Effects of fire and invasive *Paulownia tomentosa* on native tree regeneration in southern Ohio after two years

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ABSTRACT

Paulownia (*Paulownia tomentosa*) is a tree native to southeast Asia that has shown invasive behavior in the eastern United States. The objective of this project was to determine the effects of paulownia invasion, wildfire, and harvesting activity on native tree seedling growth and establishment, including red maple (*Acer rubrum*), yellow-poplar (*Liriodendron tulipifera*), white oak group species, and red oak group species (*Quercus* spp.). The study took place during summer 2011 in Shawnee State Forest near West Portsmouth, Ohio, where a wildfire burned approximately 1175 hectares in April of 2009. The majority of the burned areas were salvaged the following summer.

In general, paulownia had negative impacts on red maple, red oak group species and white oak group species seedling heights and density. However, this was generally not the case with yellow-poplar. This is most likely because paulownia and yellow-poplar both exhibit early successional traits and thrive in similar microsite conditions. The presence of fire and harvesting was generally associated with decreased numbers of red maple, red oak group species, and white oak group species seedlings, but the seedlings were all taller. This suggests that fire and harvesting may accelerate seedling growth through competition reduction, nutrient cycling, and increased sunlight, which is consistent with other research. Fire and harvesting were associated with higher yellow-poplar seedling density, likely because the resulting soil scarification enabled greater yellow-poplar seedling establishment. Paulownia also appears to benefit from the effects of fire and increase competitive capabilities, as it was associated with significantly fewer red maple and white oak group seedlings in the plots with fire, harvesting, and paulownia than in the plots with paulownia but without fire and harvesting.

While paulownia is a non-native species that invades open areas, it may not persist in mature forest areas where the canopy is too dense to regenerate this shade-intolerant species, and therefore may not be as persistent in a particular area as other invasive species. Further studies should establish permanent plots to monitor the effects of paulownia on native seedlings as they mature, determine any allelopathic relationships between paulownia and native species, and examine potential beneficial relationships between paulownia and yellow-poplar. To investigate the possibility that paulownia will not persist in mature forests, studies should also be conducted to monitor its existence and ability to reproduce and persist in mature forest areas over several years.

INTRODUCTION

Invasive plant species have been negatively impacting North American ecosystems for over 100 years (Barnes et al. 1998). Some successfully invade areas affected by disturbances such as fire or hurricanes by taking advantage of and populating the newly-opened canopy and forest floor, out-competing native vegetation and sometimes creating a monoculture (Barnes et al. 1998; Chornesky et al. 2005; Crawford et al. 2001; Harrod & Reichard 2001; Hobbs & Huenneke 1992). The use of fire has been attempted to manage both herbaceous and woody non-native plant invasions, often with negative results. Studies suggest that using fire as a control method is largely ineffective in exterminating some exotic species and may even contribute to their spread (Crawford et al. 2001; Jacquemyn et al. 2005; Keeley et al. 2003; Westbrooks 1998). Exotic plant establishment can also change the natural fire regime of an ecosystem, which can further affect the alteration of that particular ecosystem (D'Antonio & Vitousek 2002; Levine et al. 2003; Mandle et al. 2011).

Paulownia (*Paulownia tomentosa*), the princess tree or empress tree, was introduced to the U.S. as an ornamental plant in the mid-1800s, but has since escaped and spread, creating problems in ecosystems of the eastern U.S. since the 1980s (Hu 1961; Kuppinger 2008). It is especially common along field edges and roads in the Appalachian region (Braun 1989; Sibley 2009). Some people still plant paulownia for ornamental purposes due to its fragrant purple-blue flowers and large heart-shaped leaves. Others plant paulownia on tree farms because of its fast growth, lightweight wood, and demand in China and Japan. There are even organizations dedicated to promoting the advancement of paulownia (American Paulownia Association, Inc. 2012; Hu 1961; Sibley 2009). The tree is still popular for its use to reclaim surface-mined sites because of its vigorous growth and ability to establish and survive in harsh, exposed areas (Burns & Honkala 1990; Carpenter 1977; Tang et al. 1980; Turner et al. 1988).

Paulownia, native to southeast Asia, has many characteristics of an early successional species including small, wind-dispersed seeds, fast growth rate, vigorous resprouting ability, and shade intolerance (Kuppinger 2008; Longbrake 2001). These characteristics make areas that have experienced a disturbance an ideal environment for paulownia establishment. Paulownia grows best in full sunlight (Carpenter et al. 1983). Its bark is gray to brown and rough with sometimes shiny furrows. The stunning purple-blue flowers are present from April to May, before the leaves open. Leaves are opposite and heart-shaped, fuzzy underneath, and can grow up to 60 cm long (Braun 1989; Petrides 1986; Sibley 2009). The tree itself can grow as tall as 13 m in 11 years. Paulownia reaches sexual maturity at eight to ten years old, producing pecan-shaped seed pods containing up to 2,000 seeds each. A mature tree can produce two million seeds per year. Seeds are extremely small and lightweight, 0.17 mg each or 170,000 seeds per ounce, and can disperse as far as ten kilometers from the parent tree by wind (Barns & Honkala 1990; Carpenter et al. 1983; Kuppinger 2008; Petrides 2009).

