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Stand Dynamics and Disturbance History of Champlain Valley Clayplain Forests

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Abstract

Studies of stand dynamics can explain how species interactions and disturbances drive forest structure and recruitment patterns of tree species. It is difficult to generate an understanding of stand dynamics and successional trends of forests in areas that have a long history of intense land use such as the Champlain Valley of Vermont, where over 230 years of agricultural activity has acutely and permanently influenced the landscape. The valley clayplain forest, a rare natural community containing endangered herbaceous plants and overstory tree species assemblages that are rare in Vermont, has been fragmented by agricultural use of the Champlain Valley. This study used dendroecological methods and assessments of forest structural conditions to describe the tree recruitment history and structural dynamics of two old-growth valley clayplain forest patches. Our results indicate that the valley clayplain forest has a species composition and recruitment history that has been heavily influenced by human land use throughout at least the past 230 years. We found that *Quercus spp.*, typically considered characteristic of the valley clayplain forest, are being replaced by late-successional species such as *Tsuga canadensis*. Additionally, other human influences such as invasive species threaten to further alter the composition and dynamics of valley clayplain forests in the near future.

Keywords: Champlain Valley, valley clayplain forest, stand dynamics, land-use history, dendroecology

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Introduction

An understanding of natural forest stand dynamics is critical for informing ecologically sound forest management actions (Oliver and Larson, 1990; Pretzsch et al., 2013). Studies of stand dynamics can explain how species interactions and disturbances drive forest structure and recruitment patterns of tree species (Spies, 2008). Using data such as tree establishment dates allows forest scientists to better understand the historical processes and patterns of a forest (Abrams et al., 1997; D'Amato et al., 2006, 2008; Pederson et al., 2014). This information can be used to predict how a forest might respond to future disturbances, including those related to climate change and forest management activities.

It is difficult to generate an understanding of stand dynamics and successional trends of forests in areas that have a long history of intense land use (Sprugel, 1991; Foster et al., 1998; Lapin, 2003; Russel Southgate and Thompson, 2014). Fragmentation of forests, heavy logging, and other human land uses can drastically alter forest composition, structure and successional trends (Sprugel, 1991; Russel Southgate and Thompson, 2014; Danneyrolles et al., 2016). Forest fragmentation can have a large impact on natural processes. Despite this, it is particularly important to study stand dynamics in fragmented landscapes given that forest fragments may represent important ecological communities, have cultural value, or be of great significance for guiding ecological restoration of the broader landscape (Lapin, 2003; Copenheaver et al., 2014).

New England is one region in which the structure and composition of the forests have been greatly shaped by past land use, particularly historic forest clearing for agriculture followed by reforestation (Cronon, 1983; Foster et al., 1998). In areas of this region where fertile soils suitable for agriculture exist, such as the Champlain Valley of Vermont, ecological transformation of the landscape has been more acute and permanent with limited recovery of previously forested conditions. This valley has been heavily cleared and farmed since Europeans began settling the Champlain Valley in the late 1700s (Hemenway, 1867; Siccama, 1971), particularly the fertile clay soils that historically supported mixed hardwood-conifer forests, referred to as valley clayplain forests, that contained a mixture of species more common in southern New England. Because of the over 230-year history of European settlement and agriculture in the area, the forest is now very fragmented and only exists in a matrix of small patches across the region.

The valley clayplain forest is characterized as a rare community in the state (Thompson and Sorenson, 2000). This natural community is home to many endangered herbaceous plants and contains tree species assemblages that are less common throughout the rest of Vermont, including *Quercus alba* (Lapin, 1998). Given the rarity of the valley clayplain forest, particularly in relation to its historic abundance, there is increasing interest in restoring this forest type to agricultural lands and other land on which it historically occurred. However, the ecological history and tree species dynamics of this forest type is understudied, particularly in relation to tree recruitment and structural dynamics. Several studies have examined the early successional trends, species composition, classification, and description of this forest type (Lapin, 1998, 2001, 2003; Otsuka, 2004); however, key knowledge gaps remain regarding the recruitment dynamics and structural conditions characterizing these forests and associated implications for restoration efforts.

This study used dendroecological methods and assessments of forest structural conditions to describe the tree recruitment history and structural dynamics of two Champlain Valley clayplain forest patches. The first objective of the study was to use tree, seedling, and coarse woody debris data to quantify current structural and composition conditions of two late-successional Champlain Valley clayplain forest patches. The second objective was to determine the tree recruitment history of these sites to draw conclusions about long-term species interactions with disturbance and the successional trajectory of the forest.

Methods

Study Site:

The study took place in two forests in the Champlain Valley region of Vermont—Williams Woods in Charlotte, VT and Church Woods at Shelburne Farms in Shelburne, VT (Figure 1). These sites were chosen because they had previously been identified as some of the best remaining examples of late-successional valley clayplain forest patches in the Champlain Valley (Lapin, 1998, 2001, 2003; Nature Conservancy, 2010).

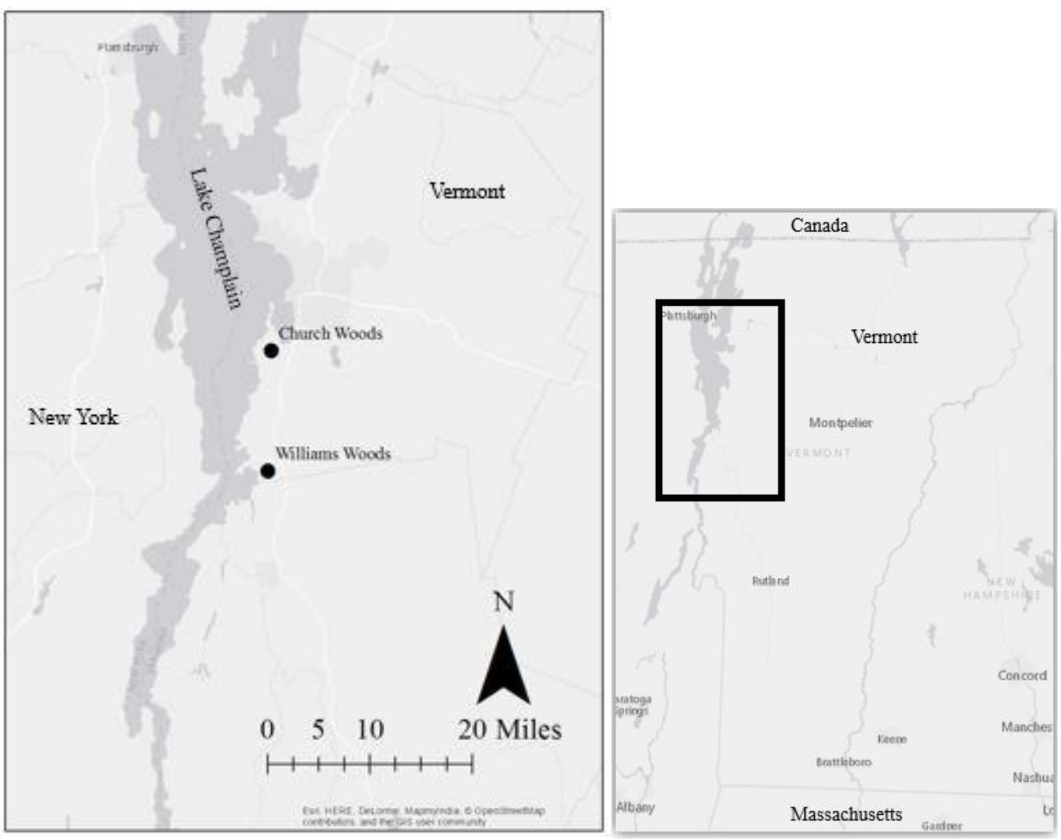


Figure 1: Locations of each plot within the Champlain Valley. Maps made using ESRI ArcMap 10.4.1

Plot Design:

One 0.25 hectare plot was established at each site for collecting vegetation and dendrochronological data. A square plot design was chosen for ease of mapping the trees and to minimize edge corrections in the calculation of spatial statistics. Each 0.25 ha plot had nine 2 meter radius regeneration plots spaced 12.5 meters apart, and eight 25 meter transects radiating from the center for measuring coarse woody debris (Figure 2). Plots were located at each site in representative areas of the larger stand that exhibited valley clayplain forest characteristics. Presence of overstory *Quercus* species was an important criterion for plot location because the recruitment history of these trees were of specific interest.

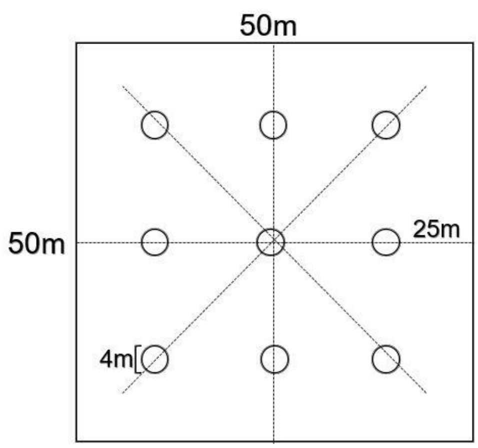


Figure 2: The plot design used in the study. The entire plot is 50m x 50m. Each 4m diameter circle is a regeneration plot, used to measure seedling and saplings. These plots are 12.5m apart. Each line radiating from the plot center is a coarse woody debris transect.

Field Methods:

In each plot, each tree >10 cm in diameter at breast height (DBH; 1.3m) was mapped using an (x,y) coordinate system. For each tree, the species, diameter, and crown class was recorded. In total 242 and 224 trees were measured at Williams Woods and Church Woods, respectively. Then, an increment core was taken at approximately 30 cm above the ground from each tree rooted within each plot >10cm DBH. Four additional *Q. alba* individuals exhibiting bark and crown characteristics of older trees were cored in close proximity to the plot at Williams Woods to capture the age range of this species. In the 2m radius regeneration plots, seedlings and saplings were tallied. For this study, seedlings are considered to be all individual tree stems shorter than breast height and saplings are considered to be all individual stems taller than breast height and smaller than 10 cm in diameter. Species presence/absence data for each plot was also taken to determine regeneration stocking levels. Coarse woody debris (CWD) was measured in each plot using the line-intersect method (van Wagner, 1968). On each transect, the intercept diameter, species, orientation, and decay class were recorded for each piece of downed CWD >6cm diameter encountered along the transect. Decay classes were determined using the characteristics outlined in the USFS field guide (2005, reproduced in Appendix G). Volume of CWD was calculated using the formula described by van Wagner (1968).

Lab Methods:

In the lab, each increment core was mounted and sanded up to 800 grit. Rings on each core were counted under a microscope to determine the approximate establishment date of each individual. For cores that did not reach the pith of the tree, pith indicators were used to estimate the establishment date based on inner curvature (Applequist, 1958). Cores that did not reach the inner curvature of the tree were not included in reconstructions of age distribution. In total., 228 and 205 cores were used for Williams Woods and Church Woods, respectively. Approximate aging was confirmed using the list method: recording years of irregular growth in each core as a method of visual crossdating (Yamaguchi, 1991).

Importance value of each species was calculated based on Curtis and McIntosh (1951) using this formula:

$$\text{Importance Value of Species A} = \frac{(\#\text{of species A / total \# of trees}) + (\text{basal area of species A / total basal area})}{2}$$

The shape of each diameter distribution was determined using the methods outlined by Janowiak et al (2008). In short, polynomial regression in which the base 10 logarithm of each DBH class was regressed against various combinations of DBH, DBH^2, and DBH^3, and were evaluated based on corrected Akaike Information Criterion (AIC_c) and distribution form determined using criteria in Janowiak et al., 2008). This method was used because Janowiak (2008) determined that it was the best method for estimating diameter distributions for Northern Hardwood forests. Spatial statistics were done using the x,y coordinates of trees in each plot using a Ripley's K function (Stoyan and Stoyan 1994). The Ripley's K function is used to determine spatial patterns such as clustering in completely mapped spatial data, and therefore made sense to use in this case (Stoyan and Stoyan, 1994). Both diameter distribution curve and the spatial statistics were done in R (available at https://cran.r-project.org/). In graphs of diameter classes and establishment dates, species with less than five individual stems present in the plot were grouped into the "other species" category.

