

## MATURE PINE PLANTATIONS AS POTENTIAL SITES FOR OAK REGENERATION IN PARKS AND NATURAL AREAS OF SOUTHERN MICHIGAN

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### ABSTRACT

Poor regeneration of oak species (genus *Quercus*) is a widespread problem throughout the eastern United States. Recent research on forests managed for timber in northern Michigan has indicated that Civilian Conservation Corps (CCC) era pine (genus *Pinus*) plantations may provide better sites for oak regeneration than forests currently dominated by an oak overstory. Although not widely recognized, pine plantations were also established in southern Michigan during the same period and tend to reside on state and county parks managed primarily for conservation and recreation. We set out to determine the extent of pine plantations on three large public recreation areas in southern Michigan and to assess their potential as sites for oak regeneration. First, we analyzed aerial imagery to assess the proportion of upland areas occupied by planted conifer stands (including those dominated by pines). Next, we visited a sample of pine stands and adjacent upland oak forests to ground-truth our cover type classification and to assess the status of oak regeneration. We estimated there to be 147 ha of planted conifers in Waterloo State Recreation Area (3.2% of total upland forest area), 97 ha of planted conifers in Island Lake State Recreation Area (9.5% of total upland forest area), and 14 ha of planted conifers in Lake Lansing Park North (15.7% of total upland forest area). The plantations encountered varied in composition, but in general were dominated by either white pine (*Pinus strobus* L.) or red pine (*Pinus resinosa* Ait.). Other conifer species such as jack pine (*Pinus banksiana* Lamb.), scotch pine (*Pinus sylvestris* L.), and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) were occasionally present. One large stand of Norway spruce (*Picea abies* (L.) H. Karst.) was also encountered. Oak seedling and sapling densities were similar and did not statistically differ between pine plantations and adjacent oak forest. Additionally, oak seedlings were significantly taller under planted pine than under oak forest, suggesting that these plantations provide better conditions for growth and recruitment into larger size classes. Together our results suggest that mature pine plantations in southern Michigan could be a focal point for managers seeking to promote oak regeneration.

KEYWORDS: oak regeneration; pine plantations; restoration; natural areas

### INTRODUCTION

Historically, oaks (genus *Quercus*) comprised an important component of the eastern US landscape (Loftis 1992). Oaks have tremendous economic value for their desirable timber, but also have great ecological value as a food source for mammals and birds. Increases in disturbance following European colonization, such as logging and subsequent fires, likely increased the dominance of oaks

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across the landscape (Loftis 1992; Nowacki and Abrams 2008; Whitney 1987). Oak forests that exist today as a result of those disturbances are not returning to their former composition and are instead being replaced by more shade-tolerant competitors, such as red maple (*Acer rubrum* L.) (Nowacki and Abrams 2008; Fei et al. 2011; Knott et al. 2019). Many factors have been proposed as contributing to these failures in oak regeneration, including the reduced frequency of disturbance events, the increased presence of competitive seed sources, frost damage, deer browsing (Granger et al. 2018), and excessive shade from understory competitors (Hartman et al. 2005). Of particular concern is the apparent bottleneck between seedling and sapling size classes for oaks such that there is a dearth of sapling-size oaks able to recruit into the canopy as mature oak trees die (Crow 1988; Abrams 2003; Fei et al. 2005).

Whereas forest managers have for decades struggled to regenerate oaks in existing oak forests, several studies have shown that oaks are able to regenerate and recruit into sapling sizes much more readily under a pine (genus *Pinus*) canopy than under an oak canopy (Zhou et al. 1998; Hartman et al. 2005; Granger et al. 2018; Vander Yacht et al. 2022). Several factors have been proposed to explain improved growth and survival of oak seedlings and saplings under a pine canopy, including: (1) greater light transmission through the needle-leaved canopy (Buckley et al. 1999), (2) year-round frost protection from the evergreen canopy (Buckley et al. 1998), and (3) greater colonization of oak seedlings by beneficial ectomycorrhizal fungi (Zhou et al. 1998). Evidence for greater success of oak regeneration and recruitment under pine has led to recommendations to focus efforts on regenerating new oak stands on areas currently in mature pine plantations (Granger et al. 2018; Vander Yacht et al. 2022). Such an approach makes great sense for state and federal forestlands actively managed for timber in northern Michigan, Wisconsin, and Minnesota where red pine (*Pinus resinosa* Ait.) plantations cover over 600,000 hectares, a legacy of red pines being extensively planted across the region in the 1930s as part of the restoration efforts of the Civilian Conservation Corps (CCC) (Gilmore and Palik 2006). Because these 90+ year-old plantations are nearing maturity and final harvest, there exists a great opportunity to use them as a resource for oak regeneration on working forests managed by state and federal agencies.