Little research has been conducted to examine the relationships among paulownia, fire, and native vegetation. This topic will be of concern to forest managers where fire is present, as prescribed burning is becoming more and more popular as a management tool (Agee & Skinner 2005) and as paulownia behaves as an early successional species (Kuppinger 2008; Petrides 2009). The reaction of paulownia following fire has the potential to be detrimental to a forest manager's plans, especially relating its effect on native regeneration. Kuppinger (2008) provides most of the currently known information about paulownia and fire in his PhD dissertation. He concludes that paulownia is more likely to succeed in post-fire areas with less vegetation cover, though several years after establishment it may yield to native regeneration. He also found that 100 % seed mortality occurred at temperatures of 100 °C, suggesting that the seed bank may become unviable following fire unless buried, or at least demonstrate a low rate of germination. Another study involving paulownia and fire involved using handheld torches on paulownia stems to test for resprouting ability. Paulownia demonstrated a high rate of resprouting following direct fire to main stems (Williams & Dimov 2010). The wood itself also has a high resistance to combustion (Lizhong et al. 2005).

Tree species and genera native to southern Ohio such as oaks (*Quercus* spp.) have been shown to benefit from the effects of fire. Red maple (*Acer rubrum*) sometimes benefits from fire as well, but often exhibits higher mortality and less resprouting capabilities than oaks (Alexander et al. 2008; Burns & Honkala 1990; Fei & Steiner 2009; Green et al. 2010; Groninger & Long 2008; Hutnik & Yawney 1965; Royse et al. 2010; Schweitzer & Dey 2011). The nutrient cycling, competition reduction, and temporary increase in light availability from fire contribute to the growth of these species (Alexander et al. 2008; Barnes et al. 1998; Schweitzer & Dey 2011; Whelan 1995), and they gain increased competitive abilities compared to non-fire-adapted species. Additionally, yellow-poplar (*Liriodendron tulipifera*) seedling establishment often increases after fire or harvesting activities due to the scarification these disturbances provide for the small, wind-dispersed yellow-poplar seeds (Burns & Honkala 1990; Smith et al. 1997).

While many studies exist relating fire to its effects on native vegetation, few, if any, exist directly relating the effects of invasive paulownia on native species. This study looks at the effects of both fire and paulownia on native tree regeneration in southern Ohio. Specifically, we observed the effects of these variables on the seedling heights and densities of red maple, yellow-poplar, white oak group species, and red oak group species. We predicted that: a) native seedling heights and densities would decrease with the presence of paulownia; b) heights and densities of red maple, yellow-poplar, white oak group species, and red oak group species heights would increase with the presence of fire and c) the combination of paulownia and fire would yield mixed results, depending on which variable had the stronger influence.

METHODS

Data were collected during the summer of 2011 from late June until early September at Shawnee State Forest (N 38°43' latitude, W 83°14' longitude) near West Portsmouth, Ohio, spanning across both Adams and Scioto Counties. Soils were primarily of the Shelocta-Brownsville series (USGS Web Soil Survey 2012). The area was hilly with typical slopes between 40 and 70%. Forest cover was typically composed of chestnut oak, (*Q. prinus*), red maple, black oak (*Q. velutina*), northern red oak (*Q. rubra*), white oak (*Q. alba*), yellow-poplar, sassafras (*Sassafras albidum*), and blackgum (*Nyssa sylvatica*). The understory was primarily composed of greenbrier (*Smilax* spp.) and grape vines (*Vitis* spp.). Approximately 1175 hectares of the state forest was impacted by a wildfire during late April 2009 (Ohio State Department of Natural Resources 2009). Burn intensities were determined immediately after fire by a helicopter fly-over of the area and based on the amount of canopy leaf destruction. The highest-intensity burn areas experienced 100% mortality, and a salvage harvest was completed in July 2009 (Fig. 1).

We began by searching for paulownia near hiking trails, logging trails, and dozer lines both in the burned and harvested and the unburned areas. Each specimen was tagged and its GPS location saved and logged for future reference. To find non-fire-area paulownia specimens, we stayed along the outside boundaries of the burned area to try to ensure similar soil,