Results

Species Composition and Stand Structure

Williams Woods

The forest at Williams Woods was overwhelmingly dominated by *Tsuga canadensis* (IV=0.60). This species was present in every layer of the canopy, but was most numerous in the smaller diameter classes (Figure 3a). The two next most important trees, *Acer rubrum* (IV=0.08) and *Quercus alba* (IV=0.08) were mostly located in the upper layers of the canopy. *Pinus strobus* (IV=0.07) was found in every layer of the canopy in low abundance. The fifth most important tree was *Betula lenta* (IV=0.05) and most of these trees were found in the mid-range size classes (Figure 3a). *Betula alleghaniensis* (IV=0.03) was also found in the middle and larger diameter classes (Figure 3a). *Fagus grandifolia* (IV=0.02) and *Fraxinus nigra* (IV=0.01) were found in the lower canopy layers. Tree species with a count of less than five stems were included in “other” species. These species are *Carya ovata*, *Quercus rubra*, and *Acer saccharum*. Spatial analysis of stem locations indicated the distribution of *T. canadensis* and other species was completely spatially random at all distances (Figure 4). The diameter distribution for Williams Woods (Figure 3a) was best described by a negative exponential curve (AIC_c=5.85).

Seedling regeneration at Williams Woods (Table 1) was heavily dominated by *Acer rubrum* with over 20,000 stems/hectare and 89% stocking. The second most common seedling species was *Betula alleghaniensis* with 44% stocking. *Quercus rubra* and *Quercus alba* both had 22% stocking across the site. Only one species, *Corya cordiformis*, had seedling presence but was not present in the tree data. *Acer rubrum* was the most numerous sapling species (707 stems/ha), while *Fagus grandifolia* had the highest stocking in this size class (44%).

The total volume of CWD at Williams Woods was 77.85 m^3/ha. A larger portion of this CWD was from hardwood species in advanced stages of decay (Figure 5a). Softwood CWD was less common and was concentrated in the lowest decay classes.

Church Woods

Tsuga canadensis was also the most dominant species at Church Woods (IV=0.43). The other most important species were *Quercus alba* (IV=0.17) and *Fraxinus pennsylvanica* (IV=0.11). *Tsuga canadensis* and *Fraxinus pennsylvanica* trees were located primarily in the lower canopy layers with diameters primarily in the lower diameter classes (Figure 1b). *Quercus alba* was only found in the larger size classes (Figure 3b). *Acer rubrum, Acer saccharum, Fraxinus nigra, Tilia americana*, and *Fagus grandifolia* were also abundant in the smaller diameter classes (Figure 1b). Tree species with less than five stems in the plot were grouped into the "other" category. These species were *Ulmus americana*, *Carya cordiformis*, *Rhamnus cathartica*, *Betula papyrifera*, *Betula lenta*, *Ostrya virginiana*, *Acer platanoides*, and *Carya ovata.* These species were all small diameter individuals (Figure 3b). Spatial analysis of stem location showed significant clumping of *T. canadensis* at distances of 2-20m and clumping of all other tree species at 3-15 m (Figure 6; Appendix B). The diameter distribution for Church Woods was best explained by a negative exponential curve (AIC_{cc}=15.85).

The most common seedling species at Church Woods was *Acer saccharum* at 89% stocking (Table 2). The most numerous seedling species was *Betula lenta* with 3714 seedlings per hectare. *Fagus grandifolia* also had a heavy presence with 33% stocking. *Rhamnus cathartica* and *Lonicera spp.* were also common in the large regeneration layer. Saplings were dominated by *Fagus grandifolia* and *Rhamnus cathartica* (Table 2).

Total coarse woody debris volume at Church Woods was 48.62 m^3/ha. Most of this material was in decay class 3 (Figure 5b) and included both hardwood and softwood presence. Hardwood CWD was primarily in the higher decay classes.

Age Structure

Williams Woods

Forests at Williams Woods were uneven-aged with several distinct recruitment periods (Figure 7a). The oldest cohort at Williams Woods established between 1790 and 1839. However, two *Quercus alba* predated this cohort establishing in 1640 and 1712, respectively. A second cohort established between 1840 and 1899 and was primarily dominated by *Tsuga canadensis* as well the majority of *Acer rubrum, Betula lenta,* and *Pinus strobus* present in the plot (Figure 7a). The youngest cohort, established between 1900 and 1990, consisted of mostly *Tsuga canadensis*. Most of the *Betula alleghaniensis* present in the plot were recruited between 1930 and 1960, with an older generation established since 1840 (Figure 7a). Most of the *Fraxinus nigra* present were established after 1970, with a few individuals establishing between 1860 and 1870. Analysis of spatial distribution of trees by age cohorts, based on Figure 8, showed that cohort distribution was completely spatially random.

Church Woods

The forests at Church Woods were also uneven-aged with three distinct cohorts (Figure 7b). The oldest cohort consisted mostly of *Quercus alba* and established between 1780 and 1810. A second pulse of recruitment occurred between 1860 and 1920, when most of the *Tsuga canadensis* in the plot established. The most recent distinct recruitment event was mixed hardwood establishment from 1890-1990 with a peak between 1960 and 1970. During this time, most of the non-oak hardwoods in the plot were established. Spatial analysis based on Figure 9 showed that cohort distribution was completely spatially random.

Discussion

Prior to this study, little was known about the dynamics and development of present-day valley clayplain forests (Lapin, 2003). Descriptions based on field observations have emphasized the dominance of *Quercus spp.*, *Fraxinus pennsylvanica*, *Pinus strobus*, and *Carya spp.* (Lapin, 1998, 2003; Thompson and Sorenson, 2000; Nature Conservancy, 2010) with the projected successional trajectory of this community towards overstory dominance of *T. canadensis* in addition to the *Quercus, Carya,* and *Fraxinus* species (Thompson and Sorenson, 2000). The results of this study confirm the general pattern of *T. canadensis* as a late-successional species in these systems and provide greater detail about the recruitment dynamics of this and other constituent species. Although oak is often a defining feature of these forests (Nature Conservancy, 2010; Lapin, 1998, 2001, 2003), the lack of recent recruitment of these species and the advanced age of the individuals already present indicates that this component may not be sustained over time.

Quercus spp. Dynamics

Both study sites contained scattered *Quercus spp*. in the overstory and Williams Woods had limited *Q. alba* and *Q. rubra* seedlings in the plot; however, no individuals were present in the lower layers of the canopy at either site. Instead, these layers were dominated by *T. canadensis*, *B. alleghaniensis*, *A. rubrum*, and *F. grandifolia*, indicating a long-term shift from oak dominance to late-successional species. This successional trend away from oak has been recorded extensively in the recent decades throughout the temperate forests of the eastern United States (Lorimer, 1993; Orwig et al, 2001; Frelich and Reich, 2002; Zaczek et al., 2002; Buchanan and Hart, 2012; Knopp, 2012; Chapman and McEwan, 2016).

Evidence from these previous studies suggest that large disturbances, such as fires, that historically favored *Quercus* regeneration no longer occur in contemporary landscapes. Without these disturbances, other, more shade tolerant, species begin to predominate as small-scale disturbances generate conditions more favorable for their establishment (Lorimer, 1993; Zacek et al., 2002; Buchanan and Hart, 2011; Knopp, 2012). Because of this, Frelich and Reich (2002) listed wind disturbance as one of the three main threats to old growth oaks in fragmented ecosystems, given that these events do not create canopy gaps large enough for oak regeneration to succeed (Frelich and Reich, 2002). Past studies of clayplain forest have named small wind and ice storm events as the main disturbances currently present in the clayplain forest ecosystem (Lapin, 2003). This could be an explanation as to why oaks are germinating on the site but not surviving into the sapling and tree stages.

One question that remains regarding the valley clayplain forest is what processes originally led to the establishment of *Quercus spp*. on these sites. Records and evidence from our data show that *Quercus* was present in the Champlain Valley before European settlement. Fire is thought of as the pre-eminent driver of oak regeneration (Johnson et al., 2009), but it has previously been thought that fire probably was not present in high amounts in the Champlain Valley because of some early accounts by Europeans claiming that the Abenaki were not using large fires for management in the area (Lapin, 2003). However, it is still possible that small natural or human caused fires were present in the pre-settlement Champlain Valley as the Abenaki tribe did use fire as a management tool in portions of the Champlain Valley (Wiseman, 2001). Additionally, studies from central New England indicated that old-growth oak-hickory forests were present there in lowland areas with a higher fire presence than the surrounding areas (Orwig et al., 2001).

Structural and Compositional Conditions

The dominance of *T. canadensis* in these forests indicate that it is a late-successional forest that was never cleared for agriculture (Foster et al., 1998; Burns and Honkala, 1990; D'Amato et al., 2008). At Williams Woods, *Betula lenta* and *B. alleghaniensis* were also abundant, which is consistent with other work in the region that has highlighted these two species as common components of old-growth hemlock forests (D'Amato et al., 2006). Our data shows a cohort of *B. lenta* that established between 1850 and 1900, around the same time that many of the hemlocks in the plot were established. *B. alleghaniensis* is a late successional species that regenerates on downed logs and exposed mineral soil (Burns and Honkala, 1990). The high presence of CWD in Williams Woods and historic windthrows likely provided ideal environments for *B. alleghaniensis* regeneration.

Tsuga canadensis also dominated the Church Woods site. However, the hardwood component included several species associated with wet forest conditions, including *Fraxinus nigra, F. pennsylvanica,* and *Acer rubrum*. The tree patterns at this site indicated significant clumping and this likely reflected an underlying environmental gradient in the plot, as there was a wetter portion of the stand in the southwestern corner that contained a high number of hardwood species associated with lowland areas. This supports Lapin's (2003) claim that species composition can change drastically in the valley clayplain forest with slight changes in environmental conditions.

Invasive species were also found at Church Woods: *Acer platanoides*, *R. cathartica,* and *Lonicera spp.* The presence of invasive species such as *R. cathartica* and *Lonicera* has been recognized as being one of the three main threats to old-growth oak communities in fragmented landscapes (Frelich and Reich, 2002). Our regeneration survey shows that both of these species are present in large quantities in the plot. Additionally, one *R. cathartica* individual in the plot was over 10 cm DBH and had established in 1965. The presence of these species in Church Woods represents a significant challenge to future maintenance of the ecological conditions in this area and aggressive management actions for their removal may be necessary.

Previous studies of forests similar in composition to valley clayplain forest have not measured CWD (Zaczek et al., 2002; Buchanan et al., 2012; Knopp, 2012; Chapman et al., 2016). However, the volume of CWD we documented fell between amounts recorded for *Quercus*- and *T. canadensis*- dominated forests (Wilson and Mc Comb, 2005; Goebel and Hix, 1996; and D'Amato et al., 2008). This likely reflects the transition from detrital inputs dominated by hardwood species towards the more decay-resistant *T. canadensis*, as oak becomes a lesser component over time and hemlock ascends into dominant canopy positions. The difference in CWD volumes at Williams Woods and Church Woods is likely due to a difference in land-use history between the two sites and a recent large wind disturbance in 2007 at Williams Woods that blew down many trees (Nature Conservancy, 2010).

