mounted samples were tapped down to allow the core to lay flat on the mount as the samples dried. Once completely dried, the mounted samples were gradually sanded using rough to fine sandpaper to reveal the rings of the tree (Image 5). The core was first sanded using 280 grit paper until smooth, then sanded with 320 grit paper, and lastly it was polished using 400 grit paper (UWICER 2017). After the mounts were prepared, ring width measurements were taken using the Velmex Tree Measuring System (Image 4). This streamlined the process of obtaining width measurements, as it took the measurements of each ring width and sent that data to a digital spreadsheet (UWICER 2017). Ring width measurements were taken in millimeters.

After measurements were completed, the data was cleaned up for future analysis. Cracks were denoted and removed from the data, rings adjacent to cracks and other abnormalities were flagged as uncertain. Furthermore, measurements from deeply slanted rings were removed entirely from the database to reduce potential error in analysis. The A and B cores of each tree were visually cross-dated to check for excessive variation between the samples. Samples that had large standard deviations between the average ring widths of A and B cores were removed from the data set. Additionally, data on Palmer's Drought Severity Index was obtained from the National Centers for Environmental Information. The monthly PDSI data was derived from the Northeast region of the United States, and the database included statistics from 1885-2023.

Image 4; *Velmex Tree Measuring System set up to collect data on a core sample.*

Image 5; *All mounted and sanded core samples.*

Analysis

Prior to running inferential statistics, multiple datasets had to be prepared for analysis. Ring width data was further organized into groups based wet and dry periods displayed in Palmer's Drought Severity Index. Identifying these groups was a multistep process.

Average ring width was subtracted from all ring width measurements to obtain ring width variance. Next, ring width variance data was used to create a three- year running average. Using the three-year running average, periods of prolonged drought or deluge were identified. Identification was completed in three steps: First, groups were identified based on periods of consecutive negative values. That was then expanded to include interruptions from negative values that only lasted one year.

Second, the upper boundaries were refined to ensure that drought periods didn't overlap with wet years. This was accomplished by examining the ring width variance dataset to confirm that the current year was negative. Breaks would be made between groups if there were two or more consecutive positive years. Lastly, the lower boundaries were refined to ensure that there was no overlap between wet and dry periods. This was accomplished using the same process as the second step, this time paying attention to the lower boundaries of each group. This resulted in 20 total groups, or a 10 -year cycle between periods of drought and deluge. These groups would be used to explore the connection between extreme precipitation periods and poor ring growth. To be specific, these groups were used when performing a linear regression to determine if there was a relationship between drought index and Tulip growth.

In addition, tree ages for all samples had to be determined. Only 23 out of 47 of the samples contained a pith necessary to determine the tree's age. The ages of the remaining 24 samples were estimated using the average rate of growth of the pithed cores. This provided a rough approximation of the age range of Tulip Poplars within Blind Brook forest. This Tulip

Poplar age dataset was used to perform an additional linear regression that sought to determine a relationship between tree age and DBH size.

Results

When visualizing climate change impacts through the lens of precipitation changes, Palmer’s Drought Severity Index suggests that the East coast is experiencing a dramatic increase in precipitation events (Fig. 1). While there have been more extreme periods of deluge, such as in the 1970s, there is an increasing trend in precipitation levels that began in the 1980s (Fig. 1). This trend of increased deluge evident in PDSI corresponds with climate change impacts in the Northeastern United States.

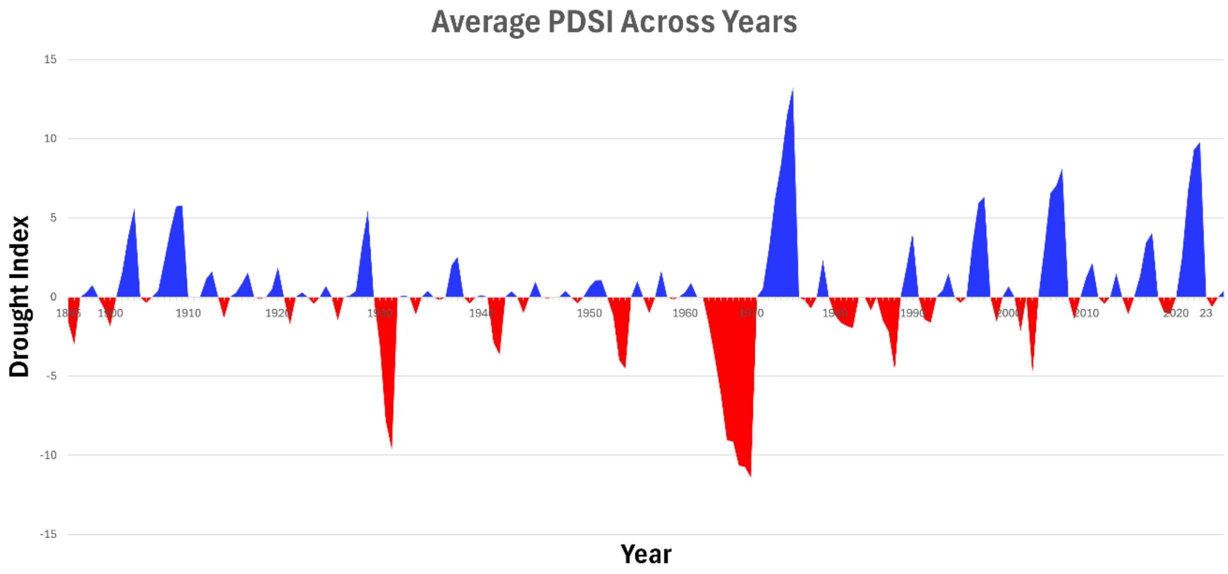


Figure 1; *This graph depicts the average Palmers Drought Severity Index per year from 1895 to 2023. PDSI data was obtained from the National Oceanic and Atmospheric Administration, and it quantifies periods of drought and deluge within the East coast of the United States The positive, blue line represents periods of drought. The negative, red line represents periods of flood. Higher peaks depict periods of more severe drought or flood. Since the 1980s, the East coast has experienced an increase in the severity of deluge. This is reflective of the predicted increase in precipitation levels within the Northeast as a result of climate change.*

Tulip Poplars within Blind Brook show how the samples are part of a mature overstory forest. Variability within sample DBH was reflective of a mature forest, with values ranging from 30 cm to 149 cm (Fig. 2). There was a lack of young Tulip Poplars within Blind Brook, evident in the absence of small DBH measurements (Fig. 2). Furthermore, there was a significant positive relationship between forest age and DBH (linear regression, F= 10.43 p= 0.002, r2 =0.187, N= 42). As Tulip Poplars increase in age, they increase in DBH (Fig. 2, Fig. 3).

