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Characteristics, Histories, and Future Succession of Northern Pinus pungens Stands

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ABSTRACT.—*Pinus pungens* (Table Mountain pine) stands are rare conifer-dominated communities that occur on xeric ridges and upper slopes throughout the central and southern Appalachian Mountains. At the northern end of this range, this uncommon forest community is essentially unstudied. Therefore, in 2006 I initiated a dendroecology study of three *Pinus pungens* stands growing in Pennsylvania to better understand their current conditions, histories, and likely future succession. These stands contained from four to 14 tree species with *Pinus pungens* or *Quercus montana* (chestnut oak) dominating the main canopy. *Quercus coccinea* (scarlet oak), *Acer rubrum* (red maple), or *Nyssa sylvatica* (black gum) were the primary species of the midstory. *Kalmia latifolia* (mountain laurel) was the principal understory shrub. Two of the communities had *Pinus pungens* and *Quercus montana* trees dating back into the mid-1800s and were likely heavily influenced by the charcoal iron industry of that century. Periodic fire was also part of their history. The other *Pinus pungens* community arose following abandonment of an agricultural field in the 1910s and fire does not seem to have been a factor in its ecological history. Two of the communities appear to be losing their *Pinus pungens* component as their understories are dominated by hardwood saplings or shrubs and there are no pine seedlings present. Perpetuating these and other *Pinus pungens* communities in Pennsylvania will require reducing the understory vegetation and creating suitable seed beds for *Pinus pungens* seedling establishment.

INTRODUCTION

Pinus pungens (Table Mountain pine) is a native hard pine of the eastern United States. It, along with *Pinus rigida* (pitch pine), *Pinus echinata* (shortleaf pine), and *Pinus virginiana* (Virginia pine), forms small conifer-dominated communities throughout the hardwood forests of the Appalachian Mountains. *Pinus pungens* stands occur from central Pennsylvania to northern Georgia on thin, dry soils of south and west facing ridges and upper slopes between 300 and 1200 m elevation (Zobel, 1969; Della Bianca, 1990; Williams, 1998). All of these hard pine species have one or more characteristics that suggest periodic fire was an important disturbance in the origin and maintenance of these communities (Williams, 1998; Welch *et al.*, 2000; Brose and Waldrop, 2006; Aldrich *et al.*, 2010). In this era of fire exclusion, these isolated montane pine communities are in various stages of ecological decline and are becoming rare (Noss *et al.*, 1995; Williams, 1998). Consequently, they are becoming increasingly valued for diversity by land managers because they constitute an uncommon conifer community in an otherwise hardwood dominated forest landscape.

Because of this inherent diversity value and their association with periodic fire, *Pinus pungens* communities have been extensively studied and that research can be divided into two groups: descriptive and fire-related. *Pinus pungens* was described and named by Aylmer Lambert from samples collected by Andre Michaux from Tablerock Mountain, North Carolina (Lambert, 1803, 1805). Zobel (1969) compiled the relevant literature to that time and thoroughly described *Pinus pungens* communities in his monograph of the species. More recently, age structure, stand development, and regeneration requirements of *Pinus pungens* communities have been well addressed by several scientists (Barden, 1988; Williams and

Johnson, 1990; Williams *et al.,* 1990; Barden, 2000; Brose *et al.*, 2002; Brose and Waldrop, 2012).

While many of the aforementioned scientists commented on the likely role of fire in *Pinus pungens* communities, the substantial fire-related research has occurred in the past 25 y. Groeschl *et al.* (1992, 1993) reported the responses of a *Pinus pungens* community to a summer wildfire while Waldrop and Brose (1999) did likewise for a variable intensity spring prescribed fire. Large-scale studies examining multiple fire variables and vegetative responses have been conducted at several locations (Welch *et al.*, 2000; Jenkins *et al.*, 2011; Schwartz *et al.*, 2016). A major part of this fire-related research has been determining the fire history of *Pinus pungens* communities via dendrochronology studies (Sutherland *et al.*, 1995; Brose and Waldrop, 2006; Aldrich *et al.*, 2010, 2014; Hessl *et al.*, 2011; Flatley *et al.*, 2013, 2015).

A common characteristic of most of this *Pinus pungens* research is that it occurred in the southern half of the species range. Much less research has been performed on *Pinus pungens* communities at the northern end of its range. Best (1886) described the formation of a *Pinus pungens* stand in an abandoned farm field in New Jersey. In Pennsylvania, McIntyre (1929), studied *Pinus pungens* cone and seed production and Mollenhauer (1939) reported on red squirrels (*Sciurus hudsonicus*) opening the cones and feeding on the seeds. Zobel (1969) included five *Pinus pungens* stands from Pennsylvania in his monograph and Hunter and Swisher (1983) provided *Pinus pungens* data in a descriptive study of a natural area. Finally, Gibson and Hamrick (1991) used branches and needles from 48 *Pinus pungens* trees in Pennsylvania for a genetics study.

Owing to the lack of studies on northern *Pinus pungens* communities, I initiated a dendroecology study in 2006 of three *Pinus pungens* stands in Pennsylvania to elucidate basic ecological information about these montane pine communities. Specific questions included: (1) what are their current attributes and how do these compare to southern *Pinus pungens* communities? (2) What has been their disturbance histories? and (3) What are their likely futures? Answering these questions will provide basic ecological knowledge and ideas for management options to land managers striving to maintain or restore *Pinus pungens* communities throughout the Appalachian Mountains.

METHODS

STUDY SITES

In 2006 I selected three *Pinus pungens* stands for the study based on the presence of *Pinus pungens* in the main canopy, one or more hardwood tree species, and the appearance of having been undisturbed for decades. Two of the *Pinus pungens* communities, Martin Hill (MH) and Mont Alto Mountain (MAM), were in southern Pennsylvania while the other, Masseyburg (MS), was in the central part of the state. The MH site (39°44′26″N; 78°35′07″W) was an 8 ha stand on a broad, flat, south facing ridge at an elevation of 650 m on the Buchanan State Forest. The MAM site (39°50′33″N; 77°31′55″W) was a 4 ha stand on steep, west facing, upper slope at an elevation of 500 m on the Michaux State Forest. The MS site (40°39′45″N; 77°56′36″W) was a 6 ha stand on a narrow, south facing, mid slope bench at an elevation of 250 m on Pennsylvania State University property.