Recruitment History

As has been demonstrated for much of New England (Cronon, 1983; Foster, 1998), land use history can drastically influence forest composition, structure, and long term dynamics. Evidence from this study suggests that land use was the driving factor for recruitment events in both forests, despite their general characterization as old forest remnants. In Williams Woods, two *Quercus alba* trees were cored that predate European settlement in the Champlain Valley, 1640 and 1712, respectively. Although there were some Europeans present in the Champlain Valley before the signing of the Treaty of Paris in 1783, it was after this event that settlement increased substantially as people streamed into Vermont from other areas of New England

(Hemenway, 1867). Local experts believe that most trees were felled in the area during this period and that even the oldest stands in the valley are mostly second growth, with oaks sprouting from the original old-growth trees that were felled (E. Tapper and M. Lapin, personal communication). The *Q. alba* individuals still living in Williams Woods that predate European settlement were probably too small to cut at the time when the forest would have been logged, which likely contributed to their survival. The third oldest tree at this site, a hemlock, established to coring height in 1792, roughly 10 years after the beginning of extensive settlement in the region.

The two oldest trees at Williams Woods displayed a period of suppression in the late 1700s and early 1800s, which likely reflects that this area was never completely cleared of trees. However, both cores showed evidence of a release event in the early-mid 1800s; a potential response to selective logging of trees in the area by farms adjacent to this fragment (Beers, 1869; Appendix E) and there are no physical barriers that would prevent logging at the site. Grazing was also a common practice in farm woodlots during this time and the cessation of grazing as farms were abandoned or converted to other agricultural uses may have contributed to the recruitment of *T. canadensis* in the mid-1800s (Cronon, 1983; Foster, 1998; M. Lapin, personal communication). Since cattle have been shown to prefer hardwood seedlings to conifers (Lutz, 1930), there may have been greater levels of *T. canadensis* advance regeneration than other species, leading to an increase in *T. canadensis* in the canopy during the mid-late 1800s.

Natural disturbances and drought have also likely played a role in recruitment history at Williams Woods. The recruitment event documented between 1810 and 1840 corresponds with a 1815 hurricane which may have contributed to gap formation favoring advance regeneration of shade tolerant species (Orwig, 2001). The recruitment event documented between 1930 and 1960 overlaps with a major hurricane event in New England (1938 hurricane) and the most severe drought in the region over the last century (1960s drought, Pederson et al., 2013). Given the shallow rooting depth in these forests, overstory trees are quite susceptible to wind disturbance and moisture stress, possibly having a large impact on tree mortality and recruitment in these systems. The amount of hardwood CWD in decay class four in Williams Woods likely corresponds with the events that could have caused the most recent recruitment event (1938 hurricane, 1960s drought). There has not been a stand-replacing disturbance in Williams Woods since European settlement (Lapin, 2003). The largest documented disturbance recent history was a large wind event in 2007 (Nature Conservancy, 2010). Trees that established or recruited after the wind event of 2007 were too small at the time of the study to be surveyed but do show up in the abundance of *B. alleghaniensis* in the regeneration layer.

Most of the recruitment patterns documented at Church Woods were directly or indirectly related to human disturbance. This includes a heavier and more recent history of logging than Williams Woods, with the last harvest in the area occurring in 1975 and 1976 (Lapin, 2000; Shelburne Farms Woodlands Logging Summary, 1976).

The first permanent settlement in Shelburne was made in 1784 (Hemenway, 1867); a time period corresponding with the establishment of *Q. alba* at Church Woods. The area that is now Church Woods was part of four different farms prior to its purchase in 1886 by the Webb family (Lipke, 1979). Anecdotal accounts indicate that the area was forested at the time of purchase by the Webbs (M. Webb, personal communication); however, given that it was located at the corner of four different farms, it most likely was used as a grazing woodland in the early 1800s. The recruitment of *T. canadensis* around the time that the Webbs bought the property

(Figure 7b), may also be a result of preferential grazing of hardwood seedlings to the benefit of *T. canadensis*, as discussed above.

A recent harvest in Church Woods has had a large impact on hardwood species recruitment in this forest. During this harvest, 50,000 board feet of *Pinus strobus* was harvested from the site. Anecdotal accounts from the logger suggest that this *P. strobus* dated from pre-settlement times (M. Webb and M. Lapin, personal communication). Harvest summaries provided to the Chittenden County Forester after the harvest in 1976 by the logger on the job (Appendix D), Art Lavigne, indicate that large volumes of many other species were harvested as well. These include *A. saccharum, F. grandifolia,* and *Q. rubra*. This harvest allowed advance hardwood regeneration and other hardwood species to establish and recruit into the canopy. The presence of *A. saccharum, F. grandifolia*, and large *P. strobus* indicates that the pre-settlement Church Woods was likely dominated by these species. This composition matches descriptions by Siccama (1971) and Cogbill (2002) about pre-settlement vegetation in the area.

Limitations and Suggestions for Future Research

The largest limitation of this study was that we were unable to measure the rings and statistically verify cross-dating in COFECHA due to time constraints. Without this data, we were unable to formally analyze patterns of suppression and release so as to increase our ability to elucidate the possible causes and patterns of tree recruitment. If release events had been analyzed in the cores, more accurate suggestions about the effect of individual disturbances on the individual forests could have been discussed. Future studies could incorporate release data from our cores. Another limitation is that the sites we used in this study may not represent the full range of valley clayplain conditions since they were never cleared for agriculture. Perhaps there was something about our sites that discouraged settlers from fully clearing them, which is why they now contain old-growth trees and characteristics. It would be valuable to have more studies done on the age structure and compositional characteristics of other forests in the Champlain Valley or Vermont in general.

Conclusions

Our results indicate that the valley clayplain forest has a species composition and recruitment history that has been heavily influenced by human land use throughout the past 225 years. Our data on species composition indicates that species present in the clayplain forest are extremely variable and there is no one stable condition that can describe a "typical" clayplain forest. This conclusion is corroborated by local valley clayplain forest experts, who agree that tree species composition is not the most important metric for identifying valley clayplain forest, but that soils, location, and understory plant assemblages are so unique that it can be identified even when none of the typical tree species are present (E. Tapper and M. Lapin, personal communication).

However, the valley clayplain forest does contain unique tree species assemblages that managers, landowners, and conservationists might want to preserve. *Quercus spp.*, generally described as notable features of the valley clayplain forest (Cogbill et al., 2002; Lapin, 2003; Nature Conservancy, 2010), could disappear from the area soon as there has been no recent recruitment of these species. If *Quercus* is a desired future component of these forests, management actions should be taken to encourage regeneration. Lorimer (1993) suggests removing the understory of shade-tolerant species in order to promote *Quercus* regeneration if those species are desired. This action would remove competition and shade, allowing *Quercus* spp. to better succeed.

If landowners and managers want to restore valley clayplain forest to post-agricultural land, there are different ways they could do this. As was discussed above, there are many different species assemblages that can thrive on valley clayplain forest sites. If the goal is the mixed hardwood-conifer forests described in *Wetland, Woodland, Wildland* (Thompson and Sorenson, 2001), then planting *Q. alba, C. ovata, P. strobus* and assorted hardwoods would be the best way to ensure that these species are present. Evidence from our study suggests that regeneration of late-successional species will happen naturally despite the forest fragmentation. However, invasive species must be aggressively managed in all areas where clayplain forest restoration is a goal. A large threat to valley clayplain forest systems is invasive species, many of which were present in large concentrations in the Church Woods plot. Invasive species such as *A. platanoides* and *R. cathartica* could potentially change the species composition of valley clayplain forests permanently. Intensive invasive species control would be the best way to manage this issue.

Our results suggest that *T. canadensis* is the late-successional phase of the Clayplain forest. However, because the dynamics of these forests are so entrenched in human land uses, this could change based on other influences such as infestation of the hemlock wolly adelgid (Adelges tsugae), which would change the species composition away from *T. canadensis* and toward other hardwood species such as *B. lenta* (Orwig, 1998; D'Amato, 2006). Our study of the valley clayplain forest shows the importance of studying fragmented forest ecosystems in depth before drawing conclusions about their origin and dynamics.

Literature Cited

Abrams, M., Orwig, D., and Dockry, M. 1997. Dendroecology and successional status of two contrasting old-growth oak forests in the Blue Ridge Mountains, U.S.A. Canadian Journal of Forest Research 27 (7): 994-1002.

Applequist, M.B., 1958. A simple pith locator for use with off-center increment cores. Journal of Forestry *56*(2):141.

Beers, F.W., Ellis, A.D., Soule, G.G. 1971 (1869) Atlas of Chittenden Co., Vermont from actual surveys by and under the direction of F.W. Beers assisted by Geo. P. Sanford and others. Charles E Tuttle Co, Rutland, VT.

Buchanan, M.L. and Hart, J.L. 2012. Canopy disturbance history of old-growth *Quercus alba* sites in the eastern United States: Examination of long-term trends and broad scale patterns. Forest Ecology and Management 267: 28-31.

Burns, R.M., and Honkala, B.H. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

Chapman, J.I and McEwan, R.W. 2016. Thirty years of compositional change in an old-growth temperate torest: The role of topographic gradients in oak-maple dynamics. PLoS ONE 11(7): e0160238. doi: 10.1371/journal.pone.0160238.

Cogbill1, C.V., Burke, J. and Motzkin, G. 2002. The forests of presettlement New England, USA: spatial and compositional patterns based on town proprietor surveys. Journal of Biogeography 29: 1279–1304.

Copenheaver, C.A., Seiler, J.R., Peterson, J.A., Evans, A.M., McVay, J.L. and White, J.H. (2014). Stadium Woods: A dendroecological analysis of an old-growth forest fragment on a university campus. Dendrochronologia 32:62-70.

Cronon, W. 1983. Changes in the Land: Indians, Colonists, and the Ecology of New England. Hill and Wang, New York.

Curtis, J.T., and McIntosh, R.P. 1951. An upland forest continuum in the prairie-forest border region of Wisconsin. Ecology **32**(3): 476-496. doi: 10.2307/1931725.

D’Amato, A.W., Orwig, D.A. and Foster, D.R. 2006. New estimates of Massachusetts old-growth Forests: useful data for regional conservation and forest reserve planning. Northeastern Naturalist 13(4): 495-506.

D'Amato, A.W., and Orwig, D.A. 2008. Stand and landscape-level disturbance dynamics in old-growth forests in western Massachusetts. Ecological Monographs 78(4): 507-522.

D’Amato, A.W., Orwig, D.A. and Foster, D.R. 2008. The influence of successional processes and disturbance on the structure of *Tsuga canadensis* forests. Ecological Applications 18(5):1182-1199.

Danneyrolles, D., Arseneault, D., Bergeron, Y. Long-term compositional changes following partial disturbance revealed by the resurvey of logging concession limits in the northern temperate forest of eastern Canada. Canadian Journal of Forest Research 46: 943-949. doi: 10.1139/cjfr-2016-0047

Foster, D.R., Motzkin, G. and Slater, B. 1998. Land-use history as a long-term broad-scale disturbance: Regional forest dynamics in Central New England. Ecosystems 1(1): 96-119.

Foster, D.R., Orwig, D.A., and McLachlan, J.S. 1996. Ecological and conservation insights from reconstructive studies of temperate old-growth forests. TREE 11(10):419-424.

Frelich, L.E. and Lorimer, C.G. 1991. Natural disturbance regimes in hemlock-hardwood forests of the Upper Great Lakes region. Ecological Monographs 61(2):145-164

Frelich, L.E., Reich, P.B., 2002. Dynamics of old-growth oak forests in the eastern United States. In: McShea, W.J., Healy, W.M. (Eds.), Oak Forest Ecosystems: Ecology and Management for Wildlife. Johns Hopkins University Press, Baltimore, Maryland, pp. 113–126.

