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Likely Successors of Ash Species in Response to the Emerald Ash Borer in Ohio Forests

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LIKELY SUCCESSORS OF ASH SPECIES IN RESPONSE TO THE EMERALD ASH BORER IN OHIO FORESTS

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By

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Brian Michael Good ENTITLED Likely Successors of Ash Species in Response to the Emerald Ash Borer in Ohio Forests BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science

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ABSTRACT

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Invasive species have the capability to alter landscapes and change the composition of a forest in a very short time. The recent invasive pest, *Agrilus planipennis,* emerald ash borer, was unintentionally introduced to the United States via ship route to Michigan. The pest attacks and kills all five native ash species in Ohio. This study focused on an area in west central Ohio not yet affected by the borer. Ash centered plots were used to record all species and sizes (diameter at breast height) within a 5m radius of a central ash tree. Plots ranged in topography and all five ash species were sampled. Moisture contents were calculated for each plot based on topographical variables in ArcGIS. My objectives were to answer the following questions: What species will replace ash and how do replacement species vary among different ashes and with topography? Also, how does the understory composition vary among ash species as related to topography? Results suggest that sugar maple will be the likely successor of ash species. Sugar maple was the most important species in all plots and under all ash species except for the black and pumpkin ash which were associated with hydric species. American elm was highly associated with both white and blue ash. A moisture index (IMI) showed a significant separation of black and pumpkin ash, found in swampy regions, from the other three ashes. Black and pumpkin ashes were found in the wettest sites followed by blue, green, and white ash. Detrended correspondence analysis found the five ash species to segregate in a two-dimensional space based on a moisture gradient. Significant correlations were found between the ordination scores and both the size of the central tree and the nearest neighbor indicating a possible succession gradient as well. Post emerald ash borer trends appear to be toward a forest dominated by maples and possibly elms.

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I. INTRODUCTION

Invasive species are plants, animals, or diseases that have invaded a foreign territory and caused some sort of change of habitat or environment. Invasive species have been around for a very long time and can be a common sight in the landscape. The United States has an estimated 50,000 non-native invasive species, altering the landscape in major ways (Pimentel et al. 2001). Typically, non-native species are considered to have negative impacts on society and biodiversity, but that is not always the case. Not only can non-native species have positive impacts, but they can be a driving force for economic growth and productivity. Some of the most important non-natives include corn, wheat, poultry, and cattle (USBC 2001). The previous non-natives are listed as having positive impacts because they are a source of food for the country, but in reality, they have drastic and sometimes harmful effects on the environment. Damage estimates from invasive and non-native species are quite hard to determine but range anywhere from $120 billion to $1.4 trillion per year (Pimentel et al. 2001, Rangi 2009).

One of the more recent invaders is the emerald ash borer, introduced from Asia in about 2002. The borer was most likely present in the mid to late 90's but survived in low numbers and remained undetected. Emerald ash borer, *Agrilus planipennis*, is an invasive pest killing ash (*Fraxinus*) species in the Midwest United States. Of the 50,000 invasive North American species of all kinds, 4,500 are arthropods (ODNR). Despite those numbers, little information is known about native or introduced wood-boring beetles and their impacts on angiosperm trees (Dunn et al. 1990). As an example of their potential importance, in New Zealand, three species of wood-boring beetles from the genus *Platypus* are known to colonize fallen logs and stumps. If there is an abundant supply of decaying logs, the large densities of *Platypus* beetles can threaten healthy *Nothofagus* (southern beech) species and potentially kill them (Reay et al. 2007). Emerald ash borer (EAB) was detected in July 2002 but it is believed that EAB invaded Detroit, Michigan, through a ship route from Asia at least 5 years earlier (Poland and McCullough 2006). EAB is not problematic in Asia perhaps because Asian ash trees produce specific phenolic compounds and other defenses that keep EAB in check (Cipollini et al. 2011). American ash trees may lack these same defenses.

Ash trees are widely distributed across the Midwest and were planted in urban areas after the Dutch elm disease that killed many street trees (MacFarlane and Meyer, 2003). Common species planted include *Fraxinus americana* (white ash) and *Fraxinus pennsylvanica* (green ash). One EAB resistant species is *Fraxinus mandshurica* (Manchurian ash), which originated in Asia and coevolved with EAB (Eyles et al. 2007). Green and white North American ashes are both native and susceptible to the attacks of EAB (Cipollini et al. 2011) with green ash being preferred over white ash (Anulewicz et al. 2007). Other species found in Ohio are black (*Fraxinus nigra*), blue (*Fraxinus quadrangulata*), and pumpkin ash (*Fraxinus profunda*), all of which are most likely susceptible to EAB. Black is the most susceptible species and blue is showing possible signs of resistance. When invasive species are introduced into new habitats, various changes lead to an alteration in the forest dynamics. In the borer's native habitat, located in Eastern Asia (Akiyama and Ohmomo 2000), trees have evolved defense mechanisms to counteract EAB. Studies in Asia show only stressed trees are attacked and killed by EAB (Gould et al. 2005), but in North America, all ash species (whether healthy or stressed) are attacked and killed (Poland and McCullough 2006). Ash were once free of insects and major diseases but are now being threatened by the emerald ash borer (Barnes and Wagner 2003).

Ohio is home to approximately 5 billion ash trees of all size classes in forested land, with saplings (<2.54 centimeters) making up the majority of those trees (U.S. Department of Agriculture 2013). Ash trees as little as 2.54 centimeters (1 in.) diameter at breast height (DBH) and larger than 152.4 centimeters (60 in.) DBH have been infected and killed by EAB (McCullough and Siegert 2007). Therefore, a more realistic number of susceptible ash trees is near 283 million after eliminating trees less than one inch DBH (U.S. Department of Agriculture 2013). In a given year, one tree can sequester a huge amount of carbon, release oxygen into the atmosphere, clean pollutants, reduce erosion, and provide a wide range of other benefits. Losing 283 million trees would greatly alter the cleanliness of the environment and the dynamics of a forest. The topic of forest dynamics is one of the main areas of research that are currently taking place. Some possible changes following a large disturbance within the forest system include an increase of deadwood, increase woodpecker activity, decrease in air quality, gap formations, change in the nutrient cycling, species interactions, and species replacement. Multiple studies have looked at each of these variables within the forest following some type of disturbance, whether by plant or insect.

