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Water Table Height and Microtopography in Swamps of Southeastern Michigan as Influences of Black Ash Tree Establishment and Survival in the Presence of Emerald Ash Borer

Samantha Chauvin
Wayne State University, samanthachauvin1@gmail.com

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Water Table Height and Microtopography in Swamps of Southeastern Michigan as Influences of Black Ash Tree Establishment and Survival in the Presence of Emerald Ash Borer

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Abstract

The detrimental impact of invasive species on native biota is a source for many studies spanning all kinds of biological systems. The introduction of emerald ash borer in southeastern Michigan in the early 2000's has decimated the region's mature black ash tree population, but its regeneration, both asexual (sprouts) and sexual (seedlings) still occurs. The arrangement and features of the wetlands' land surfaces may play a role in black ash establishment. Black ash is generally found on wet-mesic to wet soils, but rising water table levels due to climate change and overstory tree mortality in on these sites may inundate microsites where germination is able to occur, thereby reducing the area available for black ash regeneration. Thus, quantifying the microtopography of wetland sites where black ash has successfully established is critical to understanding black ash persistence in the presence of emerald ash borer. This project characterized the microtopography of selected forested wetlands in southeastern Michigan using handheld LiDAR technology to examine the spatial correlation of black ash seedings and saplings with small changes in elevation. Three-dimensional pointclouds of eight plots with high black ash abundance at sites in southeastern Michigan were analyzed. Estimating land area above a threshold elevation highlight sites that support black ash regeneration; at sites where flooding remains minimal, black ash survival may increase due to microsite availability.

Introduction

In the glaciated eastern U.S., forested wetlands (also called swamps) are found in poorly drained depressions on moraines, ice-contact features such as kettles, as well as outwash plains and lake plains (Cohen et al. 2014). Such depressions are adjacent to upland areas with drier soil and vegetation characteristics. The transition from upland dry to downland wet is explained by the position of the water table. Forested wetlands are located lower in the landscapes where the water table lies at or close to the soil's surface in depressions. Increased snow melt and rainfall in the spring and summer drive seasonal groundwater increases, but some swamps may experience permanent flooding all year round.

Interannual and seasonal fluctuations in soil water saturation dictate nearly every process in a wetland, which helps explain why the wetland group is as large and variable as it is. The soil development and inhabitant vegetation are dependent on the hydrologic regime (Cowardin et al. 1979), although all wetlands have hydric soil and hydrophytic vegetation. Hydric soil develops from extended periods of water saturation and the anaerobic conditions that result (Berkowitz et al. 2021, Vepraskas et al. 2016). Anaerobic conditions discourage rapid decomposition, thus plant litter found on the wetland forest floor will break down slowly and become organic soil called muck.

Swamp vegetation is adapted to survive in hydric soils, and swamps are often classified based on their dominant vegetation and species composition as described by Cohen (2014). In southeastern Michigan, a particularly common wetland forest type was black ash (Fraxinus nigra)- red maple (Acer rubrum)- American elm (Ulmus americana). Most sites in the region were dominated by deciduous hardwoods such as red maple, American elm, yellow birch (Betula alleghaniensis); tamarack (Larix laricina) as a common conifer; and shrubs such as winterberry (Ilex verticillata).

The spatial location of black ash in the southeastern Michigan swamps is influenced by the microtopography of the swamp itself. The species is often found at the edges of the swamp where elevation was low enough to maintain a wet environment, but high enough so that the site is not permanently under water. Numbers of black ash seedlings and saplings decline further (lower in elevation) into the swamp. Black ash may be present throughout an entire swamp if the slope is gentle enough. Smaller scale elevation differences such mounds (caused by hummocky vegetation, stumps, or fallen logs) within swamps will indicate what specific areas that will remain above water during seasonal flooding. The availability of these microsites is valuable for determining where black ash seedlings and sprouts can establish since they are unable to do so under water.

Black ash seed dispersal occurs between July and October, and germination may take place the following spring unless the seeds remain dormant, a trait common in most ash species (Schopmeyer 1974). Seeds may stay viable for up to eight years (Sutherland et al. 2000) and germinate when optimal temperature and moisture conditions are met. Black ash seeds are unlikely to germinate and seedlings are even less likely to establish in flooded conditions. High water levels therefore generally prevent germination and establishment in the spring, and successful black ash establishment correlates well to dry years or an absence of intensive flooding for long time periods (Tardif and Bergeron 1999). Therefore, changes that may occur in the local water table – particularly if such changes reduce the number of available germination sites - may have important implications for the long-term persistence of black ash in this region.