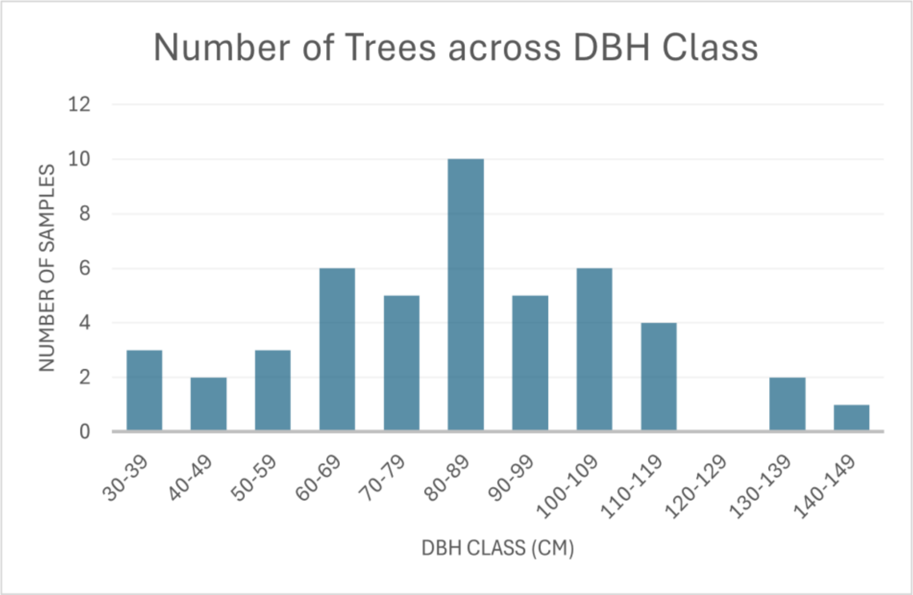


Figure 2; *This histogram depicts the number of samples within each DBH range. There are 42 total samples, the maximum DBH obtained was 32 cm and the minimum DBH obtained was 146 cm. The mean DBH of the samples was 84.9 cm. The range of DBH values reflects typical trunk growth for mature overstory trees.*

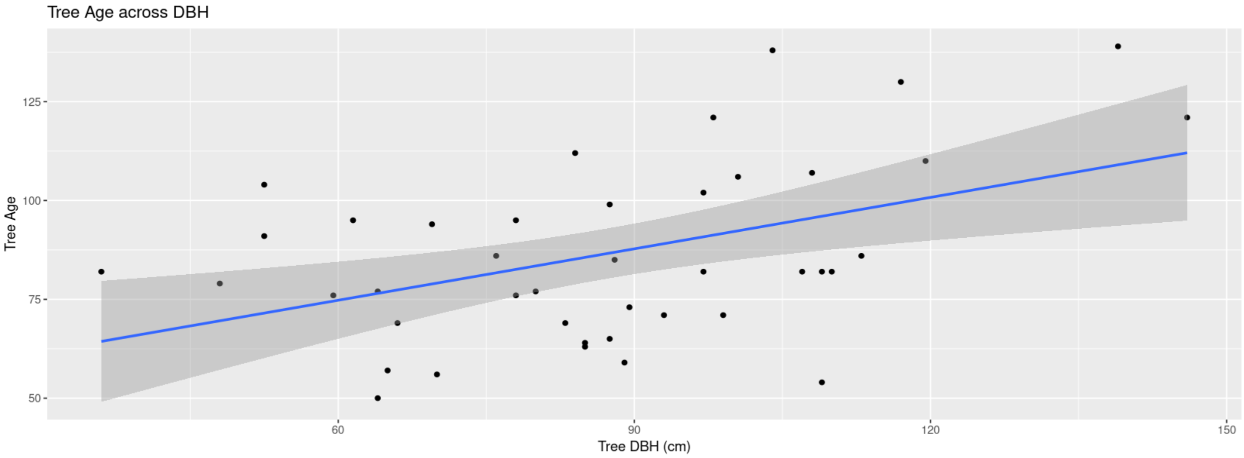


Figure 3*; This line of best fit illustrates the results of a linear regression comparing tree age and DBH. A statistically significant relationship was found (p= 0.002, r2 =0.187). There is a positive relationship between tree age and tree DBH. This is a frequently found relationship, where trees obtain larger DBH's as they increase in age.*

The age range of samples further supports the Tulip Poplars' maturity, as the youngest sample was 50 and the oldest was 146 (Fig. 4). Once again, there was a lack of young trees in this forest as evident in the minimum sample age. When comparing DBH values to tree age, there appears to be similarity between means; With the mean DBH of 84.9 cm and the mean age of 93.9, we can roughly estimate Tulip Poplars to gain a little more than an inch of growth per year (Fig. 3, Fig. 4).

