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COMPARING STAND COMPOSITION AND FLORISTIC QUALITY OF TWO ADJACENT UPLAND OAK-HICKORY WOODLANDS IN SOUTHERN ILLINOIS: OLD-GROWTH AND SECOND-GROWTH DYNAMICS

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by

Leah Kleiman

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TITLE: COMPARING STAND COMPOSITION AND FLORISTIC QUALITY OF TWO ADJACENT UPLAND OAK-HICKORY WOODLANDS IN SOUTHERN ILLINOIS: OLD-GROWTH AND SECOND-GROWTH DYNAMICS

MAJOR PROFESSOR: Dr. Charles Ruffner

Illinois has no official parameters for old-growth oak-hickory (*Quercus-Carya*) forests despite oak-hickory being the historically dominant ecosystem in the forested parts of Illinois (Fralish, 1997; Thompson & Dessecker, 1997)**.** The purpose of this study was to better understand the characteristics of old-growth oak-hickory stands, as well as make management recommendations for preserving the integrity of old-growth forests and shifting second-growth stands to old-growth status. Stand structure analysis was conducted in June and July of 2022 on an old-growth oak-hickory stand (Otey-Grisley Nature Preserve) and nearby second-growth oak-hickory stand (Grisley Woods Land and Water Reserve) near Pittsburg, Illinois using dendrochronology, various stand composition analyses, and floristic assessments to compare the two forests across multiple nodes of inquiry from their canopies to their ground layers. White oak (*Quercus alba* L.) was of higher importance in the more open old-growth canopy than the closed second-growth canopy which had more shagbark hickory (*Carya ovata* L.). The old-growth stand had higher floristic quality (mean Coefficient of Conservatism and adjusted Floristic Quality Index) and lower frequency of invasive species than the second-growth stand. The dominant white oak appear to have suppressed the hickories (*Carya)* for over a century on both sites. However, in the sapling and seedling layer, it appears the oaks and hickories are failing to recruit into the canopy on either site. The average age of the old-growth canopy is 67 years greater than that of the second-growth canopy, the majority of which seeded in after a

heavy cut in the early 1940s. The second-growth site rapidly gained early successional species after the logging. The second-growth site could come to resemble the open oak dominated character of the old-growth site. However, this will require management with fire, thinning, and invasive species treatments. The old-growth, where sassafras (*Sassafras albidum* L.) is crowding the understory, will also require invasive species management, prescribed fire, and thinning if it is to remain the open oak-hickory woodland it is today.
Key Words: Old-growth, Second-growth, Dendroecology, Floristic Quality, Land-use history, Mesophication

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CHAPTER 1

INTRODUCTION

Old-growth forests in Eastern North America are generally considered areas that were never heavily logged for timber. Essentially, these are places on the landscape that have remained forested since before European settlement. In contrast, second-growth forests are those that were heavily logged after settlement (within the last 250 years approximately). My introduction will review the literature on hardwood forests, focusing on the historical development of oak-hickory (*Quercus-Carya*) woodlands of Southern Illinois.

Dendroecology is the study of environmental changes over time through tree ring records and is a crucial technique for studying stand dynamics and site history, particularly in old-growth stands (Foster, 1988). Typically applied via cross-dating tree rings, measuring the variation in annual ring widths, and standardizing these measurements into master chronologies that can be used in climate modeling and understanding disturbance histories (Sheppard & Cook, 1988). Dr. Marc Abrams is well known for his expertise in dendrochronology, particularly as it is used to understand species recruitment in relation to canopy disturbances (Abrams & Downs, 1990; Abrams & Ruffner, 1995; Abrams et al., 1998; Ruffner & Abrams, 1998). Several papers have compared radial growth, stand composition, and stand density data between pre-settlement forests and present-day forests using witness tree data, historical records, and stand structure analysis. Nearly all report a lack of fire occurrences in the last 100 years of fire suppression has led to the increase of shade-tolerant mesophytic species in oak-hickory stands, a concept referred to as mesophication (Abrams & Downs, 1990; Abrams & Ruffner, 1995; Nowacki & Abrams, 2008). Other studies have confirmed that periodic canopy disturbance is required for oak recruitment (Lorimer et al., 1994; Spetich et al., 2022). It has also been shown that logging events in oak woodlands with mesophytic understories will accelerate succession towards a mesophytic overstory (Abrams & Downs, 1990; Holzmueller et al., 2012).

Two studies found dense old-growth is not the "standard" for pre-settlement forests based on stand structure gleaned from witness tree data. Pre-settlement woodlands generally had greater levels of disturbance and fewer trees per acre, with historic fire suppression activity largely responsible for current old-growth density and composition patterns (Crooks, 1988; Fralish, 1997). By the mid-1990s, it had become apparent that oak recruitment was largely lacking, even in old-growth, due to the lack of disturbance allowing for increased stand density (Cho & Boerner, 1995). Boyles & Jones (2008) compared canopy gaps, stand density, and species distribution of old-growth oak woodlands in the Chicago region between pre-settlement times (early 1800s) and the 1990s and reported these northern stands were much more open in the early 1800s and oaks more often seeded into canopy gaps (Boyles & Jones, 2008).

Spetich et al. (2022) compiled studies of old-growth stands from across Eastern North America in an attempt to better define old-growth hardwood forests. The study areas ranged from Eastern Pennsylvania, to Southern Illinois, to East Texas. They found the more mesophytic stands (typically more Eastern) had higher coarse woody debris (CWD) levels than the dryer stands (typically more Western). Oaks were reported as the predominant canopy species on dry-mesic sites with an average stem density of 460 trees per hectare on these sites (Spetich et al., 2022). In Illinois Taft et al. (1995) studied oak flatwoods in the Southern Till Plain Natural Division by recording density and diversity of trees, as well as species richness and diversity of the groundcover. These metrics were compared against each other as well as to the soil types and soil moisture present on each of the 10 sites. They found post oak (*Quercus stellata L.*) to have the highest importance value in the canopy, with the next being blackjack oak (*Quercus* *marilandica L.*). Herbaceous species diversity and richness were lower in stands with high tree density and high tree diversity. The soil moisture levels varied greatly across the flatwoods creating a complex mosaic of wet and dry sites that promote species diversity in the herbaceous understory (Taft et al., 1995).

Studying the floristic quality of woodlands has increased in popularity recently as a means of examining successional patterns and selecting areas for land protection. Floristic Quality Assessment (FQA) is a system for determining the conservation value of a site through census of the floristic species present. Each floristic species is assigned a Conservatism-value (C-value) 0-10 that identifies how likely they are to be found in remnant habitats, a.k.a. those that have experienced little anthropogenic disturbance. Species with low C-values can tolerate high levels of anthropogenic disturbance and do not have an affinity for remnant habitats. The Mean Coefficient of Conservatism (Mean C) and The Floristic Quality Index (FQI) are the standard metrics produced by an FQA. Mean C is the average of C-values from the species present on the study site or plot, while FQI is generated by multiplying Mean C by the square root of the species richness (Spyreas, 2016).

Spyreas & Matthews (2006) is a prime example of the use of floristic quality assessments. They sampled herbaceous vegetation in 106 forests using 0.5 x 0.5 m plots along random transects. 10 x 50 m plots were used to sample the stand diameter and species distribution. The forests they sampled were of varying ages, while none were old-growth. They concluded that species of high floristic quality were found on sites with high species richness and that species poor sites had plant communities that were subsets of the species rich populations. They also found that species richness decreased in later successional forests. They did not conclude there were unique nested species for mature second-growth and did not find a connection between overstory disturbance and understory degradation. They attributed this to their methodology of basal area (BA) measures potentially failing to accurately account for overlapping disturbances in the area and recommended future studies looking at floristic quality variations would do well not to over-generalize disturbance types within a forest (Spyreas & Matthews, 2006).

Spyreas et al (2012) studied floristic quality through a more temporal lens. Floristic quality of abandoned fields was studied over 50 years of undisturbed succession. They found the mean C and FQI values increased over-time eventually reaching an asymptote, suggesting that 50 years of succession brought these values near their maximum. However, when compared with floristic quality values reported for remnant old-growth habitats the abandoned field values were still significantly lower (Spyreas et al., 2012). The intermediate disturbance hypothesis would suggest that the species composition leveled-off due to the frequency of disturbance on the site (Connell & Slatyer, 1977). A different disturbance regime might have allowed the abandoned field to continue increasing in floristic quality. Species richness has been found to be higher in mid-successional forests in the central hardwoods region (Fralish, 1997). On the Shawnee National Forest, sites with less human disturbance were found to have lower levels of non-native taxa in the understory (Basinger & Robinson, 1997). These studies may point to old-growth woodlands containing high conservation value species that second-growth cannot obtain, at least not without management.

Bishop et al. (2021) looked at both stand structure/composition and floristic quality of old-growth and second-growth oak woodlands in Indiana. They found the boundary between second-growth and old-growth starting to blur as their older second-growth reflected similar characteristics to old-growth. The maximum age in the second-growth stand was approaching that of the old-growth stands they examined. The second-growth had high levels of CWD with a moderately dense stand that showed a reverse J-shaped curve diameter distribution, which is typically characteristic of old-growth forests. The floristic quality of the second-growth site was similar to or higher than nearby old-growth sites (Bishop et al., 2021). I came across two studies from 2015 and 2016 by Danny Wilson from University of Wisconsin-Parkside that looked at floristic quality variations in old-growth and second-growth in Southeastern Wisconsin. These studies were never published and only made it to posters. However, the preliminary research could be highly useful in understanding floristic quality in old-growth. Counter to Bishop's results, in both years they found second-growth forests to have lower floristic quality. They found distance from old-growth to be the greatest indicator of floristic quality in the second-growth forests, with the second-growth forests bordering old-growth having higher floristic quality than those of a greater distance (Wilson, 2015; Wilson & Rogers, 2016).

The importance of old-growth forests for scientific and ecological reasons has been discussed in the literature for decades. In their article "Scientific value of trees in old-growth natural areas" Sheppard & Cook (1988) discuss the use of old-growth forests by dendrochronologists to reconstruct disturbance chronologies, without which our understanding of land-use history would be greatly limited (Sheppard & Cook, 1988). There are many species of flora and fauna that require old-growth forests such as Hobblebush (*Viburnum alnifolium*) and the Prothonotary warbler (*Protonotaria citrea*) (Probst et al., 1992; Thompson & Dessecker, 1997; Orwig, 2009).

Old-growth forests are said to contain a unique set of characteristics that younger forests often lack. However, suggestions of what these are vary in the literature, with different authors focusing on different characteristics. Shifley et al. (1995) brought this variation to light when they compared the old-growth characteristics given by three papers on midwestern hardwoods (Meyer, 1986; Parker, 1989; Martin, 1991). All three papers agreed that species richness in the canopy, dense CWD, and canopy gaps were inherent characteristics of old-growth forests. However, they disagreed on many other characteristics. Such as Meyer (1986) posited dominant trees ought to be at least 100 years old, while Martin (1991) said at least 200 years old. Parker (1989) specified a range of bd ft/ac and mortality rates, while the other papers made no mention of such measures. Shifley et al. conducted their own study quantifying multiple variables such as BA, density, diameter distribution, and CWD. They reported that old-growth and (older) second-growth sites varied little, with old-growth only showing significant differences in the larger size classes of trees and more CWD (Shifley et al., 1995).

While general characteristics exist, there is no list of criteria for what an old-growth forest should look like in every unique ecosystem. Spetich et al. (2022) note that it was difficult to make assertions about Eastern North American forests as the various studies they referenced used a variety of research techniques and criteria. They recommend future researchers of old-growth stands attempt to find a uniform approach to their studies so they may be better compared and contrasted (Spetich et al., 2022). Even within Illinois there are no official parameters for old-growth oak-hickory forests despite oak-hickory being the historically dominant ecosystem in the forested parts of Illinois (Fralish, 1997; Thompson & Dessecker, 1997). I was not able to find any statewide or national registry of old-growth forests. Fralish (1991) defines old-growth as being undisturbed by everything including fire (Fralish et al., 1991). However, in his 1997 paper Fralish reiterates the importance of fire in maintaining oak-hickory systems that would otherwise become mesophytic (Fralish, 1997). Fires in the Eastern North American hardwoods rarely consume mature trees (Parker & Ruffner, 2004). For this reason I will not be assuming a lack of fire is necessary for an oak-hickory stand to be old-growth.