Emerald ash borer (EAB) has killed millions of ash trees of every ash species in the eastern United States and Canada since its initial detection in 2002. Adult beetles lay eggs inside the tree's bark, and the larvae feed off the phloem once hatched. Extensive phloem feeding inhibits the tree's sugar transport and kills the tree; this is the usual route of EAB infestations. Knight et al. (2012) found a greater than 99% of mortality among ash trees was probable once EAB exit holes existed on the trees for about four years. EAB prefers to infest stressed ash trees (Cappaert et al. 2005) but attacks healthy trees as well when the EAB population is high. This high mortality rate, together with an ability to infest any species and condition of ash tree larger than about one inch in diameter has resulted in an extremely large loss of overstory ash. In swamps, loss of large, overstory black ash trees is likely to cause the water table level to rise because transpiration is reduced, and the amount of water left in the soil increases. EAB-caused damage to black as therefore results both in the major loss of mature ash as well as an increased difficulty of residual ash seed to germinate, and black ash regeneration is negatively impacted.

This project mapped the microtopography of forested wetlands in southeastern Michigan as an attempt to better understand the potential for black ash to persist after its overstory was lost to emerald ash borer. Specifically, the following questions were asked:

1. What is the range of elevations of established black ash with the seven swamps, and how does this range compare to the rest of the swamp?
2. What proportion of each swamp is available for future establishment of black ash due to its likely location above the water table?

Methods

Black ash occurs sporadically in southeastern Michigan, but seven forested swamps containing black ash were located at the Proud Lake Recreation Area; Embury Road, in Chelsea; Burgess-Shadbush Nature Center; North Lake, in Gregory; Indian Springs Metropark; Highland Recreation Area; and the Matthaei Botanical Gardens. Within these sites, 200 meter^2 plots (10 m x 20 m) were established where relatively high concentrations (relative) of black ash seedlings and saplings occurred to identify the species' distribution among the plot's small-scale elevation. Black ash was identified, located, and marked with pink flagging within the plots.

A Pix4D Vidoc RTK Rover and a light detection and ranging (LiDAR) equipped iPhone were used to map the plots. The Rover is a portable device that attaches to an iPhone (or iPad) case. The Rover uses real-time kinematic (RTK) positioning which is a form of differential global positioning system (DGPS) connected to a Networked Transport of RTCM via Internet Protocol (NTRIP) service. RTK positioning data has accuracy within centimeters (Feng & Wang 2008). MDOT CORS-MSRN Port IP address, port number, standard mountpoint as well as the United States region NAD83(2011) coordinate reference system was used for NTRIP service. The iPhone takes images and sends pulsed lasers to establish geographical locations within each frame. The Rover is used in combination with the iPhone to obtain highly accurate positions on the Earth's surface from signals between satellites and receivers such as known stations and the Rover. The Rover-iPhone pair is equipped with LiDAR and provides distance, spatial position, and elevation data at one-centimeter resolution.

Thorough imaging of all land surfaces in each plot generated pointclouds, a mass of measurements depicting the landscape's microfeatures which create a mosaic of the area. When one image was taken, hundreds of points with specific coordinates and elevations were assigned to the various surroundings of the frame. Thousands of frames compiling the millions of points at the end of the imaging run complete the pointcloud. Grasses, trees, mounds and small rises, and other similar objects in the field all appear as a full "pixelated" image of the plot with the measured points serving as the "pixels". The resulting image has a high resolution (Figure 1). Points also register the environment's pigmentation. Thus, the pink flagging used to