EAB LIFECYCLE

The life cycle of the EAB begins in the spring (May) when new adults begin to chew D-shaped holes through the bark and emerge. After feeding on ash foliage for about a week, the beetles begin to mate and females continue the feeding for an additional week before beginning to lay their eggs. Males use eyesight to locate potential mates. The elytron (hardened shell over wings) is an iridescent green and reflects light waves back toward the light source. When males are flying overhead, they paratroop in a diving aerial attack and mount the stationary female (Pulsifer et al. 2013). Lelito et al. (2007) found that males used visual cues from 30-100 centimeters above their mate and would try to copulate with both males and females. Fertile females can lay 50-90 eggs during their lifetime (Poland and McCullough 2006). Adults continue to feed and mate for the next month and a half before they die (Bauer et al. 2004, Lyons et al. 2004). Females find cracks and crevices in the bark to deposit eggs, which will hatch in two weeks. The larvae eat through the bark and feed on the phloem of the tree creating S-shaped galleries. These galleries cut off the nutrient flow from the top of the tree to the roots, stunting leaf growth and development. As larvae feed on the phloem, the tree's defense mechanism kicks in and tries to repair the damage by sealing the wounds. Over time, the excess sealing of the tree, can further block the nutrient flow. This act of girdling the tree can seriously impact the health of the ash and leads to death of the tree within 1-3 years of infestation (Liu et al. 2003; Poland and McCullough 2006). Feeding occurs throughout the summer and is completed near the end of fall, at which time the larvae will pupate and overwinter to produce the following year's adults.

VARIABLES AFFECTED BY ASH DECLINE

Deadwood or "coarse woody debris" is the name given to snags (standing dead trees), dead branches, or fallen logs. Deadwood can contribute a number of benefits to the dynamics of the forest. The dying ash trees will result in a huge spike in the number of dead trees available to organisms that rely on such habitats. Death of trees is natural, which drives the succession of a forest, but losing millions of trees at once could have dramatic impacts. Deadwood can provide shelter and homes to owls, raccoons, squirrels, birds, and even some bat species. One bat species, the Indiana bat, will roost and nest under peeling bark of decaying trees (Carter and Feldhamer 2005).

Many woodpeckers will use the dying trees to nest and to forage. As trees die, insects and detritivores begin to break down the cellulose and lignin within the tree. The increase in food availability for the insects results in an increase of food for woodpeckers as well. Lindell et al. (2008) found that woodpecker foraging was directly related to the density of EAB found within the infected tree. This increased foraging by woodpeckers could positively affect the secondary cavity nesters that will find and occupy abandoned cavities. Woodpeckers will create cavities in trees and use them for one season, abandoning the cavity post breeding. Once abandoned, species will take over the cavity and use it for additional breeding purposes. These species are referred to as secondary cavity nesters. Examples of secondary cavity nesters include chickadees, tufted titmice, eastern bluebirds, and wood ducks (Santiago and Rodewald 2007).

Deadwood benefits not only woodpeckers and cavity nesters, but it can benefit amphibians, reptiles, invertebrates, and decomposers (Bolen and Robinson 1995). Observations found that tip-up mounds, created by fallen dead trees, produced vernal pools of water in the spring. These areas of moist soil and standing water are an important habitat for frogs and salamanders. Decomposers will recycle the deadwood and return some of the nutrients back into the ground. The constant recycling of nutrients is important for future generations of plants that need, for example, nitrogen or phosphorus to grow.

Trees are an important aspect of the environment by providing clean air and water. Trees are a cheap and easy way to remove smog and pollutants from the atmosphere. Without trees, the amount of pollutant in the air increases and can lead to increased cases of cardiovascular and lower-respiratory diseases (Donovan et al. 2013). As the succession of the borer moved from Detroit to the southern states, human mortality increased in cities with EAB outbreaks. This result suggests that trees play an important role in the natural environment by providing organisms, especially humans, with clean air to breathe.

Treefall gaps are formed when a standing tree is removed from the canopy, by weather or death, and leaves an open space in which light can penetrate. Ash mortality leads to the production of multiple treefall gaps. These gaps are the main mode of disturbance in woods and occur at an average rate of 1% of the total land area per year (Runkle 1982; Runkle 1985). Gaps in the forest canopy increase light availability and alter the understory species composition. These short periods of relatively rapid change set the stage for forest succession. The factors determining the structure and composition of mesic hardwood forest communities are determined in these short periods of rapid change. These short periods were termed the gap phase in the forest turnover cycle (Watt 1947; Bray 1956; Runkle 1984).

Tree species have varying tolerances for shade. For example, *Acer saccharum* (sugar maple) is dominant in the understory of many forests in the Midwest due to its tolerance of low light on the forest floor. In a five year study of a beech-sugar maple forest in northeast Ohio, the relative basal area and density of beech trees decreased, whereas sugar maple basal area and density increased (Forrester and Runkle 2000).

The removal of ash would drastically change the available light on the forest floor. Gaps can be created by the death of a single branch producing a small gap in the canopy. EAB infestation kills entire trees potentially creating enormous canopy gaps where several canopy ash were found clustered together. Ash species are important throughout forested areas in Ohio. Ramey and Runkle (1992) found *Fraxinus americana* in all 17 woodlots studied in Greene County, Ohio; it had the highest species importance rating with a value of 13.4%. In the same study, *Acer saccharum* was the second most important species with a value of 12.6%. The large number of ash present in Ohio's forests would create multiple canopy gaps causing a possible shift in understory and converting the overstory species composition from shade tolerant species to more shade intolerant species.