Goebel, P.C. and Hix, D.M. 1996. Developmnt of mixed-oak forests in southeastern Ohio: a comparison of second-growth and old-growth forests. Forest Ecology and Management 84:1-21.

Hart, J.L., Clark, S.L., Torreano, S.J. and Buchannan, M.L. 2012. Composition, structure, and dendroecology of an old-growth Quercus forest on the tablelands of the Cumberland Plateau, USA. Forest Ecology and Management 266:11-24.

Hemenway, A. M. 1867. Vermont Historical Gazetteer: a magazine, embracing a history of each town, civil, ecclesiastical., biographical and military. Published by A. M. Hemenway, Burlington, VT.

Janowiak, M.K., Nagel, L.M., Webster, C.R. 2008. Spatial scale and stand structure in northern hardwood forests: implications for quantifying diameter distributions. Forest Science 54(5):497-506.

Johnson, P.S., Shifley, S.R., Rogers, R. 2009. The Ecology and Silviculture of Oaks (2nd Edition). Oxford: CABI Publishing, New York, NY.

Knopp, P.D. 2012. The Distribution of Quercus rubra in the Maumee Lake Plain of Southeastern Michigan. American Midland Naturalist 168: 70-92.

Lapin, M., Vermont Nongame Natural Heritage Program, Vermont Agency of Natural Resources. (1998). Champlain Valley clayplain forests of Vermont: some sites of ecological significance. Waterbury, Vt.: Nongame and Natural Heritage Program.

Lapin, M. 2001. Church Woods clayplain forest fragment ecological and botanical assessment. Cornwall, Vermont: Champlain Valley Clayplain Forest Project.

Lapin, M. F. 2003. Nature conservation in an agricultural landscape: forest ecology, fragmentation analysis, and systematic site prioritization, southern Champlain Valley, Vermont, USA. Cornell University.

Lipke, W.C. 1979. Shelburne Farms: The History of an Agricultural Estate. The Robert Hull Fleming Museum, University of Vermont.

Lorimer, C.G., 1993. Causes of the oak regeneration problem. Proceedings of the Oak regeneration: serious problems, practical recommendations symposium. Gen. Tech. Rep. SE-84. US Forest Service, Southeastern Forest Experiment Station, Asheville, North Carolina.

Lorimer, C.G., and White, A.S. 2003. Scale and frequency of natural disturbances in the northeastern US: implications for early successional forest habitats and regional age distributions. Forest Ecology and Management 185(1-2): 41-64. doi: 10.1016/s0378-1127(03)00245-7.

Lutz, H.J. 1930. Effect of cattle grazing on vegetation of a virgin forest in northwestern Pennsylvania. Journal of Agricultural Research 41(7):561-570

Nowacki, G. J., and M. D. Abrams. 1997. Radial-growth averaging criteria for reconstructing disturbance histories from presettlement-origin oaks. Ecological Monographs 67: 225–249

Oliver, C.D. 1980. Forest development in North America following major disturbances. Forest Ecology and Management 3:153-168

Oliver, C.D., Larson, B.C. 1990. Forest Stand Dynamics. Mc-Graw Hill inc

Oliver, C.D and Stephens, E.P. 1977. Reconstruction of a mixed-species forest in central New England. Ecology 58: 562-572.

Orwig, D.A., Cogbill, C.V., Foster, D.R., and O'Keefe, J.R. 2001. Variations in old-growth structure and definitions: Forest Dynamics on Wachusett Mountain, Massachusetts. Ecological Applications 11(2): 437. doi:10.2307/3060900.

Orwig, D.A., Foster, D.R. 1998. Forest Response to the introduced hemlock woolly adelgid in southern New England, USA. Journal of the Torrey Botanical Society 125(1):60-73.

Otsuka, B. G. 2004. Natural regeneration processes on post-agricultural land on the clayplain of the Champlain Valley, Vermont USA. Antioch University Graduate School.

Pederson, N., D'Amato, A.W., and Orwig, D.A. Natural History from Dendrochronology: Maximum Ages and Canopy Persistence of Rarely Studied Hardwood species. Proceedings of the 15th Central Hardwood Forest Conference

Pederson, N., Bell, A.R., Cook, E.R., Lall, U., Devineni, N., Seager, R., Eggleston, K. and Vranes, KP. 2013. Is an epic pluvial masking the water insecurity of the greater New York City region? Journal of Climate 26:1339-1354.

Pretzsch, H., Biber, P., Schutza, G., and Bielak, K. 2013. Changes of forest stand dynamics in Europe: Facts from long-term observational plots and their relevance for forest ecology and management. Forest Ecology and Management 316: 65-77.

Runkle, J.R. 1982. Patterns of disturbance in some old-growth mesic forests of eastern North America. Ecology 63(5): 1533-1546.

Russell Southgate, E.W.B. and Thompson, J.E. 2014. Secondary forest succession in a post-agricultural landscape in the Hudson Valley, New York. Northeastern Naturalist 21(1): 35-50.

Stoyan, D., and Stoyan, H. 1994. Fractals, Random Shapes, and Point Fields: Methods of Geometrical Statistics. John Wiley & Sons, New York.

Schwarz, P.A., Fahey, T.J., Martin, C. W., Siccama, T. G., Bailey, A. 2001. Structure and composition of three northern hardwood-conifer forests with differing disturbance histories. Forest Ecology and Management 144: 201-212.

Siccama, T.G. 1971. Presettlement and Present Forest Vegetation in Northern Vermont with Special Reference to Chittenden County. American Midland Naturalist 85(1): 153-172.

Spies, T. A. 1998. Forest structure: a key to the ecosystem. Northwest Science 72:34–39.

Sprugel, D.G. 1991. Disturbance, Equilibrium, and Environmental Variability: What is “natural” vegetation in a changing environment? Biological Conservation 58:1-18.

The Nature Conservancy. 2010. The Nature Conservancy: Places to walk, paddle, and explore in Vermont. The Nature Conservancy, Montpelier, VT.

Thompson, E. H., Sorenson, E. R. 2000. Wetland, woodland, wildland: a guide to the natural communities of Vermont. Vermont Dept. of Fish and Wildlife and the Nature Conservancy; Distributed by University Press of New England.

United States Forest Service, 2005. Phase 3 Field Guide- Coarse Woody Debris. Accessed from https://www.fia.fs.fed.us/library/field-guides-methods-proc/docs/2006/p3_3-0_sec14_10_2005.pdf on 5/9/2017

Wilson, B. F., and B. C. McComb. 2005. Dynamics of dead wood over 20 years in a New England oak forest. Canadian Journal of Forest Research 35:682–692. doi:10.1139/x05-003

Wiseman, F. M. 2001. The Voice of the Dawn: An Autohistory of the Abenaki Nation. Hanover, NH: University Press of New England.

Yamaguchi, D.K. 1991. A simple method for cross-dating increment cores from living trees. Canadian Journal of Forest Research 21(3): 414-416

Zaczek, J.J., Groninger, J.W., Van Sambeek, J.W. 2002. Stand Dynamics in an Old-Growth Hardwood Forest in Southern Illinois, USA. The Natural Areas Journal 22(3): 211-219.

Figures and Tables

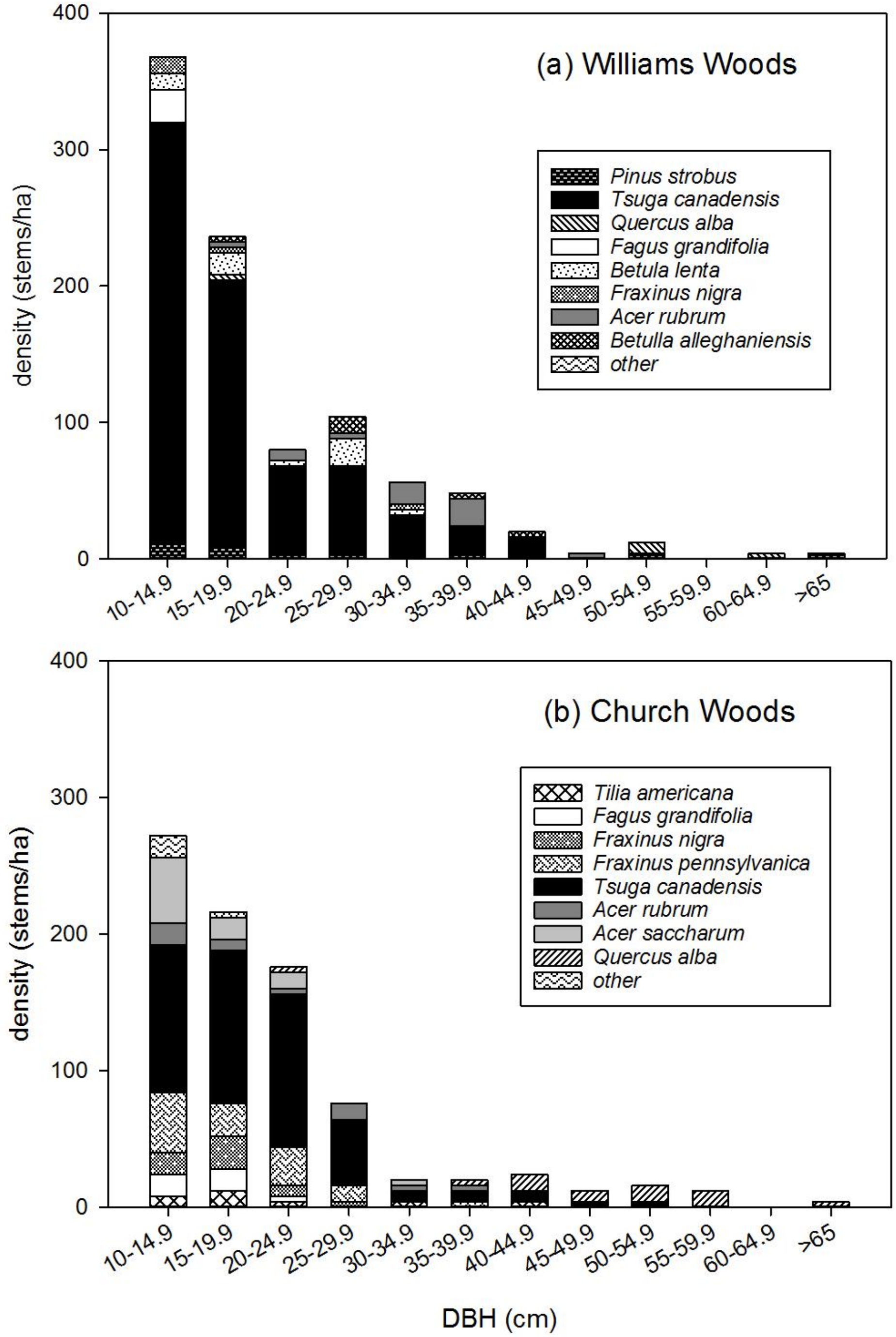


Figure 3: Tree diameter distributions for Williams Woods in Charlotte, Vermont (a) and Church Woods at Shelburne Farms in Shelburne, Vermont (b). "Other" species in Williams Woods include *Carya ovata*, *Tilia americana*, *Fraxinus pennsylvanica*, *Quercus rubra*, and *Acer saccharum*. "Other" species in Church Woods include *Ulmus americana*, *Carya cordiformis*, *Rhamnus cathartica*, *Betula papyrifera*, *Betula lenta*, *Ostrya virginiana*, *Acer platanoides*, and *Carya ovata*.