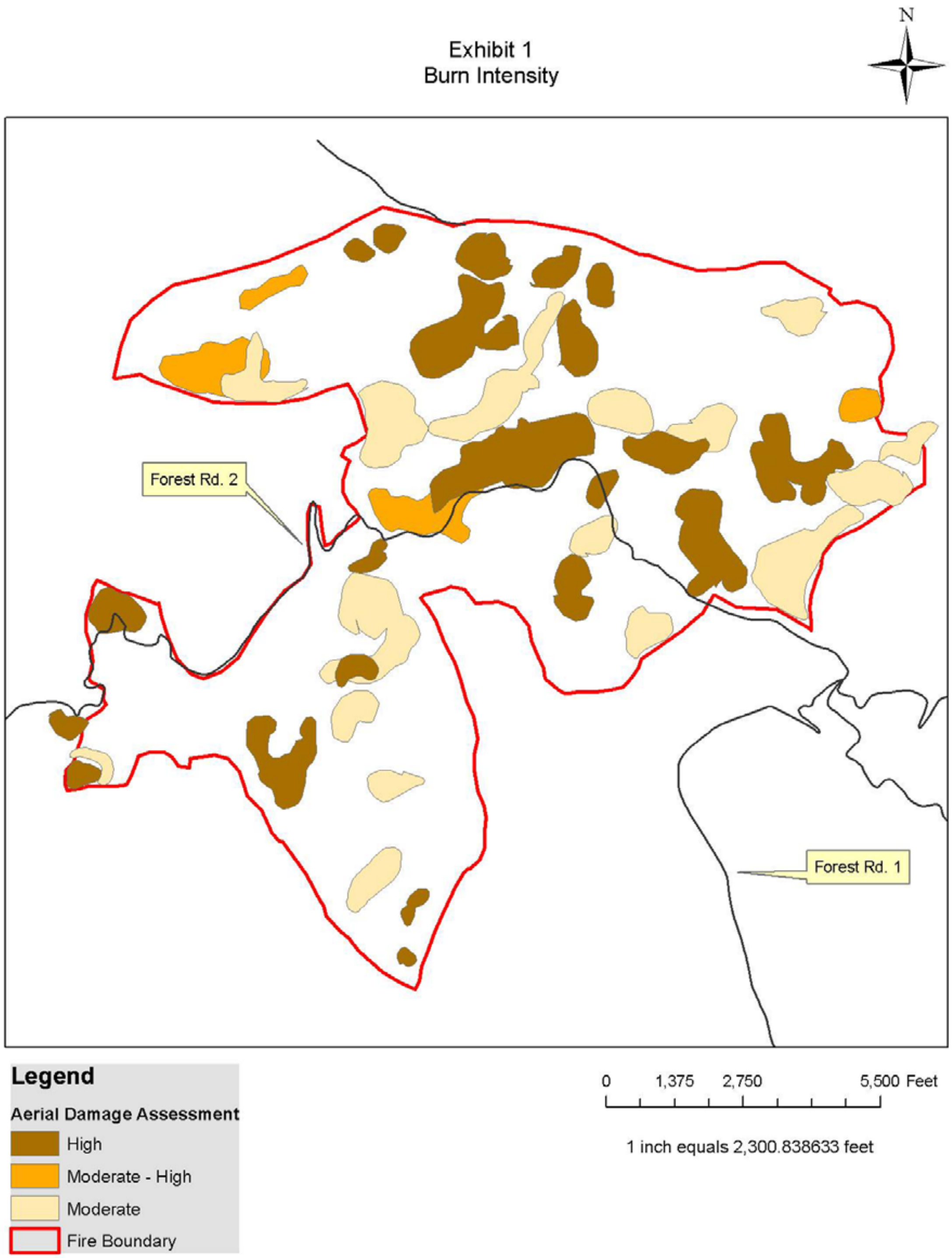

Figure 1: Map of burn intensity in the Shawnee State Forest wildfire area. Division of Forestry, Ohio State Department of Natural Resources. (2009). http://ohiodnr.com/forests/shawnee/tabid/5166/Default.aspx

topographic, geologic, and soil moisture characteristics for comparison between burned and unburned areas. Once we recorded the locations of over 200 paulownia trees spread throughout the burned and unburned areas, we randomly selected 61 specimens around which we would establish experimental plots. Sixty-one control plots, 30 the burned and 31 in the unburned areas, contained no paulownia and were located 10-25 m away from corresponding experimental plots to reduce potential effects of the paulownia on control areas. We took care to place our control plots in areas with similar aspect, slope, elevation, soil, and canopy cover as the experimental plots. In the event that paulownia density in the vicinity of the experimental plot was too high to set up a control plot, control plots were established elsewhere in the state forest with care to ensure similar aspect, elevation, canopy cover, vegetation features, etc.

Our 61 experimental plots (those containing paulownia in either the burn and harvest or the non-burn areas) were established with the paulownia specimen in the center of the plot. The plots were 10 m by 4 m, measured using metric tape and the boundaries marked with flagging. The plots ran lengthwise along the trail or road nearest to which they were located. They were divided into four 5 m x 2 m quadrants. The quadrants were labeled by their location in reference to the trail or road, with quadrant I in the bottom right corner closest to the trail, quadrant II in the upper right corner, quadrant III in the upper left corner, and quadrant IV in the lower left corner (Fig. 2). These quadrants were established to simplify the data-recording process.

Within each experimental plot, the diameter of the tree at breast height (DBH) and total height of each paulownia stem was recorded. DBH is the diameter of a tree at 4.5 feet (1.37 m). The total number of leaves on each specimen was counted up to 100. The number of stems was recorded, distinguishing different stems if they split below DBH-height.