Soil, weather, and general forest conditions varied slightly among the three sites. Soils in the southern Pennsylvania stands were sandy loams that formed in place by the weathering of gneiss, sandstone, and schist parent material (Long, 1975; Knight, 1998). Consequently, they were of low fertility and strongly acidic. Soil at the MS site was a stony loam that formed in place from the weathering of colluviul limestone, sandstone, and shale parent material (Merkel, 1978). This soil was moderately fertile and mildly acidic. Average annual temperature and precipitation records indicated that MS was cooler (4.4 to 27.0 C), moister (1075 mm rain and 680 mm snow), and had a shorter growing season (168 d) than the two southern Pennsylvania sites (7.2 to 30.0 C, 965 mm rain, 610 mm snow, and 188 d growing season).

FIELD METHODS

In each *Pinus pungens* community, I systematically established 15 pairs of nested circular plots to uniformly sample the woody vegetation. The inner plot was 0.001 ha and was used to inventory all seedlings and saplings by height class: less than 0.3 m, 0.3 to 1.5 m, and 1.6 to 3.0 m. The outer plot was 0.02 ha and in it all trees more than 3 m tall were identified to species and measured for diameter at breast height (dbh) to the nearest cm. In this plot I also identified the shrubs by species and estimated the percent cover of each species by standing in the center and visually grouping all the shrubs of that species together (Brose *et al.*, 2008). Shrub height was measured to the nearest 0.1 m for each species by measuring one representative shrub visually judged to be the average height of all shrubs of that species present on the plot. Slope and aspect were determined from plot center and recorded to the nearest degree and azimuth.

In each outer plot, I randomly selected two dominant or co-dominant trees and two intermediate or suppressed trees for aging and radial growth analysis. If the selected tree was larger than 10 cm dbh, I extracted two increment cores from its bole at a height of approximately 30 cm above the ground. These cores were taken from the opposite sides of the tree and parallel to the contour so as to avoid any reaction wood that may distort the annual rings (Speer, 2010). Selected trees less than 10 cm dbh were felled with a chain saw and a cross section was cut from the base at ground level. Finally, the shrub with a basal diameter greater than 2.5 cm located nearest each sampled overstory tree was identified and a cross section was cut from its base.

Because fire was an important disturbance throughout the Appalachian Mountains until the early 1900s (Brose *et al.*, 2014), I inspected the bases of the mature *Pinus pungens* in each plot for fire scars. I intended to collect a partial or complete cross section from 10 to 15 fire scarred *Pinus pungens* at each site, but at MAM and MH, I was limited to just one sample because these two stands were in protected natural areas. Therefore, in each of these two communities I selected the one *Pinus pungens* that appeared to have the most scars, but was also sound, *i.e.*, no sign of wood-boring insects. The tree was felled and an 8- to 10-cm thick cross section cut from within 30 cm of the ground. MS had no such sampling restriction.

LAB METHODS

The cores were glued into core mounts and the cores and cross sections were air dried for several weeks then sanded to expose the annual rings. I aged each core and cross section to the innermost ring or pith under a 40x dissecting microscope to determine a tentative establishment date. To arrive at a final establishment date for the cores, I made two adjustments. First, if the core did not contain the pith, I used a pith estimator (Speer, 2010) to determine how many annual rings were missed and then adjusted the tentative establishment year back in time. No adjustments were made to cores containing piths. Second, for all cores, I moved each tentative establishment date back 5 y (*e.g.*, 1910 became 1905) to account for the time needed by the trees to grow to the 30 cm coring height

(Waldrop *et al.*, 2002). No adjustments were made to cross sections because they contained piths and were cut at ground level.

For each site, I visually inspected all the *Pinus pungens* cores for defects and randomly selected 20 defect free cores for radial growth analysis. These were skeleton plotted to identify signature years for cross dating to help recognize false or missing rings (Speer, 2010). After proper ages were verified for these cores and cross sections, their annual rings were measured to the nearest 0.02 mm with a Unislide "TA" Tree Ring Measurement System (Velmex Inc., Bloomfield, New York). I used the COFECHA 2.1 quality assurance program (Holmes, 1983; Grissino Mayer, 2001) to verify the cross dating. I used the default settings in COFECHA as these had been used in previous *Pinus pungens* research (Brose *et al.*, 2002; Brose and Waldrop, 2006, 2010).

Previous dendroecology studies with *Pinus pungens* used a negative exponential curve or linear regression as the standardization technique (Brose *et al.*, 2002; Brose and Waldrop, 2006, 2010). Standardization is necessary to remove the effects of differing tree ages among the samples as well as tree to tree variability due to microsite conditions (Speer, 2010). I tested both techniques on the individual *Pinus pungens* chronologies using the ARSTAN program (Cook and Holmes, 1986). There was little difference in the results produced by these two approaches; therefore, I used the negative exponential curve to combine the each communities' individual chronologies into a stand level chronology.

DATA ANALYSIS

To describe the composition of the overstory at each site, I calculated the relative importance value (RIV) of each tree species using a modified methodology of Cottam and Curtis (1956). In this technique each species' density (trees per ha), basal area (m^2/ha), frequency (number of plots on which the species occurs), and stocking (proportion of the canopy occupied by the species based on crown area equations (Brose *et al.*, 2008)) are divided by the totals of those measures and then averaged to arrive at a number expressing the relative importance of that species to the community. Understory tree tallies were converted from plot counts to per ha estimates for each of the three height classes. Plot level shrub cover appraisals were converted to per ha estimates.