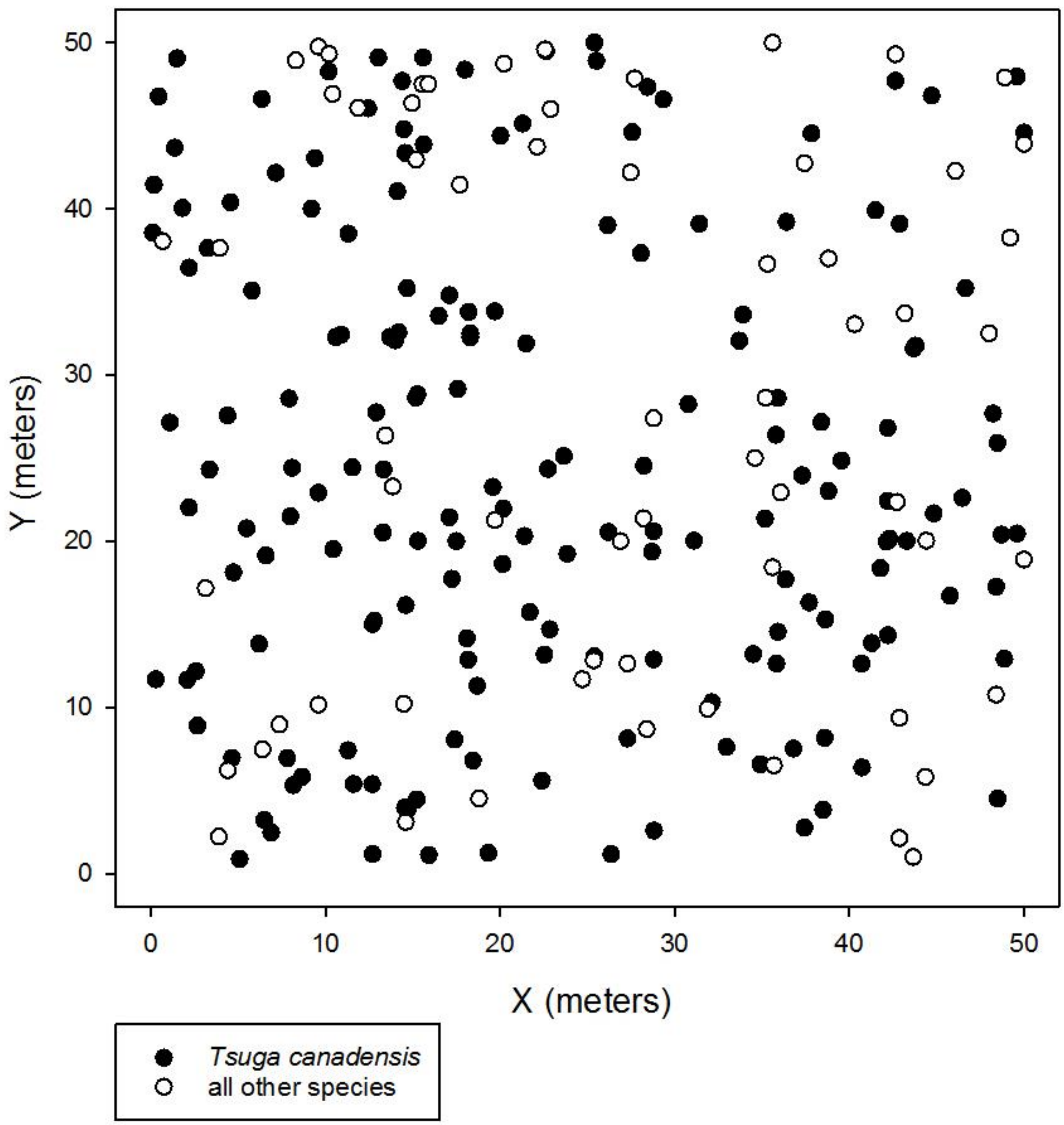


Figure 4: Map of living trees at Williams Woods in Charlotte, Vermont. Trees are grouped based on species.

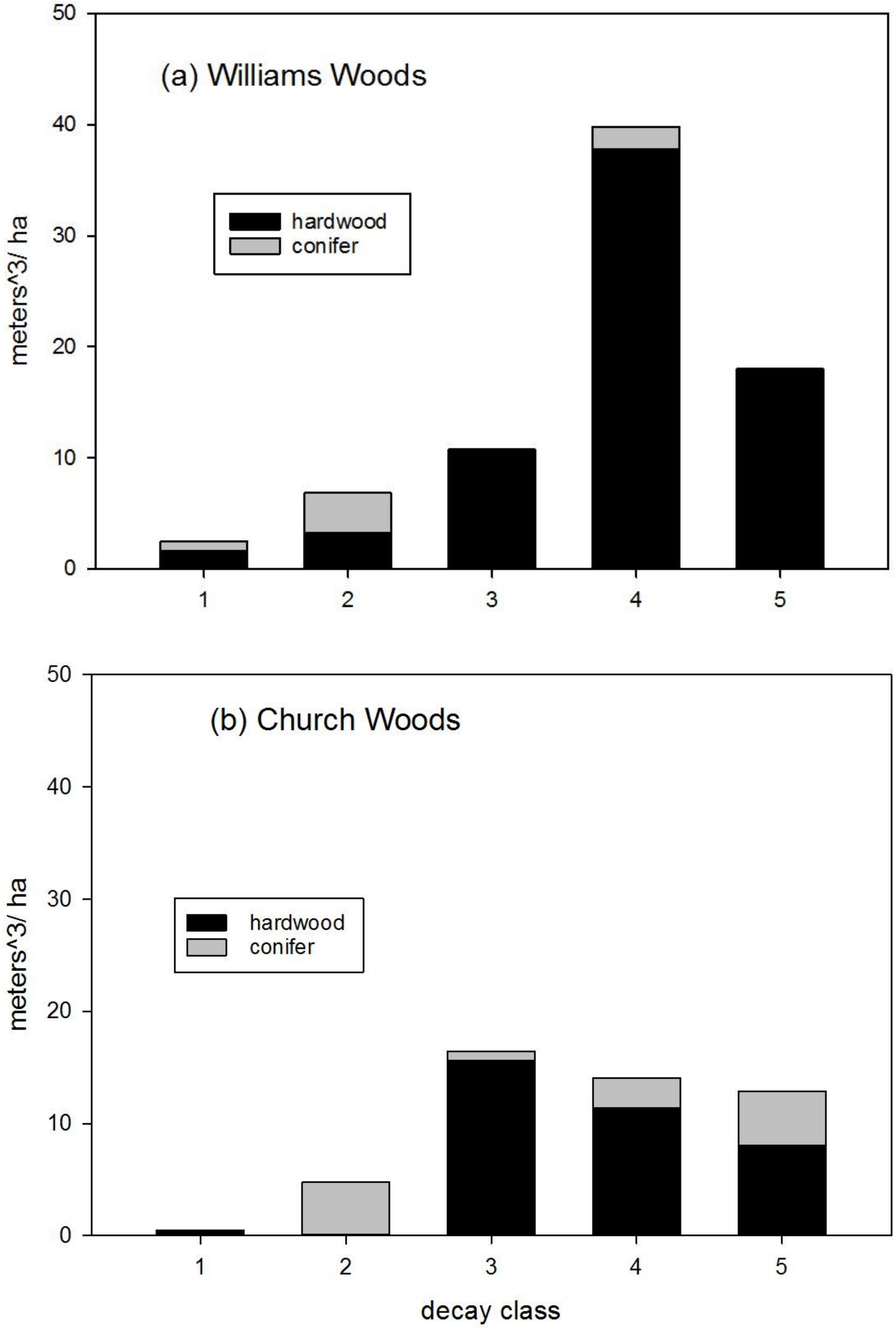


Figure 5: Volume (m³/hectare) of course woody debris present in Williams Woods in Charlotte, Vermont (a) and Church Woods at Shelburne Farms in Shelburne, Vermont (b) grouped by decay class.

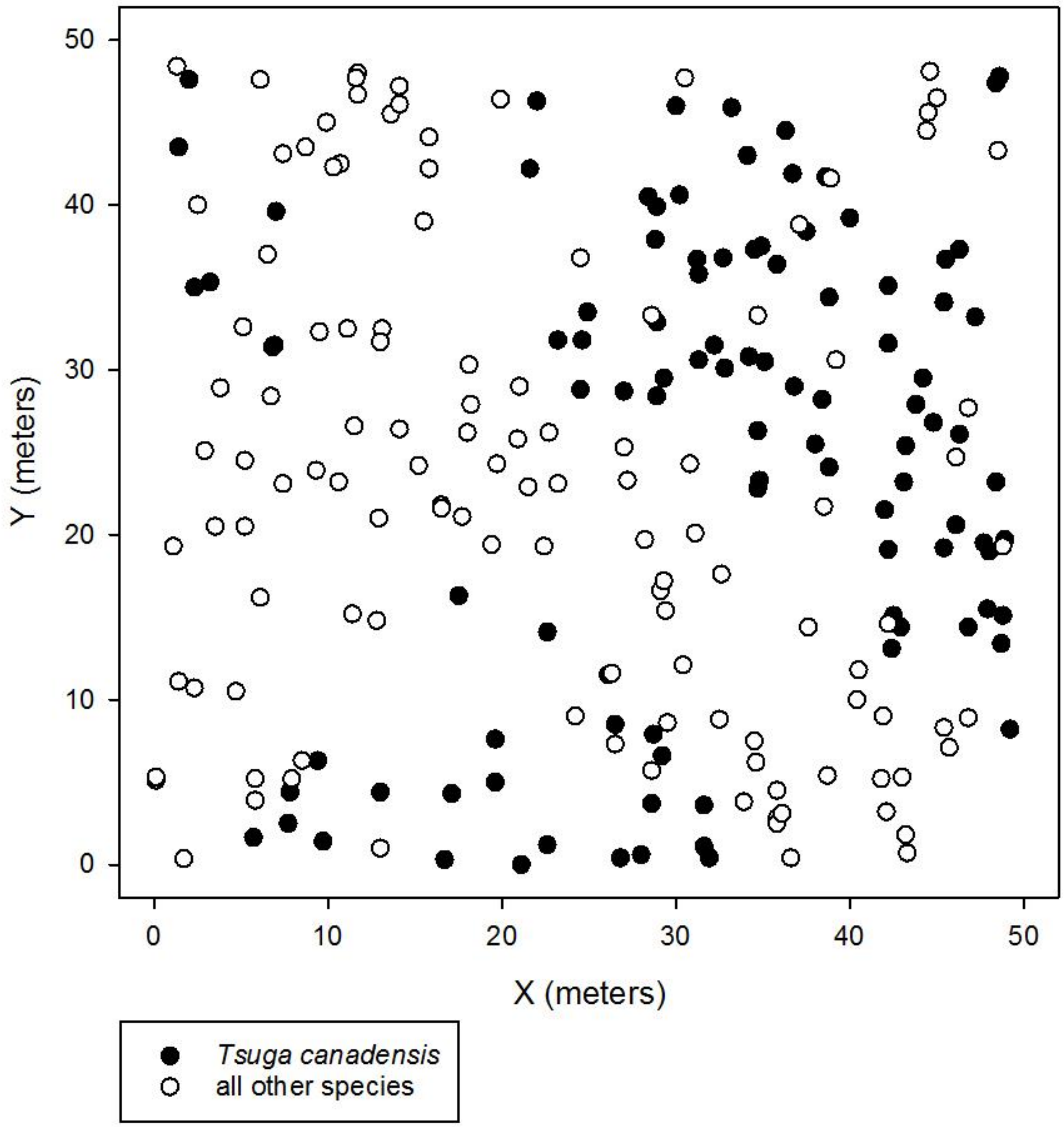


Figure 6: Map of living trees at Church Woods at Shelburne Farms in Shelburne, Vermont. Trees are grouped based on species.