Although CCC-era pine plantations are mostly associated with state and federal forest lands of northern Michigan, we have frequently encountered mature pine plantations from this era in forested parklands of southern Michigan, and in fact several studies from Ohio document the widespread occurrence of pine plantations established on abandoned agricultural lands in the 1930s and 1940s (Artigas and Boerner 1989; Abella 2010). Public lands in the southern portion of the Lower Peninsula occur in the heart of the oak–hickory forest region (Albert et al. 2014) and are managed for recreation and conservation rather than for timber (MDNR 2012a, 2012b). In this study we sought to assess both the prevalence of mature pine plantations in forested recreation areas in southern Michigan, as well as their suitability as sites for oak restoration efforts.

## MATERIALS AND METHODS

We assessed the extent of pine plantations and their suitability for oak regeneration in three large, forested recreation areas in the southern Lower Peninsula of Michigan. Waterloo Recreation Area (8000 ha) located between Jackson and Ann Arbor, Michigan and Island Lake State Recreation Area (1600 ha) located just southeast of Brighton, Michigan are large tracts managed by the Parks and Recreation Division of the Michigan Department of Natural Resources (MDNR) and are managed for both recreation and preservation of natural and cultural resources (MDNR 2012a and 2012b). Lake Lansing Park North just east of Lansing, Michigan is a 214-ha forested park managed as a natural recreation area by the Ingham County Parks Department. Uplands of all three parks are dominated by glaciofluvial landforms including outwash and ice-contact terrain, and all have excellent representation of oak-dominated Dry Southern Forest and Dry-Mesic Southern Forest natural communities as defined in Albert et al. (2014).

To estimate the areal extent of conifer plantations we digitized areas of evergreen cover within the park boundaries from 1998 Digital Orthophoto Quadrangle aerial imagery in ArcGIS Pro (version 3.0.2). We also used our GIS to create a layer of upland habitat by excluding any areas classed as wetlands or lakes or within 10 m of a stream according to the National Wetlands Inventory (U.S. Fish & Wildlife Service 2005), as well as any areas classed as open land, roads or development. We then calculated the total area classed as upland conifer within each park and expressed this as a proportion of the total area of upland forest habitat within each park.

We sorted contiguous stands of evergreen cover identified in our analysis of aerial imagery into three different area classes and then randomly selected stands from within these area classes for ground truthing and sampling of oak regeneration and recruitment. Sampling within these stands was conducted on a systematically arranged  $80 \times 80$  m grid. Sampling effort differed by the area class, with the smallest stands ( $<1.62$  hectares) receiving one centralized sample point, the next largest stands (1.62–6.1 hectares) receiving up to three systematically spaced points, and the largest stands ( $>6.1$  hectares) receiving up to 10 systematically spaced points. For each sampled conifer stand, we identified an adjacent upland hardwood stand of equivalent area using aerial imagery. We arranged upland deciduous sample points on the same systematic sampling frame utilized for the samples in the pine plantations.

We navigated to our predetermined sampling points using a handheld GPS, where we measured the overstory composition, understory composition, and seedling layer oak regeneration. To characterize the overstory we used a 10-BAF (basal area factor) point sample from our sampling point, including only stems greater than 10 cm in diameter at breast height (DBH). To characterize the understory layer, we laid out a 6-m radius (0.11 ha) circular plot with our sampling point as the center and recorded any stems  $> 1.37$  m high but  $< 10$  cm DBH. Understory stems were tallied and recorded by species and 2.5 cm DBH size classes. For oak seedling measurements, we used three 2-m by 6-m belt transects originating at the sampling point and oriented at 0-, 120-, or 240-degree azimuths. Within these transects we counted and recorded the height of all oak seedlings. Because of challenges in distinguishing black oak (*Q. velutina* Lam.), northern red oak (*Q. rubra* L.), and their hybrids in young seedlings and mature trees from bark alone, upland oaks were identified as either *Q. rubra/velutina* or white oak (*Q. alba* L.).