To determine the overall stand age structure and help identify when regeneration initiating events occurred, I created a history timeline for each site. Cores and cross sections were organized into four species groups: *Pinus* species, *Quercus* species, miscellaneous hardwoods, and *Kalmia latifolia* (mountain laurel). *Pinus* contained not only *Pinus pungens* but also the occasional *Pinus echinata, Pinus rigida, Pinus strobus,* and *Pinus virginiana. Quercus* included all the oaks as well as other hardwoods generally associated with xeric sites (*e.g., Carya glabra*). Miscellaneous hardwoods included all other hardwoods with *Acer rubrum* (red maple) and *Nyssa sylvatica* (black gum) being the most abundant species. *Kalmia latifolia* was a monospecific group containing just this shrub. Each timeline began in a different year and extended to 2005 with data divided into 5 y intervals (*e.g.*, 1880–1884, 1885–1889). In each of these intervals, I tallied the cores and cross sections of each species group by their final establishment date. I used Smith's (1986) age structure criteria to determine whether the stands were even aged, two aged, or uneven aged. Even aged stands consist of one cohort with 80% of the stems originating within 20% of the longevity of the dominant species (200 y for *Pinus pungens* (Della Bianca, 1990)). Two aged stands contain two cohorts and uneven aged stands contain three or more cohorts.

Following methods used in previous dendroecology studies involving *Pinus pungens* (Brose *et al.*, 2002; Brose and Waldrop, 2006, 2010), I used the JOLTS program (Holmes, 1999) and criteria developed by Lorimer and Frelich (1989) to identify major and moderate disturbances in the individual *Pinus pungens* chronologies. A major disturbance consisted of more than a 100% increase in growth lasting at least 15 y. A moderate disturbance was an increase in growth of 50 to 100% for at least 10 y. These changes indicate events such as insect/disease outbreaks, timber harvests, severe wildfires, or windstorms that kill some overstory trees but allow the remaining ones to accelerate growth due to increased light, nutrients, and water.

Finally, I examined all cores and cross sections for evidence of past fires by looking for external or internal scars. Scars in a cross section were dated by comparing them to adjacent unscarred annual rings and scars in a core were dated by comparing them to the other core extracted from the same tree. Because scars can be caused by means other than fires, three or more scars had to occur in the same year at the same site for them to be considered of fire origin. Fires were classified by seasonality based on criteria by Baisan and Swetnam (1990).

RESULTS

COMMUNITY CHARACTERISTICS AND COMPOSITION

Of the three communities, MH had the fewest tree species (4), the fewest trees (690 stems/ha), the lowest basal area (30 m^2/ha), and the lowest stocking (80%) (Table 1). *Quercus montana* and *Pinus pungens* were the most important species with RIVs of 54.1 and 28.2, respectively. These two species occurred throughout the stand but occupied different strata. Virtually all the pines were dominants or codominants (22 to 55 cm dbh, 14 to 17 m tall) in the main canopy while most of the oaks were intermediates (8 to 38 cm dbh, 5 to 12 m tall) in the midstory canopy. Oak or pine seedlings were found on 80% of the plots and their combined densities averaged 18,000 stems/ha. The vast majority of this reproduction was in the smallest height class, less than 0.3 m tall, but approximately 740 oaks and pines per ha had grown into the two larger height classes. *Kalmia latifolia* was limited in its cover (13%), height (0.7 m tall), and frequency of occurrence (20% of plots).

The MS stand was the most diverse *Pinus pungens* community with 14 tree species and had the most trees (1230/ha), most basal area (37 m^2/ha), and highest stocking (100%) (Table 1). *Pinus pungens* and *Pinus strobus* dominated the stand with RIVs of 29.5 and 14.0, respectively. These importance values reflected their inordinate contribution to the stand's basal area (68%) and stocking (66%). Virtually all of the trees of these two species were in the main canopy. *Acer rubrum*, *Quercus rubra*, and a mix of miscellaneous hardwoods composed the midstory and understory strata. Collectively, these species added 11 m^2/ha to the stand's basal area and 31% to its stocking, but their stem densities accounted for 80% of all stems. Consequently, their RIVs ranged from 1.9 (*Prunus serotina*) to 13.1 (*Acer rubrum*) with the latter almost equaling the RIV of *Pinus strobus* (14.0) despite drastic differences in their diameters and heights. No shrubs of any species or hardwood seedlings were found in the understory at the MS site.

The *Pinus pungens* stand on MAM consisted of nine species that averaged 1035 stems/ha, 33 m^2/ha of basal area, and 90% stocking (Table 1). *Pinus pungens* accounted for just 18% of the stems but made up 42% of the basal area and 39% of the stocking. Consequently, it had the highest RIV (29.4). *Quercus montana* and *Quercus coccinea* were more plentiful than *Pinus pungens*, but their smaller diameters resulted in RIVs of 19.6 and 16.5, respectively. *Acer rubrum* and *Nyssa sylvatica* were also common hardwood species in the midstory, but they contributed little to the overall stand basal area and stocking. *Kalmia latifolia* was widespread

TABLE 1.—The relative importance values (RIV) of the tree species found at the Martin Hill, Masseyburg, and Mont Alto Mountain study sites. Density is trees/ha, basal area is m^2/ha, frequency is the number of plots containing that species, and stocking is the proportion of the canopy occupied by that species

Scientific name	Density	Basal area	Frequency	Stocking	RIV
Martin Hill					
Quercus montana	430	17	15	51	54.1
Pinus pungens	82	10	15	24	28.2
Quercus coccinea	131	2	8	3	12.4
Acer rubrum	47	1	4	2	5.3
Totals	690	30	42	80	100.0
Masseyburg					
Pinus pungens	183	16	15	45	29.5
Pinus strobus	47	9	7	21	14.0
Acer rubrum	358	2	11	7	13.1
Quercus rubra	170	2	8	7	8.6
Cornus florida	119	1	11	2	6.3
Fraxinus americana	62	1	10	3	5.2
Liriodendron tulipifera	62	1	7	4	4.7
Fagus grandifolia	74	1	6	1	3.9
Acer saccharum	54	1	4	2	3.3
Betula lenta	27	1	6	2	3.2
Pinus virginiana	20	1	2	3	2.3
Carya glabra	27	<1	5	1	2.1
Robinia pseudoacacia	17	<1	4	1	2.0
Prunus serotina	10	<1	4	1	1.9
Totals	1230	37	100	100	100.0
Mont Alto Mountain					
Pinus pungens	185	14	15	35	29.4
Quercus montana	264	7	12	15	19.6
Quercus coccinea	199	5	12	15	16.5
Nyssa sylvatica	151	2	12	8	11.1
Acer rubrum	135	1	12	7	9.7
Pinus rigida	42	3	6	7	7.1
Amerlanchier alnifolia	30	<1	6	1	3.1
Betula lenta	22	<1	5	1	2.6
Sassafras albidum	7	<1	1	1	<1.0
Totals	1035	33	81	90	100.0

and tall, averaging 80% cover and 2 m in height, respectively. Hardwood seedlings were nonexistent.