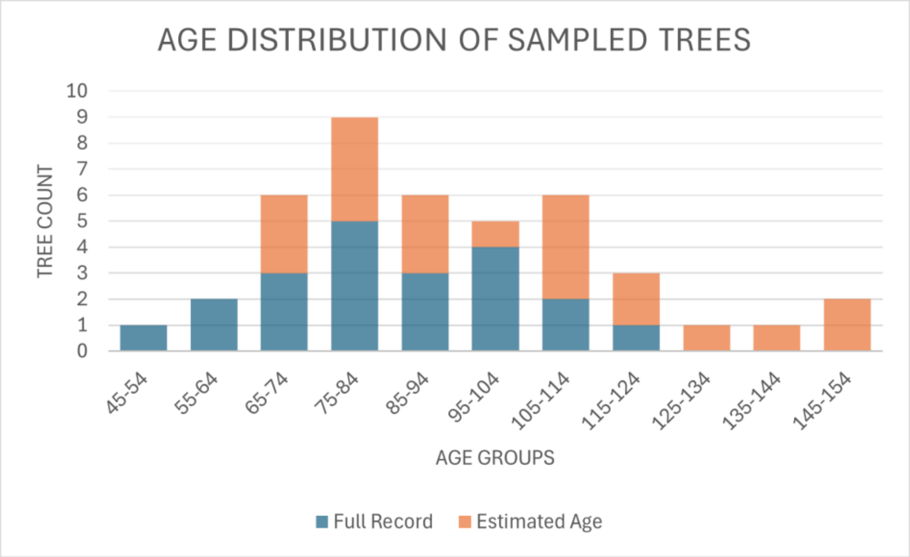


Figure 4*; This histogram depicts how samples are distributed among age classes. The oldest tree was 153 years old while the youngest was 50. The mean age of the sample was 93.5. The age range reflects the characteristics of a mature overstory forest. There were notably no younger Tulip Poplar stands throughout the forest or evidence of sprouting growth.*

Ring width measurements had the greatest variability, with lots of samples falling within the 2.0 to 3.0 mm range (Fig. 5). Despite this, the mean ring width measurement was 3.75 mm (Fig. 5), which demonstrates variability in ring width growth across samples. This is expected as ring width varies across years due to many environmental factors. Generally, ring width measurements are consistent with DBH, and age data obtained in terms of reflecting how the sample is from a mature forest. Moreover, ring width data is important in quantifying what is normal growth for Tulip Poplars within Blind Brook forest. Ring width is the variable that responds to variation in environmental factors, changes in ring width within the sample indicates when the trees were undergoing stress. Our results demonstrate that Tulips in this forest tend to have ring widths between 2.0 mm to 3.5 mm (Fig. 5).

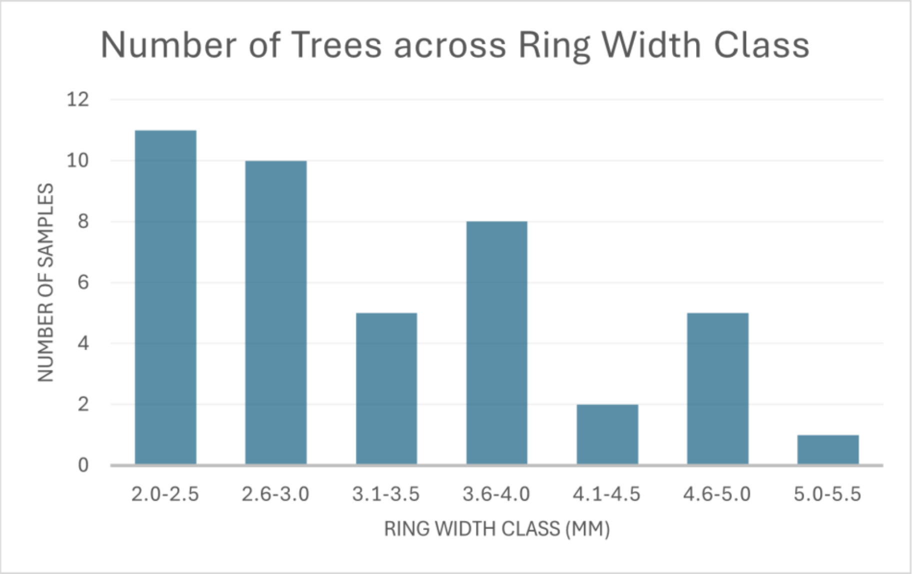


Figure 5; *This histogram depicts the number samples within ring width groups. The maximum ring width obtained was 5.03 mm, the minimum ring width obtained was 2.05 mm and the grand mean ring width was 3.75 mm. This graph demonstrates typical ring width size within the sample. There is a tendency for Tulip Poplars within Blind Brook forest to have moderately small rings, often ranging between 2.0-3.0 mm.*

When quantifying periods of healthy or poor growth for Tulip Poplars, it appears that since the 1980s Tulips in Blind Brook Forest have been experiencing stressful conditions, which is evident in their poor growth (Fig. 6). There has been a lack of consecutive periods of healthy growth among the Poplars during the late 20th century into the 21st century (Fig. 6) This pattern of poor growth corresponds with the trend of increasing precipitation demonstrated through PDSI, both appearing in the 1980s and increasing in severity as time progresses (Fig. 6, Fig. 1).