In order to assess the effects of forest cover type (pine plantation vs. natural hardwood) on oak regeneration and recruitment we used linear mixed-effects models with cover type as our main fixed effect and stand nested within park as a random effect. Response parameters included oak seedling density, oak sapling density, and mean height of oak seedlings. Reported p-values are derived from F-tests based on Satterwaite's method using the "lmerTest" package in R. All statistical analyses were conducted with RStudio version 4.3.2 (2023-10-31).

## RESULTS

Our GIS analysis revealed 147 ha of conifer plantation at Waterloo State Recreation Area (3.2% of the total upland forest area of the park), 97 ha of conifer plantation at Island Lake State Recreation Area (9.5% of the total upland

forest area of the park), and 14 ha of conifer plantation at Lake Lansing Park North (15.7% of the total upland forest area of the park). Across all three parks these conifer plantations occurred as patches within a larger matrix of surrounding hardwood forests (Figure 1). Detailed data on the composition of conifer plantations and native hardwood forests across the three parks are presented in Table 1. Red pine, white pine (*Pinus strobus* L.) and Norway spruce (*Picea abies* (L.) H. Karst.) were the most dominant and frequently encountered species in conifer plantations with minor contributions from Scotch pine (*Pinus sylvestris* L.), jack pine (*Pinus banksiana* Lamb.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco). Groundtruthing data indicated the presence of planted conifers (whether pines or other evergreen conifers) in all areas identified as conifer plantations from aerial imagery, with average conifer relative dominance (percentage of total stand basal area) of 76%, 65%, and 73% in Waterloo, Island Lake and Lake Lansing parks, respectively. Northern red oak and black oak dominated the overstory of the upland hardwood forests across all three parks. White oak, red maple, and black cherry (*Prunus serotina* Ehrh) were consistent, but smaller, contributors to overstory basal area across all three parks. Big-tooth aspen (*Populus grandidentata* Michx.) was locally important at Lake Lansing Park North. Across all three parks, stocking was about 25% higher in the planted conifer stands compared to the adjacent hardwood stands, as indicated by basal area measurements (Table 1). The Norway spruce plantations encountered at Waterloo and Lake Lansing were clearly distinct from pine-dominated plantations in terms of casting a deep shade, such that we encountered zero regeneration by oaks and very little regeneration of any hardwoods in these stands. Therefore, we excluded pure Norway spruce plantations from our subsequent analyses and focused solely on pine plantations for the remainder of this study.

Oak seedling density in pine plantations and native oak forests across all the parks is shown in Figure 2. Overall, there was no statistically significant difference in oak seedling density between pine plantations and native oak forests ( $p = 0.365$ ), although patterns in the data varied across the parks. Oak seedling density tended to be greater at Island Lake State Recreation Area and lower overall at Lake Lansing Park North and Waterloo State Recreation Area.

In contrast to oak seedling density, there was a statistically-significant effect of cover type on oak seedling height ( $p = 0.017$ ), whereby oak seedlings were much taller under pine plantations than they were under native oak forest canopy (Figure 3). Note that because all but two oak forest plots at Waterloo had zero oak seedlings, we confined our analysis of seedling heights to Island Lake and Lake Lansing parks. This pattern was pronounced and consistent across the two parks, with oak seedlings growing under an oak canopy rarely exceeding 20 cm in height (Figure 3). Finally, there was no statistically significant difference in oak sapling density between pine plantations and native oak forests ( $p = 0.340$ ) (Figure 4). Oak saplings were almost entirely absent from either cover type at Lake Lansing Park North, whereas they were more common at the other two parks (Figure 3).