The Illinois Department of Natural Resources (IDNR) classifies old-growth forests as "minimum disturbance" with a range of tree sizes and CWD, although they do not give any parameters to these (IDNR report). On their website, IDNR has descriptions of the lands they own/manage. Several of their sites they mention are old-growth oak-hickory woodlands – Beall Woods, Miller-Anderson Woods, Spitler Woods, and Carpenter Park. We know that the Otey-Grisley Nature Preserve in Southern Illinois is old-growth oak-hickory woodland. The deeds showed it had been owned by the same family for over a century with no clear cutting in the land-use history. However, while it is on IDNR's website, it is not noted as old-growth. The Morton Arboretum identified multiple patches of old-growth oak woodland in the Chicago region (Boyles & Jones, 2008). However, none of these are mentioned by IDNR despite at least one being in state holdings. It is likely that other old-growth woodlands are held by private landowners and have gone unnoticed, as was the Otey-Grisley woods before becoming a nature preserve.

It is important to understand the growth dynamics of unique forest systems and functions of old-growth in Illinois so ecologists can better identify, protect, and manage similar stands. The literature is clear that, due to fire suppression, many old-growth oak-hickory forests are filling with mesophytic species and starting to shift away from oak-hickory cohorts (Abrams & Downs, 1990; Basinger & Robertson, 1997; Boyles & Jones, 2008). Due to reduced disturbances and increased in-growth of mesophytes they may become unrecognizable as old-growth and fail to sustain themselves into the future. Old-growth oak and oak-hickory woodlands not only have high conservation value species but affect the floristic quality of secondary forests in proximity to them. However, oak recruitment is still an issue in both old-growth and second-growth woodlands with closing canopies due to lack of canopy-level disturbance (Abrams & Downs, 1990; Lorimer et al., 1994; Abrams & Ruffner, 1995; Boyles & Jones, 2008; Nowacki & Abrams, 2008; Lhotka et al., 2016; Spetich et al., 2022).

The literature in this region on distinguishing factors between old-growth and second-growth is fairly scant. This study offers a unique opportunity to observe an old-growth oak-hickory woodland in Southern Illinois using dendroecology to elucidate the history of the site regarding disturbance trends and their impact on biodiversity. I chose a neighboring second-growth site to determine which characters were unique to the old-growth, using various stand composition analyses and floristic assessments to compare the two forests across multiple types of inquiry from their canopies to their ground layers. My goal is to assist in developing management recommendations for local old-growth forests, and potentially helping second-growth stands shift to older-growth condition by better understanding what characteristics define an old-growth oak-hickory woodland. As one of only a few known old-growth woodlands in all of Illinois, this study could be of use to all hardwood forest ecologists to better understand the typical conditions that constitute old-growth as well as develop, perhaps a clearer set of metrics by which we consider second-growth stands as they mature towards future "old-growth."

Research Questions / Hypotheses

Specific objectives of the research were to determine the characteristics of old-growth oak-hickory woodlands (in the southern IL region) and whether old-growth oak-hickory forests can be defined. I hypothesize that this old-growth oak-hickory forest can be distinguished from the second-growth by the following characteristics.

H1: Oaks and hickories will have significantly higher importance values in the old-growth than in the second-growth, consistent with Wilson (2015), Wilson & Rogers (2016), and Spetich (2022). The old-growth will have a reverse J-shaped diameter distribution, indicating an uneven-aged stand, whereas the second-growth's diameter distribution will be representative of an even-aged stand (Old-growth has a wider range of ages and trees older than 100 years, as well as more large trees, greater than or equal to 43cm in diameter suggested by Shifley et al., 1995). The density of trees will be lower in the old-growth stand than in the second-growth stand, consistent with Crooks (1988), Abrams & Downs (1990), Abrams & Ruffner (1995), Taft et al. (1995), Fralish (1997), and Boyles & Jones (2008).

H2: There will be multiple canopy level disturbances in the tree ring record of the old-growth site that have allowed oak recruitment in the stand through time. Within the second-growth tree ring record there will be few release events, concurrent with previous studies (Abrams & Downs, 1990; Ruffner & Abrams, 1998).

H3: The old-growth will have higher floristic quality (mean C and adjusted FQI) than that of the second-growth. The old-growth site will contain species of high conservation value that are absent from the second-growth. Consistent with Spyreas et al. (2012), Wilson (2015), and Wilson & Rogers (2016).

CHAPTER 2

METHODOLOGY

SITE DESCRIPTION/STUDY AREA

The study sites are located in Williamson County, Illinois just north of Pittsburg within the Mount Vernon Hill Country section of the Southern Till Plain Natural Division (Schwegman et al., 1973) (**Fig. 1**). Both the old-growth and second-growth sites are owned by William Grisley, with the old-growth site protected as a Nature Preserve (NP) and the second-growth protected as a Land and Water Reserve (LWR) by the Illinois Nature Preserve Commission (INPC). These sites were protected because of their relatively undegraded state and high potential for restoration. 14 birds listed as Species of Greatest Concern are known to breed in these woods (Sierzega, 2019). Both woodlands were hit by the derecho in May 2009 that downed a large number of canopy trees which resulted in several stems being removed, but not all.

The old-growth woodland is the Otey-Grisley Nature Preserve managed by INPC (37°47'17.18"N 88°50'14.06"W). This site contains 12.4 hectares of dry-mesic upland woods with the 11.2 hectares classified as Grade B, meaning it is not very degraded (INAI #1614). The soils are Bluford and Ava silt loams (Web Soil Survey, 2022). The canopy is dominated by upland hardwood species. Some canopy trees were reported to be over 200 years old (Edgin, 2015). The ground flora comprise many species typical of dry-mesic woodlands. Invasive species encroachment is a concern on the sites, particularly from autumn olive (*Elaeagnus umbellate L.*), Japanese honeysuckle (*Lonicera japonica L.*) and the recent arrival of Japanese chaff flower (*Achyranthes japonica L.*) (Kevin Sierzega, *personal communication* 2022). Before it was purchased by Mr. Grisley this tract had been in the ownership of the Otey family for over 100 years. In 1965 a powerline right of way was cut into the western side of the tract and this easement remains cleared of trees. According to the landowner there had not been fire on this site in over 80 years, until the prescribed burn conducted on January 30th, 2022 (William Grisley, *personal communication* 2022). The prescribed fire successfully top-killed many sassafras saplings and autumn olive, although many have resprouted. Kevin Sierzega (INPC field staff) has conducted invasive species control over the last 3 years, removing a large portion of the autumn olive.

The second-growth site is part of a designated Land and Water Reserve. This site is less than a ¼ mile north of the old-growth site along the same ridgeline with more pronounced topography (37°47’41.67”N 88°50’14.50”W). The section we studied is the southern 10.1 hectares of dry upland Grade C and bottomland Grade C woods of the total 43.5-hectare site. The soils are mainly Belknap and Hickory-Kells silt loam, as well as Hickory clay loam (Web Soil Survey, 2022). The canopy is also dominated by upland hardwood species. The second-growth LWR had changed hands many times over the last century before it was purchased by Grisley. It was clearcut in the late 30s to early 40s and experienced subsurface mining that only disturbed 0.8 hectares of the surface. This site has the same invasive species concerns as the nature preserve. A prescribed burn was also conducted on this site January 31st, 2022, and the INPC team have conducted invasive species control similar to that on the nature preserve.

FIELD DATA COLLECTION

I collected field data over the summer of 2022 with the help of my undergrad intern Nicole Launius. Dr. Ruffner assisted with the overall sampling design and use of equipment, particularly the extraction of cores. Using ArcMap 10.8.1 I set up transects running East/West across each site, with 5 transects for the old-growth site and 4 transects for the second-growth site. On each site I marked plots along the transects 75 meters apart and at least 20 meters away from the site boundaries, with 17 plots on the old-growth site and 13 plots on the second-growth site. I then transferred these data from ArcMap to a Garmin GPS which I used to locate points on the ground. For each plot I marked the center with a stake before collecting data and flagged the center with tree tape before leaving. We recorded all data on printed sheets of water-resistant paper and transferred them to Excel spreadsheets in the lab. The data for the two study sites were kept in two different excel files, with each plot as a separate spreadsheet within their respective site files.

Stand Structure Analysis

My assistant and I sampled species, canopy position, and diameter at breast height (DBH) for all trees with a diameter greater than 10cm within a 15m radius of the plot center. I categorized canopy position as dominant, codominant, intermediate, or over-topped. Trees within the 15-meter radius that were dead were left out of the analysis. We quantified seedlings by species in a 1.2m radius from the plot center and the saplings by species at a 1.7m radius from the plot center, so that these measures were nested within the larger 15-meter plots. I defined seedlings as any tree less than 0.6cm in diameter, while I defined saplings as any tree 0.6-10cm in diameter. I also used a densiometer to record the percent canopy cover at the center of each plot. Back in the lab, we transferred these data to the excel files for the respective study sites, and then based on relative frequency, cover (basal area), and density I calculated the importance values of trees by species on each site. As well as the number of each species per canopy class, the density (trees per hectare), and basal area (meters squared per hectare) on each site. I calculated the mean, density (per hectare), and frequency of seedlings and saplings for each site.

Coring and Cookies

We collected 3-4 cores per plot across multiple species and diameter classes, with the largest white oak always cored if present and in sound condition. The goal was to take 1-2 cores in the largest size class (>45cm DBH), 1 in a medium size class (25-45cm DBH), and 1 in the smallest size class (10-25cm). We were able to stick to this goal for the most part, with the exception of a few plots that did not have trees in every size class or the trees were not in sound condition for coring. We also took cores from individual trees that appeared to be the largest on site if they fell outside the 15m plots, these were not included in the stand inventory calculations and were only used for disturbance chronologies. We destructively sampled 2 cookies from each 15m radius plot of varying species of saplings (<10cm DBH) to attain ages of this diameter class.

The cores were placed in paper straws for transportation to the lab where we let them air dry on wooden core mounts before gluing them into place. Once the glue dried, we sanded each core first with a hand-held electric sander (150-350 grit), then manually with increasingly finer grit sandpaper (400-800 grit). The cookies were sanded in the same fashion as the cores (not requiring mounts). Once sanded, I began dating the cores and cookies by ring counting and skeleton plotting each to establish cross-dating and signature years (Stokes, 1996). Once I obtained the established pith dates of the trees, I plotted them against their diameters to create diameter-age distributions for the two study sites. I marked the genera of trees in the diameter-age graphs but did not depict them to the species-level as it made the graph difficult to interpret.

Floristic Quality Assessment

I used a 0.5x0.5-meter collapsible quadrat made of PVC and elastic string. I placed the quadrat first 2 meters to the North and then 2 meters to the South of the plot center so there were two quadrat measures per 15-meter plot. I counted the herbaceous species per quadrat, keeping

North and South separate. There was a total of 34 quadrats in the old-growth site and 26 in the second-growth. With the help of my field assistant, we counted every species within each quadrat, using a dichotomous key and plant identification app when necessary to determine species. We collected floristic data before the stand structure analysis data at each plot so as not to trample the herbaceous species before identifying them. These data were collected in the height of the growing season (June-July) when vegetation was the easiest to identify.

In the excel spreadsheet for each plot I kept the north and south quadrats in separate columns. I entered each quadrat into the Universal Floristic Quality Assessment Calculator as separate assessments to obtain the mean C and adjusted FQI for each quadrat across both sites. The adjusted FQI depicts the influence of non-native species and reduces sensitivity to species richness in the calculations.

Statistical Analyses

I ran Welch's two-sample t-tests on the Mean C, the Adjusted FQI, tree density, sapling density, seedling density, DBH measures, basal areas, and percent canopy treating each quadrat or plot as an observation and the two sites as two groups to test for a significant difference in the means. Grouping the saplings and seedlings into *Quercus*, *Carya*, non-*Quercus/Carya*, and non-*Quercus*, I found their densities on each site within the total plot areas and scaled this up to estimate saplings and seedlings per hectare in each group.

I created an importance value table for each site by finding the relative density, relative frequency, and relative dominance of each species in the canopy. Once the age was found for each core, I plotted it against the diameter of the corresponding tree to create a diameter-age graph for each site. I took the ages of the dominant and co-dominant trees in the canopy of each site and ran another Welch's two-sample t-test on these.

Dr. Ruffner and I skeleton plotted the cores from the white oak and 10 of the hickories from each site. I then scanned these cores to create ring width (0.001 mm) files using the WinDENDRO system. I detrended the ring width data for each tree using either a negative exponential regression or mean growth and created chronologies for white oak and hickory for each site using the dplR package in RStudio (Bunn, 2008; Bunn, 2010; Bunn et al., 2022; R Core Team, 2022). Detrending is the process of fitting the ring width data from a core to a line that removes the noise of standard growth variations of each tree. A master chronology combines the ring width indices from many cores to create a standardized trendline showing canopy-level periods of below or above average growth. Radial growth analysis (Nowacki & Abrams method) marks specific years of release in each tree using raw ring width measures. When many trees display a common decade of release it can be assumed that a canopy-level disturbance took place. Nowacki & Abrams reported 10-year intervals accurately displayed intermediate release periods while ignoring short-term climatic variations. Canopy-level disturbances were those that had more than 25% of samples experiencing at least a moderate/major change in growth rates (Nowacki & Abrams, 1997; Bunn, 2008; Bunn, 2010; Altman et al., 2014; Zang & Biondi, 2015; Bunn et al., 2022; R Core Team, 2022).