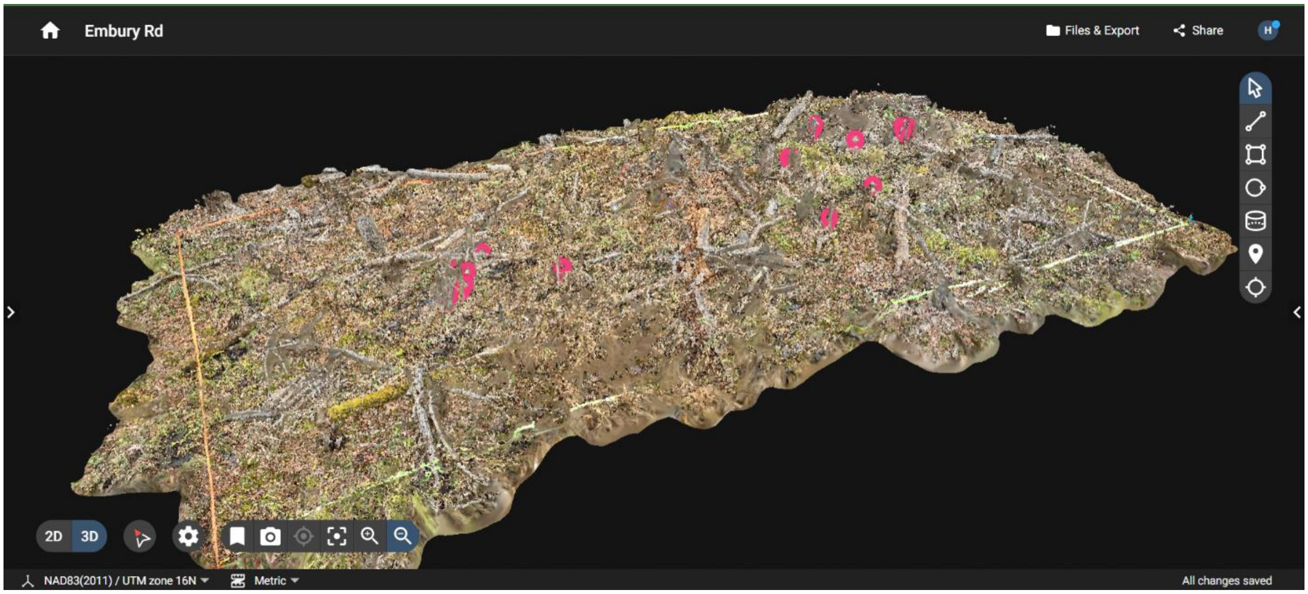

Figure 1. Full 20 x 10 meter plot of Embury Rd in PIX4Dcloud after upload and processing. Pink markers indicate the locations of black ash trees.

mark the black ash trees provided contrast against the greens and browns of the landscape (Figure 2). This was useful for determining the elevation of established black ash. Once the Rover obtained precise measurements, corrected data was imported to the PIX4Dcloud software for point cloud observation.

Figure 2. Black ash trees marked with pink flagging at the lowest part of the trunk. PIX4Dcloud pink markers are also seen here.

Within PIX4Dcloud, individual flagged black ash trees were located and marked at ground level to determine their elevation. Once a list of black ash elevations for each plot was obtained, the surrounding points were used as elevation references to draw polygon areas of the plot below the minimum ash elevation (Figure 3). The proportion of the plot unavailable for black ash establishment was determined by summing the areas of these polygons and dividing by the total plot area.

Figure 3. Area polygons under minimum ash elevation for the Embury Road plot. A total of 59 blue polygons were drawn for this plot.

Results

The abundance of ash was highly variable among plots, but each sample plot represents a high black ash abundance for that site. Indian Springs had the highest abundance of ash trees at 13,250 stems/ha, and Haven Hill had the lowest at 550 stems/ha (Table 1). Ranges did not extend past a full meter for any plot. The difference between the maximum and minimum ash elevation was surprisingly similar among sites (mean = 0.41 m), but was lowest at Proud Lake (0.27 m) and Shadbush (0.21 m). Indian Springs had the largest difference for maximum and minimum black ash occurrence (0.57 m).

Table 1. Ash metrics recorded for each plot for all adult, seedling, and sapling ash trees.

Site	**Black Ash Density (stems/ha)**	**Min. Elevation (m)**	**Max. Elevation (m)**	**Difference (m)**	**Avg. Elevation (m)**
Embury Road	2850	245.34	245.86	0.52	245.57
Proud Lake	800	242.45	242.72	0.27	242.57
Shadbush	2050	165.34	165.55	0.21	165.43
North Lake	6550	248.97	249.46	0.49	249.22
Indian Springs	13250	268.28	268.85	0.57	268.56
Haven Hill	550	261.13	261.57	0.44	261.44
Fleming Creek	1300	201.75	202.09	0.34	201.88

Plot elevation also varied among the sites because it depended strongly on local geography and landscape features. All sites were located between 150 to 300 meters above sea level. Haven Hill had the largest range in elevation within the plot (1.34 m), and Proud Lake had the smallest at 0.47 m (Table 2). The mean elevation difference among the plots was 0.8 m. Based on the elevation of the plot relative to the minimum ash elevation, all the plots had between 84%-98% of their land area available for future black ash establishment (Table 2). Shadbush was an outlier (cutoff values for outliers in a dataset were: upper fence: 108.11%, lower fence: 70.51%) and had the lowest area percentage at 55.61%. The plot with the highest percentage was Indian Springs at 97.31%.