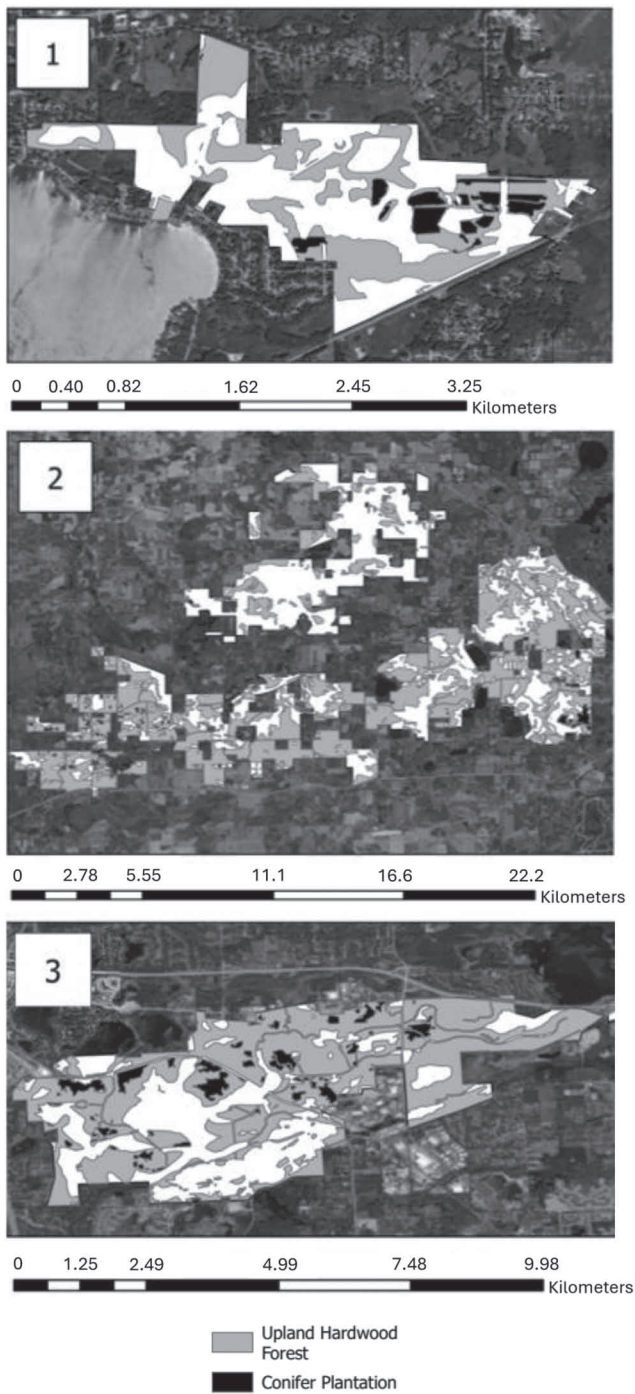


FIGURE 1. Upland forest cover of Lake Lansing Park North (1), Waterloo State Recreation Area (2), and Island Lake State Recreation Area (3). In Panels 1, 2, and 3 upland hardwood forests are mapped in grey, conifer plantations in black, and all excluded wetlands, open lands and developed areas in white.

TABLE 1. Overstory basal areas (m<sup>2</sup> per ha) from ground truthing plots located in areas predicted to be planted conifers (Plantation) vs natural hardwood stands (Hardwood) from aerial imagery. Data are means for each species within each classified forest type with ranges given in parentheses.