CHAPTER 3

RESULTS

Stand Structure Analysis

The difference in mean percent canopy cover between the two sites was found to be significant ($T_{df} = -4.604_{26.162}$, p-value = 9.442e-05). The second-growth stand had a significantly higher mean percent canopy cover of 91.9% than the old-growth which was 84.5%. The most important species in the canopy of the old-growth was white oak with a value of 78.5 comprising nearly half of the BA in the stand (**Table 1**). The next most important was pignut hickory (*Carya glabra L.*) with a value of 43.4 based on its high relative density. The most important species in the canopy of the second-growth was shagbark hickory with a value of 53.2, followed by white oak with a value of 41.2 (**Table 2**). Black oak was more important in the second-growth, with a value of 36.2, than in the old-growth, with a value of 16.7. Sassafras was more important in the old-growth, with a value of 33.6, than in the second-growth, with a value of 15.9. American elm (*Ulmus americana L.*) though not of high importance due to its small basal area, was the 4th highest in density on the second-growth site. The second-growth was significantly more dense with 337 trees per hectare, while the old-growth had 280 trees per hectare ($T_{df} = -3.024_{25.247}$, p-value = 0.005). The difference in average BA between the sites was insignificant ($T_{df} = 1.111_{27.809}$, p-value = 0.276), as was the difference in average diameter ($T_{df} = 0.770_{26.919}$, p-value = 0.448).

Oaks and hickories dominate the co-dominant and dominant canopy classes on both sites (**Fig. 2 and 3**). Oaks are scarce in the intermediate and over-topped canopy classes. However, hickories are more abundant in the intermediate class than any other group and are still fairly abundant in the over-topped class on both sites. The density of sassafras on the old-growth site can again be seen here in the intermediate and over-topped classes. On the second-growth site elms are more common in these canopy classes.

A Welch's two-sample t-test proved the difference in seedling density to be insignificant ($T_{df} = -1.951_{14.373}$, p-value = 0.071), as was the difference in sapling density ($T_{df} = 0.539_{26.638}$, p-value = 0.594). The sapling and seedling layers on both sites were dominated by species other than oak and hickory (**Table 4**). This suggests there is virtually no recruitment of oak and hickory into the canopy (Arthur et al., 2012).

Disturbance Chronology

The oldest tree cored on the old-growth site was a shagbark hickory that was 227 years old. The oldest tree cored on the second-growth site was a white oak that was 152 years old. The average age of dominant/co-dominant trees in the old-growth was 138.8 years, while the average age of dominant/co-dominant trees in the second-growth was 71.5 years. That is a difference of 67.3 years which a two-sample t-test displayed as highly significant ($T_{df} = 9.881_{50.826}$, p-value = 2.008e-13).

Hickories appear suppressed on both sites throughout time, with their diameters never reaching above 60cm even when their ages exceed some of the oaks which frequently achieve diameters greater than 80cm (**Fig. 6 and 7**). Several trees on the second-growth are older than the logging disturbance in the late 1930s to early 40s, but most seeded in after this period as expected. While sassafras is more abundant on the old-growth now, it entered the stand much later in the 1980s, and does not appear to have become common until the late 1990s. The old-growth white oak chronology revealed periods of above average growth in 1860, 1880-95, 1920, 1940-50, and 1980-2005. The old-growth hickory chronology revealed above average growth in 1870-75, 1905-1920, 1940-50, 1985, 2010. Between these periods of above average growth there were periods of suppression that were much more pronounced in the hickories (**Fig. 6 and 7**). The second-growth chronologies show above average growth around the 1940s in both white oak and hickory (just after heavy cutting took place on the site). The second-growth chronologies show a period of extremely high growth before 1915 and a period of extremely low growth between 1920-1940. However, it should be noted that these measures come from only 3 individual trees, 1 hickory and 2 oaks.

Radial Growth Analysis (Nowacki & Abrams, 1997) revealed release events in the old-growth stand in the 1930s-40s with lesser events in the early 1900s and 1980s (**Fig. 8-13**). The second-growth site showed release events in the 1980s-90s and 2000-2010. The increased hickory growth seen in the old-growth chronology after 2010 did not appear as significant in the Radial Growth Analysis. The increased growth on the second-growth site in the 1940s is not visible through this method as it is due to trees seeding in and not released after years of suppressed growth.

Floristic Quality Assessment

A t-test revealed site Mean C of the old-growth stand was significantly higher than that of the second-growth stand, with the old-growth averaging 2.69 and the second-growth averaging 2.34 ($T_{df} = 2.662_{53.327}$, p-value = 0.010). The same was true for the Adjusted FQI, with the old-growth stand averaging 28.5 and the second-growth stand averaging 25.03 ($T_{df} = 2.800_{50.421}$, p-value = 0.007). There were 49 species on the old-growth site, 41 of them native. On the second-growth site there were 43 species, 37 of them native. The sites had 25 species in common (**Table 5**). Virginia creeper (*Parthenocissus quinquefolia*) was common on both sites. Though on the second-growth site its occurrence was equal with the invasive Japanese honeysuckle (*Lonicera japonica*). Of the top 10 species of highest occurrence on the old-growth site none were invasive (**Table 6**).

CHAPTER 4

DISCUSSION

Stand Dynamics

My first hypothesis (H1) was that oaks and hickories would be of higher importance in the old-growth than in the second-growth based on Wilson (2015), Wilson & Rogers (2016), and Spetich (2022). This was confirmed in oak, while hickories were important in both sites. White oak is highly dominant in the old-growth due to high relative BA, density, and frequency. On the second-growth site white oak appears less important as shagbark hickory has become the principle canopy species with highest importance. This is due to their high frequency and density, as no single species exhibited high BA in the second-growth. However, in the sapling and seedling layer it appears the hickories are struggling, with very few in the seedlings and no saplings on the second-growth site. Both oaks and hickories showed some regeneration in the seedling layer of the old-growth, but very few saplings. This is the sapling bottleneck trend seen across the eastern hardwoods causing the failure of oak-hickory to successfully recruit into the overstory (Abrams & Downs, 1990; Lorimer et al., 1994; Abrams & Ruffner, 1995; Nowacki & Abrams, 2008; Boyles & Jones, 2008; Arthur et al., 2012; Lhotka et al., 2016; Spetich et al., 2022).

Sassafras had higher importance in the old-growth stand. This is due to the high density as all the sassafras are in the smaller size classes. However, only 40% of the trees in the old-growth were mesophytic and early successional species, while 58% of the trees in the second-growth were considered mesophytic and early successional.

As hypothesized, the old-growth stand had lower density (trees per ha) than the second-growth stand, as has been suggested as a characteristic of old-growth oak-hickory woodlands by previous studies (Crooks, 1988; Abrams & Downs, 1990; Abrams & Ruffner, 1995; Taft et al., 1995; Fralish, 1997; Boyles & Jones, 2008). However, the BA per hectare and average DBH was not significantly different between sites. Fralish et al. (1991) studied 6 forest types across the Shawnee Hills and reported old-growth had higher basal area than presettlement and second-growth stands, while second-growth stands were denser with lower mean diameters than either (Fralish et al., 1991). In the current study the second-growth canopy is denser than the old-growth canopy according to the average canopy covers that revealed the second-growth stand having significantly less light.

In 2015 the Otey-Grisley Nature Preserve was sampled by INPC for density and BA. Both metrics were lower than what was sampled in this study. They reported a density of 247 trees per hectare (TPH) and a BA of 13.83 square meters per hectare, while I reported 280 TPH and a BA of 23.5 square meters per hectare. INPC compared the 2015 Otey-Grisley results with their 1997 report from Beall Woods Nature Preserve located in Wabash County, IL. Beall Woods is considered to be a high quality old-growth oak-hickory woodland with 330 TPH and BA of 26.23 square meters per hectare (Edgin, 2015). Perhaps this is a sign that the Otey-Grisley old-growth is approaching the conditions of Beall Woods. Although, this may also mean it is moving further away from presettlement conditions in which oaks and hickories thrived. Fralish et al. (1991) noted that on dry-mesic and ridgetop sites, old-growth stands were highly similar to presettlement conditions with open canopies dominated by large white and black oaks. Based on their description, this old-growth stand would be considered a dry-mesic ridgetop site out of the 6 site types. It is not as open as the presettlement communities described due to crowding in the midstory, but it certainly could become so with a fire regime resembling that of presettlement times (Fralish et al., 1991).

Shifley et al. (1995) suggested that old-growth should display a reverse J-shaped diameter distribution within an uneven aged stand (Shifley et al., 1995). The Otey-Grisley old-growth stand displayed a reverse J-shaped diameter distribution curve with the few trees in the larger size classes and many trees in the smaller size classes (**Fig 4**). However, the second-growth also displayed a reverse J-shaped diameter distribution, though on a smaller scale (**Fig. 5**). This is due to some older oaks that survived the logging likely because they were small at the time. Overall, the second-growth was much younger, but the diameter distributions are similar and it could not be said to be even aged. This stand composition having two distinct cohorts, one from before a logging event and one after, reflects the similar findings of Lhotka et al. (2016) in a central Illinois upland oak forest.

Disturbance Chronology

My second hypothesis (H2) was that the old-growth stand had been receiving some level of periodic canopy disturbances, fostering the continued oak recruitment through time concurrent with several studies (Abrams & Downs, 1990; Ruffner & Abrams, 1998). This was confirmed in the chronologies and radial growth analysis which displayed multiple periods of moderate release in the old-growth through time. The second-growth chronologies show a spike in growth for white oaks and hickories around the 1940s corresponding to when the majority seeded in just after heavy cutting took place on the site. There is a similar period of increased growth in the chronologies of the old-growth, however, for which we have no record of a disturbance during this time period. Whatever the disturbance may have been, it was not enough to cause a cohort to seed into the canopy of the old-growth. Several hickories seeded into the old-growth between 1940 and 1990, but only two oaks did.

The continued suppression of the hickories was not in my original hypotheses, however, their ability to persist in this manner has been reported in the past (Nixon et al., 1983; Knapp et al., 2021). The white oak (*Q. alba)* may have suppressed the hickories (*Carya)* for over a century on both sites, seeding in slightly before the hickory cohorts and keeping them from reaching the largest size classes. However, hickory releases do not align with oak suppression periods. Rather, they oscillate in tandem for the most part, with hickories having more extreme periods of suppression and release. Hickories are nevertheless high in density in the overstory and occupy more of the intermediate layer than oak species. This may be due to their slightly higher shade tolerance than oaks and ability to respond rapidly to canopy gaps (Nixon et al., 1983; Knapp et al., 2021). There was a spike in growth of the hickories in 2010 on the old-growth stand, this may be attributed to the 2009 derecho which felled several large canopy trees on the site, most of them dominant oaks.

The white oak and hickory chronologies on the second-growth show little variation from the average growth after 1960. However, the radial growth analysis displays individual release events on the second-growth in the 1980s and 2000s in both white oak and hickories. The old-growth stand displayed many release events from the 1980s-2000s as well. Before 1960 the periods of release marked by the radial growth analyses line up with those seen in the chronologies. Although the high growth of the 1930s-40s is not as pronounced in the radial growth analyses. Because the radial growth analyses are conducted on raw ring widths and not detrended across the stand, this suggests many individuals seeded in during this time period, however, each individual did not exhibit high growth rates.

The second-growth site rapidly gained early successional species after the logging, as the intermediate disturbance hypothesis would anticipate (Connell & Slatyer, 1977). Abrams &

Downs (1990) reported mesophytic trees replacing oaks after a logging event in southeast Pennsylvania. In their case it was late-stage oak replacement with oaks only in the largest classes and exhibiting low importance values. Our site has not reached this declining stage but is perhaps headed down that path. This study did not have the maple, beech, or tulip poplar components they had as our mesophytic species are generally more on the early successional side such as elms (*Ulmus*), black cherry (*Prunus serotina*), and ash (*Fraxinus*) (Abrams & Downs, 1990). Regardless, the second-growth stand is still dominated by hickory and oak in the canopy, although the midstory and understory show elms taking over. Currently similar early successional species are replacing oaks in the old-growth understory.