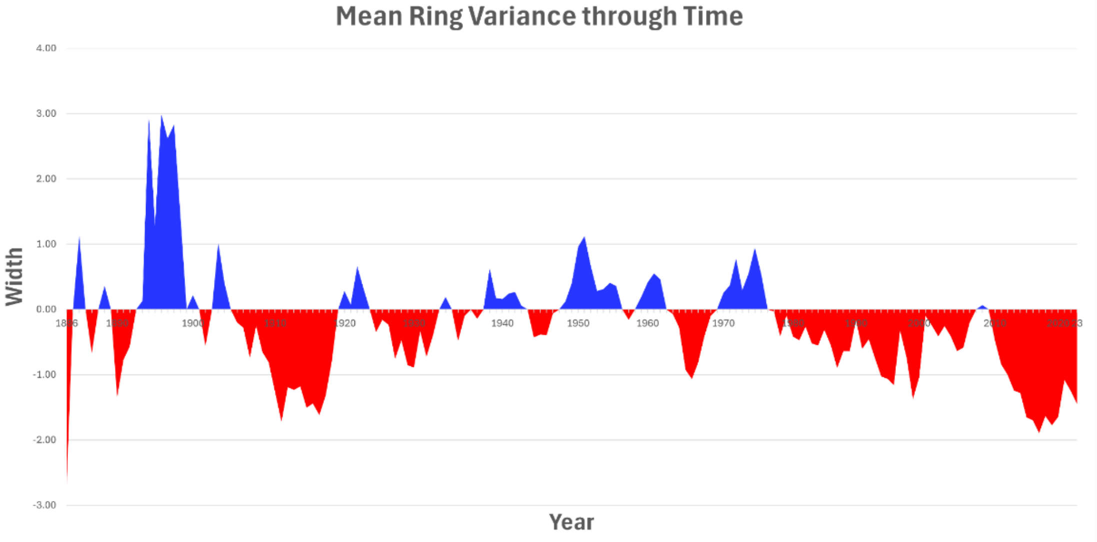


Figure 6; *This area line graph displays periods of healthy growth and poor growth in the Tulip Poplar sample. This data was obtained by subtracting the grand mean width from the yearly average width. Thus, this graph uses the difference between yearly ring width average and mean width growth to determine periods of health vs poor growth since 1886. The blue positive values represent periods of healthy growth, and the red negative values represent periods of poor growth. Since the 1980s, there has been a downward trend in Tulip Poplar growth.*

As we are experiencing an increasingly wet climate in the Northeast, Tulip Poplars have entered a period of poor growth. This was supported by the significant relationship found between PDSI and ring width (Fig. 7). As PDSI indicates periods of increased deluge, ring widths become smaller (linear regression, F= 10.1 p= 0.005, r2 =0.336, N = 19). This implies that Tulip Poplars of Blind Brook forest will experience worse growth under our increasingly wet climate.

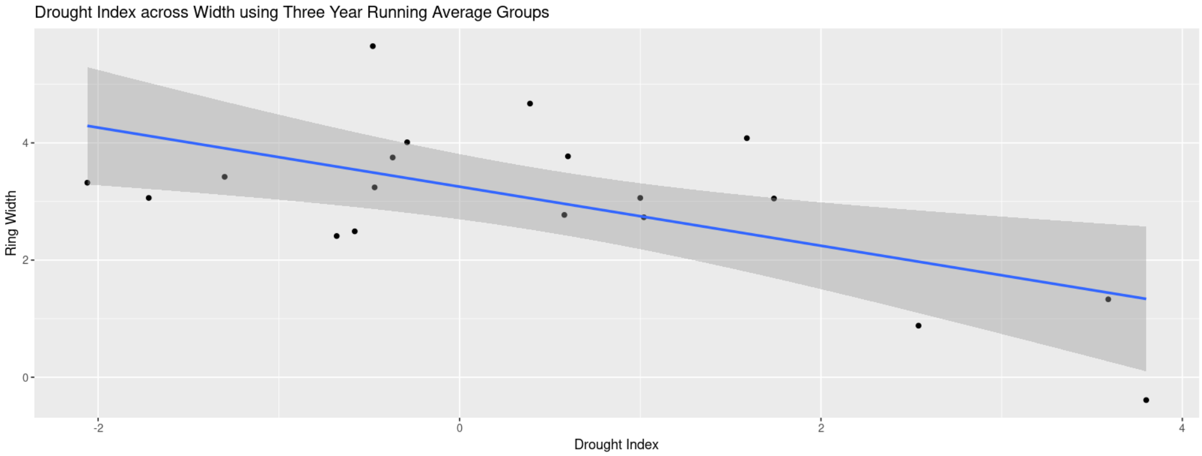


Figure 7; *This graph is a linear regression that shows the relationship between drought index and average ring width utilizing groups derived from a three-year running average. A significant negative relationship between drought and ring width was found (p=0.005, r2 =0.336).*

An additional linear regression was performed using the same data but with trees younger than one-hundred to determine if this relationship was skewed to do the mature age of the sample (Fig. 8). The same trend was found, in which increased wetness corresponds with small ring widths (linear regression, F= 5.08 p= 0.046, r2 = 0.254, N= 13).

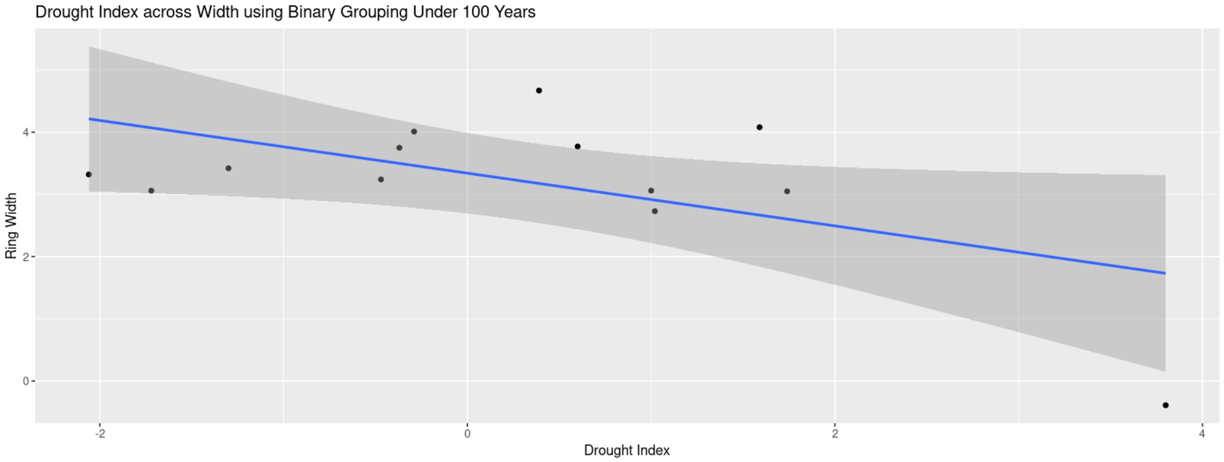


Figure 8; *This graph is a linear regression that shows the relationship between drought index and average ring width across three year running average groups for samples under 100 years old. A significant negative relationship between drought and ring width was found (p= 0.046, r2 = 0.254).*

This declining trend in ring width growth since the 1980s is also reflected within the variability of dry and wet periods (Fig 9). From the 1890s through the 1930s, there was much more variability in ring widths, indicating fewer external factors stressing Tulip growth (Fig 9). This contrasts with ring widths from the 1940s through present day, which had much less variability among widths (Fig 9). Furthermore, since the 1950s, there has been a steady decline in ring width that is reflected across both wet and dry groups (Fig 9). This supports the prior evidence that suggests that Tulip Poplars are experiencing worse growth in our increasingly wet climate.