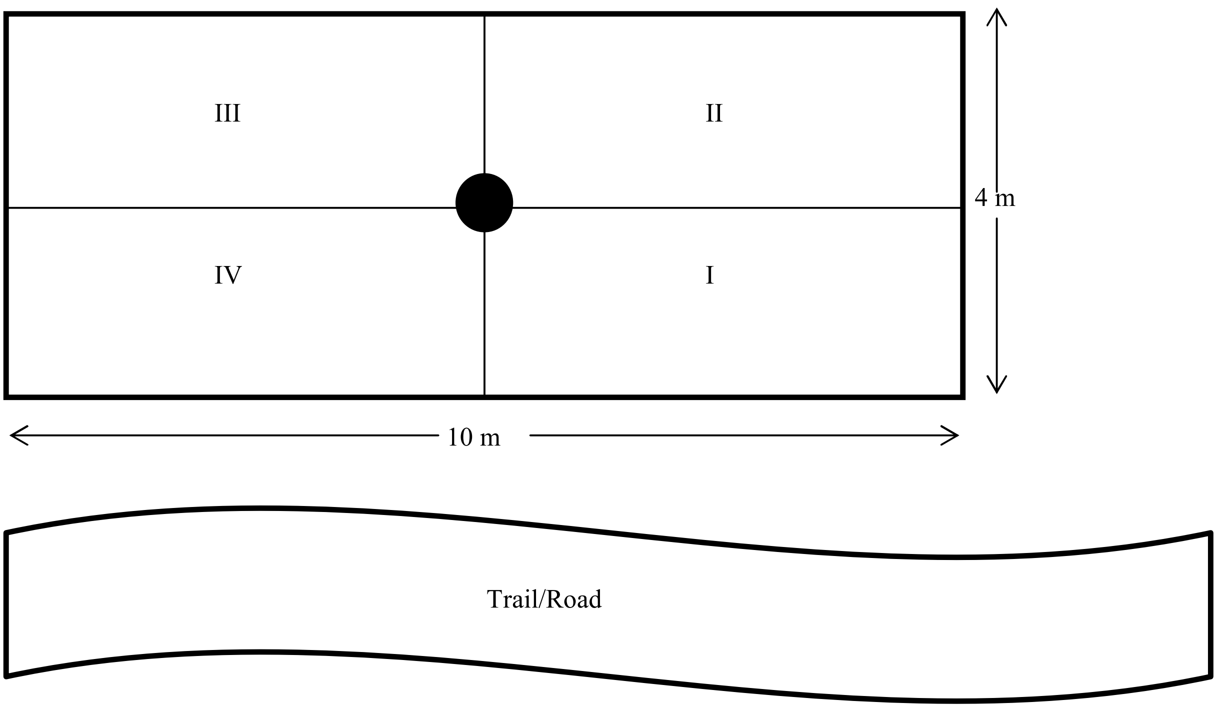

Figure 2: Experimental plot diagram. The black circle in the center represents a paulownia specimen.

In both the experimental and control plots, data for selected native species (*Acer rubrum*, *Liriodendron tulipifera*, *Quercus alba*, *Q. marilandica*, *Q. prinus*, *Q. rubra* and *Q. velutina*) of seedling size were collected in each quadrant. Any specimen under 137 cm height was considered a seedling, and the seedling density of each species was recorded. We also randomly selected and recorded the heights of up to three seedlings per species per quadrant.

The oak species were divided into a red oak group (*Q. marilandica*, *Q. velutina*, and *Q. rubra*) and a white oak group (*Q. alba* and *Q. prinus*). Data analyses were conducted using Statistical Analysis Software (SAS) version 9.3 and Microsoft Excel. Seedling height and density data were evaluated using Duncan's multiple range test with a 95% confidence level ($p < 0.05$).

RESULTS

In the presence of fire, red maple seedling densities decreased by an average of 57 % and heights increased by an average of 67 % ($p = 0.0026$ and $p < 0.0001$ from Duncan's multiple range test, Fig. 3). There was no significant difference in red maple seedling densities in the presence of paulownia ($p = 0.2885$, Fig. 4a). However, red maple seedlings were, on average, 20 % shorter in the presence of paulownia ($p = 0.0031$, Fig. 4b).

Figure 4 shows native seedling densities and heights in order of increasing disturbance. The first bars per species group indicate non-fire plots with no paulownia (–fire/–paulownia), the second bars indicate non-fire plots with paulownia present (–fire/+paulownia), the third bars indicate burn/harvest plots with no paulownia (+fire/–paulownia), and the fourth bars indicate burn/harvest plots with paulownia (+fire/+paulownia). Red maple density decreased steadily with an increase in disturbance, with the highest density (3250 seedlings/ha, $p = 0.171$) in the "undisturbed" –fire/–paulownia plots and lowest density (2690 seedlings/ha, $p = 0.171$) in the "highly disturbed" +fire/+paulownia plots (Fig. 5a).

The red oak group was composed of mostly black oak (*Q. velutina*) and blackjack oak (*Q. marilandica*) seedlings with some northern red oak (*Q. rubra*). Red oak group seedling heights increased by an average of 62 % ($p < 0.0001$) with the presence of fire and harvesting, with no significant difference in density between fire and harvest and non-fire plots ($p = 0.795$) (Fig. 3). On average, red oak group seedling density decreased by 57 % and heights decreased by 19% in the presence of paulownia ($p = 0.0333$ and $p = 0.0018$, Fig. 4). Red oak group seedling density was generally unaffected when analyzing the fire/harvest and paulownia variables together, though the lowest density was found in the +fire/+paulownia plots (p =