COMMUNITY AGE STRUCTURE

Overall, the MH site was unevenly aged; consisting of four cohorts that formed between 1850 and 1990 (Fig. 1). The first cohort arose from 1865 to 1900 with peak establishment occurring in the 1870s. *Pinus pungens* dominated this cohort with some establishment of *Quercus montana* also occurring, especially about 1870 and 1900. The next two cohorts consisted of more Quercus *montana*, and *Quercus coccinea* than *Pinus pungens*. These two cohorts formed from 1915 to 1920 and 1930 to 1940. The final cohort developed between

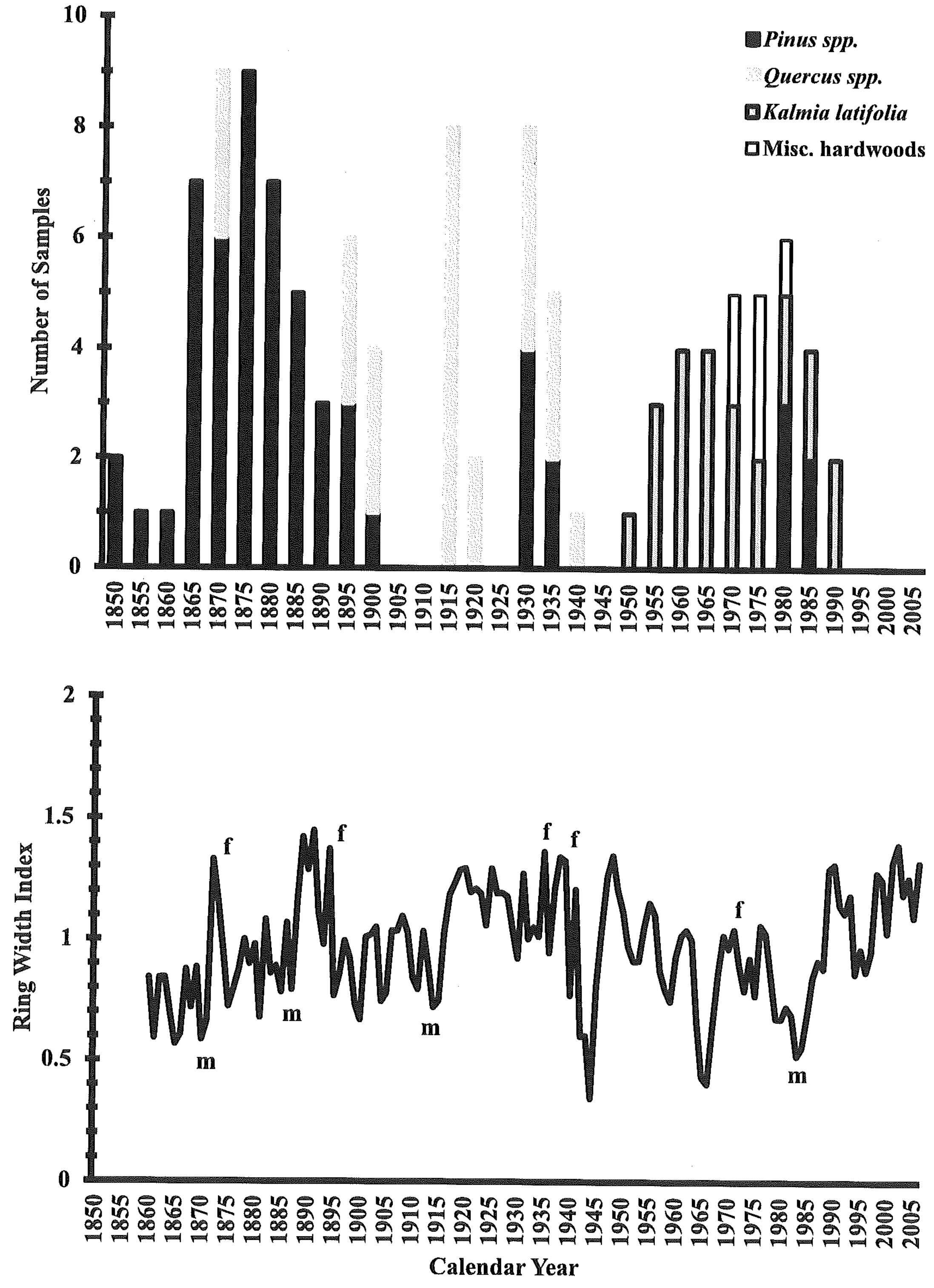

FIG. 1.—The species establishment timeline (upper graph) and radial growth chronology (lower graph) of the *Pinus pungens* community at Martin Hill in southern Pennsylvania. Abbreviations are: f = low intensity surface fire and m = moderate canopy disturbance. Please note that the fires generally correspond with sharp sudden declines in radial growth and with establishment of *Pinus* and *Quercus* cohorts

1955 and 1990 and was a mix of *Kalmia latifolia, Pinus pungens,* and *Acer rubrum,* but no *Quercus* species.