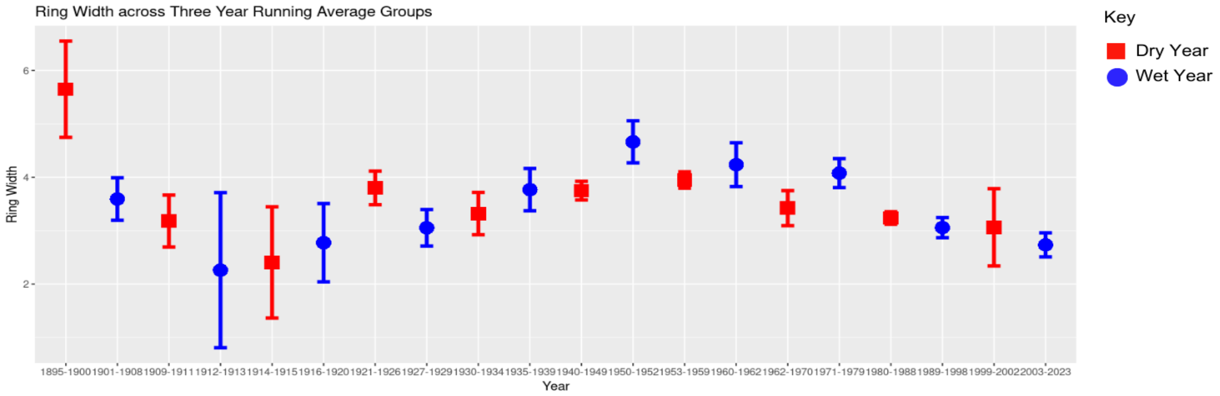


Figure 9; *This graph shows ring width variability since 1895 utilizing three year running average groups. Periods of dryness are coded with red squares. Periods of wetness are coded* *with blue circles. There was greater variability in ring width during the early 20th century compared to the early 21st century. The standard deviation of ring width between 1895-1939 was 1.07 and the standard deviation of the ring width between 1940-2023 was 0.69. Additionally, there has been a declining trend in ring width since the 1950s.*

Discussion

This research found that Tulip Poplars are not adapted to increased precipitation and will likely face stress under the progressively wetter climate in the Northeast. This was evident in their stressed growth over the past fifty years, which overlaps with our increasingly wet climate indicated by trends in PDSI. This data was further confirmed by the secondary linear regression that found the same relationship between PDSI and Tulip growth for samples under 100 years old. Field observations suggest that there is no new growth of Tulip Poplars within Blind Brook determined by the lack of small diameter trees, which further supports evidence suggesting this new climate will not promote Tulip Poplar growth. The lack of new growth is also supported by the fact that the youngest tulip was 50 years old. Evidently, the Tulip Poplar population of Blind Brook is already declining as there seems to be a lack of new growth. This could be explained by past research that has found that Tulip seedings struggle to subsist in mature overstory forests that limit the amount light reaching the forest floor (Beck 1990). With the predicted loss of Tulip Poplars in Blind Brook, there is a need to identify other species that could sustain their structural role as mature overstory species.

Tulip Poplars' inability to adapt to climate change can be expected, as they have been identified in the past to have the narrowest niche breadth among 24 common species in the Northeast (Martin and Canham 2020). Moreover, research has found that Tulip Poplars are sensitive to moisture content in their environment thus their adverse reaction to increased precipitation is supported by prior evidence (LeBlanc et al. 2020). The aggregation of Tulip Poplar stands in the northeastern half of the forest also corresponds with past research that has shown Poplars to have a preference for northeast aspects (Fekedulegn et al. 2003). While past studies have focused on the opposite end of the precipitation scale by researching Tulip health in relation to prolonged droughts (Fekedulegn et al. 2003, Keyser and Brown 2014, LeBlanc et al. 2020, Jang et al. 2023), this research suggests that species growth is also negatively impacted by excessive precipitation. This research suggests that without intervention, the Tulip Poplars of Blind Brook Forest is unlikely to remain an overstory species and will likely be outcompeted by a more flood-tolerant species.

Blind Brook Forest is already subject to multiple stressors, such as the clear-cut on its southernmost border and shifts in climate. Furthermore, like other Northern Hardwood Forests, Blind Brook has undergone an acceleration in the successional cycle. The compounding impacts of these variables can weaken the resilience of Blind Brook and could potentially cause a shift in the ecosystem's function, structure, identity, and feedback (Chapin et al. 2009). As the Tulip Poplar population of Blind Brook is declining, this could result in a lack of larger overstory species. The lack of the overstory species which generates habitat and leaf litter has consequences on the ecosystem's function and structure. Sustainable management framework would suggest intervening in Blind Brook Forest to maintain the ecosystem's current function and gain resilience towards changes (Chapin et al. 2009). A new fast growing, overstory species must take Tulip Poplars' place if Blind Brook should maintain its identity and respective ecosystem services. This may require intervention and sustainable forest management practices. Specifically, a species that could replace Tulip Poplars must be identified as well as potential removal of diseased Poplars from Blind Brook to foster an environment that would support the growth of young trees.