Fast-growing sassafras took advantage of the light in the semi-open canopy and likely seeded in from bordering early successional property. In 1965 the powerline right of way was cut into the western side of what is now the Otey-Grisley Nature Preserve where it now borders the old-growth site. This strip is now 4.3 acres of early successional species including sassafras. The 2009 derecho may have added to this (Holzmueller et al., 2012), but many individuals date back to the late 1990s. There was a higher presence of black oak (*Q. velutina*) on the second-growth site. It has been suggested before that black oaks belong to an earlier successional stage than white oaks as they respond faster to canopy openings and colonize readily (Nowacki & Abrams, 1997).

As to what the disturbances were that caused so many release events on these sites through time, there are no specific reports other than the heavy logging and minimal mining in the late 1930s to early 1940s and the derecho of 2009. Heavy wind storms are a common cause of canopy damage in Southern Illinois. Tornados periodically pass through Williamson county, but the records do not have data before 1950 or specify which areas were affected (National

Oceanic and Atmospheric Association, 2022). I could not find records of any other major disturbance. The 1938 historical photo (**Fig. 14**) shows that the second-growth site was already greatly altered from the old-growth site. The second-growth canopy is patchy with very few large trees and open meadows in the lowlands suggesting it had experienced some cutting and was likely being grazed at that time. Meanwhile the old-growth canopy is virtually indistinguishable from current satellite images. It is likely that the site experienced multiple logging events prior the 1940s. Exogenous disturbances, such as the powerline right-of-way, agriculture, and other land-uses would have influenced both stands in a myriad of ways but could not be parsed out in exacting detail for this study.

Floristic Quality Assessment

I hypothesized (H3) the floristic quality would be higher in the old-growth understory than in the second-growth understory consistent with Spyreas et al. (2012), Wilson (2015), and Wilson & Rogers (2016). My results confirmed this with both Mean C and Adjusted FQI significantly higher in the old-growth. However, the site Mean C on both sites was lower than I expected with very few species higher than a C5. Basinger & Robinson (1997) found that less disturbed areas had less non-native taxa (Basinger & Robinson, 1997). While we did not find less non-native species in the old-growth, their frequency was much lower. The second-growth had more invasive Japanese honeysuckle than any other species, while the old-growth did not have an invasive species in the top 10 most common species found.

Other studies point to old-growth woodlands containing high conservation value species that second-growth cannot obtain, at least not without management (Basinger & Robinson, 1997; Fralish, 1997; Spyreas et al., 2012). Both sites had unique species. However, the old-growth ddid not have any species that would be considered high floristic quality (C values of 7-10), while the second-growth did have one species that would be considered of high floristic quality, downy yellow violet (*Viola pubescens L.*) (C7). It should be noted that INPC has observed high quality species on the old-growth site, such as purple milkweed (*Asclepias purpurascens L.*) (C7) and American columbo (*Frasera caroliniensis L.*) (C8). However, none of these appeared in my sampling quadrats. A study method with a finer grain (more quadrats) would potentially find more species.

Bishop et al. (2021) reported older second-growth forests developing characteristics of old-growth. I think this is possible in many places. There is also an idea that forests need to be completely undisturbed to be old-growth (Fralish et al., 1991). However, this is not the case in most oak-hickory woodlands. If they remain untouched by fire they will not be old-growth oak-hickory, they will become a mixed mesophytic stand (Abrams & Downs, 1990; Ruffner & Abrams, 1998; Nowacki & Abrams, 2008). Wiley et al. (2008) reported oak woodlands in southeastern Wisconsin were experiencing native species richness loss as mid-successional generalist species dominated the understory and shade-tolerant specialists failed to recruit into the increasingly shaded conditions. While they acknowledged the importance of fire in maintaining oak stands, they warned that other factors are at work. Fragmentation prevents native species from colonizing new areas and heavy deer browse has damaged the understory of many woodlands. My study sites are small fragments of woodlands recognized for their quality among agricultural land and highly degraded forest. It is likely they suffer from the same limitations discussed above (Wiley et al., 2008).

I compared my results with those of previous studies that have attempted to better define the characteristics of old-growth in the Eastern hardwoods (**Table 7**) (Meyer, 1986; Parker, 1989; Martin, 1991; Shifley et al., 1995; Bishop et al., 2021; Spetich et al., 2022). There was a lot of overlap, but no two studies had measured the same metrics across the board. As mentioned by Spetich et al. (2022), many studies vary greatly in methods, making it difficult to compare them. Of these studies, Bishop et al. (2021) was the only other one to report on floristic quality, although Spetich et al. (2022) reported species richness. There was a striking similarity in diameter distribution and basal area across the studies, with all but one reporting a reverse J-shaped diameter distribution and in no significant difference between old-growth and "older" second-growth stands (Meyer, 1986; Parker, 1989; Martin, 1991; Shifley et al., 1995; Bishop et al., 2021; Spetich et al., 2022). Of these metrics, species composition, density, canopy age, and floristic quality appear to be the most important in distinguishing old-growth from second-growth.

High floristic quality species are not commonly found in anthropogenically disturbed areas and therefore, should be found in less disturbed areas such as old-growth stands. It is important to understand whether or not this is reflected in the data, and if not, why? Only then can habitat be managed for the survival of such species and biodiversity as a whole.

CHAPTER 5

CONCLUSION

It appears the old-growth stand has some notable characteristics, with higher floristic quality under a semi-open canopy dominated by mature white oak with a strong hickory component. Despite a lack of fire, mesophytic species have not yet taken over the site. Whereas, in the second-growth they seem to be establishing in the midstory more rapidly. However, the sapling and seedling layers tell us that both sites are likely to succeed into mixed mesophytic canopies as the mature oaks and hickories die out. The similarities between the two sites in their species diversity, diameter distributions, and basal areas point to the second-growth stand maturing toward an old-growth stand. This second-growth site, the Grisley Woods Land and Water Reserve, could come to resemble the old-growth site on the Otey-Grisley Nature Preserve. However, this will require management with fire, thinning, and invasive species treatments. The old-growth will also require some management if it is to remain the open oak-hickory woodland it is today. Thanks to INPC, Bill Grisley, SIU Forestry, and other volunteers, this effort is already underway.

Limitations

I did not collect coarse woody debris (CWD) data on either site, despite this being a common metric in the literature. Both sites had experiences salvage logging of downed trees after the derecho of 2009 which greatly altered the CWD levels that would otherwise have been present. I also believe a floristic quality assessment with a higher quadrat density may have more accurately depicted the herbaceous species on both sites. I did not have the time and resources for a study on that scale. Potential future research could involve measuring fuel type and conducting prescribed fire on both sites with sampling in the following growing season. While this study may not provide an objective definition for considering old-growth conditions within and across various stands, it is an example of the current conditions of oak-hickory stands in these two contrasting states of succession and will hopefully be a resource for managers to use in moving current older second-growth stands into "old-growth status." It is important for studies such as this to be repeated with similar methods over time to build legacy data that has the potential to further enlighten the ecological community (Spetich et al., 2022).

EXHIBITS

TABLES

Table 1. Components of the Importance Values for overstory trees in the old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL. Importance being the sum of relative frequency, relative density, and relative dominance.

Species	Relative Frequency (%)	Relative Density (%)	Relative Dominance (%)	Importance (sum)
Quercus alba	**12.93**	**17.26**	**48.36**	**78.55**
Carya glabra	**12.93**	**16.67**	**13.84**	**43.44**
Carya ovata	**12.07**	**13.99**	**11.57**	**37.63**
Sassafras albidum	**12.07**	**18.45**	**3.12**	**33.64**
Carya tomentosa	**9.48**	**10.42**	**6.47**	**26.37**
Quercus velutina	**6.03**	**2.68**	**7.95**	**16.66**
Ulmus rubra	**6.90**	**5.06**	**0.89**	**12.84**
Morus rubra	**6.90**	**4.46**	**1.07**	**12.43**
Cornus florida	**6.90**	**4.76**	**0.58**	**12.23**
Quercus rubra	**3.45**	**1.49**	**3.04**	**7.98**
Ulmus americana	**3.45**	**1.19**	**0.27**	**4.91**
Prunus serotina	**2.59**	**1.49**	**0.75**	**4.83**
Quercus falcata	**1.72**	**0.60**	**0.94**	**3.25**
Quercus stellata	**1.72**	**0.60**	**0.65**	**2.97**
Acer saccharum	**0.86**	**0.89**	**0.50**	**2.25**
Total	**100.00**	**100.00**	**100.00**	**300.00**

Table 2. Components of the Importance Values for overstory trees in the second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL. Importance being the sum of relative frequency, relative density, and relative dominance.

Species	**Relative Frequency (%)**	**Relative Density (%)**	**Relative Dominance (%)**	**Importance (sum)**
Carya ovata	**10.53**	**25.48**	**17.20**	**53.21**
Quercus alba	**11.40**	**10.00**	**19.79**	**41.20**
Quercus velutina	**8.77**	**6.45**	**21.01**	**36.23**
Carya glabra	**7.89**	**11.94**	**14.97**	**34.80**
Quercus rubra	7.02	4.84	10.98	22.84
Ulmus americana	7.89	7.42	1.66	16.98
Sassafras albidum	7.02	6.45	2.46	15.93
Ulmus rubra	6.14	7.10	2.00	15.24
Cercis canadensis	6.14	5.81	1.38	13.32
Cornus florida	4.39	3.87	0.58	8.83
Prunus serotina	3.51	2.58	2.08	8.17
Quercus stellata	2.63	0.97	1.66	5.26
Ulmus alata	2.63	1.61	0.42	4.67
Juglans nigra	2.63	1.29	0.54	4.46
Quercus falcata	1.75	0.65	1.83	4.23
Nyssa sylvatica	2.63	0.97	0.49	4.09
Carya tomentosa	2.63	0.97	0.42	4.02
Fraxinus pennsylvanica	2.63	0.97	0.41	4.01
Morus rubra	1.75	0.65	0.12	2.52
Total	**100.00**	**100.00**	**100.00**	**300.00**

Table 3. The density of trees and basal area (BA) per hectare in the old-growth and second-growth stands at the Otey-Grisley Nature Preserve and Grisley Woods Land and Water Reserve, Pittsburg, IL.

Per Hectare	**Old-Growth**	**Second-Growth**
Trees (#)	280	337
Basal area (m^2)	23.50	24.76

Table 4. Density of saplings and seedlings per hectare on old-growth site (Otey-Grisley Nature Preserve) and second-growth site (Grisley Woods Land and Water Reserve), Pittsburg, IL.

Saplings per hectare						**Seedlings per hectare**				
Old-growth			**Second-growth**			**Old-growth**			**Second-growth**	
Quercus	65		*Quercus*	85		*Quercus*	1300		*Quercus*	2381
Carya	259		*Carya*	0		*Carya*	3641		*Carya*	2041
non *Q-C*	843		non *Q-C*	847		non *Q-C*	6632		non *Q-C*	19728
non *Q*	1102		non *Q*	847		non *Q*	10273		non *Q*	21769
Total	1167		**Total**	932		**Total**	11573		**Total**	24150

Table 5. Native and non-native species unique to each site and those present on the on old-growth site (OG) (Otey-Grisley Nature Preserve) and second-growth site (SG) (Grisley Woods Land and Water Reserve), Pittsburg, IL.

Status	OG Unique Species	SG Unique Species	Shared Species
Native	17	12	25
Non-Native	2	1	6

Table 6. The 10 species with the highest occurrence (the number of quadrats in which they were present) on the on old-growth site (Otey-Grisley Nature Preserve) and second-growth site (Grisley Woods Land and Water Reserve) respectively. Pittsburg, IL.

OG Species	C value	Quadrats	SG Species	C value	Quadrats
Parthenocissus quinquefolia	2	25	*Lonicera japonica*	0	12
Eupatorium rugosum	2	21	*Parthenocissus quinquefolia*	2	12
Galium circaezans	4	20	*Sanicula canadensis*	4	11
Polygonum virginianum	3	16	*Carex pensylvanica*	5	10
Sanicula canadensis	4	15	*Viola sororia*	3	10
Carex pensylvanica	5	14	*Erichtites hieraciifolius*	2	8
Erichtites hieraciifolius	2	13	*Phytolacca americana*	1	8
Phytolacca americana	1	12	*Polygonum virginianum*	3	8
Acalypha virginica	2	11	*Oxalis stricta*	0	7
Viola sororia	3	11	*Acalypha virginica*	2	6
Average	**2.8**		**Average**	**2.2**	

Table 7. Comparing metrics across previous studies with this one. OG = old-growth and SG = second-growth. Metrics from top down are as follows, species of highest importance value, density (trees/hectare), basal area (m^2/hectare), mean canopy age (years), coarse woody debris (CWD, units vary), reverse J-shaped diameter distribution, mean coefficient of conservatism (mean C), and herbaceous species count. Cells left blank refers to metrics not reported in that study.