|                                 | Waterloo   |            | Island Lake |            | Lake Lansing |            |
|---------------------------------|------------|------------|-------------|------------|--------------|------------|
|                                 | Plantation | Hardwood   | Plantation  | Hardwood   | Plantation   | Hardwood   |
| <b>Conifers</b>                 |            |            |             |            |              |            |
| <i>Picea abies</i>              | 13 (0–53)  | 0 (0–0)    | 0 (0–0)     | 0 (0–0)    | 12 (0–48)    | 0 (0–0)    |
| <i>Pinus banksiana</i>          | 0 (0–0)    | 0 (0–0)    | 1 (0–6)     | 0 (0–0)    | 2 (0–9)      | 0 (0–0)    |
| <i>Pinus resinosa</i>           | 6 (0–20)   | 0 (0–0)    | 18 (0–41)   | 1 (0–5)    | 8 (0–24)     | 0 (0–0)    |
| <i>Pinus strobus</i>            | 14 (0–34)  | 3 (0–6)    | 7 (0–29)    | 1 (0–5)    | 5 (0–18)     | 0 (0–0)    |
| <i>Pinus sylvestris</i>         | 0 (0–0)    | 0 (0–0)    | 1 (0–8)     | 0 (0–0)    | 3 (0–9)      | 0 (0–0)    |
| <i>Pseudotsuga menziesii</i>    | 0 (0–0)    | 0 (0–0)    | 0 (0–0)     | 0 (0–0)    | 2 (0–14)     | 0 (0–0)    |
| <b>Hardwoods</b>                |            |            |             |            |              |            |
| <i>Acer rubrum</i>              | 1 (0–4)    | 2 (0–5)    | 1 (0–3)     | 2 (0–8)    | 2 (0–3)      | 4 (1–7)    |
| <i>Carya glabra/ovata</i>       | 0 (0–0)    | 1 (0–1)    | 0 (0–2)     | 0 (0–2)    | 0 (0–0)      | 1 (0–2)    |
| <i>Quercus alba</i>             | 0 (0–1)    | 2 (0–5)    | 0 (0–0)     | 2 (0–6)    | 1 (0–5)      | 2 (0–7)    |
| <i>Quercus rubra/velutina</i>   | 4 (1–9)    | 23 (17–29) | 4 (1–13)    | 19 (11–27) | 4 (0–16)     | 13 (2–29)  |
| <i>Populus grandidentata</i>    | 0 (0–0)    | 0 (0–0)    | 0 (0–0)     | 0 (0–0)    | 0 (0–1)      | 11 (0–37)  |
| <i>Prunus serotina</i>          | 3 (0–5)    | 2 (0–5)    | 3 (0–7)     | 2 (0–6)    | 2 (1–4)      | 5 (0–9)    |
| <i>Ulmus americana</i>          | 0 (0–0)    | 0 (0–0)    | 1 (0–3)     | 0 (0–1)    | 0 (0–1)      | 0 (0–1)    |
| Other native trees <sup>1</sup> | 1 (0–2)    | 2 (1–3)    | 2 (0–6)     | 1 (0–5)    | 0 (0–1)      | 1 (0–3)    |
| <b>Total Stand Basal Area</b>   |            |            |             |            |              |            |
| <b>% BA in Conifers</b>         |            |            |             |            |              |            |
|                                 | 44 (26–57) | 36 (30–41) | 37 (25–51)  | 29 (21–40) | 44 (14–55)   | 38 (30–46) |
|                                 | 76 (64–95) | 5 (0–11)   | 65 (14–93)  | 5 (0–18)   | 73 (52–89)   | 0 (0–1)    |

<sup>1</sup>Includes: *Acer negundo* L., *Acer saccharinum* L., *Acer saccharum* Marsh., *Amelanchier* spp., *Carpinus caroliniana* Walter, *Cornus florida* L., *Elaeagnus umbellata* Thunb., *Fagus grandifolia* Ehrh., *Juglans nigra* L., *Juniperus virginiana* L., *Malus* spp., *Ostrya virginiana* (Mill.) K. Koch, *Populus tremuloides* Michx., *Rhamnus cathartica* L., *Robinia pseudoacacia* L., *Sassafras albidum* (Nutt.) Nees, *Tilia americana* L.

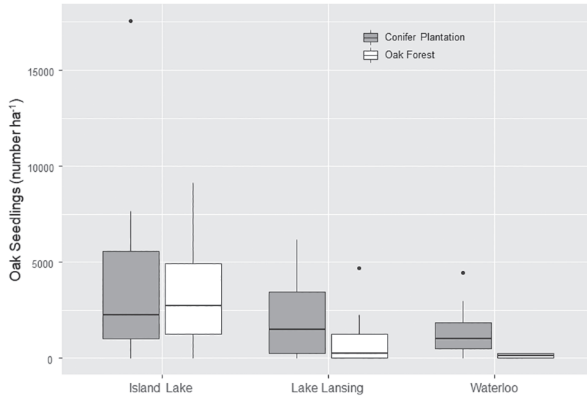


FIGURE 2. Oak seedling density under conifer plantation vs. oak forest across the three southern Michigan parks. In the box-and-whiskers diagram the horizontal black line represents the median, the box represents the middle 50th percentile of data. Upper and lower 25th percentiles are represented by the whiskers, and outlying data are shown as black dots.