Studies have shown that the formation of a gap may lead to additional gaps created nearby. It is uncertain whether trees near gaps have a higher mortality rate than trees not near gaps or if it is because each gap has several tree neighbors and the odds are high that one of them will die by chance within a few years of the initial gap formation. Runkle (1984) studied 36 gaps between 1977 and 1981 and found that trees bordering the gap were dead or dying in 11 of the cases. Four cases showed the formation of a new gap and 3 cases found evidence of branch deterioration or death. The neighboring or border trees were dying at the same rate (1% a year) as the canopy tree species.

Gap creation affects not only woody plants but can also have effects on herbaceous understory plants. Ash trees are one of the last trees to leaf out in the spring, which makes it an important species for insects that feed only on ash leaves (Meo 2012). The bigger concern will be for the spring flowers that require an adequate amount of sunlight to reach the forest floor. Flowers found under ash trees are found nowhere else within the landscape. The flowers have adapted to the late leaf out of the ash trees and use the penetrating light for growth and survival (Meo 2012). Losing the ash trees will decrease the light available to these flowers in the early spring. Once a gap is formed, nearby trees will increase their growth and fill in the gaps within a short time (Flower et al. 2013). The following spring, with the absence of ash, the rare flowers would no longer have the necessary light and die.

This is not the first case in which an entire population of trees was at risk for removal. Numerous diseases and insects have posed similar threats. Some of the most devastating include the American chestnut blight (Gilland et al. 2012, Schlarbaum et al. 1998), beech bark disease (Garnas et al. 2011), gypsy moth (Fajvan et al. 2012), sudden oak death (O'Brien et al. 2002), and the Dutch elm disease (Schlarbaum et al. 1998). Forest composition and dynamics were greatly altered during these times of rapid change.

Invasive species are a normal sight in today's landscape. The increasing human population, faster movement of materials around the world, and global warming have made it possible for invasives to travel large distances in short time periods. *Lonicera maackii,* or bush honeysuckle, is very common and dense throughout the Dayton area. Originally introduced as an ornamental bush in gardens, honeysuckle has now rapidly spread throughout the area. Honeysuckle can leaf out early in the spring and stay green late into the fall which threatens native species, unable to compete (ODNR 2013). Plants are also responding to the changing climate and moving their geographic distribution northward, following the trend of a warming climate. Humans have drastically changed the landscape and the effects of the emerald ash borer will begin to emerge in the coming years. It is important to learn and adapt to these changes to avoid large scale changes in the future. The world is a valuable resource and without the proper care and maintenance, important species and habitats will be lost. The landscape, species, and interactions of the future are unknown, but it is important to learn all we can about the current situation in the present time.

<u>BENEFITS AND SPECIAL USES OF ASH (*FRAXINUS)* SPECIES</u>

Ash trees are widely distributed throughout the Eastern and Midwest United States and therefore have been incorporated into many products ranging from furniture to baseball bats. The strong and shock resistant wood has many uses. White ash is the most abundant, ranging 21-24 meters (70-80 feet) in height and up to 0.9 meter (3 feet) in diameter. White ash is highly resistant to shock and can be used in handles, oars, and baseball bats (Burns and Honkala 1990). The seeds provide food for a variety of birds and small animals including wood ducks, bob whites, purple finches, pine grosbeaks, and fox squirrels. White ash has also been found to be a snake bite preventative (Burns and Honkala 1990). Green ash is similar to white in that it is highly resistant to shock and bending (Burns and Honkala 1990). Green ash is widely used in tool handles and occasionally in baseball bats. The seeds are an important food source for game and nongame birds. Black ash is a slow growing tree which produces wood that is easily split. Black ash is commonly used in pack baskets constructed by the Indians of the Northeast (Harlow et al. 1979). The seeds are eaten by a variety of game birds, song birds, and small animals. Pumpkin ash produces a high quality factory lumber and is used for doors, moldings, or frames. Wood ducks also rely on the pumpkin ash seeds for food and nutrition. Blue ash is scattered throughout the Midwest and was planted in the prairie region (Harlow et al. 1979). The inner bark, when exposed to air, turns a blue color and was used by the pioneers as a dye for clothing (Harlow et al. 1979). The decline in ash populations will have an impact on multiple manufacturing companies, possibly costing them a lot of money. The Animal and Plant Health Inspection Service (APHIS), part of the U.S. Department of Agriculture, has spent nearly $30 million annually since 2008 (Kovacs et al. 2011). Kovacs et al. (2011) and the National Forest Service (NFS) estimates that by 2020, the total economic cost of the EAB could be over $12 billion. This figure covers 25 states and includes the treatment, removal, and replacement of more than 17 million ash trees. Alternative wood sources may need to be used if the entire ash population is destroyed.

ASH SPECIES AND ASSOCIATED FOREST COVER

Ash species are found in a variety of landscapes ranging from moist, wet soils to dry, upland soils. The present study focuses on five ash species typically found in the southwestern part of Ohio. Over the years, each of the five ash species has evolved to occupy a different environmental space, or niche. A niche is the space occupied by a species in the community and can vary in soil moisture, light availability, and soil pH among other factors (Gause 1934, Dice 1952, Whittaker et al. 1973). Not only do ash species adapt to these variables but all tree species follow similar patterns of organization. For example, sugar maple is a shade tolerant species and will develop under low levels of light. Box elder and cottonwood are typically found on wetter sites.

Species can be grouped or associated with other species based on these qualities and adaptations.

Every tree species adapts to a specific area to avoid competition and increase its chances of survival. Understory trees typically are more shade tolerant than canopy trees (Canham 1989). As light enters the forest, canopy trees will capture most of the light, with only a fraction of that light reaching the understory. Understory stems require less light to survive and will thrive in the low light environment (Burns and Honkala 1990). Certain species of trees will adapt to similar environmental conditions and are grouped accordingly. Species that require little light are found together in the understory and species with similar water needs or tolerances are also found in similar geographic locations. The associated forest cover is the term given to trees with similar traits and characteristics.