	Shifley et al. (1995)		**Meyer (1986)**	**Parker (1989)**	**Martin (1991)**	**Bishop et al. (2021)**		**Spetich et al. (2022)**	**This study**	
	OG	**SG**	**OG**	**OG**	**OG**	**OG**	**SG**	**OG**	**OG**	**SG**
Spp. high IV	COFL, QUAL	QUAL, QUCO					ACSA	QUAL, QURU, QUVE	QUAL	CAOV
Density trees/ha	582, 623	439, 675		160-427	247	226	310	341-620	280	337
BA m^2/ha				25.2-34.4	>20.6	31.4	31.9	<23.0 in S IL.	23.5	24.8
Mean canopy age (years)			>100	>100	>100	105-173	113	170-365	139	72
CWD				15.6-24.6 Mg/ha	"high levels"	30.4 m3/ha	45.89 m3/ha	52 m3/ha		
Reverse J	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Yes
Mean C						2.7-4.4	4.3		2.7	2.3
Herb. Spp.						118-525	428	4-51	49	43

FIGURES

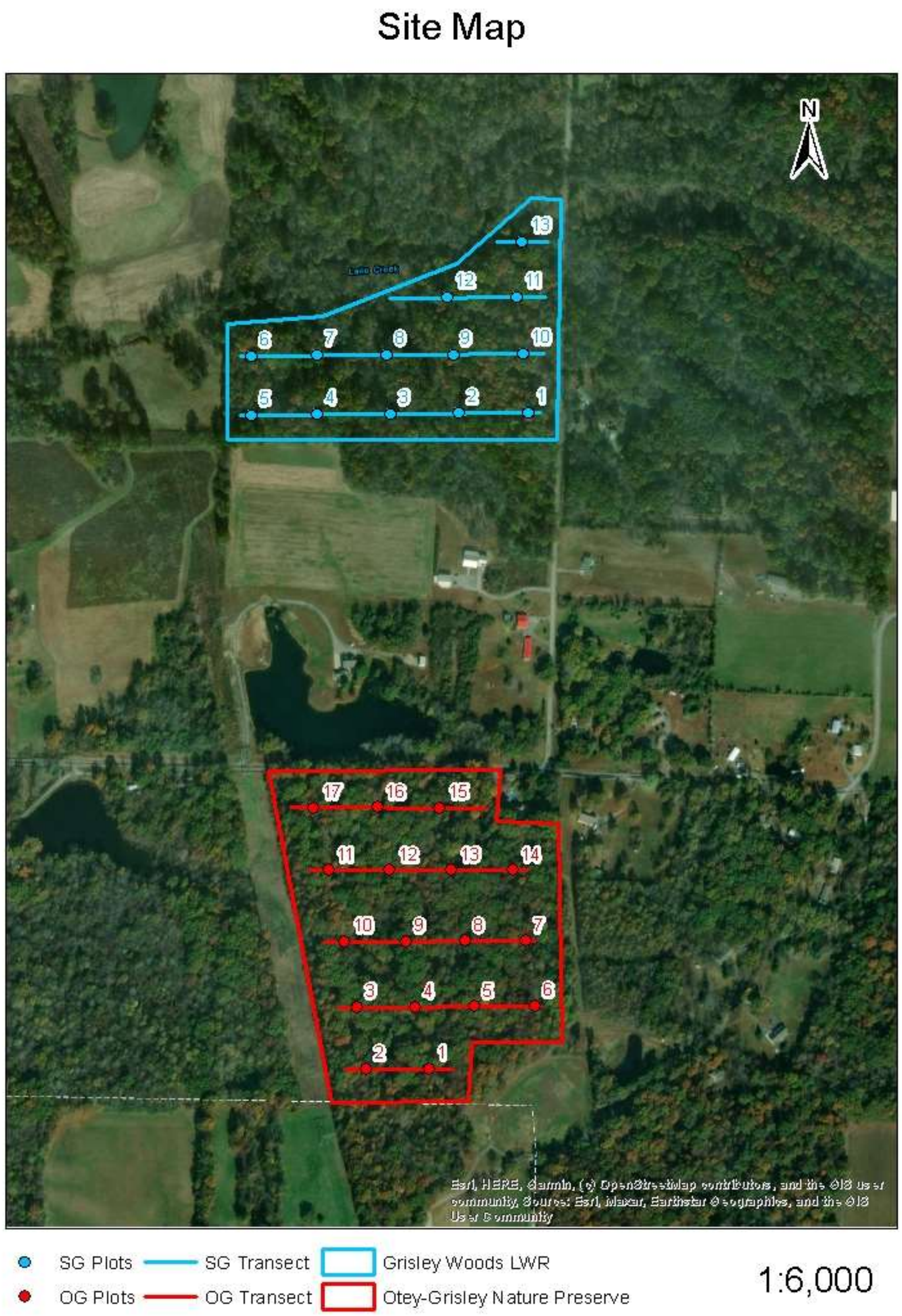

Figure 1. Map of the two study sites. The Otey-Grisley Nature Preserve (old-growth) is in red (to the south) and the Grisley Woods Land and Water Reserve (second-growth) is in blue (to the north).

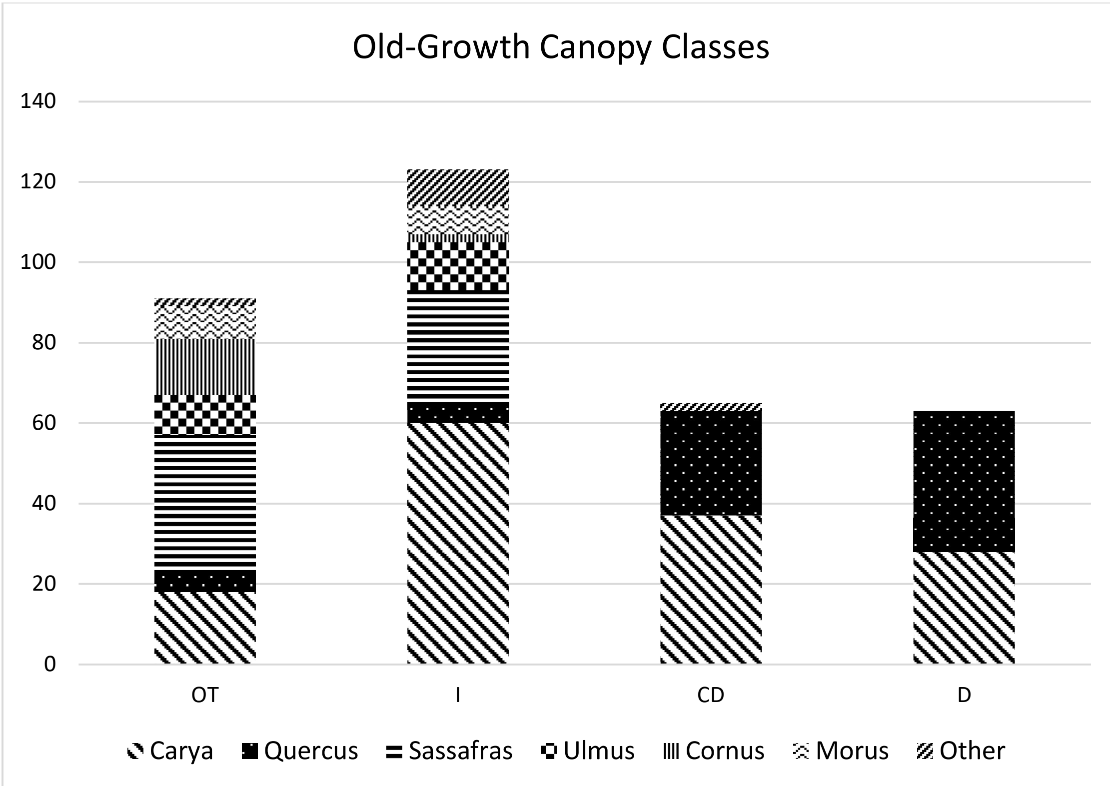

Figure 2. Trees per canopy class based on species group in the old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL.

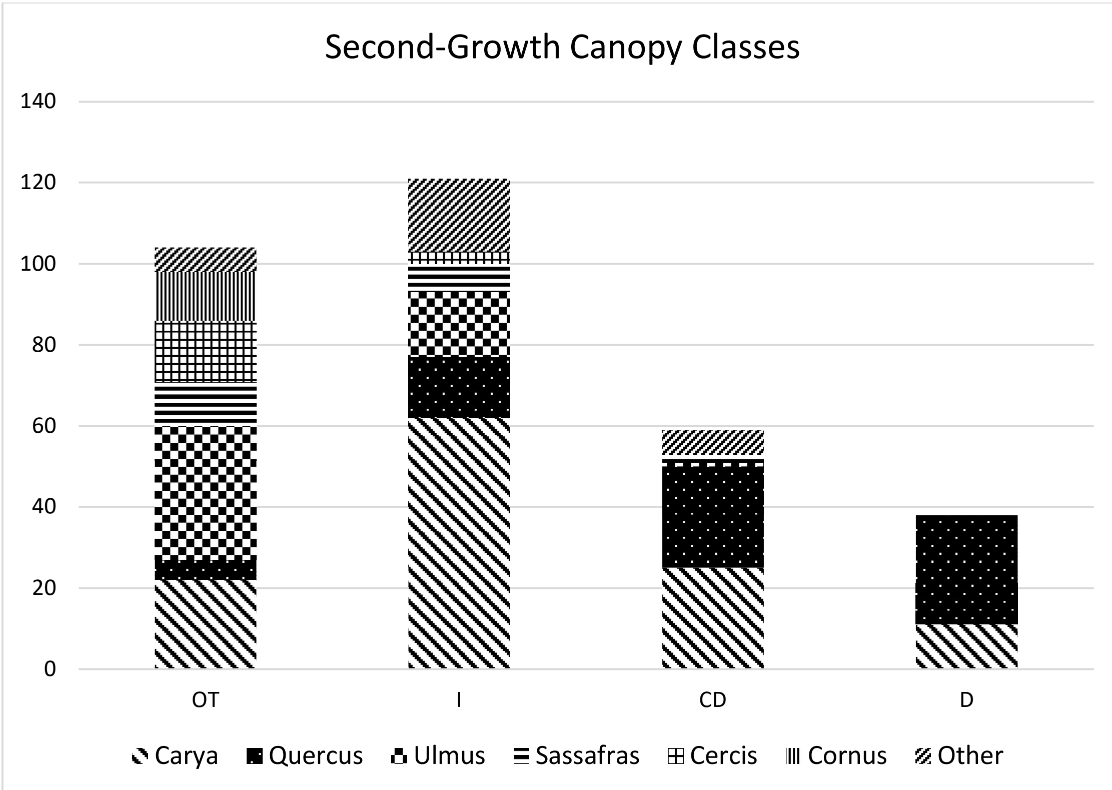

Figure 3. Trees per canopy class based on species group in the second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL.