As there has been a lack of research into Tulip Poplar health in relation to flood conditions, there is a gap in knowledge regarding how exactly flood impacts species health. In the field, many samples appeared to be experiencing rot, particularly among the largest trees. Past research on Tulip Poplars has found that individuals with larger DBH's are better suited to withstand periods of drought (D'Orangeville et al. 2018). Thus, it may be worth researching DBH size as an indicator of poor Tulip health when stands are subject to floods, as these large DBH trees appeared to have a higher frequency of rot. Rot within Tulip Poplars is often caused by fungal infection, some common fungal pests include Phytophthora, Cylindrocladium and Armillaria (Brown et al. 2019, Lauritzen and J.E. 2023, MacDonald and Butler 1981). These rot-inducing diseases are often a result of opportunistic fungi that invade already stressed species (Lauritzen and J.E. 2023). Research has made connections between increased fungal infections and drought conditions (Beck 1990), thus flood-induced stress may result in increased disease. Future research may want to focus flood impacts on Tulip Poplars and their associated diseases.

It's important to note areas of potential error in this study. First, due to the sheer number of core samples taken, there could have been a lack of accuracy and precision across all samples. Within 100 cores taken in total, there is greater likelihood for error in sampling.

Furthermore, there is potential error in the mounting and measuring of cores. In mounting the cores, there may have been errors with aligning broken core pieces that could skew the true measurement of ring width. There was also mislabeling of some core mounts, which were removed from the dataset to reduce uncertainty.

In terms of ring measurements, while the Velmex Tree Measuring System removed some potential for human error, there is still the possibility of inaccurate measurements and the necessity for more subjective judgment calls of false rings.

There are various ways to support the resiliency of Blind Brook Forest in the face of climate change. This study illustrates that flood-intolerant species in Blind Brook will not survive the increased precipitation predicted in the Northeast.

One way we could build up the resiliency of this forest would be to implement methods to reduce stormwater runoff into Blind Brook. This would require a flood water mitigation strategy, one method that could be implemented is a rainwater harvesting system. These systems collect stormwater runoff and redistribute that excess water to be used as a supplementary water supply. Research has found that use of rainwater harvesting systems in conjunction with real time monitoring technology, which regulates the release of stored water, can significantly reduce network flood volume (Xu et al. 2022). Another way to address this region's flooding problem that would fall under the socio-ecological frameworks in sustainable management would be to restore the existing floodplain ecosystem (Serra-Llobet et al. 2022). As floodplains function to store excessive water runoff, this would reduce the frequency of flood damage for surrounding municipalities as well as improving the other ecosystem services provided. By going the route of restoring and elevating the resilience of this ecosystem, there would be both ecological and social benefits. Firstly, it would reduce the costs of construction and maintaining alternative flood-mitigation infrastructure. Secondly, it could provide additional recreational resources for the surrounding communities. Lastly, it would support the Blind Brook Forest by elevating its resiliency and enhancing existing ecosystem services.

Another method to build up resilience in Blind Brook would be to support the existing flood tolerant species and continue to build up flood-tolerant populations. Some species in Blind Brook that may persist in the wetter include swamp white oak, green ash and red maple. While these species will tolerate saturated soils much better than Tulip Poplars, they will not fill the same niche due to their small stature. One candidate for the replacement of Poplars could be Sycamore. These are a fast-growing overstory species, that can reach 100 feet in height and 10 feet in diameter (“Platanus occidentalis”). They could fill the structural role as an overstory species in Blind Brook while being a flood-tolerant species that could persist in the newly wet climate of the Northeast (“American Sycamore”). One other route to consider when considering replacements for the Tulip Poplars of Blind Brook is Tulip Poplars themselves; This species is known to have substantial genetic diversity across their native range (Parks et al. 1994). A Tulip Poplar ecotype existing in the southeast could be a replacement candidate. This ecotype is both morphologically and ecologically distinct, growing in moist environments (Parks et al. 1994). Introduction of this ecotype could mean the persistence of Tulip Poplars in Blind Brook, as this ecotype would likely be better adapted to the increasingly wet climate. However, extensive research would be required prior to the introduction of a replacement species within Blind Brook. Continued research into broad forest health would be helpful in determining which species may support climate change resiliency. Additionally, there could be research into fungicide and other pest-mitigation strategies to support the remaining Tulip Poplar stands in Blind Brook.

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Literature Cited

Beck, D.E. 1990, *Liriodendron tulipifera* L. *In* R.M. Burns and B. H. Honkala [eds.], Silvics of North America: 2 Hardwoods, Agriculture Handbook 654, 406-416. United States Department of Agriculture, Forest Service, Washington, DC.

Chicago Botanical Gardens. “Tulip Tree”. *Chicago Botanical Gardens,* https://www.chicagobotanic.org/plantinfo/tree_alternatives/tuliptree. Accessed 10 May 2024.

DeMarco, George M. 1979. Differences in Site Characteristics Five Major Shrubs of a Floodplains Forest. State University of New York Purchase College. Accessed 13 September 2023

Duquesne,Garret 2001. Forest Community Composition: A Study of a Northeast Deciduous Forest, Purchase College, New York. State University of New York Purchase College. Accessed 13 September 2023

Environmental Protection Agency. “Climate Impacts in the Northeast”. *Climate Change Chicago*. https://climatechange.chicago.gov/climate-impacts/climate-impacts-northeast. Accessed 13 May 2024

Farmscape Ecology Program. “Northern Hardwood Forest.” *Hawthorne Valley Farmscape Ecology,* https://www.hvfarmscape.org/sites/default/files/northern_hardwood_forest.pdf. Accessed 13 May 2024

FitzGerald, Randall W. 1979. Bird Species Diversity and Habitat Diversity in a Southern New York Floodplains Forest. State University of New York Purchase College. Accessed 13 September 2023

Laboratory of Tree Ring Research. “About Tree Rings”. *The University of Arizona,* https://ltrr.arizona.edu/about/treerings. Accessed 5 May 2024

Lauritzen, J.E. 2023. Plant Guide for Tulip Poplar (Liriodendron tulipifera). USDA-Natural Resources Conservation Service, Rose Lake Plant Materials Center. East Lansing, MI 48823.