The MS stand was also unevenly aged, but was comprised of three cohorts, *Pinus spp, Quercus spp.*, and miscellaneous hardwoods, that formed between 1915 and 1995 (Fig. 2). *Pinus pungens, Quercus rubra,* and *Acer rubrum* comprised the majority of stems in these three cohorts, respectively. The *Pinus* cohort formed over a 35 y period, 1915 to 1950, with *Pinus pungens* and a few *Pinus virginiana* establishing before 1930 and *Pinus strobus* establishing after 1930. The *Quercus* cohort started in the late 1940s, peaked in the 1960s, and ended by the early 1970s. The miscellaneous hardwoods cohort started in the late 1940s and lasted until the 1990s with peak establishment occurring since 1970.

The MAM stand was unevenly aged and consisted of three cohorts that formed between 1850 and 1990 (Fig. 3). *Pinus pungens* was the primary species in the first cohort with regeneration occurring prior to 1890, especially between 1855 and 1875. A second cohort composed mostly of *Quercus montana* and *Quercus coccinea* arose between 1895 and 1945 with a peak about 1915. The final cohort formed between 1925 and 1990 and consisted of miscellaneous hardwoods, especially *Acer rubrum* and *Nyssa sylvatica,* and the shrub *Kalmia latifolia.* Of these three species, the two tree species generally established during the 1950s and 1960s while *Kalmia latifolia* continued to establish throughout the entire period.

COMMUNITY DEVELOPMENT AND DISTURBANCES

The *Pinus pungens* chronology at MH was from 1860 to 2005 and had an interseries correlation of 0.487 (Fig. 1). From 1860 to 1945 the chronology consisted of a period of abrupt increases and decreases in growth followed by a period of more gradual changes in growth after 1945. Moderate disturbances occurred in or about 1872, 1885, 1915, and 1983. Finally, fire scars were rare on the mature trees. The *Pinus pungens* cross section indicated that at least five dormant season fires burned portions of the stand in 1872, 1894, 1933, 1936, and 1971.

The *Pinus pungens* growth chronology at MS was from 1915 to 2005 and had an interseries correlation of 0.564 (Fig. 2). Throughout the entire chronology, there was little year to year fluctuation in radial growth and showed no evidence of moderate or major canopy disturbances. I found no fire-scarred *Pinus pungens* at the MS site.

The *Pinus pungens* chronology for the MAM site was from 1835 to 2005 and had an interseries correlation of 0.462 (Fig. 3). During those 170 y, the pattern of radial growth took two forms (small and large fluctuations) with 1915 marking the change from small to large fluctuations. In the mid-1800s, moderate and major disturbances impacted the community with the latter leading to 50 y of average but slowly declining growth with little year to year variation. About 1915 another major disturbance impacted the community. After that, annual radial growth of *Pinus pungens* fluctuated considerably with a slow steady increase starting about 1945. Finally, fire scars were rare on the mature trees. The *Pinus pungens* cross section indicated dormant season fires burned in 1889, 1906, and 1923.

DISCUSSION

SIMILARITY OF NORTHERN AND SOUTHERN COMMUNITIES

Even though the three Pennsylvania *Pinus pungens* stands I used in this study were 300 to 800 hundred km north of the *Pinus pungens* communities used in earlier studies, the Pennsylvania stands had numerous characteristics in common with their southern counterparts. In my overstory and midstory inventories, I found four to 14 tree species.