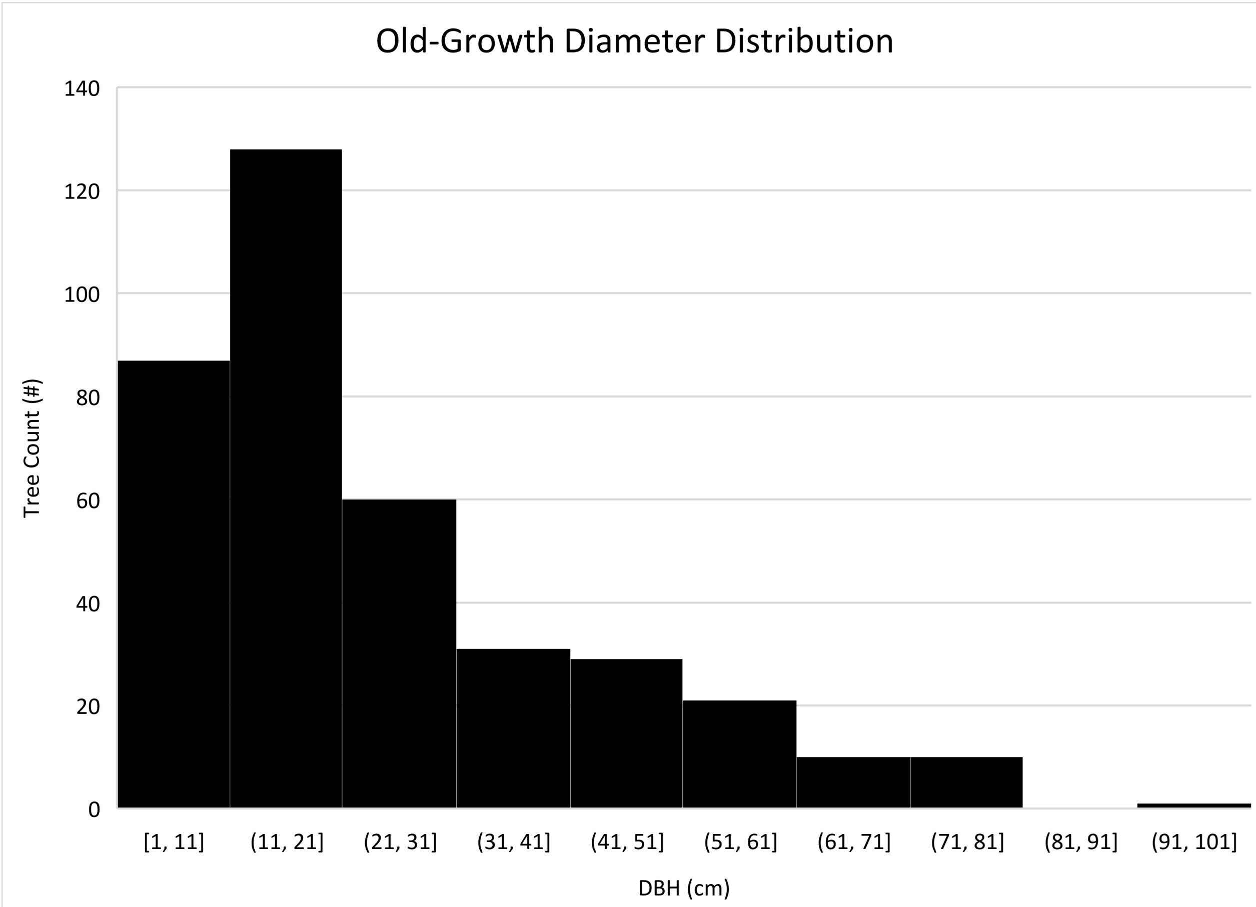

Figure 4. The diameter distribution of trees sampled on the old-growth site (Otey-Grisley Nature Preserve) displaying a reverse J-shaped diameter distribution curve. Pittsburg, IL.

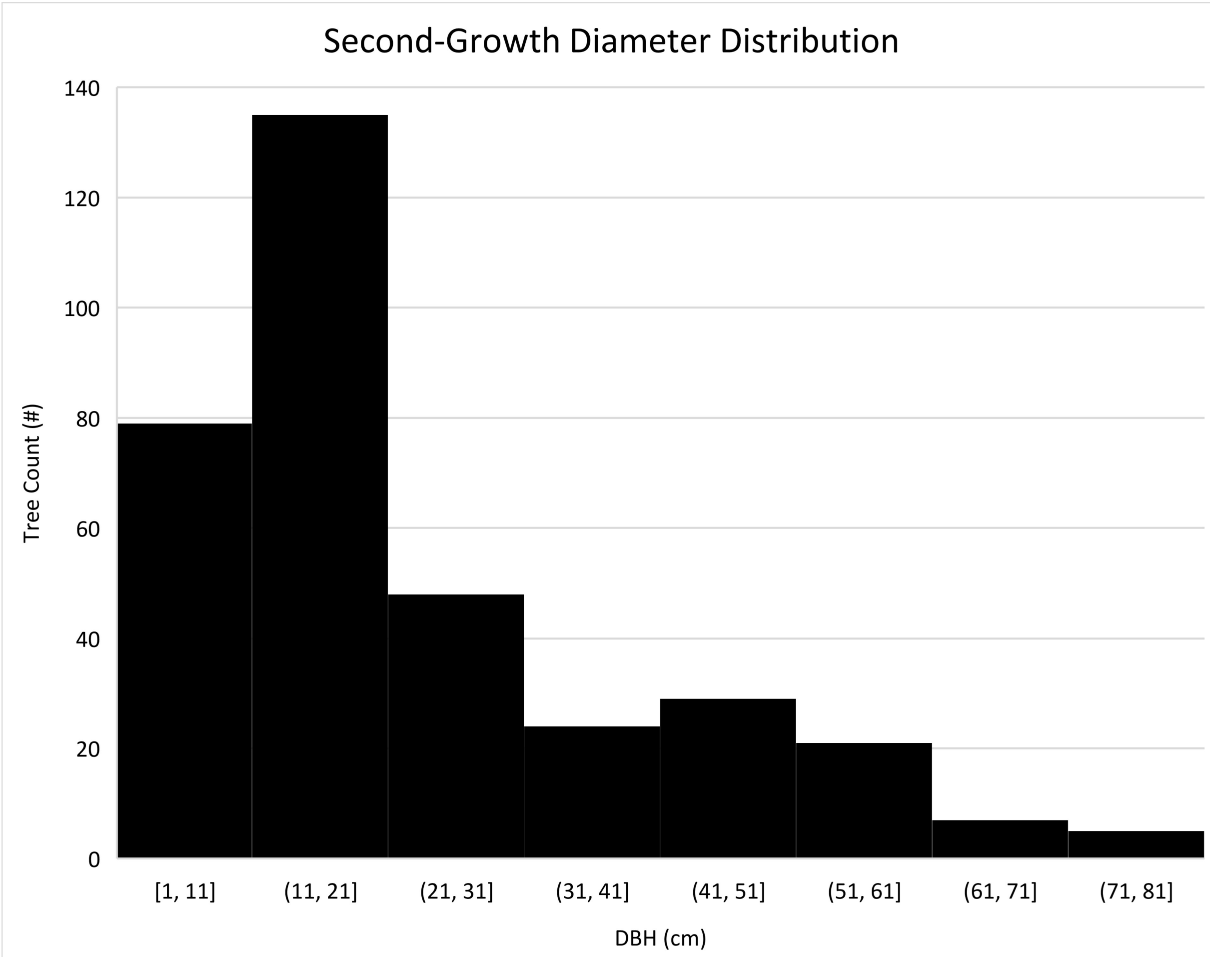

Figure 5. The diameter distribution of trees sampled on the second-growth site (Grisley Woods Land and Water Reserve) displaying a reverse J-shaped diameter distribution curve. Pittsburg, IL.

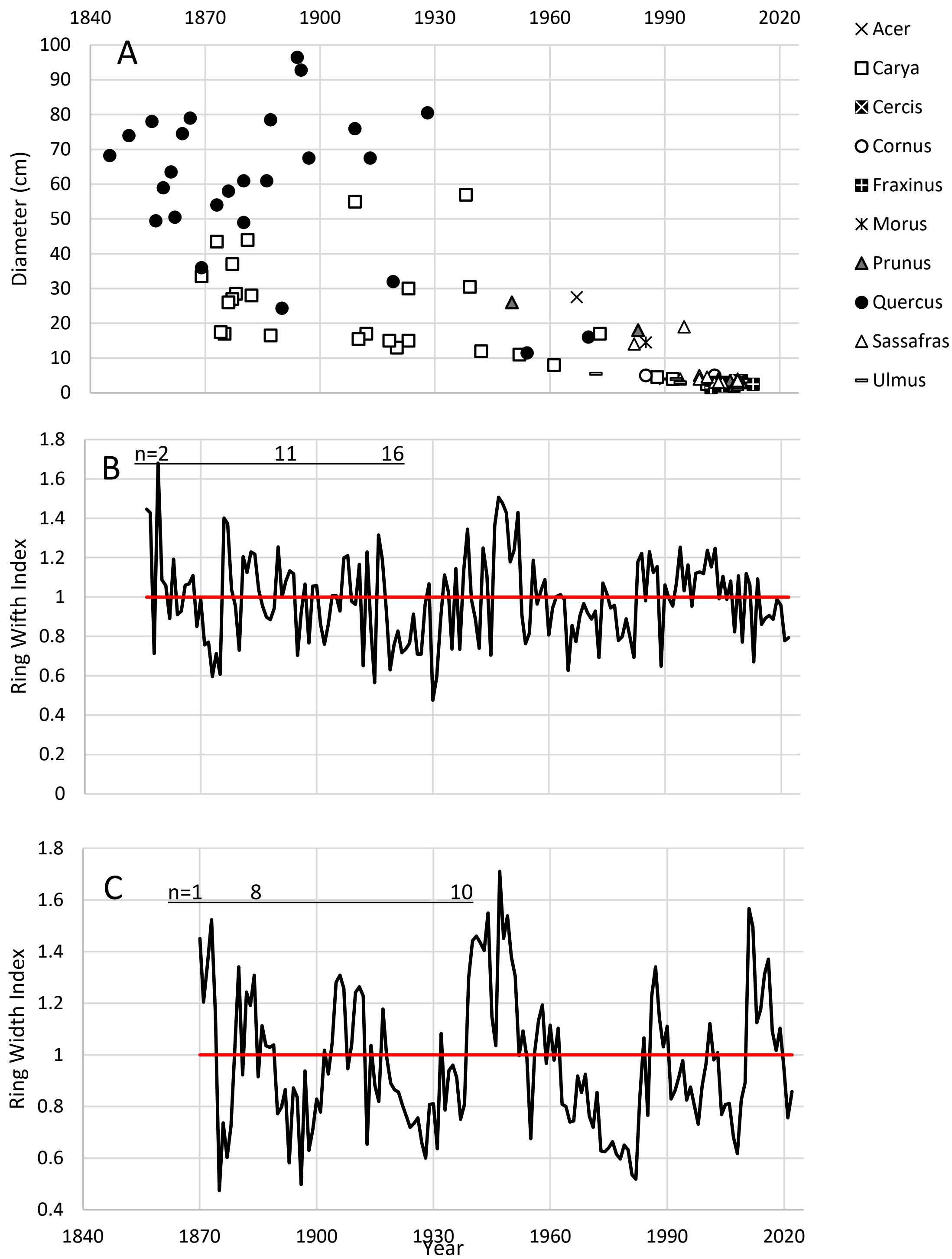

Figure 6. Stacked illustration of the age-diameter graph (A), master chronology for *Quercus alba* (B), and master chronology for *Carya* spp. (C) from the old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL.

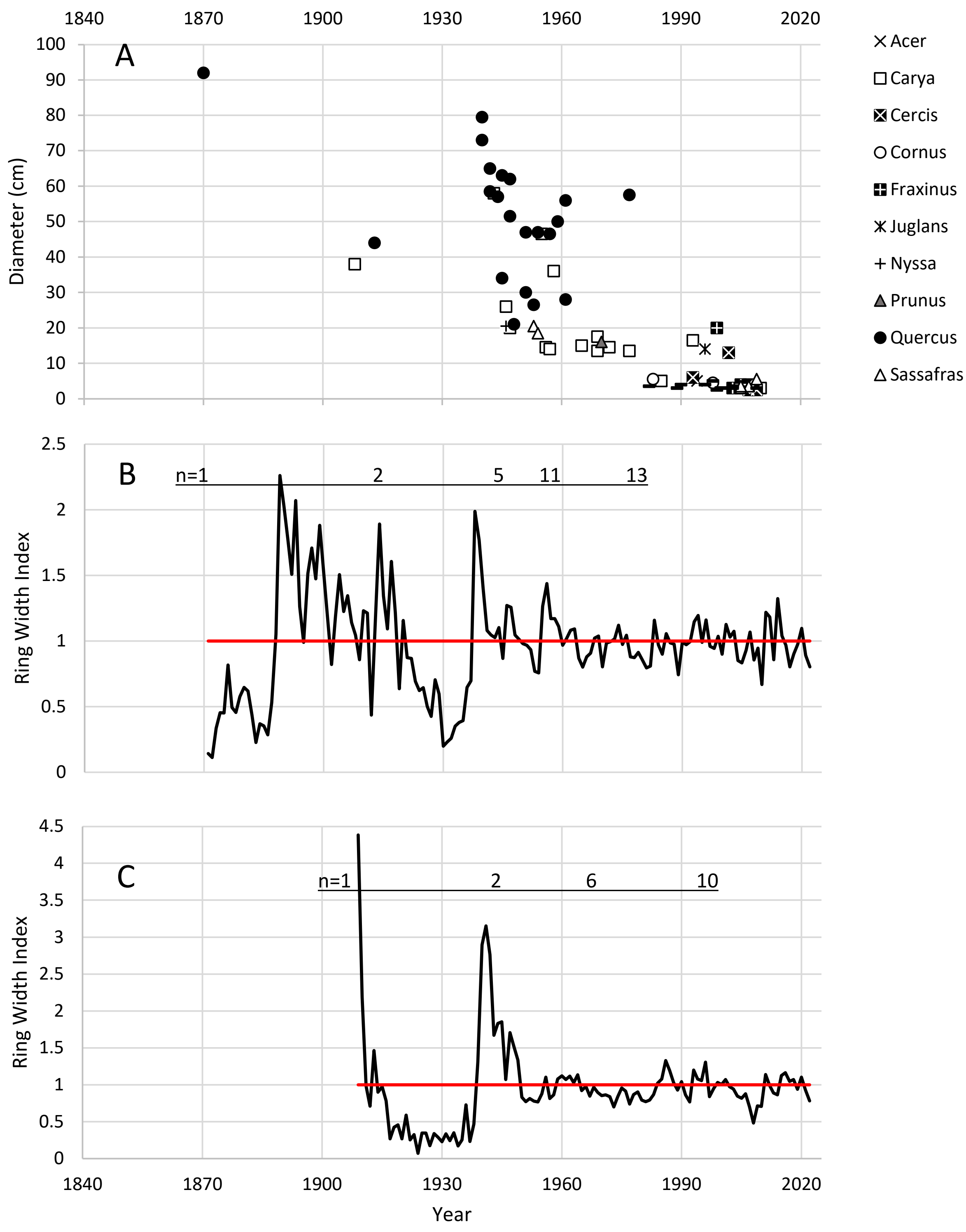

Figure 7. Stacked illustration of the age-diameter graph (A), master chronology for *Quercus alba* (B), and master chronology for *Carya* spp. (C) from the second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL.