Normandia, Susan 1978. The Ferns of The Blind Brook Watershed Their Distribution and Relative Niche Specificities. State University of New York Purchase College. Accessed 13 September 2023

North Carolina Wildlife Resource Commission "Northern Hardwood Forests" *NC Wildlife*, https://www.ncwildlife.org/Portals/0/Conserving/documents/ActionPlan/Habitat_Assessment_Rpts/Mountain/UP_Northern_Hardwood_Forests.pdf. Accessed 13 May 2024

North Carolina University. "Liriodendron tulipifera", *North Carolina Extension Gardner Plant Tool Box,* https://plants.ces.ncsu.edu/plants/liriodendron-tulipifera/. Accessed 10 May 2024.

North Carolina University. "Platanus occidentalis". *North Carolina Extension Gardner Plant Tool Box,* https://plants.ces.ncsu.edu/plants/platanus-occidentalis/. Accessed 14 May 2024.

Purchase College State University of New York. "20th Century History" *Purchase College,* https://www.purchase.edu/purchase-history/20th-century-history-1900-1964/. Accessed 13 May 2024

Pryer, Joanna Teevan 2002. Change in The Tree Community of a Fragmented Campus Forest Over 20 Years. State University of New York Purchase College. Accessed 13 September 2023

Stokes, Marvin A., and Smiley, Terah L. 1968 *An Introduction to Tree-Ring Dating [by] Marvin A. Stokes and Terah L. Smiley.* University of Chicago Press.

UWICER (2017). Dendrochronology Manual. Ugyen Wangchuck Institute for Conservation and Environmental Research, Department of Forests and Park Services. UWICER Press, Lamai Goempa, Bumthang, Bhutan

Abbass, K., M. Z. Qasim, H. Song, M. Murshed, H. Mahmood, and I. Younis. 2022. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environmental Science and Pollution Research 29:42539–42559.

Asbjornsen, H., C. D. McIntire, M. A. Vadeboncoeur, K. A. Jennings, A. P. Coble, and Z. C. Berry. 2021. Sensitivity and threshold dynamics of *Pinus strobus* and *Quercus* spp. in response to experimental and naturally occurring severe droughts. Tree Physiology 41:1819–1835.

Au, T. F., and J. T. Maxwell. 2022. Drought Sensitivity and Resilience of Oak–Hickory Stands in the Eastern United States. Forests 13:389.

Au, T. F., J. T. Maxwell, K. A. Novick, S. M. Robeson, S. M. Warner, B. R. Lockwood, R. P. Phillips, G. L. Harley, F. W. Telewski, M. D. Therrell, and N. Pederson. 2020. Demographic shifts in eastern US forests increase the impact of late-season drought on forest growth. Ecography 43:1475–1486.

Brockerhoff, E. G., L. Barbaro, B. Castagneyrol, D. I. Forrester, B. Gardiner, J. R. González-Olabarria, P. O. Lyver, N. Meurisse, A. Oxbrough, H. Taki, I. D. Thompson, F. Van Der Plas, and H. Jactel. 2017. Forest biodiversity, ecosystem functioning and the provision of ecosystem services. Biodiversity and Conservation 26:3005–3035.

Brown, M. S., F. Baysal-Gurel, J. B. Oliver, and K. M. Addesso. 2019. Evaluation of fungicides and biofungicide to control Phytophthora root rot (Phytophthora cinnamomi Rands) and ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) on flowering dogwoods exposed to simulated flood events. Crop Protection 124:104834.

Canning, C. M., B. J. Mood, B. Bonsal, B. Howat, and C. P. Laroque. 2023. Comparison of tree-growth drought legacies of three shelterbelt species in the Canadian Prairies. Agricultural and Forest Meteorology 330:109317.

Chapin, F. S., C. Folke, and G. Kofinas. 2009. Principles of ecosystem stewardship: resilience-based natural resource management in a changing world. Choice Reviews Online 47:47-1379-47–1379.

Chhin, S., R. S. Zalesny, W. C. Parker, and J. Brissette. 2018. Dendroclimatic analysis of white pine (Pinus strobus L.) using long-term provenance test sites across eastern North America. Forest Ecosystems 5:18.

D’Orangeville, L., J. Maxwell, D. Kneeshaw, N. Pederson, L. Duchesne, T. Logan, D. Houle, D. Arseneault, C. M. Beier, D. A. Bishop, D. Druckenbrod, S. Fraver, F. Girard, J. Halman, C. Hansen, J. L. Hart, H. Hartmann, M. Kaye, D. Leblanc, S. Manzoni, R. Ouimet, S. Rayback, C. R. Rollinson, and R. P. Phillips. 2018. Drought timing and local climate determine the sensitivity of eastern temperate forests to drought. Global Change Biology 24:2339–2351.

Fekedulegn, D., R. R. Hicks, and J. J. Colbert. 2003. Influence of topographic aspect, precipitation and drought on radial growth of four major tree species in an Appalachian watershed. Forest Ecology and Management 177:409–425.

Gauli, A., P. R. Neupane, P. Mundhenk, and M. Köhl. 2022. Effect of Climate Change on the Growth of Tree Species: Dendroclimatological Analysis. Forests 13:496.

Hanson, P. J., D. E. Todd, and J. S. Amthor. 2001. A six-year study of sapling and large-tree growth and mortality responses to natural and induced variability in precipitation and throughfall. Tree Physiology 21:345–358.

Islam, S. N., and J. Winkel. 2017. Climate Change and Social Inequality.

Jang, K., I. H. Lee, C. Oh, S. Byeon, and E. J. Cheong. 2023. Environmental Factors Affecting Volume Growth of Yellow Poplar Plantations in South Korea. Forests 14:2003.