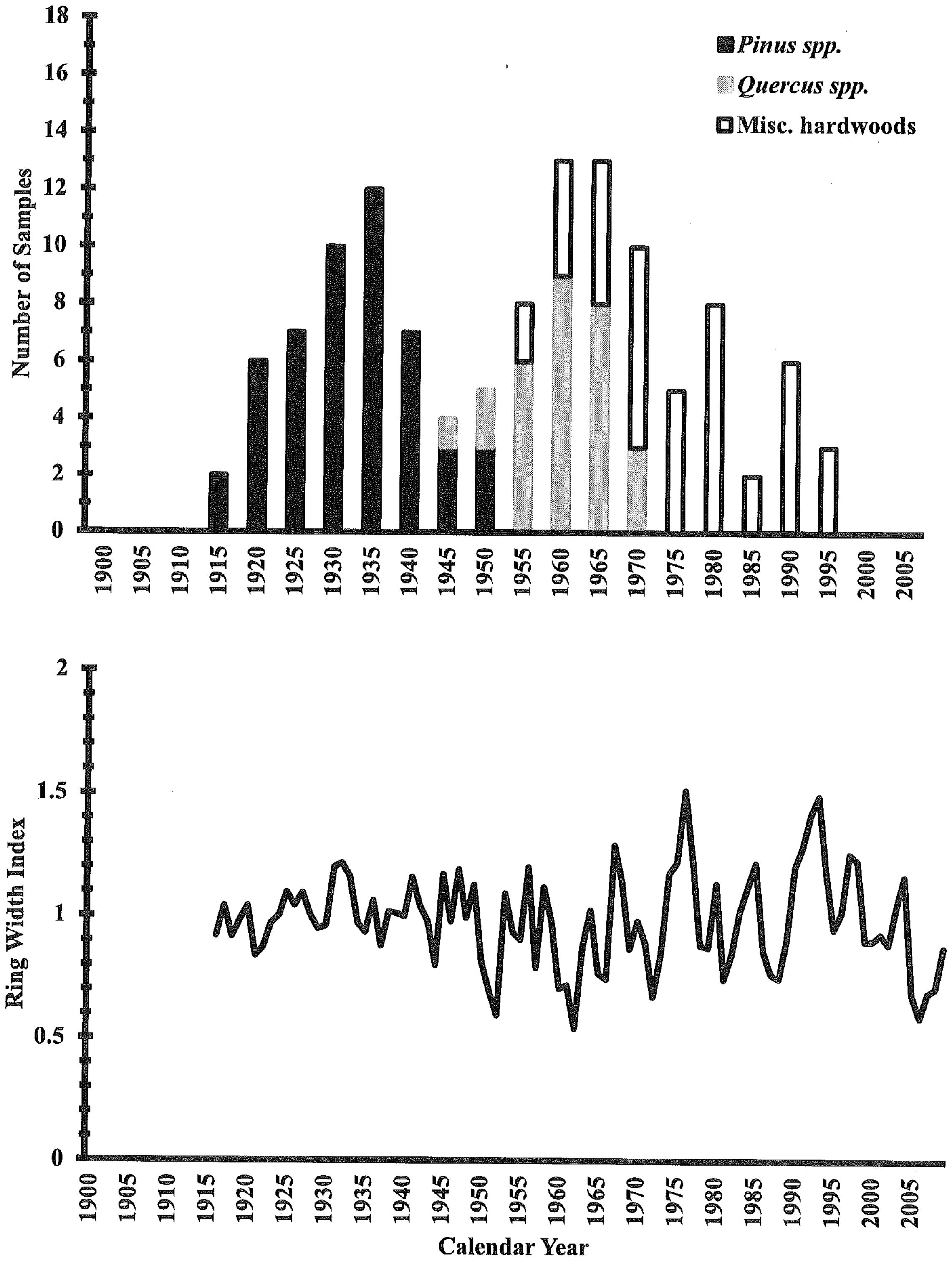

FIG. 2.—The species establishment timeline (upper graph) and radial growth chronology (lower graph) of the *Pinus pungens* community near Masseyburg in central Pennsylvania

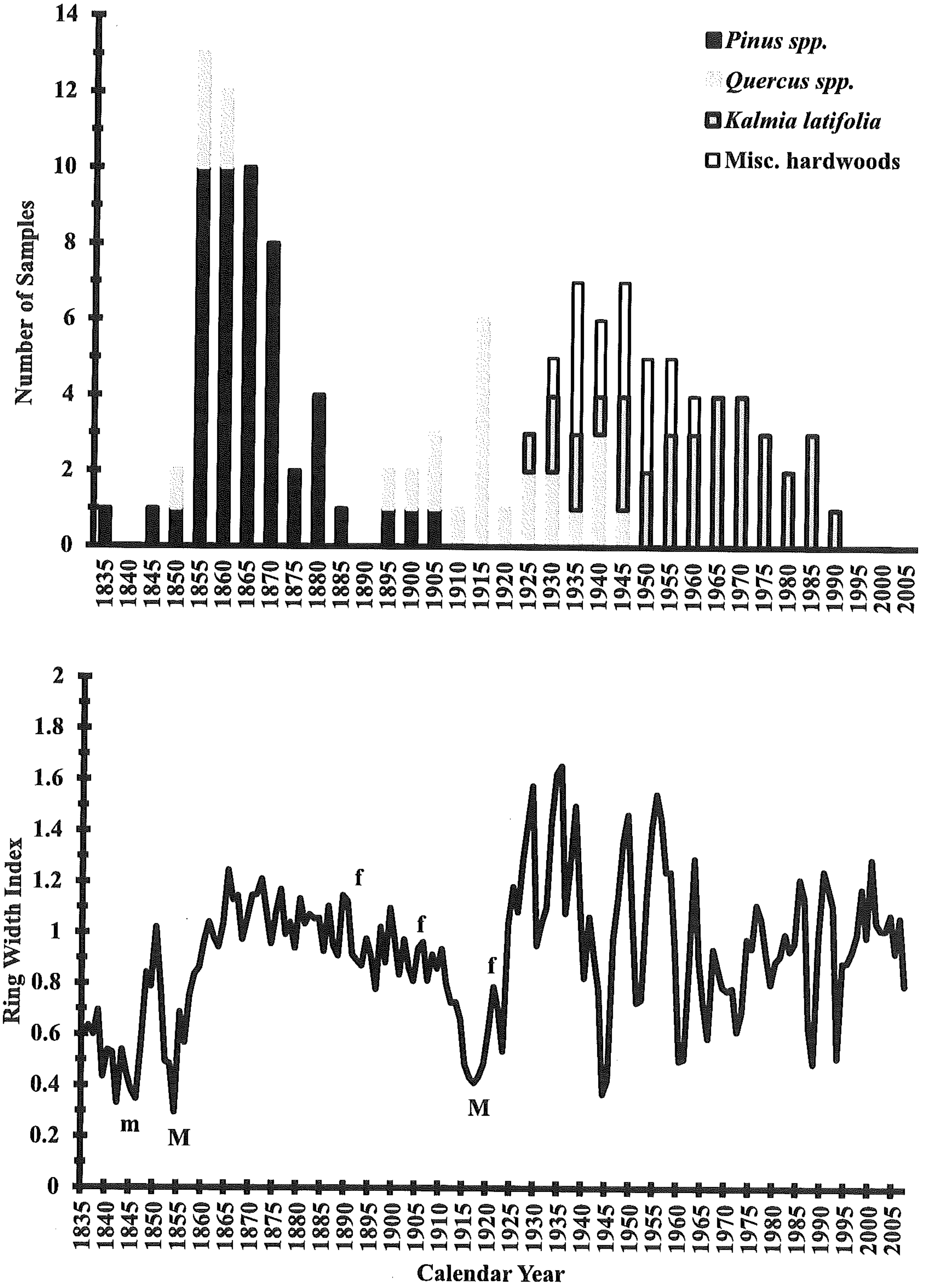

FIG. 3.—The species establishment timeline (upper graph) and radial growth chronology (lower graph) of the *Pinus pungens* community at Mont Alto Mountain in southern Pennsylvania. Abbreviations are: f = low intensity surface fire, m = moderate canopy disturbance, and M = major canopy disturbance. Please note that the fires generally correspond with sharp sudden declines in radial growth and with establishment of *Pinus* and *Quercus* cohorts