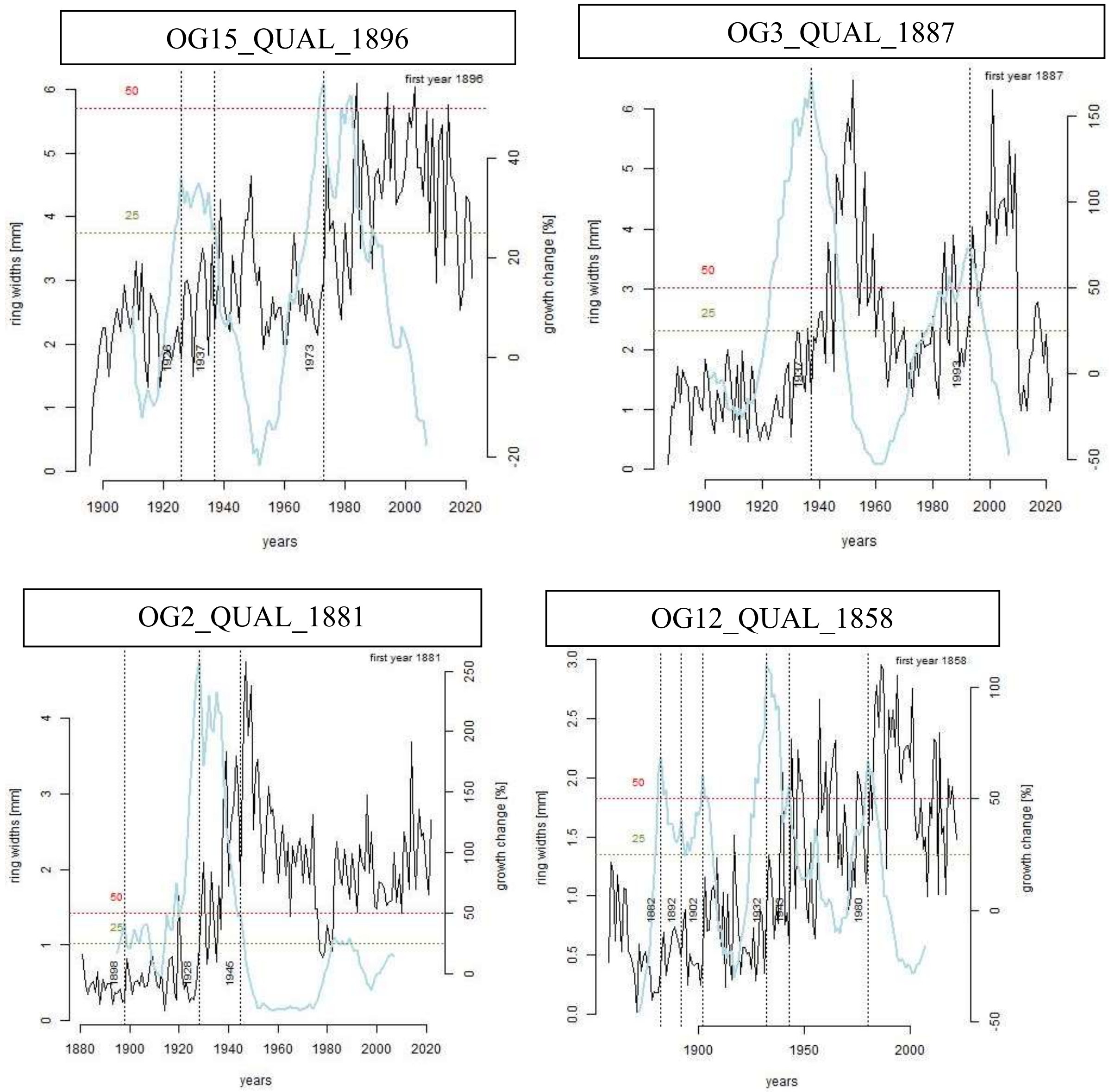

Figure 8. Radial Growth Analysis illustrating various growth releases of 4 *Quercus alba* from the old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL. The code above each graph refers to the tree from which the core was taken: plot_species_pith date.

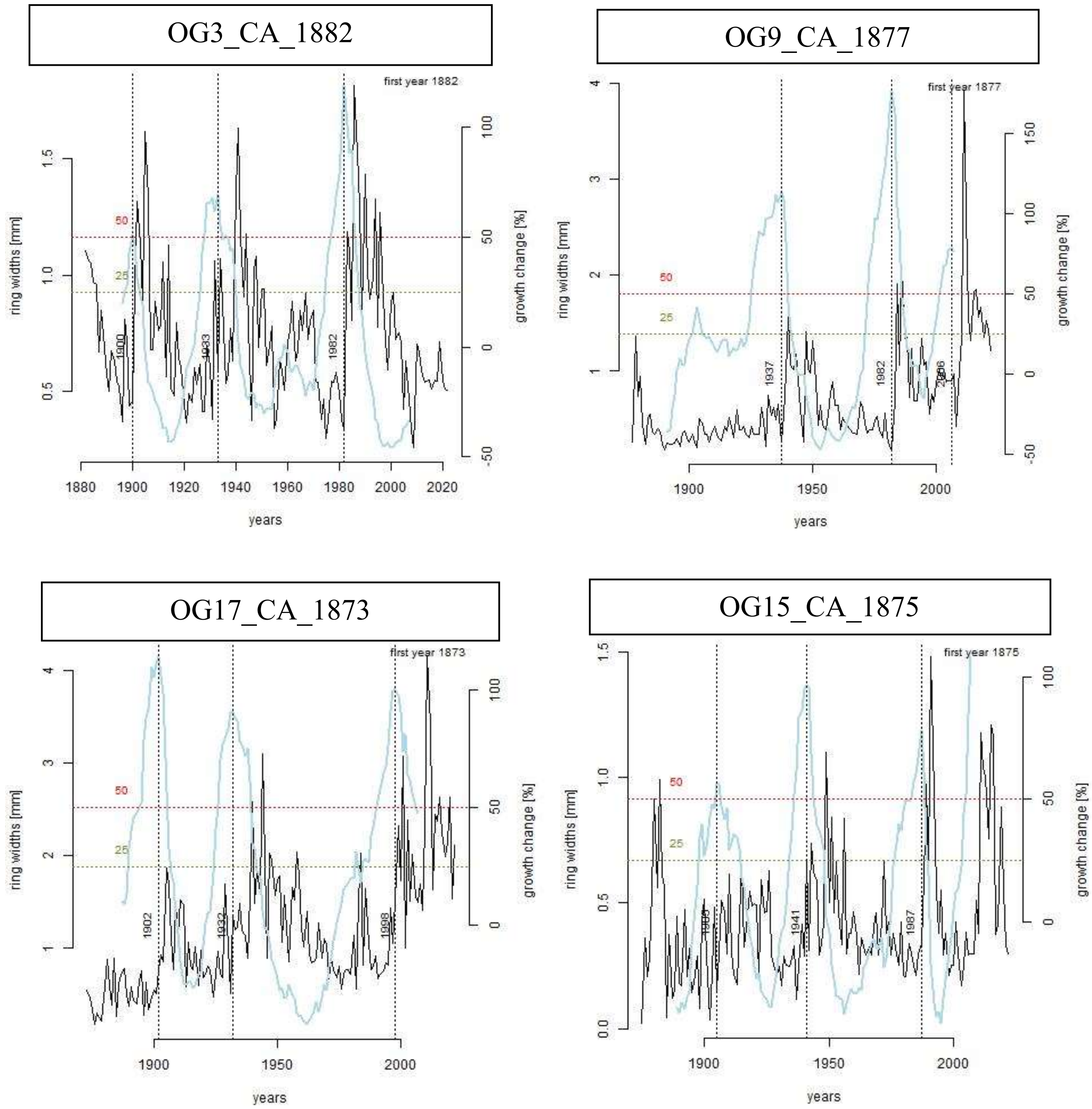

Figure 9. Radial Growth Analysis illustrating various growth releases of 4 *Carya spp.* from the old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL.

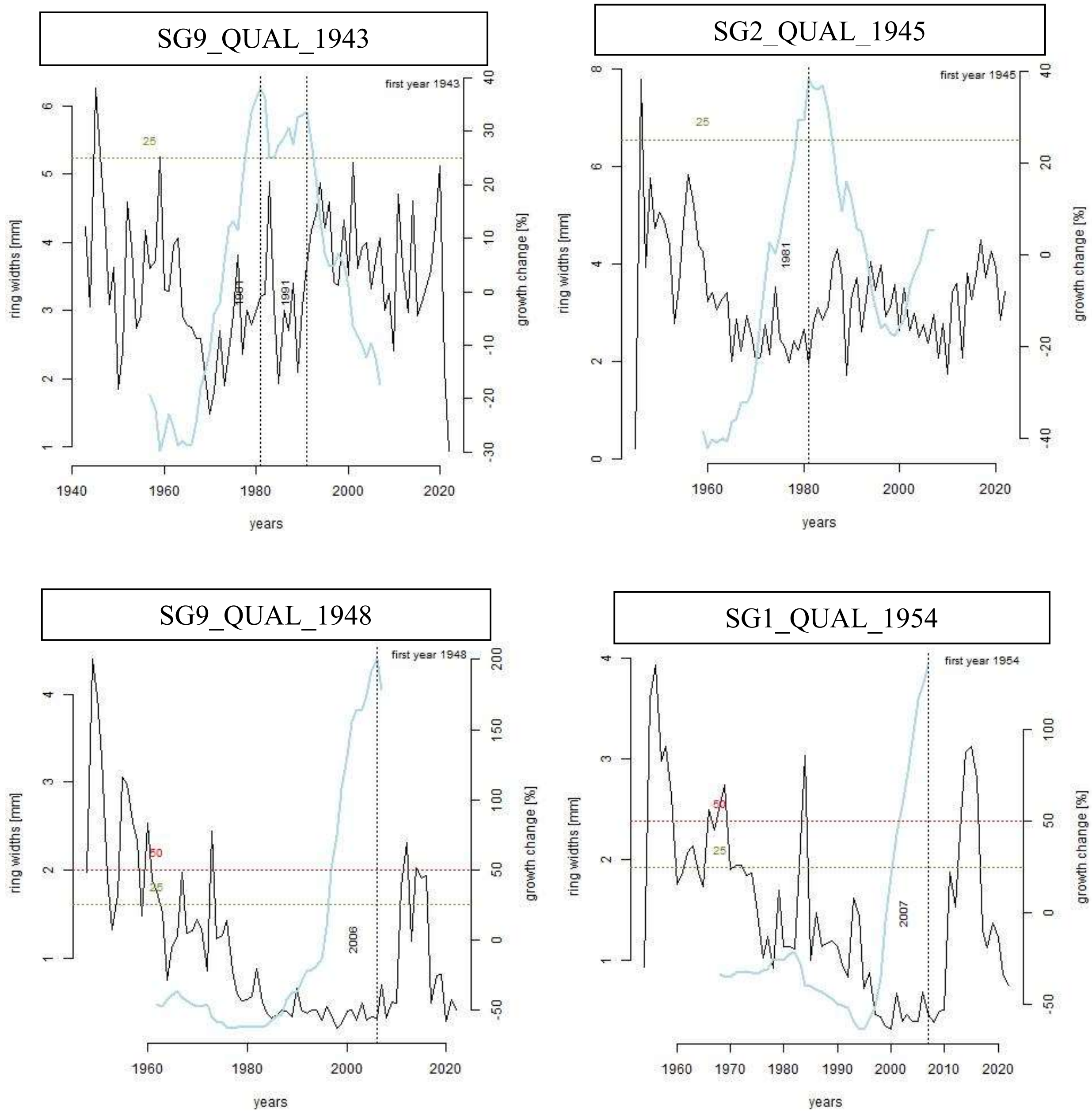

Figure 10. Radial Growth Analysis illustrating various growth releases of 4 *Quercus alba* from the second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL.