Table 2. Plot metrics recorded at each site, including minimum and maximum plot elevation and the difference between maximum and minimum plot elevation. The area of the entire plot above the minimum black ash elevation is also provided.

Site	Min. Elevation (m)	Max. Elevation (m)	Difference (m)	Plot Area above Min. Ash Elevation (%)
Embury Road	245.13	246.04	0.91	84.76
Proud Lake	242.29	242.76	0.47	84.61
Shadbush	165.08	165.71	0.63	55.61
North Lake	248.77	249.65	0.88	94.01
Indian Springs	268.22	268.99	0.77	97.31
Haven Hill	260.95	262.29	1.34	89.99
Fleming Creek	201.58	202.21	0.63	87.38

Discussion

As water tables rise in swamps with loss of overstory trees and potentially with climate change, the area of higher ground in these forested wetlands will be important sites for trees to germinate and establish. The availability of germination sites is even more critical for black ash, as regeneration (seedlings and saplings) is not susceptible to emerald ash borer and may determine the future persistence of the species (Kashian and Witter 2011). Sites that appear to have less microtopography and thus less area unlikely to be inundated, such as Shadbush (at which nearly half the area is located lower in elevation than the lowest established black ash), may be less likely to exhibit black ash regeneration and the species may become permanently extirpated by emerald ash borer. On the other hand, at sites with higher elevations and more of their total area above the minimum ash elevation, such as Indian Springs (97.3%) and North Lake (94%), black ash is likely to be more resilient and persistent because there are germination and establishment sites readily available even if water table rises continue. Similar speculation could be made for the remaining four plots where at least 85% of the plot area was higher than the lowest established black ash. These results may indicate that a number of sites in southeastern Michigan may support black ash establishment with minimal increases in water table height and duration. Understanding rising groundwater levels in the face of these issues is therefore crucial for predicting future trends of black ash persistence.

The loss of overstory ash trees to EAB represents a dangerous positive feedback loop; when EAB kills adult trees, establishment of the black ash regeneration is prevented due to increased flooding and fewer available germination sites, which continues to foster rising or high water tables. Mortality caused by EAB has been shown to be analogous to clear-cutting in terms of reduced evapotranspiration, and an increase in water table height occurs similarly in both situations (Slesak et al. 2014). In southeastern Michigan, where EAB has been established the longest, ash regeneration is relatively abundant in upland forests but is hindered in lowlands due to challenges in seed establishment on wet sites (Kashian and Witter 2011). This study also found a lack of new seedlings (1-2 years old) between the span of two years; as overstory ash die, so does their ability to act as a source of seeds. While black ash seed production and dispersal has not been studied in the aftermath of EAB, green ash seed dispersal from sprouts from EAB-killed trees and from surviving trees has been shown to be sufficient to maintain the species even in the presence of EAB (Kashian 2016). These observations of black ash regeneration that have likely been established after EAB suggest that there is a source of black ash seed in southeastern Michigan, and that the persistence of black ash in the presence of EAB is more likely to be driven by available germination sites in swamps than it is by the availability of seed.

The loss of ash due to EAB has greater ecological impacts beyond the persistence of ash alone. The loss of black ash in swamps may result in shifting swamp forest composition towards shrubs wetlands or marshes. Increased height and duration of the water table favors water tolerant species over forested wetland species, creating new open marshes in place of these swamps (Ridolfi et al 2006). The major change in the hydrologic regime at these sites (decreased evapotranspiration, increased rainfall and snowmelt, and decreased drainage) would likely favor the persistence of marsh species composition unless factors came into play that lowered water table levels. To avoid the conversion of forested wetlands to shrubby wetlands or marshes, some studies have suggested the silvicultural replacement of black ash by other tree species. Species replacements for black ash in Michigan might include silver maple (Acer saccharinum), northern white cedar (Thuja occidentalis), basswood (Tilia americana), and American elm (D’Amato et al. 2018). Whether black ash is naturally replaced, or replacement occurs via silvicultural techniques, maintaining forested wetlands using other species leaves room for uncertainty in performance and suitability (D’Amato et al. 2018). Both the conversion to marches and the replacement with other trees would likely alter ecosystem services, such as water table regulation, carbon storage, nutrient cycling, pollutant mitigation, contributions towards the mitigation of climate change, or provision of habitat for species reliant on black ash.