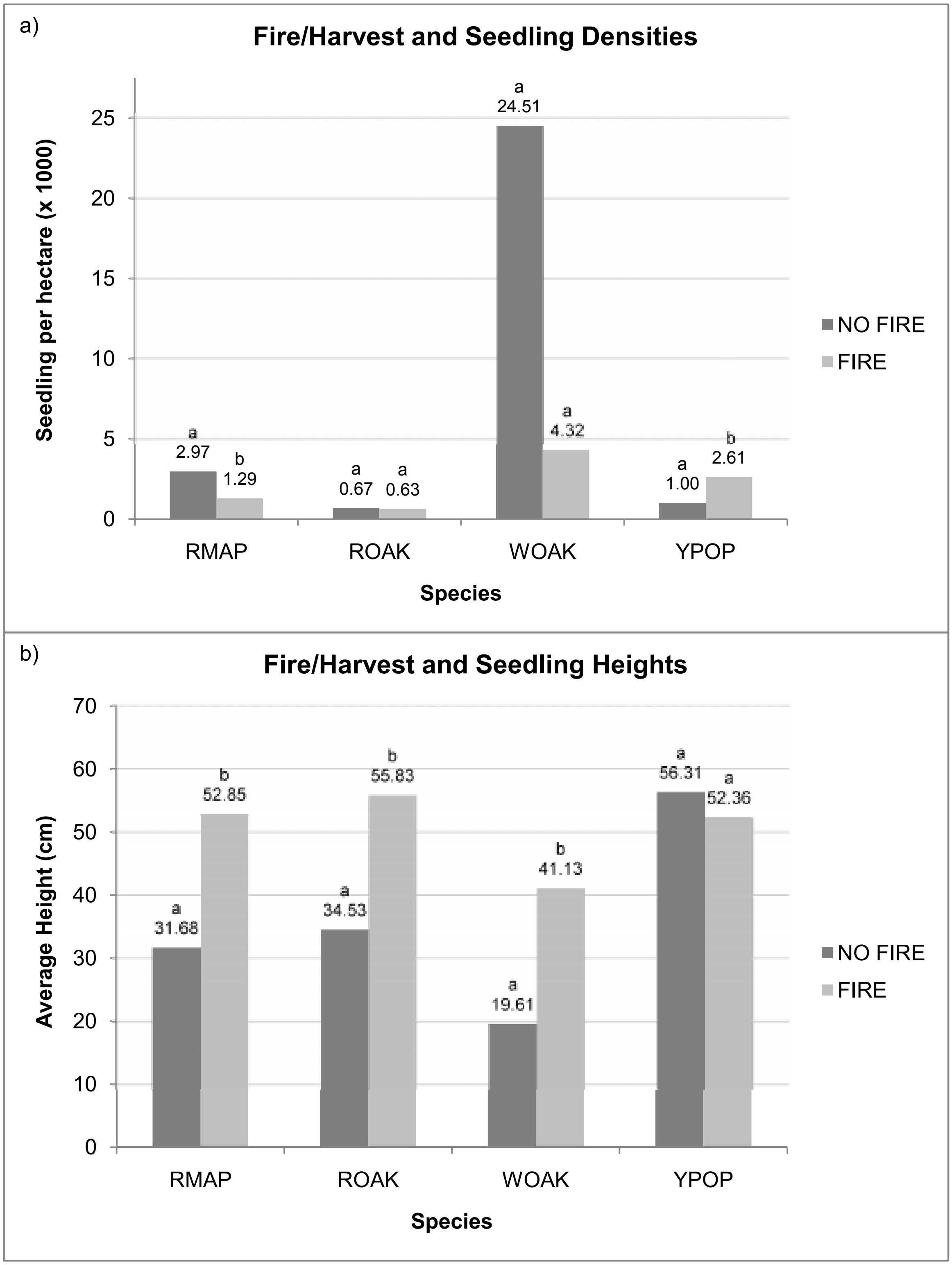

Figure 3: Fire/harvesting and native seedling densities and heights. Figure 3a shows how fire presence generally correlates with fewer seedlings per hectare. Figure 3b shows how fire presence generally correlates with taller seedling heights. Yellow-poplar is the exception in both 3a and 3b. RMAP = red maple, ROAK = red oak group, WOAK = white oak group, YPOP = yellow-poplar.