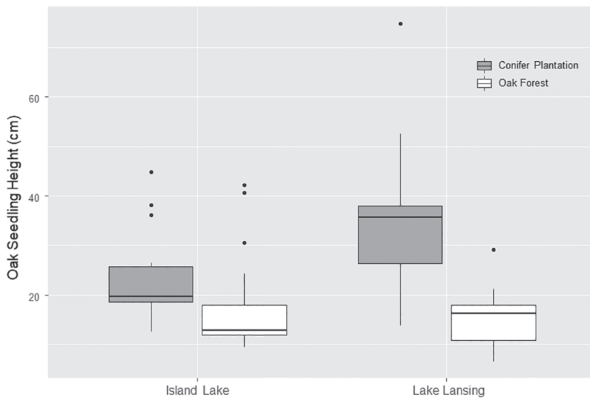


FIGURE 3. Average height of oak seedlings in plots under conifer plantation vs. oak forest at Island Lake State Recreation Area and Lake Lansing Park North. Data representation for the box-and-whiskers diagrams are as described in the caption for Figure 2.

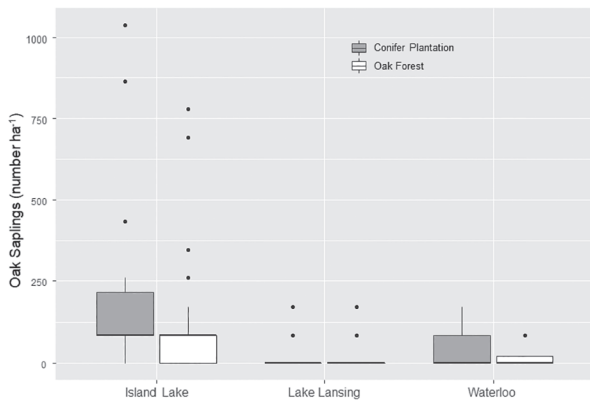


FIGURE 4. Oak sapling density under conifer plantation vs. oak forest across the three southern Michigan Parks. Data representation for the box-and-whiskers diagrams are as described in the caption for Figure 2.

## DISCUSSION

Results from our assessment of oak regeneration across these parks are consistent with, and provide further support for, a growing body of research showing that environmental conditions underneath a pine canopy are more conducive to the growth and survival of oak seedlings compared to conditions beneath an oak canopy (Zhou et al. 1998; Hartman et al. 2005; Granger et al. 2018; Vander Yacht et al. 2022). Initially, our finding of no statistically-significant difference in oak seedling density between pine plantations and surrounding oak forests would seem to indicate no difference in suitability for oak regeneration between these two habitats. However, when we consider the fact that seedling densities at any given time reflect the demographic balance between inputs of new germinants and outputs from seedling mortality or growth into the sapling layer, we argue that these data are actually suggestive of more favorable conditions for oak seedlings under pine plantations. Because the vast majority of seeds fall within a short distance of the parent tree, especially for heavy seeded species such as oaks (Sork 1984; Clark et al. 1999; Hewitt and Kellman 2002), it is undoubtedly the case that the input of acorns to the seedbank is much greater in our oak-forest stands than within the pine plantations. Acorn inputs to our pine plantations likely result from infrequent long-distance animal dispersal events (Sork 1984; Hewitt and Kellman 2002; Vander Yacht et al. 2022). Therefore, if inputs of new germinants are greater under an oak canopy than under pines, then the equivalent seedling densities must arise from lower seedling mortality under pines, faster growth out of the seedling layer under pines, or a combination of both.