Over time, ash species have evolved to require varying degrees of moisture and light. The five species of interest are green ash, blue ash, white ash, pumpkin ash, and black ash. These species are found in slightly different habitats, leading to associations with a wide range of species. Moisture levels can be determined by an integrated moisture index (IMI) that incorporates topographical features and soil (Iverson et al. 1997). Varying degrees of moisture can be associated with different ash species. Light levels increase as ash species die, leaving only the “skeleton” or the dead twigs and branches. The decrease in leaf number allows for more light to penetrate the understory.

Green ash is the most widely distributed ash and is naturally found in moist bottomlands or stream banks (Wright 1959). Since green ash covers the most geographical space, it is also the most hardy and adaptable species and can be found in multiple soil types and moisture levels. Green ash is tolerant of salt, flooding, drought (Mueli and Shirley 1937), and basic soils (McComb 1949) which makes it a good candidate for reclamation projects. Typically, green ash is found in wet sites but found less frequently in swampy areas. It will remain healthy if it is flooded for less than 40% of the growing season. Associated species include boxelder, sweetgum, sycamore, elm, cottonwood, red maple, and sugar maple (Burns and Honkala 1990).

Blue ash shows a scattered pattern among the forests in Ohio. Mainly found in the dry limestone uplands, it is less frequent than white ash. Associated species include oaks, hickories, and the eastern redbud (Harlow et al. 1979, Harlow et al. 1991).

White ash is the most abundant species and is found in rich, moist, upland sites with moderately drained soil. White ash is found in such high numbers due to its ability to adapt to various soil types and conditions. Although it is highly adaptable, white ash has a demanding soil fertility and moisture requirement (Burns and Honkala 1990). Topography plays a major role in the distribution of white ash, limiting it to lower and middle slopes. Rarely will it be found on the valley bottoms due to frequent flooding.

Associated species include basswood, yellow poplar, black cherry, American beech, oaks, hickories, maples, and elm.

Black and pumpkin ash are found in similar sites, where drainage is poor and soil moisture is high (Burns and Honkala 1990). Both can be found in swampy bottomlands, bogs, or along streams that occasionally flood. Possible sites vary from wet to very wet and can include areas with standing water. Black ash is intolerant of shading whereas pumpkin ash can withstand low light levels. Black ash is associated with elm and maple, whereas pumpkin ash is associated with bald cypress, tupelo, maples, and other swampy species. Pumpkin ash is considered rare in Ohio and was discovered in Montgomery County in 1986 by Stine, which was the first report in 55 years (McCormac et al. 1995). It prefers hydric (saturated, wet) sites, growing in swampy areas.

EAB TREATMENT

PESTICIDE OPTIONS

Ash populations rapidly decline following the infestation from the EAB. However, some methods, both biological and chemical, can reduce the impact of the borer and possibly spare some tree deaths. The following summarizes some options for chemically treating trees. Rebek et al. (2008) developed a method to reduce the mortality in ash by applying imidacloprid (toxic to EAB) to the bark of infected trees. Imidacloprid is the active ingredient in most commercial-use insecticides. A study at Michigan State University used Imicide® to treat for larval infestation on ash and showed that larval densities were reduced by 60-96 percent when compared to untreated controls (Herms et al. 2009). Timing is very important when treating infected ash trees. For example, a tree that is heavily infested showing signs of canopy dieback may not respond to the insecticide. The general rule of thumb is that if the tree has lost more than 50 percent of its canopy, then it is probably too late to save the tree. Trees must be healthy enough to transport the insecticide throughout the branches, roots, and leaves. EAB feeds on the phloem tissue and a tree's health (amount of phloem remaining) is vital to the functioning and transport of the insecticide treatment. Studies have shown that applying insecticides early to healthy trees is the best option for survival (Herms et al. 2009).

EAB infestation can be very difficult to detect. The beetle attacks ash species from the top down and signs of infestation are not evident until the tree is severely injured. Signs of ash decline include epicormic shoots, canopy dieback, bark splitting, and even an increase in woodpecker activity (Lindell et al. 2008). Another sign of infestation is the presence of D-shaped exit holes left by the emerging adults. Since adults start feeding near the canopy, the exit holes are not visible until there has been a sufficient amount of time for the larvae to make their way to the base of the tree. At this time the tree is stressed and in poor health. A tree will usually die within two to three years of the initial attack (Liu et al. 2003).

A wide range of insecticide brands target EAB. Insecticides can be grouped into four main categories; based on the method of application. Treatments can be applied 1) directly to the soil or a drench, 2) as trunk injections using a needle and syringe, 3) as a lower trunk spray, or 4) as an entire cover spray (trunk, main branches, and foliage) (Herms et al. 2009). Table 1 below (modified from Herms et al. 2009) shows insecticide options with active ingredients and the methods of application. Most insecticide options are professional use products except Bayer Advanced Tree and Shrub Insect Control. Bayer Advanced is the soil drench method with the active ingredient, imidacloprid, used in most insecticides.

Table 1: Insecticide options for EAB, active ingredients, application methods, and the recommended timing for each. Included are both professional use products and homeowner formulations.

Insecticide	Active Ingredient	Application Method	Recommended Timing
Professional Use Products			
Merit®	Imidacloprid	Soil/drench injection	Mid-fall and/or mid- to late spring
Xytect®	Imidacloprid		
IMA-jet®	Imidacloprid	Trunk injection	Early May to mid-June
Imicide®	Imidacloprid		
TREE-äge™	Emamectin Benzoate		
Inject-A-Cide B®	Bidrin®		
Safari™	Dinotefuran	Bark spray	Early May to mid-June
Astro®	Permethrin	Cover spray	2 applications at 4-week intervals; first spray in early May (Ohio) to early June (Michigan)
Onyx®	Bifenthrin		
Tempo®	Cyfluthrin		
Sevin®	Carbaryl		
Homeowner Formulation			
Bayer Advanced™ Tree and Shrub Insect Control	Imidacloprid	Soil drench	Mid-fall or mid- to late spring

Table modified from Herms et al. 2009 and shows treatments options for EAB with active ingredients. Timing will depend on location and seasonal variations. Tree-äge was used in the Dayton Metroparks system.