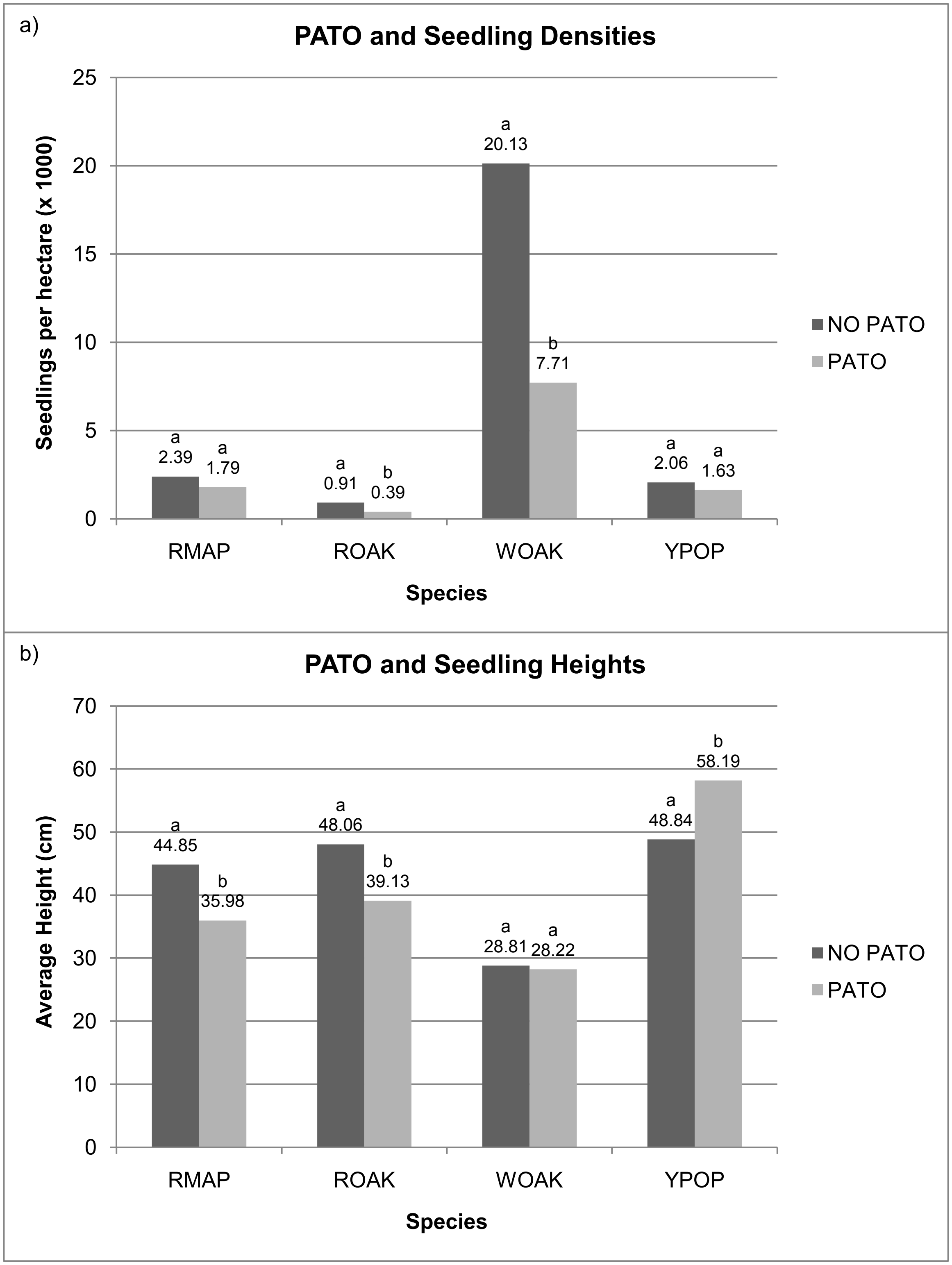

Figure 4: Paulownia and native seedling densities and heights. Figure 4a shows how paulownia presence generally correlates with the fewer seedlings per hectare. Figure 4b shows how paulownia presence generally correlates shorter seedling heights, with yellow-poplar as the exception. RMAP = red maple, ROAK = red oak group, WOAK = white oak group, YPOP = yellow-poplar.

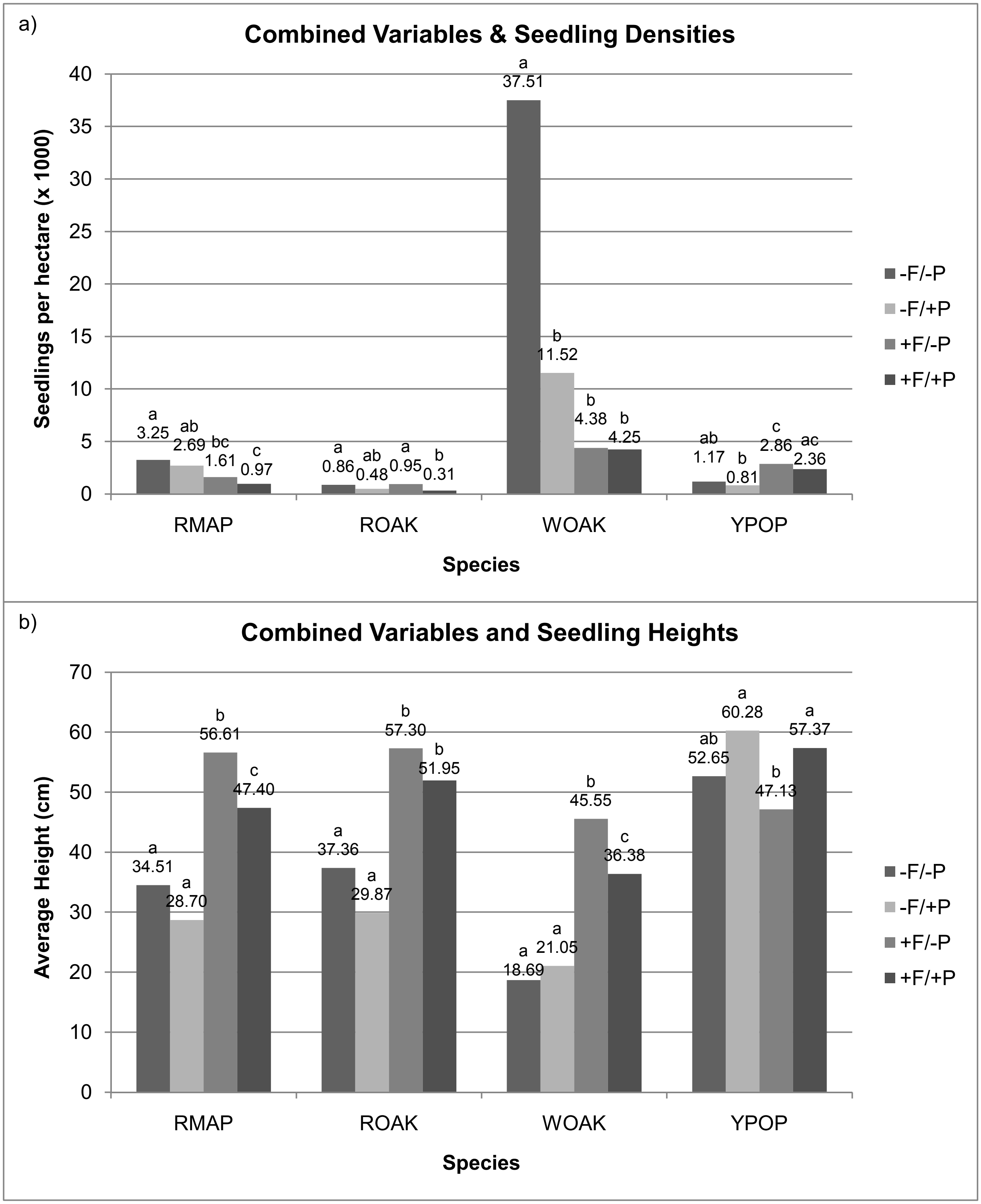

Figure 5: Combined fire/harvest and paulownia variables and seedling densities and heights, in order of increasing disturbance intensity. Figure 5a shows the combined variables and the number of seedlings per hectare. Figure 5b shows the combined variables and native seedling heights. RMAP = red maple, ROAK = red oak group, WOAK = white oak group, YPOP = yellow-poplar.

0.0156, Fig. 5a). Heights were significantly taller in the fire and harvest areas regardless of paulownia presence at $p < 0.0001$ (Fig. 5b).