Published descriptions reported from six to 23 woody species, depending whether shrubs were included in the censuses (Whittaker, 1956; Zobel, 1969; Williams, 1998; Waldrop and Brose, 1999; Welch *et al.*, 2000; Jenkins *et al.*, 2011). Among the species in the Pennsylvania stands, *Pinus pungens* was the most common conifer, but was generally outnumbered by one or more hardwoods, especially a *Quercus* species. Racine (1966), Welch *et al.* (2000), and Brose *et al.* (2002) reported comparable results from North Carolina, Virginia, and Georgia, respectively. In my study I found *Pinus pungens* dominated or co-dominated each stand with large (>45 cm dbh), well-distributed (>65% stocking) trees; resulting in RIVs ranging from 28.2 to 29.5. Similar *Pinus pungens* attributes have been reported throughout the southern Appalachian Mountains by several scientists (Williams and Johnson, 1990; Groeschl *et al.*, 1992; Welch *et al.*, 2000; Brose *et al.*, 2002; Jenkins *et al.*, 2011). In the midstory of each Pennsylvania *Pinus pungens* community, I found *Acer rubrum* and at least one *Quercus* species in substantial numbers. This is similar to the descriptions of the midstory stratum of *Pinus pungens* communities in the southern Appalachian Mountains (Whittaker, 1956; Zobel, 1969; Williams, 1998; Waldrop and Brose, 1999; Welch *et al.*, 2000; Jenkins *et al.*, 2011). Finally, the presence of *Kalmia latifolia* in the understories of the MH and MAM stands and the abundance of that shrub in the latter community are akin to the understories described in many southern Appalachian Mountain Pinus pungens stands (Whittaker, 1956; Williams and Johnson, 1990; Welch *et al.*, 2000; Brose *et al.*, 2002; Jenkins *et al.*, 2011).

Regarding age structure, each Pennsylvania *Pinus pungens* community consisted of three or four even-aged cohorts that differed in species composition and time of establishment. *Pinus pungens* was always the oldest cohort. While there were usually some *Quercus montana* intermixed with this cohort, most *Quercus montana* and all the *Q. coccinea* and *Q. rubra* began growing later, forming the next cohort. Following the *Quercus* cohort came one or two more cohorts consisting of miscellaneous hardwoods, especially *Acer rubrum*, and *Kalmia latifolia*, if present. This multi-cohort age structure and successional trend, *Pinus* to *Quercus* to *Kalmia latifolia* and miscellaneous hardwoods, have been reported by several previous *Pinus pungens* studies (Williams and Johnson, 1998; Aldrich *et al.*, 2010; Brose and Waldrop, 2010; Flatley *et al.*, 2013, 2015).

STAND HISTORIES

In central and southern Pennsylvania, there have been four major forces, wildfires, unrestricted harvesting, chestnut blight, and wildfire suppression (DeCoster, 1995), that have shaped the forests and all of these are evident in the histories of the MH and MAM. Both of these *Pinus pungens* communities are located close to charcoal iron furnaces (Bates and Fraise, 1887; Blackburn and Welfrey, 1906). This industry flourished throughout southern Pennsylvania during the 1800s and imposed a frequent cutting regime (Birkebine, 1894; Eggert, 1994). For each furnace from 50 to 150 ha of forest were clearcut annually to provide the wood that was made into charcoal (Straka, 2014). Small diameter hardwoods were especially sought after; therefore, harvesting was repeated on the same forests at 20 to 30 y intervals. *Quercus montana* was one of the preferred species and because this species is an excellent sprouter, forests subjected to this type of disturbance often developed a dominance of *Quercus montana* with cohorts starting at 20 to 30 y intervals (McQuilken, 1990; Mikan *et al.*, 1994). Both stands had at least one *Quercus montana* cohort coinciding with the operational period of the local charcoal iron furnace.

The continual regeneration of *Pinus pungens* between 1850 and 1900 at both stands also comes from the frequent harvesting to support the charcoal iron industry. Because softwoods and trees with decay, knots, and defects were the least used to make charcoal

(Straka, 2014), a species such as *Pinus pungens* probably was avoided. Additionally, *Pinus pungens* cones are only weakly serotinuous at the northern end of its range so they can open without fire (McIntyre, 1929; Zobel, 1969). Consequently, a *Pinus pungens* seed source would have remained on site and this coupled with the frequent disturbance resulted in continual regeneration during the mid to late 1800s.

The occurrence of fire near operating charcoal iron furnaces is unclear. While forest fires were common in Pennsylvania during the 1800s (DeCoster, 1995; Brose *et al.*, 2015; Marschall *et al.*, 2016), this was not necessarily the case near charcoal iron furnaces. Birkebine (1894) stated the workers at some furnaces, especially the larger ones, suppressed wildfires to protect their source for charcoal. Additionally, making charcoal was a summer job (Eggert, 1994), a time when wildfire ignition and spread were minimal. Wildfire suppression by the furnace workers explains the lack of fire scars dating to the operational periods of the nearby furnaces. Additionally, the 30 to 50 y of continual *Pinus pungens* establishment supports the idea of furnace-mediated wildfire suppression because this species lacks the ability to sprout from its root collar (Della-Bianca, 1990); therefore, frequent fires would actually eliminate seedling cohorts, not cause continual *Pinus pungens* seedling establishment.

The next formative factor occurred in the 1910s and is marked by *Quercus* cohorts forming at both southern Pennsylvania locations. These correspond to when the *Cryphonectria parasitica* fungus moved through Pennsylvania and eliminated *Castanea dentata* (American chestnut) from the forest (DeCoster, 1995). *Castanea dentata* must have been a major species in both of these stands as their *Pinus pungens* chronologies show a strong release starting about 1915. Additionally, I observed numerous *Castanea dentata* sprouts scattered throughout both stands.

Finally, widespread wildfire exclusion policies and practices were markedly reducing wildfire occurrence in Pennsylvania forests by the 1920s and by the 1930s, wildfire had become a nonfactor (DeCoster, 1995). At MAM, the last wildfire was in 1923 while at MH the penultimate fire was in 1936. These years were marked by a *Pinus/Quercus* cohort at MH and the start of continual establishment of *Kalmia latifolia* and miscellaneous hardwoods at MAM. *Kalmia latifolia* and most non*Quercus* hardwoods are easily killed by surface fires, but they are vigorous sprouters. Therefore, the oldest *Kalmia latifolia* or non*Quercus* hardwood at a site often date to when the last fire burned (Brose and Waldrop, 2010).

Since the imposition of wildfire control policies and practices, *Kalmia latifolia* and non*Quercus* hardwoods have dominated the regeneration process in both southern Pennsylvania stands. The only exception is at MH during the 1970s and 1980s when *Acer rubrum* and *Pinus pungens* regenerated due to a wildfire in 1971 and *Lymantria dispar* (gypsy moth) defoliations of *Quercus* species in 1982 and 1983.