Insecticide treatments are very inconsistent among most types of application. Effective uptake varies among sites, application type, dosage, weather, and other similar factors. Insecticides can even produce various results in the same location (Herms et al. 2009). The only insecticide with consistent results is Tree:äge, which is the only brand using the active ingredient emamectin benzoate. Tree:äge has been found to reduce larvae densities (68-132/m^2 to 0.2/m^2) by more than 99% (Herms et al. 2009). Not only does it provide consistent results but a single injection can last two, possibly three years after the initial injection. Adjacent, untreated trees remain infested with hundreds of larvae present (Herms et al. 2009). Five Rivers MetroParks (the study area) used Tree:äge to treat more than 500 trees in 17 parks in the Dayton area.

BIOLOGICAL CONTROL

Biological control (biocontrol) is removing or reducing the population of invasive organisms by means of other living organisms. In most cases, the control is achieved by predators attacking and killing prey. The prey can be either flora or fauna, both of which may have effects on the local environment. Biological control has been used in multiple instances and is shown to be effective. It has been successful in the gypsy moth, long horned borer, purple loosestrife, Klamath weed, and is currently being used to mitigate the effects of the emerald ash borer on ash trees (USDA-APHIS 2012). Emerald ash borers in their native range of Asia do not cause life threatening harm to local trees. Trees have adapted defenses to ward off and kill potential predators. Asia is also home to native species of wasps which attack and feed on the larvae of emerald ash borers, keeping the populations in check. Three species of wasps are approved to be released in the United States as a form of biocontrol (USDA-APHIS 2012). The three wasp species are native to Asia: *Oobius agrili, Spathius agrili*, and *Tetrastichus planipennisi*. These listed species attacks the EAB in different ways, which could possibly aid in reducing the population of the emerald ash borer to manageable numbers.

Oobius agrili targets the egg and can parasitize up to 60% of eggs by searching the bark and laying its own egg within the host egg (Bauer et al. 2011). Each *Oobius* adult can kill on average about 80 emerald ash borer eggs over its lifetime with peak parasitism in July and August (USDA APHIS 2012; Bauer et al. 2011). *Spathius agrili* is a larval ectoparasitoid, laying its egg on the outside of its host. Generally, *Spathius* adults can parasitize 40-50% of larvae and can parasitize nearly 90% of larvae in some instances (USDA APHIS 2012). Newly emerging young feed on EAB larva and emerge as adults in the summer months. *Tetrastichus planipennisi* is similar in life history to *Spathius agrili* in that they both attack the larval stage of the emerald ash borer. The difference is that *Tetrastichus* adults lay their eggs within the larvae and kill it from the inside out, rather than from the outside in. *Tetrastichus* adults can parasitize up to 50% of hosts, with one EAB egg producing approximately 130 *Tetrastichus* adults (USDA APHIS 2012). The varying life histories of the three parasitoids native to China give a wide range of defense against the emerald ash borer, targeting both the egg and the larvae. As of February 2012, a facility in Brighton, Michigan has released over 440,000 EAB parasitoids in multiple states (USDA APHIS 2012). The reduction in the EAB population is important to slow the spread and possibly control the infestations in the future. It may take multiple years for the parasitoid wasps to become established and make any sort of noticeable impact on the numbers of borers present.

TREE SPECIES COMMUNITIES BASED ON TOPOGRAPHY AND DISTURBANCE

Species compositions are structured by topography and its surrounding micro-climate. The term micro-climate was first used by Geiger (1950) to describe the local climate; or the area two meters above the soil. This microclimate has varying degrees of sun, shade, wind, humidity, and moisture, which all play a role in the species communities. Baldeck et al. (2013) showed that environmental variables (like the ones stated above) structure species community and composition which explained 13-39 percent of the variation within a plot. Topography, the study of the slope and contour of the land, goes hand-in-hand with microclimate. During the course of a day, southern facing slopes will receive more sun than northern facing slopes. Depressions in the ground will receive more moisture than hilltops. Topography directly impacts the micro-climate resulting in varying degrees of soil moistures and light levels.

Many other factors also play a role in species communities which include: land use history (Zimmerman and Runkle 2010; Christensen 1989), deer browse (Rooney 2001), invasives and disease (Runkle 2007), and natural death of tree species. Disturbances vary on a temporal scale, with some disturbances happening very quickly and others taking years. For example, a fire would move through an area and destroy the biomass of a tree very quickly, but the emerald ash borer takes about three years to completely kill an ash tree. These disturbances change the tree species communities.

STUDY OBJECTIVES

The main objective of this study was to predict the likely successors of ash species and to quantify the vegetation associated with ash canopy individuals by showing how plots vary with ash species and topographic position. Ash populations are decreasing and this may be the last time to perform such a study. Kathleen Knight (2010, 2010b) from the United States Forest Service is examining highly infested sites and predicting possible outcomes due to EAB outbreaks. This study will expand on Knight’s research by sampling a new region located in the Dayton area (Knight’s was done in the Huron River Watershed of Southeast Michigan) that has not yet been hit by the EAB. This study will also incorporate a geospatial variable (i.e. topographical moisture index) by combining multiple layers of data in the ArcGIS program.

The following are the specific questions I will be asking to address the main objective of the study:

What species will replace ash?

How does the replacement species vary with ash species and topography?

How does the understory differ under various ash species as related to topography?

II. MATERIALS AND METHODS

STUDY AREA

The study was conducted in Montgomery and Greene Counties, Ohio, at various parks within the Dayton Five Rivers MetroParks system. Both Montgomery and Greene County are located in a moderate climate with large fluctuations in the seasonal temperatures. Dayton, Ohio, summer temperatures are fairly hot and humid with average high temperatures near 23^{o}C in July based on records from 1965-2013 (Weatherbase 2013). Ohio winter temperatures are cold with average low temperatures near -7^{o}C in January (1965-2013). Ohio is typically flat on the western half of the state and gradually moves to gently rolling hills on the eastern side approaching the foothills of the Appalachians. The average annual precipitation (1965-2013) for Dayton, Ohio, is 940 millimeters with a peak of 90 millimeters/month from April to July (Weatherbase 2013). The parks studied were Carriage Hill, Englewood, Huffman and Taylorsville MetroParks which are all located in the southern half of the state near Dayton.