The white oak group was dominated by chestnut oak seedlings with a few white oak seedlings. On average, seedling density was 82% lower and heights were 110% taller in the presence of fire and harvesting ($p = 0.0002$ and $p < 0.0001$, Fig. 3). On average, there were 62% fewer white oak group seedlings in the presence of paulownia ($p = 0.0221$, Fig. 4a). Height growth was not affected by paulownia ($p = 0.7751$, Fig. 4b).

White oak group seedlings behaved much like the red maple seedlings when examining the paulownia and the fire and harvest variables together. Seedling density decreased with an increase in disturbance level, though the only significant difference was between the –fire/–paulownia plots and the rest of the plots ($p < 0.0001$) (Fig. 5a). White oak group seedling heights were significantly taller in the burn areas, regardless of paulownia presence ($p < 0.0001$) (Fig. 5b).

Yellow-poplar seedlings behaved very differently from the red maple, red oak group, and white oak group seedlings. There were, on average, 162% more yellow-poplar seedlings present in the burn and harvest area than the unburned area ($p = 0.0002$, Fig. 3a), but yellow-poplar seedling heights appear unaffected by fire and harvesting ($p = 0.2578$, Fig. 3b). On average, yellow-poplar density was unaffected by paulownia presence ($p = 0.3365$, Fig 4a) while heights were, on average, 19% taller in the presence of paulownia ($p = 0.0032$, Fig. 4b).

No significant difference existed between yellow-poplar densities in the –fire/–paulownia plots and +fire/+paulownia plots, though the highest densities occurred in the burn/harvest plots regardless of paulownia presence ($p = 0.0024$, Fig. 5a). Seedling heights were insignificantly affected in the fire/harvest plots indicating that fire and harvesting had no effect on yellow-poplar growth (p = 0.0160, Fig. 5b). Yellow-poplar grew tallest in the –fire/+paulownia plots and shortest in the +fire/–paulownia plots, suggesting that yellow-poplar survives best in moderately disturbed areas with full sunlight.

DISCUSSION

Due to the inconsistent pattern of salvage harvests following the 2009 wildfire, we cannot separate the effects of fire and harvesting on seedling responses. These variables must be analyzed together, as seedling data was not collected before harvests. While we did establish some fire-area plots in unharvested areas, we did not examine the differences between harvest intensities, because accurate maps regarding harvesting data were not available to aid in our analysis. There were also very few plots established in the unharvested burn areas to make accurate conclusions on their differences from the harvested burn areas.

Oak species have been shown to benefit from the effects of fire and sunlight availability due to harvesting, and red maple even benefits from some fire situations (Alexander et al. 2008; Burns & Honkala 1990; Fei & Steiner 2009; Green et al. 2010; Groninger & Long 2008; Hutnik & Yawney 1965; Royse et al. 2010; Schweitzer & Dey 2011). While red maple and white oak group seedling density was significantly lower in the fire areas and red oak group seedlings showed no significant change in density, heights of all three were significantly taller in the fire areas compared to the non-fire areas (Figs. 3a and 3b). In the absence of fire, seedling competition for light, water, and nutrients slowly reduces the total number of seedlings, potentially enabling remaining seedlings to grow taller. Fire may have acted as an accelerant to this stage. While fire typically kills aboveground seedling biomass, species such as oak, maple, and yellow-poplar have the ability to resprout and grow taller more quickly from the nutrient cycling and reduction in competition from the fire. Seedlings established after fire can also benefit from the competition reduction (Alexander et al. 2008; Barnes et al. 1998; Schweitzer & Dey 2011; Whelan 1995). Our data therefore support the idea that red maple, red oak species, and white oak species benefited from fire and subsequent harvests, suggesting that forest managers at Shawnee State Forest can expect prescribed burn or wildfire events combined with harvesting will benefit height growth during natural regeneration of these species.

However, the question remains as to why red oak group seedling density was apparently unaffected by the presence or absence of fire and harvesting while white oak group density was, on average, 82% lower in fire/harvest areas (Fig. 3a). To examine this question, we can focus on the behavior of chestnut oak species in terms of fire and harvest, as they comprised the vast majority of the white oak group species. Royse et al. (2010) found that chestnut oak seedling density was virtually the same in fire-excluded areas as prescribed burning areas. Other research suggests that chestnut oak is actually better adapted to catastrophic disturbances such as intense wildfire and clear cutting than red oak species (Abrams 2003; Weaver & Robertson 1981), as well as to more xeric conditions which due to increased sunlight of the fire/clear-cut areas (Blackman & Ware 1982), which contradicts our results (Fig. 3a). The best explanation for this contradiction may be related to mast production. The significantly high amounts of chestnut seedlings in the non-fire areas suggest a good mast year during the fall of 2010, which led to widespread seedling establishment. However, in the fire and harvest areas, chestnut oak parent trees were not present for the successful mast production in the fall of 2010 because they were harvested in July 2009. Therefore, seedling establishment was significantly lower in the fire/harvest areas. Shawnee State Forest managers may want to consider shelterwood and seed-tree methods for oak reproduction to take advantage of high mast years and to ensure successful oak establishment. Following the seed-tree method with prescribed burnings could also accelerate the stand reinitiation stage and seedling height growth.