Relative to MH and MAM, the history of the MS stand is much simpler because it starts in the 1910s, thereby missing entirely the charcoal iron era and apparently missing the chestnut blight and wildfire eras. MS's history appears to be old field succession following abandonment of an agricultural field or pasture in the late 1910s or early 1920s. This successional pathway is common in the eastern United States and is exemplified by a gradual transition from forb/grass to pine to oak to mesic hardwood occurring over many decades (Billings, 1938; Oosting, 1942; Bard, 1952; Keever, 1983). This scenario is supported by the oldest trees, all *Pinus pungens* as well as some *Pinus strobus* and *Pinus virginiana* originating over 40 y. Although *Pinus pungens* regeneration is generally linked to fire, it can establish without fire in abandoned fields (Best, 1886; McIntyre, 1929; Zobel, 1969; Della Bianca, 1990). Additionally, *Pinus pungens* produces viable seed at a young age (McIntyre, 1929;

Barden, 1977; Della Bianca, 1990; Gray *et al.*, 2002); thereby allowing juvenile and adolescent trees to extend the establishment period both spatially and temporally. The *Pinus pungens* radial growth chronology was normal (ring width index ≈ 1.0), suggesting these trees established and grew without competition from nearby trees. As *Pinus* establishment waned in the 1940s, various *Quercus* species began establishing and persisted, doing so until the 1970s. When Quercus establishment slowed, other hardwoods began establishing and they continued doing so until the 1990s. The latter part of this successional pattern also reflects the lack of fire (no evidence of fire was found) as well as the productive soils of the site.

FUTURE FOREST SUCCESSION

The presence and abundance of *Acer rubrum* and other hardwoods at the MS site indicates that without intervention this stand will eventually convert to mixed hardwoods. The understory has hundreds of hardwood saplings waiting to replace the overstory pines as they die. Additionally, there are no seedlings of any of the three *Pinus* species present in the stand and the dense understory shade and ubiquitous hardwood leaf litter create an inhospitable seedbed for future pine seedling establishment (McIntyre, 1929; Zobel, 1969, Williams *et al.*, 1990; Williams and Johnson, 1992).

A similar fate probably awaits the MAM stand, but from a different species. Instead of converting to a mixed hardwood community, this *Pinus pungens* stand appears headed to becoming a *Kalmia latifolia* thicket. This shrub dominates the understory and since its widespread establishment in the 1950s, no tree species have been able to successfully regenerate in the stand. This thwarting of the regeneration process is most likely due to *Kalmia latifolia's* evergreen leaves continually casting dense shade on the forest floor. However, the shrub is shade tolerant and is able to regenerate in its own shade as evidenced by the continual establishment of new stems into the 1990s. As the overstory trees die, the *Kalmia latifolia* will capture that growing space, making the thicket larger and denser. This trend towards arrested succession is occurring in *Pinus pungens* communities throughout the Appalachian Mountains (Brose *et al.*, 2002; Brose and Waldrop, 2010).

The *Pinus pungens* community at MH may be self-sustaining, at least at this time. While *Kalmia latifolia* is present, it exists as scattered individual shrubs that have not yet coalesced into thickets. There are numerous *Quercus montana* saplings, but these do not seem to be posing an obstacle to *Pinus pungens* regeneration as *Pinus pungens* seedlings and saplings are present, especially in and near gaps. Numerous studies have shown these two species readily intermix (Zobel, 1969; Williams, 1998; Brose and Waldrop, 2010); therefore, there is no reason to expect them to behave differently at this site.

The divergent futures of the three *Pinus pungens* communities (*Kalmia* thicket, mixed hardwood stand, *Quercus/Pinus* stand) begs the question "why are they different?" The underlying reason may be in their soils and their suitability for *Kalmia latifolia.* This shrub is a member of the heath family (Ericaceae). It needs acidic soils and the soils of these three *Pinus pungens* communities likely differ in their acidity levels. The Ridge and Valley region has a complex geology due to the repeated episodes of mountain building and subsequent erosion over the past 500 million y (Schultz, 1999). This has resulted in a mosaic of soil types originating from different parent material of varying degrees of acidity. Although I did not examine soil properties, it is likely that MAM had the most acidic soil, MS was the least acidic, and MH was intermediate. This gradient is manifest in their degree of *Kalmia latifolia* cover (thicket at MAM, scattered shrubs at MH, absent at MS). The presence of *Acer saccharum* at the MS site supports this explanation as this species has a known positive relationship with low acidity soils (Horsley *et al.*, 2008; Long *et al.*, 2009).

To restore the stalled *Pinus pungens* regeneration process at the MS and MAM stands, they need active management to remove the dense understories of *Kalmia latifolia* or non*Quercus* hardwoods and disrupt the organic soil horizons (specifically, Oi and Oe layers) of the forest floor while preserving a *Pinus pungens* seed source. Prescribed burning is probably the most applicable forestry practice to accomplish this goal because fire is compatible with the silvics of *Pinus pungens* and *Quercus montana* (Della Bianca, 1990; McQuilkin, 1990; Brose and Waldrop, 2010). However, managing the fire behavior will be of utmost importance as the fire must be hot enough to kill the understory stems without killing the overstory seed source. In the case of *Kalmia latifolia,* this degree of fire management can be challenging due to the shrub's flammability (Waldrop and Brose, 1999). Harvesting of the hardwoods, especially the small diameter stems, while retaining the overstory would also work as a regeneration technique because it would mimic the disturbance regime of the charcoal iron era.

This study has limitations. I likely underestimated the past occurrence of wildfire as I was only able to sample one fire-scarred *Pinus pungens* at each location and using cores was a poor alternative. Furthermore, my criteria of at least three scars in the same year to designate a fire probably caused me to overlook small and low-intensity fires. This may explain why no *Kalmia latifolia* predated 1950 at MH, but no fire was found in the late 1940s or early 1950s. As stated earlier I did not examine soil properties as an explanation to stand composition and successional trends.

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