SITE SELECTION AND DESCRIPTION

Parks were selected based on treated ash species present in each park. Treated ash species were irrelevant to the immediate study but will be of more importance in follow-up studies. Sampling treated and untreated trees allows me to answer the future question: Does ash treatment keep trees alive and does it affect understory composition? The current study focused on the comparison of various species of ash and their understory composition; therefore, each park was selected based on a sufficient amount of treated trees for each ash species. Ash species found in the area are white, green, blue, black, and pumpkin ash. Table 2 shows the 17 parks managed by the Five Rivers MetroParks and the corresponding number of treated ash trees for each species that are found in that park.

Table 2: Treated ash species and parks

Treated Ash by Species and Park					
	White	Green	Blue	Black	Pmpk
Carriage Hill	19	17	1	0	0
Englewood	26	5	15	8	6
Huffman	3	23	0	0	0
Taylorsville	27	3	17	0	0
Aullwood	2	0	4	0	0
Cox Arbor.	18	4	8	0	0
DWCA	10	2	0	0	3*
Eastwood	11	1	0	0	0
Germant.	70	1	6	0	0
Hills & Dales	27	4	40	2	0
Island	5	10	0	0	0
Possum Cr.	0	7	0	0	0
Sugarcreek	2	0	0	0	0
Sunrise	14	11	10	0	0
SWCA	12	0	8	0	0
Twin Creek	31	7	2	2	0
Wesleyan	19	23	1	0	0

The table shows the number of treated species of ash in each park. The trees were treated with an injected insecticide called Tree:age. The first four parks listed are the parks chosen for this study which include: Carriage Hill, Englewood, Huffman, and Taylorsville Metroparks. *Not a confirmed identification.

Carriage Hill was chosen for its number of white and green ash with 19 and 17 treated trees respectively. Carriage Hill was established in 1968 and consists of 900 acres (364 ha) including some woodlands, a prairie, pond, and a 14-acre (6 ha) lake. Englewood had a high number of white and blue ash (26 and 15 respectively). Englewood is one of the largest parks consisting of 1,900 acres (769 ha). Englewood is home to a river, lake, woods, and some wetlands. Part of the park is a reclaimed gravel quarry. The park was established in 1967. Englewood was unique in that it was the only park to contain pumpkin ash and had the highest number of treated black ash. Huffman Park consists of a dam, river, and a lake with the most common species found consisting of green ash with 23 total trees treated. Taylorsville runs along the Miami River corridor and is very diverse containing a wide range of habitats. Some habitats include old-growth forest, second-growth forest, a pine stand, and extensive floodplains. Taylorsville contained 27 white and 17 blue ash among the various sections of the park.

All the parks were located in Montgomery County except for Huffman, which was located in Greene County. The farthest any two parks are located from each other is approximately 11 miles. Taylorsville and Carriage Hill were closest in proximity at about 4 miles. The Five Rivers MetroParks are treating over 550 ash trees of various species including black, blue, white, green, and pumpkin ash. The parks chosen contain 31% (170/550) of all treated trees which gives a good representation of the total population. The close proximity and high number of different ash species in each of the parks allowed me to dismiss the idea of confounding parks and topography. Topography tends to be a strong driving force in species arrangements and the specific park has little influence on the species found at that location. For example, Englewood has pumpkin ash and black ash, not because of the park, but because of the topography. The topography is causing wet areas that favor the growth of black and pumpkin ash, and not for some reason other than topography.

SAMPLING PROTOCOL

Ash-centered plots were chosen based on the following criteria: 1) Center tree must be an ash with its leaves in full sun (canopy tree). 2) Center tree has been tagged with a GPS coordinate and was treated by the Dayton Metroparks using the insecticide, Tree:age. 3) The central ash species must be healthy and still bearing leaves.

After selecting an ash tree, I measured the diameter at breast height (DBH, 137cm) and recorded the species, tag number, and the distance to the nearest canopy tree. The species and DBH of the nearest canopy tree also were recorded. A five meter radius around the central ash tree (~80m^2) marked the boundaries of the plot. The species and DBH of all woody vegetation >137cm in height that lie within the plot were recorded. For plants that contain multiple stems, such as a shrub cluster (i.e. honeysuckle or spicebush), DBH was measured for just the largest stem. A forestry tape measure was used to find the DBH of large trees and calipers were used to find the diameter of small-sized trees.

After measuring the treated center tree, a nearby untreated tree of the same species was found. The untreated tree must: 1) Be of the same species as the center ash, 2) located within a 100 meter distance of the center tree, 3) located in the canopy, and 4) its plot must not overlap with the treated trees plot. The same procedure was done for untreated trees as for the treated. The species and DBH of the untreated center were recorded as well as the size and species of all woody vegetation within the

5m radius. If an untreated tree of the same species could be found within the 100m, then the nearest tree was found.

SPECIES REPLACEMENT

Predicting the replacement of ash was done in three ways. First, I used the relative importance of the understory species based on relative percentages of density, basal area, and frequency. Relative importance was found for each woody species under central ash species (white, green, blue, black, and pumpkin) and for all plots combined by taking the average of all three relative percentages. Relative importance is a good indicator of replacement species and was used in a study on gap regeneration in old-growth forests located in the eastern United States (Runkle 1981). The tree with the highest relative importance value will be the best indicator of replacement species following ash tree death. Second, the biggest stem is also a good indicator of replacement species and has been used in multiple studies (Runkle 1981; Spaulding and Rieske 2011). Each plot will contain a record of species and size within the plots. Replacement may vary with different species of ash and topography. I used correlations and ANOVA to determine significant differences between locations and topography. Third, the canopy species nearest each ash will benefit from ash death. The nearest neighbor tree was the closest canopy tree to the center ash species. A good indicator of replacement may be the nearest canopy tree to the newly formed gap. After the removal of an ash, the canopy trees will begin to grow and fill in the void left by the dying tree.