Black ash loss is likely to have considerable impacts upon biodiversity. While black ash loss and subsequent rises in the water table may benefit amphibians and invertebrates because longer periods of inundation create better living conditions and promote diversity (Youngquist et al. 2017), it appears to negatively affect bird diversity. In addition, rising groundwater levels have the potential to fragment upland forests, which creates stress for species originally found outside of swamps (Youngquist et al. 2017). Although amphibians such as frogs may initially benefit from the creation of marshes from swamps, in time they may also find difficulty with forest fragmentation (Grinde et al. 2022). Within swamps, however, a highly diverse understory and a mosaic of woody structures make beneficial habitats for bird species with available space for bird nests (Kolka et al. 2018, Niemi et al. 2016). Once the dead snags fall, EAB-induced eradication of overstory ash could eventually eliminate much of these nesting sites as well as resting areas for birds that may use the wetlands for migration purposes, such as rusty blackbirds (*Euphagus carolinus*) (Sauer et al. 2017). This particular bird species is vulnerable, decreasing in numbers at an alarming high rate which would be further exacerbated if essential habitat continues to disappear and percentages of plot areas above a minimum water level are reduced.

The location of black ash in forested wetlands makes its loss to EAB particularly impactful for carbon cycling because wetlands act as a large carbon store. Slow decomposition resulting from water-logged soils and anaerobic conditions maintains carbon in the soil. Trees also sequester and store carbon, so large, old forests are essential carbon sinks. As older black ash is eliminated by EAB and are replaced by smaller plants, forested wetlands shift farther away from being carbon sinks. Flower et al. (2013) found decreases of ash basal area in areas invaded by EAB, which in turn reduced net primary production of the forest. Their study indicates that carbon storage is reduced within black ash forests affected by EAB. As EAB progresses, carbon moves into the atmosphere as swamp forests die, thereby exacerbating climate change. This in turn drives the flooding that prevents black ash establishment that is crucial for the species' persistence.

Other effects of climate change also have the potential to alter forested wetland systems once the overstory has been reduced or eliminated. Rainfall and snowmelt drive the groundwater level and may inundate ecosystems if climate change increases the occurrence of extreme hydrologic events. These significant water supply changes impact wetlands more severely than other systems. Swamps are high-risk ecosystems since many of their functional events rely on a hydrologic regime (Erwin 2009). Warming temperatures encourage large periods of atmospheric water saturation (O'Gorman 2015, Trenberth 2011) which has the potential to create intense rains that may overtake hydrologic regimes of swamps. Specific to ash, studies have already documented reduced ash seedling establishment in lowlands compared to uplands (Kashian and Witter 2011) and have speculated reduced viability of ash seeds when inundated for long periods of time (Erwin et al. 2009, Mitsch et al. 2013, Ridolfi et al. 2006, Trettin et al. 2019). As the climate crisis worsens, black ash forests may experience increasingly difficult years ahead for seedling establishment and regeneration.

The microtopography of forested wetlands may be an important factor in the persistence of black ash as water tables rise from EAB-caused overstory morality and climate change-caused extreme precipitation. Small, abrupt changes in elevation in a swamp are what have always provided available sites for ash germination and establishment and are likely to continue to do so in the future. For example, the plot at Embury Road was located close to the edge of the swamp, such that the plot sloped downward away from the road and into the depression where the swamp sat. In this case, black ash at Embury Road may persist only on the very edges of the swamp, where the elevation is higher and the land is rarely inundated for the entire growing season. Similarly at Shadbush, certain areas of the plot were elevated, the middle of the plot was very low compared to the outer edges, and the plot was fully flooded in the spring. At this plot, black ash was confined to the outer edges of the plot where water table recession in the summer allowed for seedling establishment. Thus, in southeastern Michigan, where black ash occurrence is already spotty and relatively uncommon, ash persistence may occur at sites as water tables rise so long as there are enough pockets of land remaining dry enough for seed survival. It is the proportion of current forested wetlands that can remain dry enough during the growing season for species to germinate and establish that will determine how well black ash may persist and survive.

Conclusions

Although black ash is not likely to go extinct in the areas where EAB has established, the challenges the species face are substantial. In coming years, as EAB continues to attack and kill mature ash trees die and climate change exacerbates imbalances in the water cycle, the proportion of relatively dry land in forested swamps remaining for adequate black ash establishment will be critical data for understanding and predicting the survival of black ash. Forested wetlands are a diverse group, spanning many types with differing species composition, and their loss or conversion to marsh ecosystems, especially those dominated by black ash, would be a loss of and ecosystem type having both extrinsic and intrinsic values. While black ash persistence in drier areas of water table drawdown is a possibility, knowing and predicting exactly how the water table will respond is the best direction for moving forward.

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