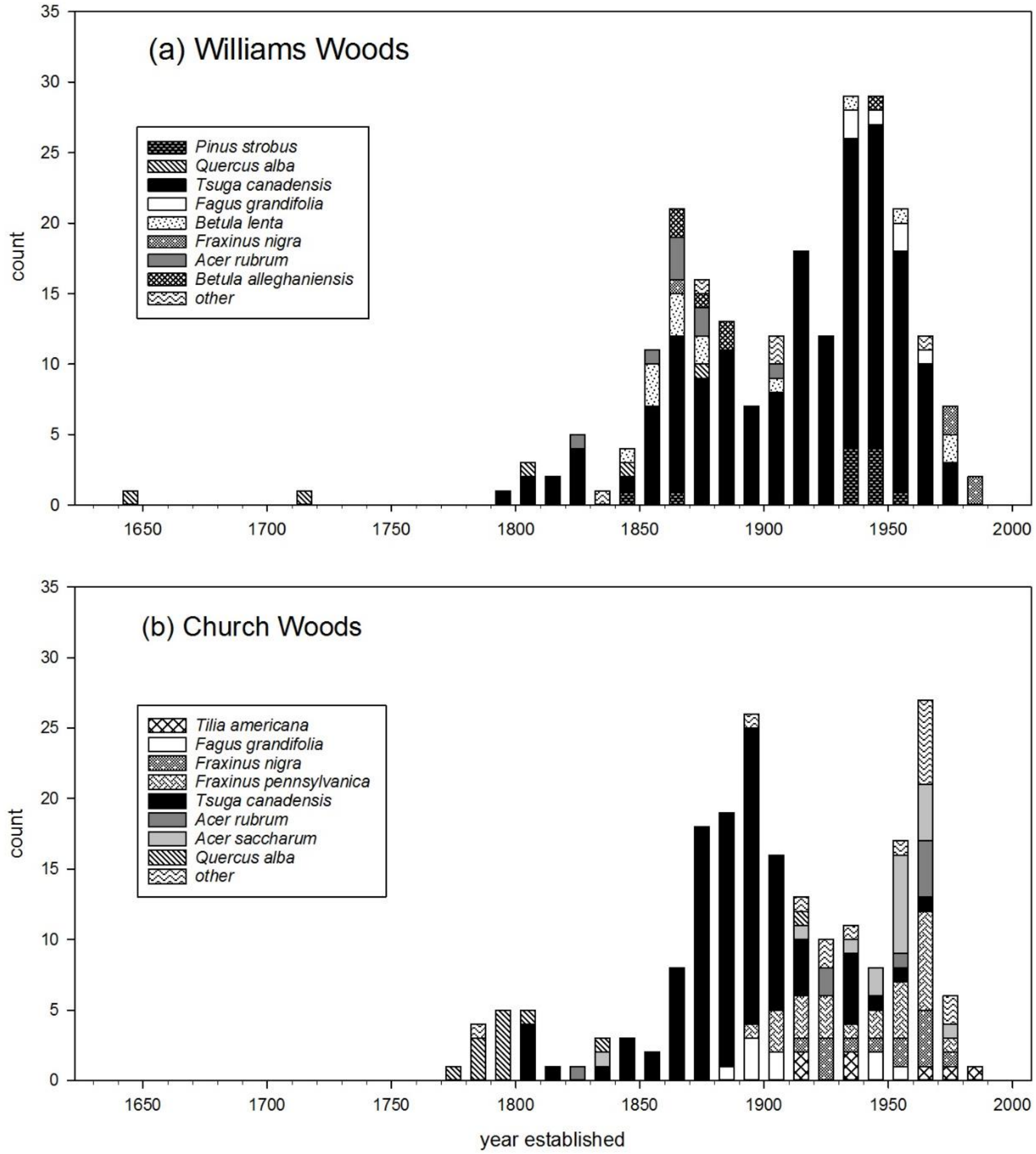


Figure 7: Establishment dates for trees in Williams Woods in Charlotte, Vermont (a) and Church Woods at Shelburne Farms in Shelburne, Vermont (b). "Other" species in Williams Woods include *Carya ovata*, *Quercus rubra*, and *Acer saccharum.* "Other" species in Church Woods include *Ulmus americana*, *Carya cordiformis*, *Rhamnus cathartica*, *Betula papyrifera*, *Betula lenta*, *Ostrya virginiana*, *Acer platanoides*, and *Carya ovata.* Trees that were not cored or had a partial core were omitted from this figure.

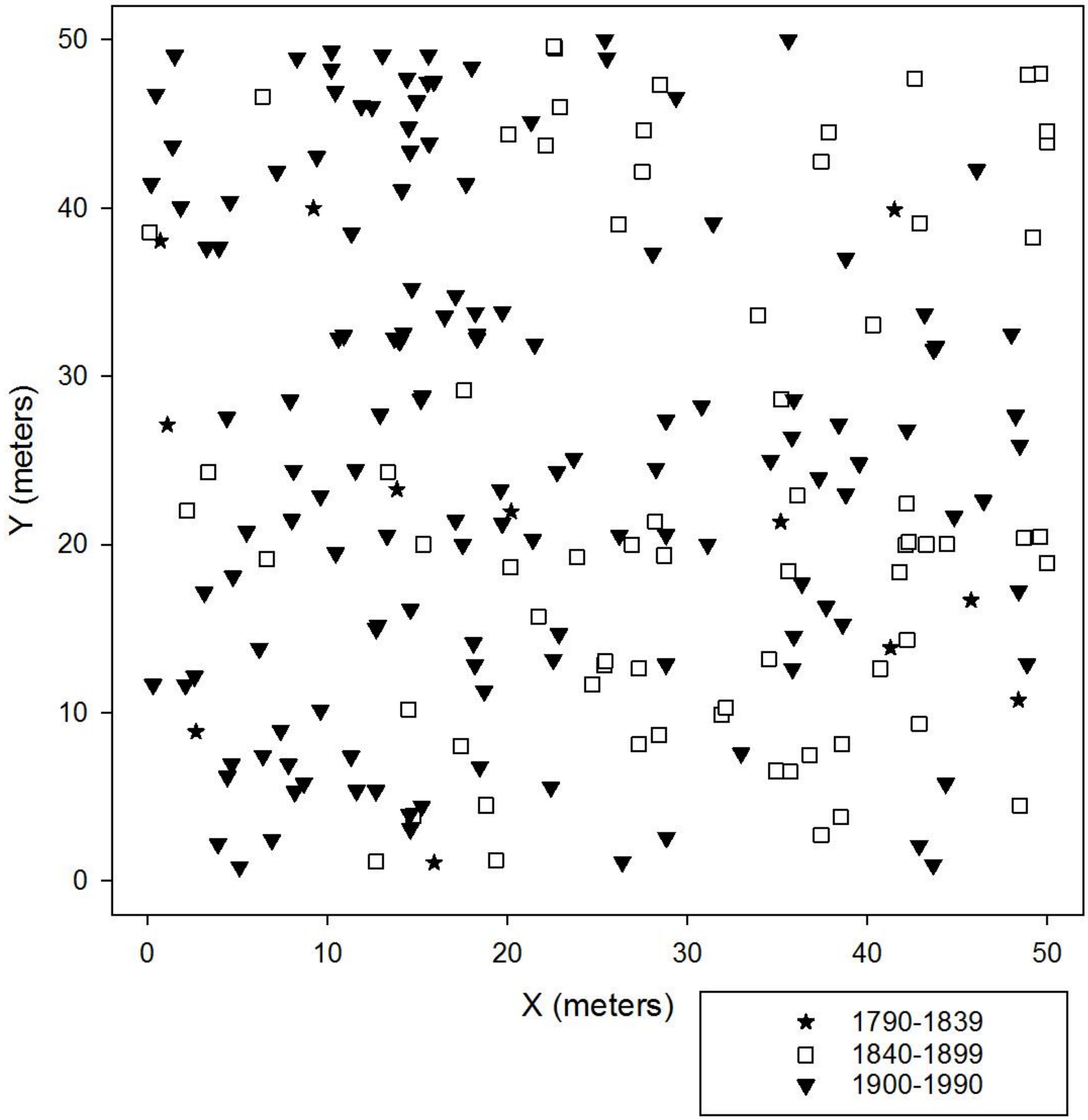


Figure 8: Map of trees in a ¼ hectare plot in Williams Woods in Charlotte, Vermont. Trees are separated into distinct age cohorts based on Figure 2a. Trees that were not cored, had a partial core, or were not located within the ¼ acre plot were not included in this figure.

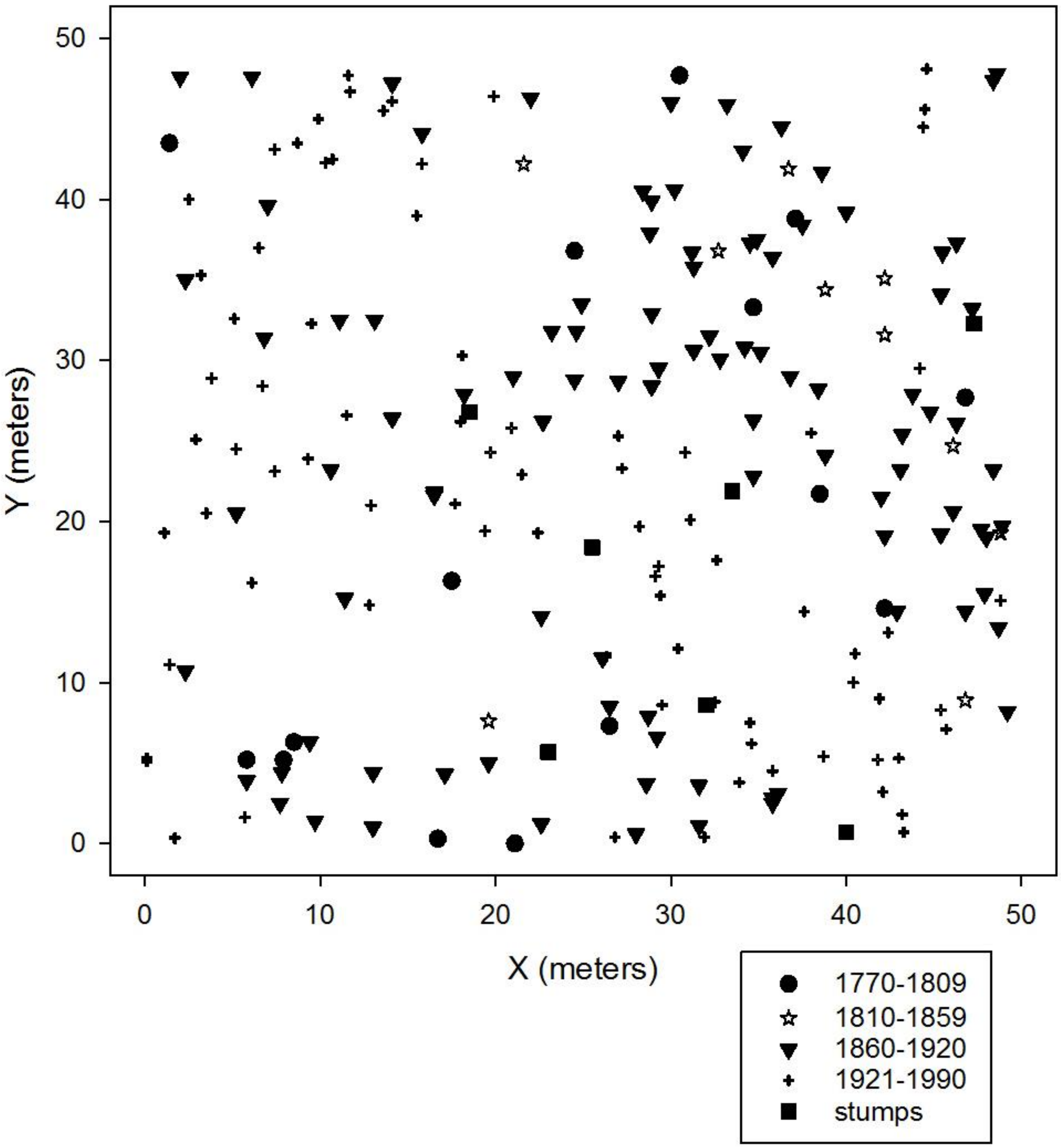


Figure 9: Map of trees and stumps in a ¼ hectare plot at Church Woods at Shelburne Farms in Shelburne, Vermont. Trees are separated into distinct age cohorts based on Figure 2b. Trees that were not cored or had a partial core are not included in the figure. Stumps were included to visualize the impact that past harvesting had on tree recruitment.