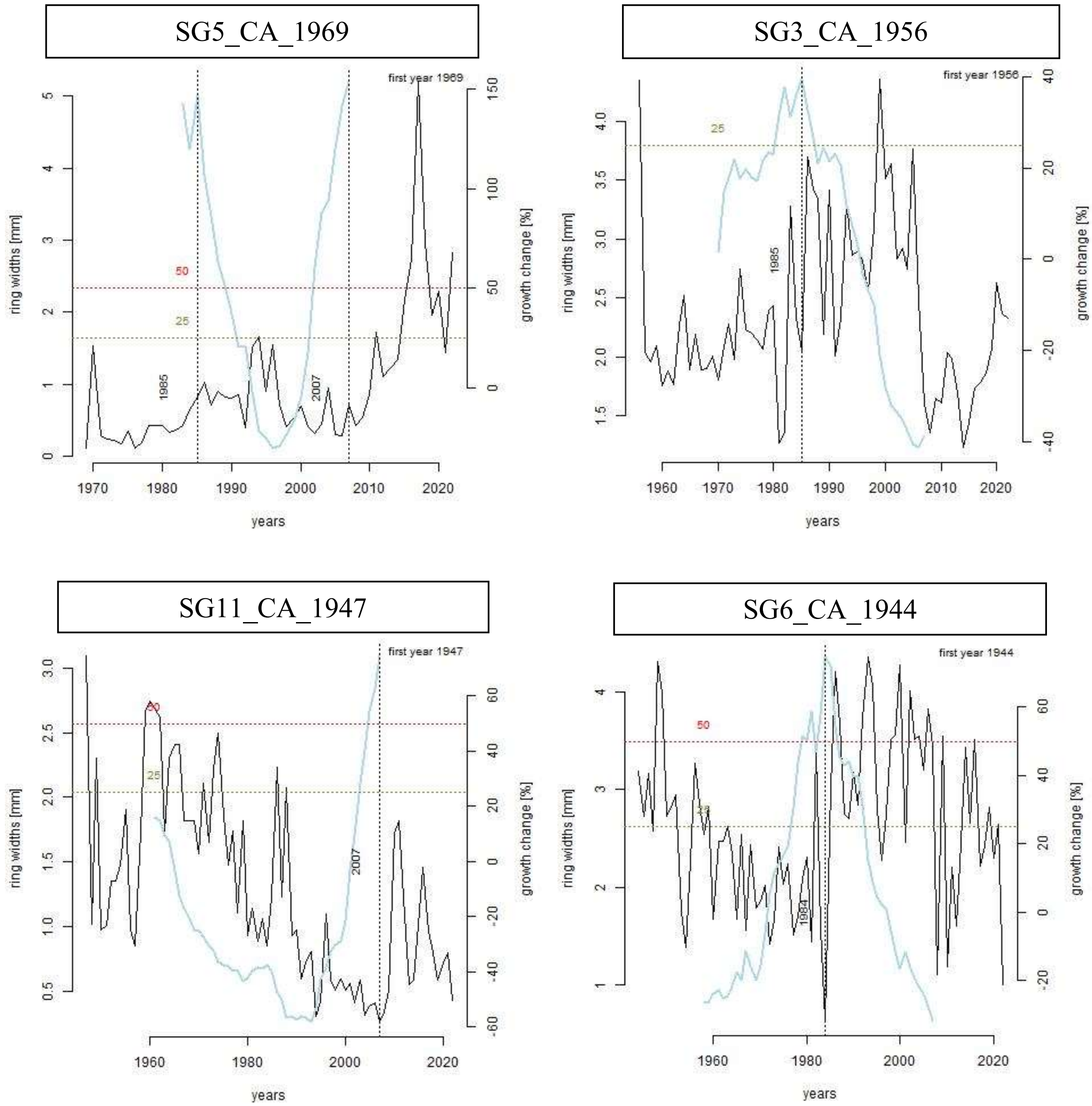

Figure 11. Radial Growth Analysis illustrating various growth releases of 4 *Carya spp.* from the second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL.

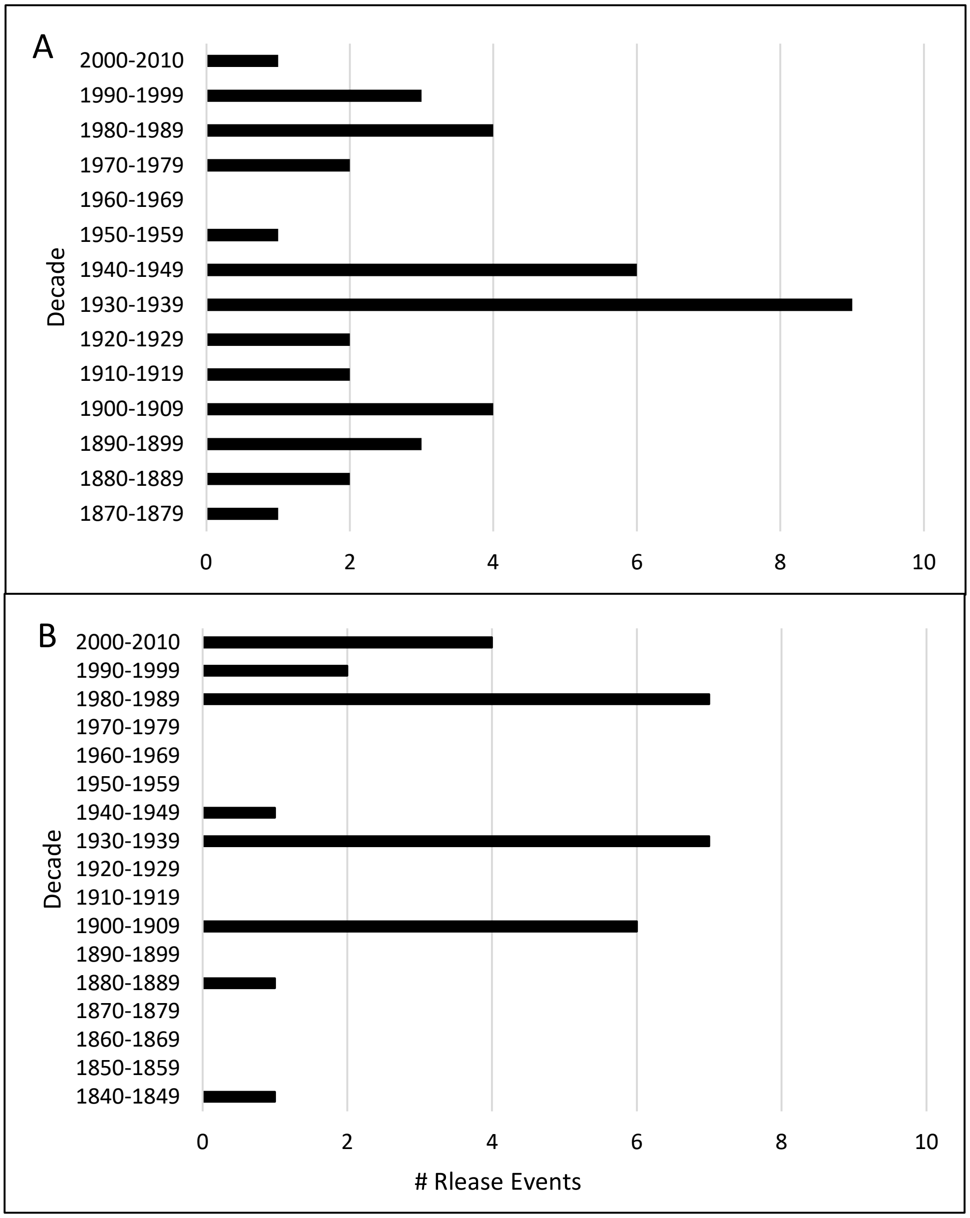

Figure 12. Release events by decade in the white oak (*Quercus alba*) (A) and hickory (*Carya*) (B) old-growth stand at Otey-Grisley Nature Preserve, Pittsburg, IL.

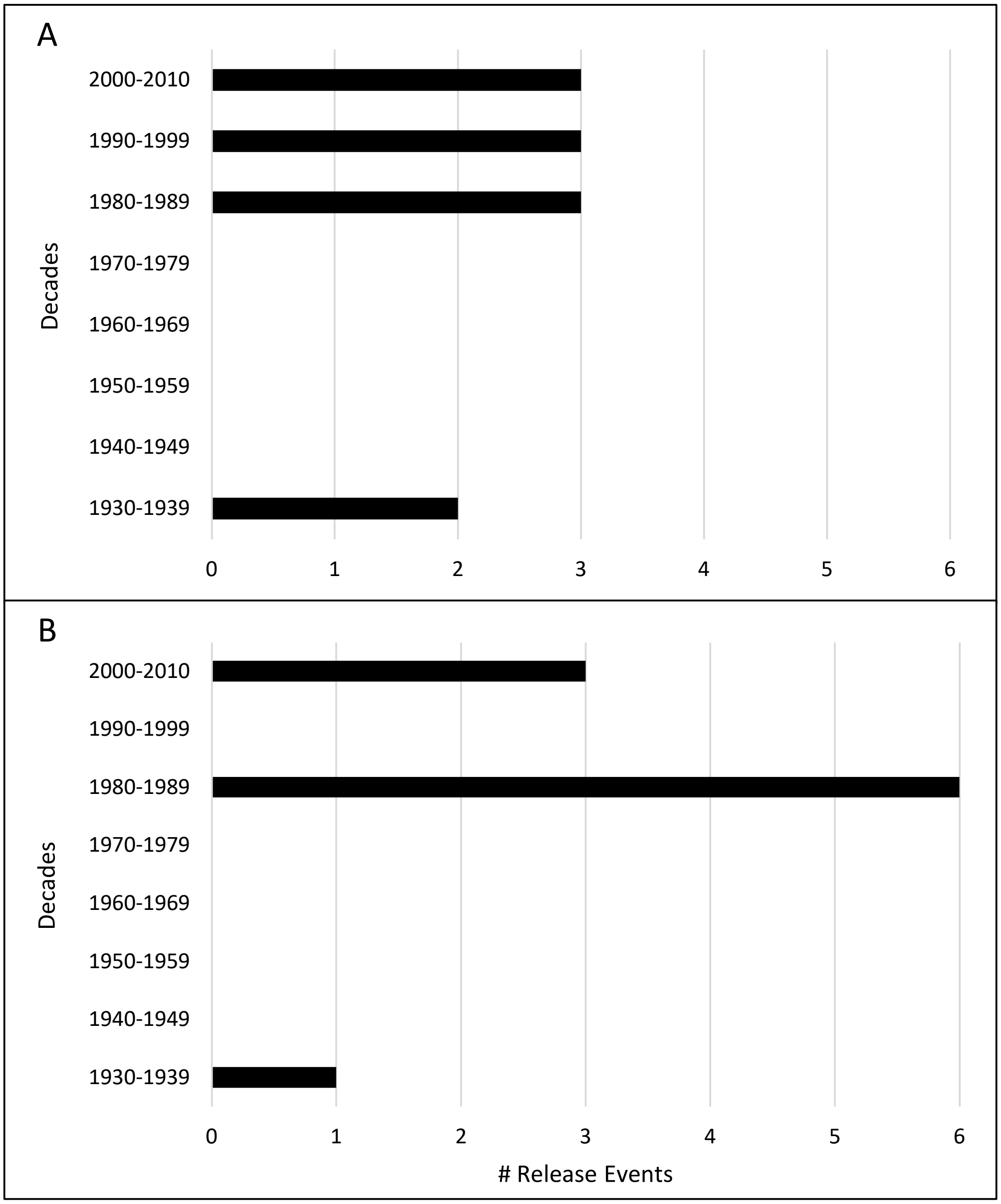

Figure 13. Release events by decade in the white oak (*Quercus alba*) (A) and hickory (*Carya*) (B) second-growth stand at the Grisley Woods Land and Water Reserve, Pittsburg, IL.

Figure 18. Historic aerial photo from 1938 depicting the old-growth stand (Otey-Grisley Nature Preseve) in red (to the south) and the second-growth stand (Grisley Woods Land and Water Reserve) in blue (to the north) Pittsburg, IL.

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