Jones, M. W., G. P. Peters, T. Gasser, R. M. Andrew, C. Schwingshackl, J. Gütschow, R. A. Houghton, P. Friedlingstein, J. Pongratz, and C. Le Quéré. 2023. National contributions to climate change due to historical emissions of carbon dioxide, methane, and nitrous oxide since 1850. Scientific Data 10:155.

Keyser, T. L., and P. M. Brown. 2014. Climate-growth relationships for yellow-poplar across structural and site quality gradients in the southern Appalachian Mountains. Forest Ecology and Management 329:158–165.

LeBlanc, D., J. Maxwell, N. Pederson, A. Berland, and T. Mandra. 2020. Radial growth responses of tulip poplar (*Liriodendron tulipifera*) to climate in the eastern United States. Ecosphere 11:e03203.

Martin, P. H., and C. D. Canham. 2020. Peaks in frequency, but not relative abundance, occur in the center of tree species distributions on climate gradients. Ecosphere 11:e03149.

Moreau, G., A. Achim, and D. Pothier. 2020. An accumulation of climatic stress events has led to years of reduced growth for sugar maple in southern Quebec, Canada. Ecosphere 11:e03183.

Nowak, D. J., and J. T. Walton. 2005. Projected Urban Growth (2000–2050) and Its Estimated Impact on the US Forest Resource. Journal of Forestry 103:383–389.

Opperman, J. J., G. E. Galloway, and S. Duvail. 2013. The Multiple Benefits of River–Floodplain Connectivity for People and Biodiversity. Pages 144–160 Encyclopedia of Biodiversity. Elsevier.

Pan, Y., K. McCullough, and D. Y. Hollinger. 2018. Forest biodiversity, relationships to structural and functional attributes, and stability in New England forests. Forest Ecosystems 5:14.

Parks, R., F. Wendel, M. M. Sewell, and Y.-L. Qiu. 1994. THE SIGNIFICANCE OF ALLOZYME VARIATION AND INTROGRESSION IN THE LIRIODENDRON TULIPIFERA COMPLEX (MAGNOLIACEAE)! AMERICAN JOURNAL OF BOTANY 8.

Payne, C. J., and R. K. Peet. 2023. Revisiting the model system for forest succession: Eighty years of resampling Piedmont forests reveals need for an improved suite of indicators of successional change. Ecological Indicators 154:110679.

Prolic, C., and D. Goldblum. 2016. Spatial and Temporal Patterns of Post Oak's (Quercus stellata) Radial Growth-Climate Relationship. Southeastern Geographer 56:171–186.

Rogers, N. S., A. W. D'Amato, C. C. Kern, and S. Bèdard. 2022. Northern hardwood silviculture at a crossroads: Sustaining a valuable resource under future change. Forest Ecology and Management 512:120139.

Rubenstein, M. A., S. R. Weiskopf, R. Bertrand, S. L. Carter, L. Comte, M. J. Eaton, C. G. Johnson, J. Lenoir, A. J. Lynch, B. W. Miller, T. L. Morelli, M. A. Rodriguez, A. Terando, and L. M. Thompson. 2023. Climate change and the global redistribution of biodiversity: substantial variation in empirical support for expected range shifts. Environmental Evidence 12:7.

Rustad, L., J. Campbell, J. S. Dukes, T. Huntington, K. Fallon Lambert, J. Mohan, and Nicholas. Rodenhouse. 2012. Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada. Page NRS-GTR-99. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.

Serra-Llobet, A., S. C. Jähnig, J. Geist, G. M. Kondolf, C. Damm, M. Scholz, J. Lund, J. J. Opperman, S. M. Yarnell, A. Pawley, E. Shader, J. Cain, A. Zingraff-Hamed, T. E. Grantham, W. Eisenstein, and R. Schmitt. 2022. Restoring Rivers and Floodplains for Habitat and Flood Risk Reduction: Experiences in Multi-Benefit Floodplain Management From California and Germany. Frontiers in Environmental Science 9:778568.

Starkey, K. V. 2021. An Assessment of Woodlot Age Structure and Invasive Plant Risk on the SUNY Purchase College Campus.

Thompson, J. R., D. N. Carpenter, C. V. Cogbill, and D. R. Foster. 2013. Four Centuries of Change in Northeastern United States Forests. PLoS ONE 8:e72540.

United States Department of Agriculture. “American Sycamore”. *Plants Database USDA,* https://plants.usda.gov/DocumentLibrary/plantguide/pdf/cs_ploc.pdf. Accessed 14 May 2024

Wang, H., J. Wu, B. Sun, D. Zhang, and S. Liu. 2016. Response of Radial Growth of Pinus armandii to Climate Change in the Qinling Mountains. Nature Environment and Pollution Technology 15.

Williams, A. P., J. Michaelsen, S. W. Leavitt, and C. J. Still. 2010. Using Tree Rings to Predict the Response of Tree Growth to Climate Change in the Continental United States during the Twenty-First Century. Earth Interactions 14:1–20.

Wolff, N. H., L. R. V. Zeppetello, L. A. Parsons, I. Aggraeni, D. S. Battisti, K. L. Ebi, E. T. Game, T. Kroeger, Y. J. Masuda, and J. T. Spector. 2021. The effect of deforestation and climate change on all-cause mortality and unsafe work conditions due to heat exposure in Berau, Indonesia: a modelling study. The Lancet Planetary Health 5:e882–e892.

Xu, W. D., M. J. Burns, F. Cherqui, S. Duchesne, G. Pelletier, and T. D. Fletcher. 2022. Real-time controlled rainwater harvesting systems can improve the performance of stormwater networks. Journal of Hydrology 614:128503.

Zhang, L., E. I. Ameca, B. Otero-Jimenez, S. K. Montaño, A. Shea, T. Kelly, D. Andrianoely, and P. C. Wright. 2022. Human-induced deforestation increases extinction risk faster than climate pressures: Evidence from long-term monitoring of the globally endangered Milne-Edward’s sifaka. Biological Conservation 274:109716.