Table 1: Seedling (all stems shorter than 1.37 meters) and sapling (all stems less than 10 cm DBH and taller than 1.37 meters) data from Williams Woods in Charlotte, VT. Regeneration is measured both in terms of stems per hectare and stocking. Stocking is based on presence or absence in each of the nine regeneration plots.

Species	Seedlings/ha	Stocking	Saplings/ha	Stocking
Betula alleghaniensis	442	44%	707	22%
Acer rubrum	20071	89%	0	0
Tsuga canadensis	88	11%	531	44%
Fagus grandifolia	265	22%	177	22%
Quercus rubra	177	22%	0	0
Carya cordiformis	88	11%	0	0
Fraxinus pennsylvanica	177	11%	88	22%
Quercus alba	442	22%	0	0
Fraxinus nigra	265	11%	0	0
Pinus strobus	531	22%	0	0
Acer saccharum	177	22%	0	0

Table 2: Seedling (all stems shorter than 1.37 meters) and sapling (all stems less than 10 cm DBH and taller than 1.37 meters) data from Church Woods in Shelburne, VT. Regeneration is measured both in terms of stems per hectare and stocking. Stocking is based on presence or absence in each of the nine regeneration plots.

Species	Seedlings/ha	Stocking	Saplings/ha	Stocking
Fagus grandifolia	1945	33%	796	22%
Acer saccharum	2210	89%	88	11%
Amalanchier arborea	0	0	88	11%
Tsuga canadensis	177	11%	88	11%
Acer rubrum	88	11%	0	0
Lonicera spp.	442	22%	0	0
Betula lenta	3714	22%	0	0
Fraxinus pennsylvanica	88	11%	0	0
Rhamnus cathartica	265	22%	531	11%

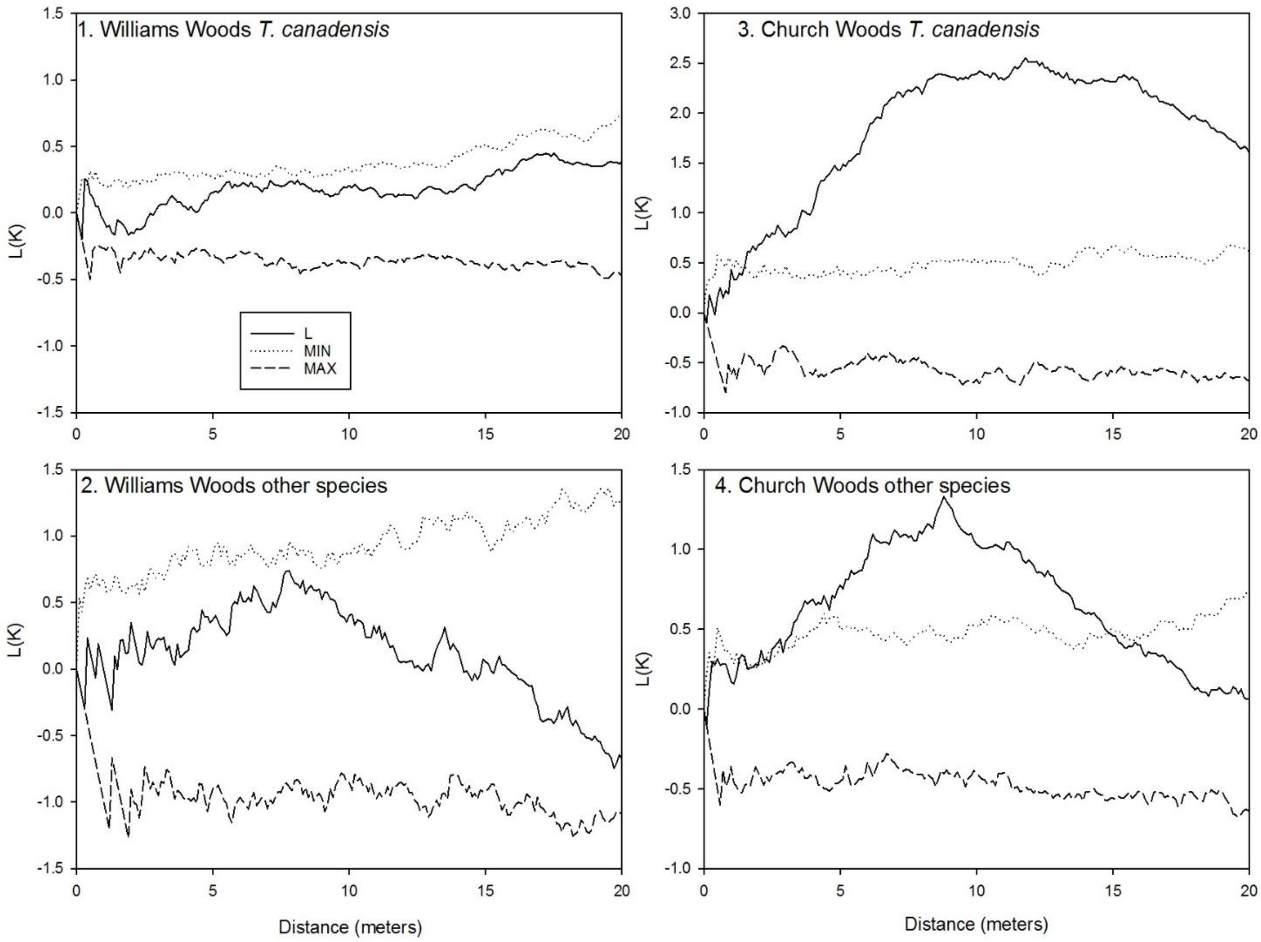
Appendix:

A. **(1)** Importance value of all species used in the study at Williams Woods in Charlotte, Vermont.

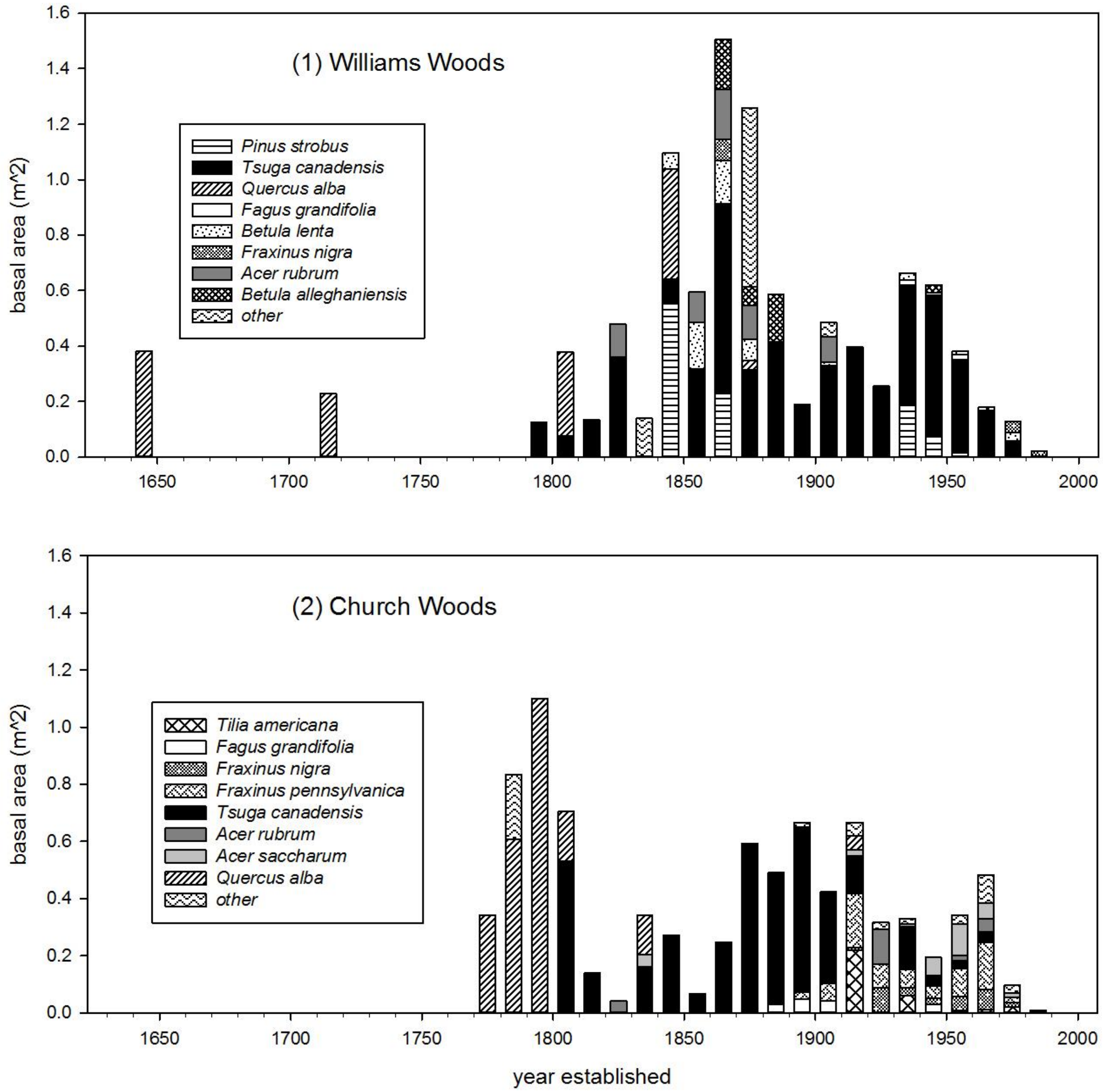
Species	Importance Value
Tsuga canadensis	0.6018
Acer rubrum	0.0814
Quercus alba	0.0800
Pinus strobus	0.0670
Betula lenta	0.0523
Betula alleghaniensis	0.0318
Quercus rubra	0.0300
Fraxinus nigra	0.0163
Fagus grandifolia	0.0147
Acer saccharum	0.0081
Carya ovata	0.0068
Fraxinus pennsylvanica	0.0061
Tilia americana	0.0036

(2) Importance value of all species used in the study at Church Woods at Shelburne Farms in Shelburne, Vermont.