INTEGRATED MOISTURE INDEX MAPS

Topographical maps were taken from the National Elevation Dataset (NED) collected and compiled by the United States Geological Survey (USGS). Maps were downloaded by a specified area (MetroPark study sites) with a 1/9 arc second resolution. 1/9 arc second corresponds to a 3 meter resolution in the real landscape. The USGS uses various techniques in collecting the data, depending on the resolution needed. Digital Elevation Models (DEMs) are used in low resolution (10-30m) maps whereas higher resolution (3-9m) maps are created from light detection and ranging (LIDAR), interferometric synthetic aperture radar (IFSAR), and high-resolution imagery (USGS 2013).

The program ArcGIS, or Arc Geographic Information System, was used to perform various algorithms on the topography map to produce multiple overlays. GIS allows for multiple layers (or maps) to be “stacked” on top of one another. Data can be extracted from points from each of the resulting maps. Maps are gridded with cells, with each cell of the map containing some form of identifier or numerical value. More cells within a map results in a greater capacity to create high resolution outputs. The Spatial Analyst package within ArcGIS was used to manipulate the topography map, building three separate maps. The three resulting maps created from the 1/9 arc second topography map are: hillshade, flow accumulation, and curvature. The map build procedure was taken from Iverson et al. (1997), where they looked at IMI and its relationship to forest productivity and composition

Hillshade accounts for the location of the sun throughout the entire day. Hills or slopes in the landscape provide shade to adjacent areas. These shaded areas receive less solar radiation and are less vulnerable to drying conditions. The sun rises on the east and sets in the west. Therefore, maximum radiation will occur on steep, southern facing slopes that are directly toward the sun (Lee and Baumgartner 1966). The hillshade command (spatial analyst -> surface -> hillshade) in ArcGIS was used to run an algorithm on the slopes with respect to the sun to determine the amount of shade. The default solar azimuth was set to 315 degrees with a solar altitude of 45 degrees, which was the approximate solar altitude at growing season (Iverson et al. 1997). Increased levels of moisture are found in areas with limited solar radiation. The resulting map will have continuous values for moisture in each cell of the raster map.

Flow accumulation tracks the flow of water as it falls on the earth. If a theoretical drop was to be placed on the landscape, it follows its path down slopes due to gravity. At the bottom of a valley or slope, water tends to accumulate, increasing the amount of moisture in that given area. Flow accumulation is calculated in ArcGIS in two steps by first creating an intermediate map that calculates the direction of flow. Flow accumulation then counts the number of cells, in the raster map, that are sending water down and determines the final destination of the water. It was assumed that each cell of the map contained the same surface type and therefore had equal affinity to surface flow. Flow accumulation was created using the spatial analyst package (spatial analyst -> hydrology -> flow direction/flow accumulation) and the 1/9 arc second topography map. The initial map build created a map of flow direction. The flow direction map was then used to produce the flow accumulation output map. This map depicts areas of high water (i.e. slope bottoms) and areas of little water (i.e. ridge tops). Moisture values are continuous across all raster cells.

Curvature is the measure of the shape of the land (i.e. whether it is flat, concave, or convex) due to knolls or depressions. Curvature is calculated using from the 1/9 arc second topography map using the curvature function (spatial analyst -> surface -> curvature). Curvature looks at each raster on the map and finds areas of concavity. These low points or depressions in the landscape tend to collect water, resulting in higher moisture. Therefore, depressions will receive a higher score in the resulting map.

The soil series map was the final map used in the creation of the Integrated Moisture Index, collected and compiled by the United States Department of Agriculture through the Natural Resources Conservation Service (NRCS). Maps were downloaded by county (Greene and Montgomery) using the Web Soil Survey (WSS) tool. Soil surveys give information on the type, location, depth, productivity, and even water holding capacity of the soil (among many other properties). Data are stored in the Soil Survey Geographic Database, also known as SSURGO. Soil maps show boundaries separating each type of soil in the landscape. These boundaries are called map units (USDA-NCRS). Information can be displayed in two ways: either by tables or maps. In order to use the two in conjunction with one another, they must be associated. For example, each soil type corresponds to a specific water holding capacity. Microsoft Excel 2010 was used to associate the water holding capacity (numerical) with the soil type (categorical). An Excel spreadsheet was created with one column containing categorical data and another column with numerical (water holding capacity) data. ArcGIS was used to associate the two using the function called "Joins and Relates." This allowed for the Excel sheet to be joined to the map containing the soil boundaries in ArcGIS. The ratings (water holding capacity values) were automatically filled in for each soil unit on the map.

ArcGIS was used to create a water-holding capacity map, with each map unit corresponding to some continuous value for the maximum amount of water capable of being contained within the soil. This map is an intermediate step since it is in feature format. The feature map contains polygons that must be converted to raster type to allow for point extraction later and to match the raster types of the previous maps. ArcGIS has conversion tools built for transforming data between feature and raster types (Conversion tools -> to raster -> feature to raster). When converting to a raster map, ArcGIS requires a specific resolution to be set. Varying degrees of resolution are possible during this step and will affect the accuracy and clarity of the map. Depending on the situation, accuracy/resolution may not be the number one priority. In this case, we chose the highest resolution possible, with a cell size of 1. The higher the cell size, results in low resolution, producing a blocky, low pixelated map. The benefit of choosing low resolution is to save time and disk space. Because we chose to use the highest degree of resolution, the processing time took about 2.5 hours for the algorithm to finish. It is important to have a sufficient amount of space on the hard drive or the algorithm may be susceptible to a crash. The resulting map yielded a high resolution map with smooth lines clearly depicting soil type boundaries.