Because we did not harvest and age seedlings, we cannot with confidence distinguish the importance of lower mortality vs faster seedling growth under pines. However, a few lines of evidence suggest that differences in mortality are likely to be the most important. First, studies of oak seedling demography in forest understories consistently show very high rates of mortality with most established oak seedlings only surviving for a few years (Royse et al. 2010; Brose and Rebbeck 2017; Cleavitt et al. 2023). Furthermore, oak seedlings that do survive tend to grow very slowly and can remain in the seedling layer for decades (Cleavitt et al. 2023). Together with the equivalent densities of saplings under oak vs pine canopies (Figure 4), this suggests that differences in seedling mortality are likely the driving difference between cover types. Thus we speculate that the equivalent densities of taller seedlings under pine plantations, combined with likely greater inputs of acorns in oak stands, suggests that oak seedlings are establishing regularly within our oak stands but are turning over rapidly due to high mortality. We rarely encountered oak seedlings greater than 20 cm in height in oak forests, indicating little potential for growth and recruitment into the sapling layer under an oak canopy. In contrast, under pine plantations with lower rates of acorn inputs, the equivalent seedling densities and much larger seedling heights suggests more favorable conditions for oak seedling survival, growth, and potential recruitment into the sapling layer.

Although the underlying mechanisms remain poorly understood, our data add to a growing number of studies indicating improved performance of oak seedlings under a pine canopy compared to their performance under an oak

canopy (Zhou et al. 1998; Hartman et al. 2005; Granger et al. 2018; Vander Yacht et al. 2022). Mature pine plantations were present across all three of the southern Michigan parks we surveyed and ranged from a low of 3% to a high of 16% of the upland forestland of these parks. Based on the size and conditions of trees in these plantations, they all likely originated in the mid-20th century, presumably as part of efforts to reforest abandoned agricultural land that were active across the state from the 1930s to the 1950s (Dickman and Leefers 2016). Although these 20th century reforestation efforts are most often associated with the state and federal forest lands in the north (Gilmore and Palik 2006), reforestation efforts were also occurring in southern Michigan (Dickman and Leefers 2016). The fact that we found these plantations distributed across all three parks that we studied suggests that they may occur in similar parks and natural areas throughout the southern portions of the state, and even in neighboring states of Ohio, Indiana, and Wisconsin (e.g., Abella 2010).

Although these plantations made up a small percentage of the total forested area, we argue that they still warrant attention by managers of these parks (and similar ones across the region) as sites on which to focus effort towards oak regeneration and habitat restoration. The most abundant plantation conifers we encountered (red pine and white pine) are both native components of the regional flora; however, their occurrence in pure stands represents a wide divergence from the native ecosystems of this region (Albert et al. 2014), and there is an interest in opportunities to transition these highly artificial systems to more site-appropriate plant communities (Artigas and Boerner 1989; Abella 2010; Palik and Kastendick 2023). Over the coming decades we can expect to see increasing levels of pine mortality in these mature plantations, especially for shorter-lived species such as Scotch pine and jack pine, and successional transitions to hardwood dominated systems (Artigas and Boerner 1989). The emerging evidence of improved performance of oak seedlings under pine canopies suggests that restoration efforts targeted at promoting oak recruitment into the large sapling layer under the existing pine canopies could guide these transitions toward a more desirable outcome. In contrast, leaving these mature plantations to their own devices may result in continuing shifts towards more mesophytic shade-tolerant species, such as red maple (Nowacki and Abrams 2008). We recommend that managers experiment with planting oak seedlings in mature pine plantations as well as protecting existing and newly planted seedlings from deer. Deer browsing is a major constraint against oak regeneration (Redick and Jacobs 2020), and we consistently observed evidence of deer browse on oak seedlings under both pine and oak canopies across our study sites. If oak seedlings grow faster under a pine canopy, then deer protection during recruitment of oaks from seedling to sapling layers will likely take less effort and expense than under an oak canopy.

#### AUTHOR CONTRIBUTIONS

CT and DR collaborated on the conception and design of the study. CT carried out the field sampling and data analysis and wrote the initial draft of the manuscript. DR supervised field sampling and data analysis and revised the initial draft for submission.

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