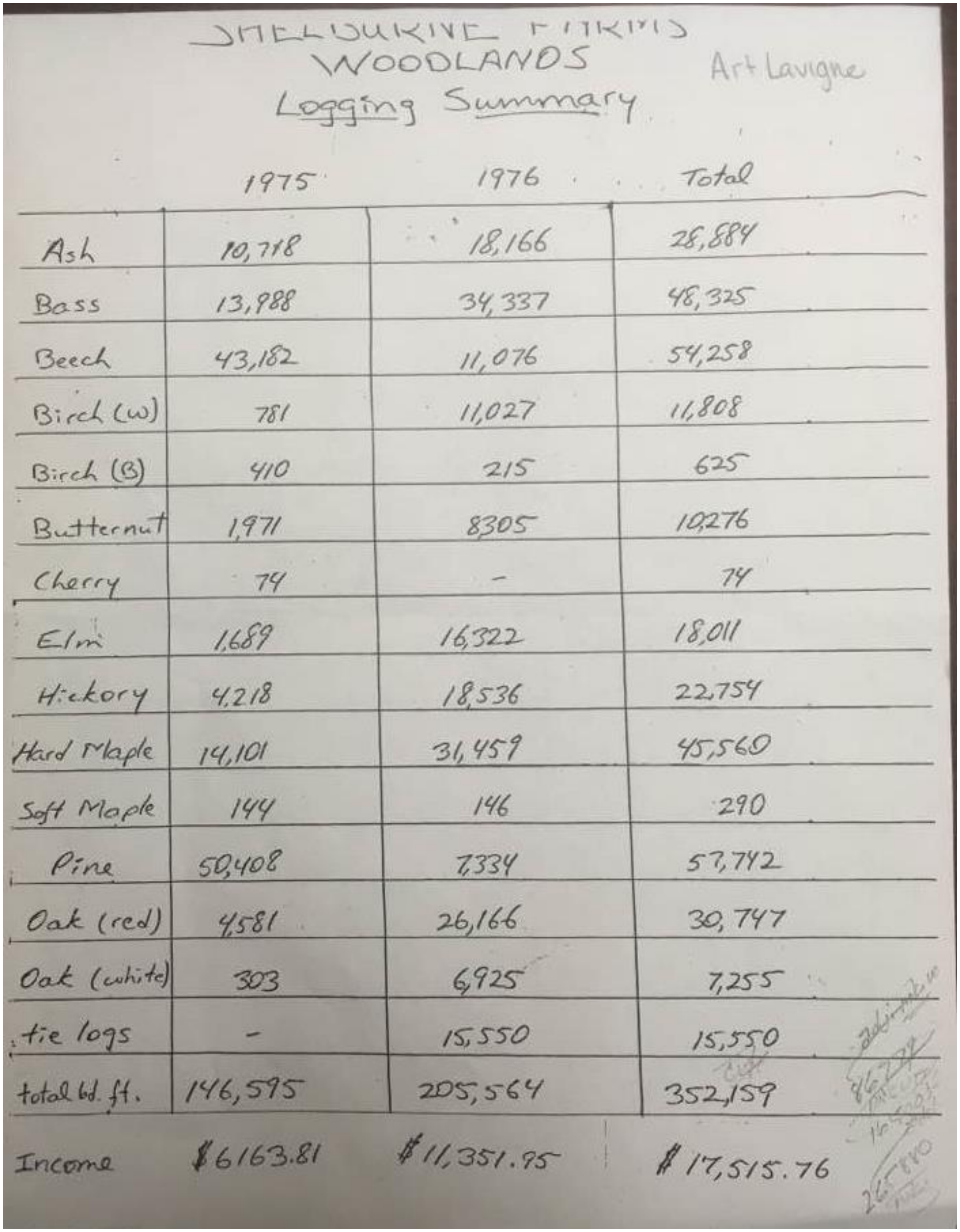
Species	Importance Value
Tsuga canadensis	0.4325
Quercus alba	0.1671
Fraxinus pennsylvanica	0.1050
Acer saccharum	0.0681
Acer rubrum	0.0531
Fraxinus nigra	0.0480
Tilia Americana	0.0360
Fagus grandifolia	0.0287
Quercus rubra	0.0172
Carya ovata	0.0117
Acer platanoides	0.0060
Ostrya virginiana	0.0058
Betula papyrifera	0.0039
Ulmus americana	0.0033
Rhamnus cathartica	0.0029
Carya cordiformis	0.0028



B. Graphs indicating Ripley's K values for species composition in Williams Woods (1&2) and Church Woods (3&4).



C. Basal area of trees in Williams Woods in Charlotte, Vermont (1) and Church Woods at Shelburne Farms in Shelburne, Vermont (2) by year established and species. "Other" species in Williams Woods include *Carya ovata*, *Quercus rubra*, and *Acer saccharum.* "Other" species in Church Woods include *Ulmus americana*, *Carya cordiformis*, *Rhamnus cathartica*, *Betula papyrifera*, *Betula lenta*, *Ostrya virginiana*, *Acer platanoides*, and *Carya ovata.* Trees that were not cored or had a partial core were omitted from this figure.

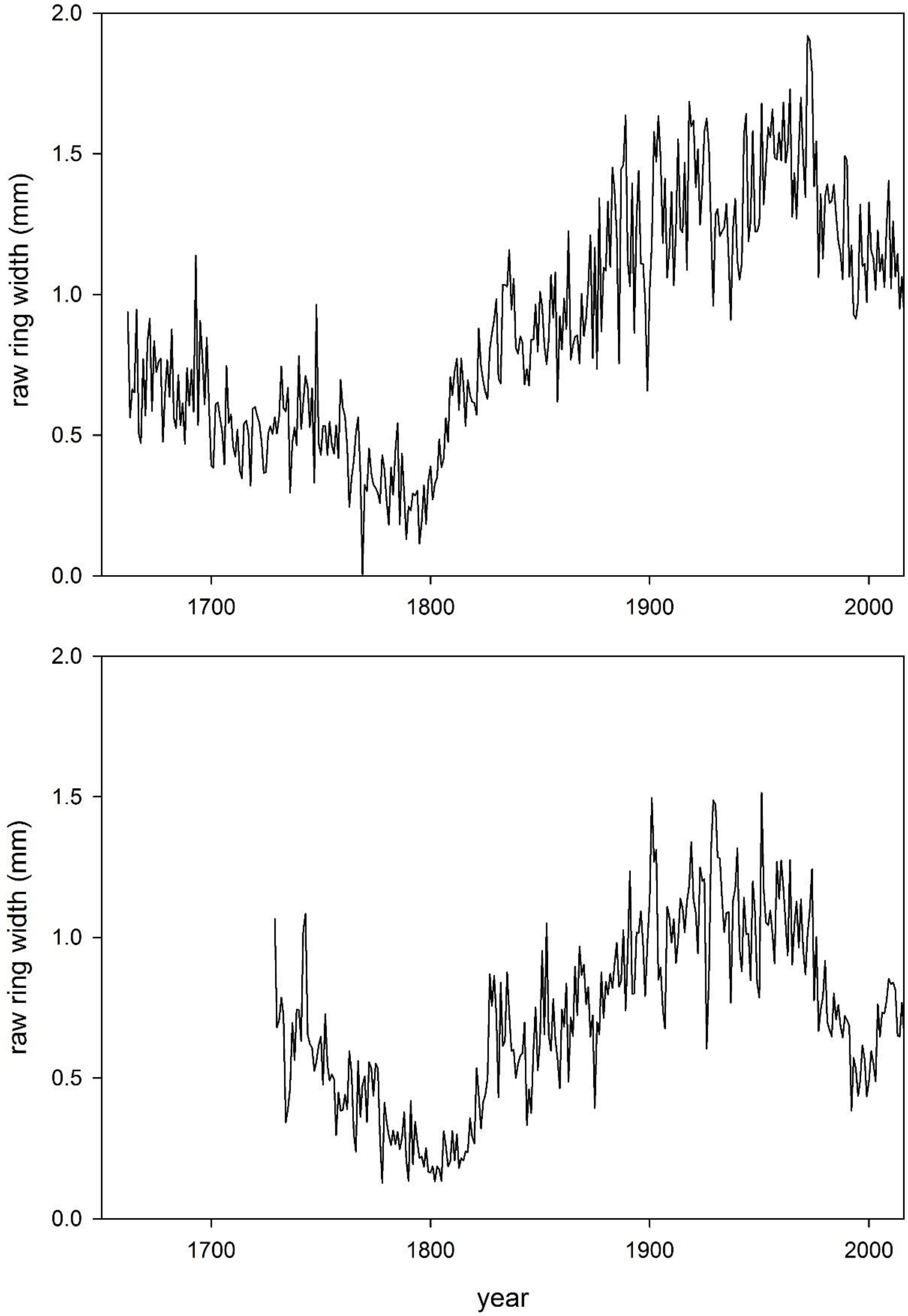


SHELBURNE FARMS
WOODLANDS
Logging Summary

Art Lavigne

	1975	1976	Total
Ash	10,718	18,166	28,884
Bass	13,988	34,337	48,325
Beech	43,182	11,076	54,258
Birch (W)	781	11,027	11,808
Birch (B)	410	215	625
Butternut	1,971	8305	10,276
Cherry	74	–	74
Elm	1,689	16,322	18,011
Hickory	4,218	18,536	22,754
Hard Maple	14,101	31,459	45,560
Soft Maple	144	146	290
Pine	50,408	7,334	57,742
Oak (red)	4,581	26,166	30,747
Oak (white)	303	6,925	7,255
tie logs	–	15,550	15,550
total bd. ft.	146,595	205,564	352,159
Income	$6163.81	$11,351.95	$17,515.76

D. Logging summary for the harvest done in Church Woods at Shelburne Farms in Shelburne, VT by logger Art Lavigne in 1975 and 1976. Accessed from the Chittenden County forester's office in Essex, VT.



E. Ring widths for two *Quercus alba* individuals cored at Williams Woods in Charlotte, VT in August, 2016.

F. **(1)** Number of trees measured and number of cores used for age structure by species in Williams Woods in Charlotte, VT.

species	trees measured	cores used	% of cores used
Tsuga canadensis	177	168	95
Acer rubrum	14	8	57
Betula lenta	14	14	100
Pinus strobus	11	11	100
Betula alleghaniensis	7	6	86
Quercus alba	6	5	83
Fagus grandifolia	6	6	100
Fraxinus nigra	5	5	100
Quercus rubra	2	2	100
Carya ovata	2	2	100
Acer saccharum	1	1	100
Tilia americana	1	0	0
Fraxinus pennsylvanica	1	0	0

(2) Number of trees measured and number of cores used for age structure by species in Church Woods at Shelburne Farms in Shelburne, VT.

species	trees measured	cores used	% of cores used
Tsuga canadensis	103	99	96
Fraxinus pennsylvanica	28	25	89
Acer saccharum	20	17	85
Quercus alba	14	12	86
Fraxinus nigra	14	13	93
Acer rubrum	12	8	67
Fagus grandifolia	9	9	100
Tilia americana	8	7	88
Carya ovata	3	3	100
Betula lenta	2	2	100
Ostrya virginiana	2	2	100
Acer platanoides	2	2	100
Quercus rubra	2	2	100
Ulmus americana	1	1	100
Carya cordiformis	1	1	100
Rhamnus cathartica	1	1	100
Betula papyrifera	1	1	100

G. Coarse woody debris decay classes, taken directly from page 12 of the USFS Phase 3 Field Guide- Coarse Woody Debris, October 2005.

Decay Class	Structural Integrity	Texture of Rotten Portions	Color of Wood	Invading Roots	Branches and Twigs
1	Sound, freshly fallen, intact logs	Intact, no rot; conks of stem decay absent	Original color	Absent	If branches are present, fine twigs are still attached and have tight bark
2	Sound	Mostly intact; sapwood partly soft (starting to decay) but can't be pulled apart by hand	Original color	Absent	If branches are present, many fine twigs are gone and remaining fine twigs have peeling bark
3	Heartwood sound; piece supports its own weight	Hard, large pieces; sapwood can be pulled apart by hand or sapwood absent	Reddish-brown or original color	Sapwood only	Branch stubs will not pull out
4	Heartwood rotten; piece does not support its own weight, but maintains its shape	Soft, small blocky pieces; a metal pin can be pushed into heartwood	Reddish or light brown	Throughout	Branch stubs pull out
5	None, piece no longer maintains its shape, it spreads out on ground	Soft; powdery when dry	Red-brown to dark brown	Throughout	Branch stubs and pitch pockets have usually rotted down