Yellow-poplar seedling density appeared to benefit from fire and harvesting, in contrast to the red maple, red oak group, and white oak group seedlings (Fig. 3a). Yellow-poplar seeds differ from the other species because they are smaller and are able to disperse farther with the wind. They also benefit from the scarification and sunlight availability caused by fire and harvesting, as yellow-poplar seedlings do not establish well in thick forest litter areas and are a shade-intolerant species (Burns & Honkala 1990; Kota et al. 2007). However, heights were apparently unaffected by the effects of fire and harvesting, though yellow-poplar has resprouting capabilities like oaks and maples (Fig. 3b). We expected the increased sunlight availability in the burn areas to have led to an increase in yellow-poplar heights. It is possible that taller seedling heights (those above 100 cm) did increase enough to put them in the sapling stage (>137 cm), as yellow-poplar is the fastest growing native species among those measured, and therefore the data did not capture this increase in height growth.

The presence of paulownia was associated with fewer red oak group and white oak group seedlings (Fig. 4a). Paulownia was also associated with significantly shorter red maple and red oak group seedlings. White oak group seedling heights were seemingly unaffected by paulownia presence. Yellow-poplar appeared completely unaffected from the presence of paulownia (Fig. 4b). Looking at both seedling height and density data (Figs. 4a and 4b), paulownia did seem to have a negative effect on red maple, red oak group, and white oak group regeneration. Since paulownia grows very quickly and has large leaves, it may able to shade out native seedlings and retard their growth. It is also possible that paulownia has a negative allelopathic impact on these species.

Strangely, yellow-poplar density was seemingly unaffected by the presence of paulownia (Fig. 4a) and heights were generally taller in its presence (Fig 4b). It would appear from these data that paulownia presence enhances the growth of yellow-poplar seedlings. However, it is important to remember that correlation does not necessarily indicate causation. Typically, yellow-poplar seedling height growth suffers in the presence of intense competition (Kolb & Steiner 1990; De Steven 1991). The best explanation for yellow-poplar's heights not being negatively correlated with the presence of paulownia as was generally the case for oaks and maples may be that because paulownia and yellow-poplar both behave as early successional species, they may just both thrive on similar microsites suited for their establishment and growth. Unless there is an undiscovered positive allelopathic influence of paulownia on yellow-poplar growth, it is most probable that paulownia and yellow-poplar will simply exist and thrive under similar site conditions.

Red maple and white oak group seedling density decreased with increasing disturbance. Red oak group seedlings showed no particular pattern related to disturbance, though density was the lowest in the plots with fire and paulownia (Fig. 5a). However, red maple, red oak group, and white oak group seedling heights were tallest in the fire and harvest areas (+fire/–paulownia and +fire/+paulownia). This indicates that all three species groups benefited more from fire/harvesting than they were inhibited by paulownia. Furthermore, paulownia presence in these burn/harvest areas was associated with significantly shorter red maple and white oak group seedlings (averages of 56.61 vs. 47.40 cm and 45.55 vs. 36.38 cm, respectively). The significant difference in heights between red maple and white oak group seedlings in the burn areas from the presence of paulownia indicates that paulownia benefits from fire and/or harvesting activities. It may gain a competitive edge from the effects of fire and harvesting, from nutrient cycling, competition reduction, and/or the increase in sunlight availability. Paulownia is known to successfully colonize xeric sites with high light availability (Carpenter et al. 2983; Kuppinger 2008; Longbrake 2001; Moore & Lacey 2009).

CONCLUSIONS

This study supports existing research that red maple and oak species benefit from the effects of fire and light availability due to harvesting and that yellow-poplar establishment increases after soil scarification events. We also show that in general, native tree seedling establishment and growth may be inhibited in the presence of paulownia. Furthermore, paulownia seems to increase its competitive capabilities in burned and harvested areas, though fire and harvesting had more effect on seedling success than paulownia. While the inhibiting effects of paulownia on native seedlings may be attributed to its fast growth and shade from its large leaves, further research needs to be conducted to determine allelopathic relationships. At least one study has suggested that invasive tree-of-heaven (*Ailanthus altissima*) produces allelopathic chemicals that inhibit the growth of surrounding plants (Heisy 1996). It is possible that paulownia creates a similar biochemical response. More research should be conducted relating paulownia to native vegetation and monitoring permanent site plots over the years as the native vegetation matures to examine if paulownia's inhibitive effects are long-lasting.

While paulownia's large leaves may create enough shade to slow growth of native seedlings, there were other competing species at Shawnee State Forest which were more prevalent and should be of greater concern to the forest managers at this time. Greenbrier (*Smilax* spp.) and grape vines (*Vitis* spp.) were almost completely blanketing areas of the forest, pulling down tree regeneration and creating intense light competition. In many plots, grape and greenbrier were so overgrown that it was difficult to find any other vegetation without crawling under their "blanket" canopy. These competitors were found both in the fire/harvest and non-fire areas. While greenbrier and grape are native to the area and may naturally occur in such high densities, its abundance at Shawnee State Forest may have economic implications for forest managers. Greenbrier and grape may be slowing tree regeneration in the area, which could increase harvesting rotation times. More research should be conducted comparing rotation lengths at Shawnee State Forest in various greenbrier and grape densities to examine their possible effects.

Some believe that paulownia cannot actually be considered a pest. Williams (1993) describes paulownia as only being present in episodic situations on disturbed sites, because the tree's large leaves can reduce its regenerative capabilities by shading out its seedlings. Paulownia is shade-intolerant. Because it grows quickly and creates a dense canopy, it creates conditions under which it cannot necessarily regenerate itself (Kuppinger 2008). In closed-canopy situations with large, mature paulownia trees at Shawnee State Forest, we found virtually no paulownia seedlings on the forest floor. Paulownia may persist on exposed, xeric sites (Williams 1993), but as the forest matures, may not be able to reproduce without colonizing other more suitable sites. More research is needed monitoring the growth and persistence of paulownia in various sites, especially in maturing forest areas.

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