INTEGRATED MOISTURE INDEX MAP CREATION

Curvature, hillshade, flow accumulation, and water holding capacity maps were used to build the Integrated Moisture Index (IMI) map. All maps were created using different variables and therefore resulting in a wide range of values. Each map was rescaled to produce a range from 0-100. This allowed for the maps to be combined and made it easier for comparisons among parks and plots. The rescaling procedure was done using the spatial analyst tool in ArcGIS (spatial analyst -> map algebra), according to the following equation:

("dataset name" – old lowest value) * new upper value / (old upper value – old lowest value) + new lowest value

In this case, the "new highest value" was 100 and the "new lowest value" was 0. Therefore, the final range for each of the variables (i.e. hillshade, curvature, etc.) was 0-100. Map algebra was again used to create the final IMI map. The created maps were weighted based on the importance to productivity and composition. Weighted percentages came from on-site visits and field experience calculated by Iverson et al. (1997). The IMI was built according to the expression:

("hillshade" * 0.4) + ("flow accumulation" * 0.3) + ("curvature" * 0.1) + ("total water holding capacity" * 0.2) as in Iverson et al. (1997).

ANALYTICAL PROCEDURES

SAS 9.3 and Excel 2010 are computer software programs with built in statistical packages to analyze large data sets. The field measurements included DBH and species, whereas the calculated data were the IMI values. Excel was used to organize data in a spreadsheet and do simple calculations for finding basal area, density, and frequency. The "PivotTable" tool allowed for easy manipulation and reorganization of the large dataset. Spreadsheets were made and imported into SAS and PC-ORD (described below). ArcGIS was used to create an integrated moisture index (IMI) map for each plot.

IMI ranges were analyzed using an ANOVA with Tukey's in SAS. Relative percentages of basal area, density, and frequency were used to calculate the importance value for each understory species in all plots and for each central ash species. Overall importance can be calculated in two ways: 1) finding the averages of all three (basal area, density, and frequency) relative percentages or 2) average of relative basal area and relative density. In this case, all three values were used (figure 1) to find importance of the most dominant species. Overall importance was found for each ash species using the three relative percentages and for statistical comparisons using basal area and density.

PC-ORD 6 (McCune and Mefford 2011) was used to show the results graphically on a two-dimensional space. Two types of correspondence analyses were performed: detrended correspondence analysis (DCA; Hill and Gauch 1980) and nonmetric multidimensional scaling (NMS). The NMS techniques and methods were first developed by Shepard (1962) and refined by Kruskal (1964). Ordination takes multiple dimensions and simplifies them to the best fit structure. An Ordination matrix of 52 species and 137 plots was used to conduct both the DCA and the NMS procedures and were analyzed using an ANOVA.

DCA uses the correspondence approach and detrends the data to fit a linear model. The basic steps are outlined in McCune and Grace (2002). The steps are as followed: solve the eigenanalysis, detrend data, and rescale. Detrending data is accomplished by dividing the axis into separate sections and using the second axis to adjust the mean scores of each section to zero. Rescaling is based on within-section variations and the section width is adjusted accordingly. The built in algorithm of DCA arranges both species and plots along axes of gradually changing composition with related species/plots close in proximity to one another.

NMS is more powerful and refined than DCA due to its ability to decipher a wider range of possible structures within the data matrix (Clarke 1993). NMS is well suited for non-normal data or discontinuous data (McCune et al. 2002) and has many advantages. It accurately performs on simulated data with high beta diversity (differences in community composition); it avoids linear relationship assumption; and it relieves the “zero-truncation” problem. These advantages make it a good technique in the ordination of community ecology. The steps are complex and can be found in McCune et al. (2002), which walks through the basic procedure. NMS searches for the best location to plot the species with the least amount of stress (departure from monotonicity). NMS uses multiple iterations to find the lowest possible scores. Iterations can be envisioned as a paratrooper being dropped on a landscape and that individual will move to the lowest point based on local information. This results in a local minimum. The global minimum is found by doing multiple iterations (dropping multiple paratroopers on random areas in the landscape). Both ordinations worked well for the particular data set. DCA adequately separated the five ash species and was therefore used in later analyses.

Correlations coefficient were found using the ordination scores from both axes and relating those to variables such as IMI, basal area, DBH, etc. Pearson (based on values) and Spearman (based on ranks of values) correlations were performed in SAS.

Importance values for the most important species were related to ordination scores in SAS. Pearson and Spearman correlations were performed to find any significant differences in successional trends. Significance refers to a value less than or equal to 0.05.

III. RESULTS

A total of 137 plots were sampled in four different MetroParks (Table 3). White ash was sampled the most with 79 plots and Carriage Hill contained the most plots with 51.

Table 3: Summary of plots sampled

	CH[1]	EN[2]	HU[3]	TA[4]	TOTAL
FRAM	42	21	6	10	79
FRPE	8	0	9	7	25
FRQU	1	14	0	9	24
FRNI	0	5	0	0	5
FRPR	0	4	0	0	4
TOTAL	51	44	15	26	137

[1]Carriage Hill MetroPark, [2]Englewood, [3]Huffman, and [4]Taylorsville.

Table 4 below shows all species found in all 137 plots. Species were given abbreviations using the first two letters of the genus and species. Abbreviations (i.e. *Fraxinus americana* = FRAM) will be used throughout the thesis with Table 4 acting as a reference/guide. A total of 47 species were found within the four MetroParks.

Table 4: List of species within the plots. Species are arranged alphabetically by common name. Abbreviations are the first two letters of the genus and species. Species with the same abbreviations such as sugar and silver maple are denoted with numbers

Common	**Abbrev.**	**Genus**	**Species**
Am. Beech	FAGR	Fagus	grandifolia
Am. Sycamore	PLOC	Platanus	occidentalis
American Basswood	TIAM	Tilia	americana
American Elm	ULAM	Ulmus	americana
Bitternut Hickory	CACO	Carya	cordiformis
Black Ash	FRNI	Fraxinus	nigra
Black Cherry	PRSE	Prunus	serotina
Black Gum	NYSY	Nyssa	sylvatica
Black Locust	ROPS	Robinia	pseudoacacia
Black Walnut	JUNI	Juglans	nigra
Blue Ash	FRQU	Fraxinus	quadrangulata
Box Elder	ACNE	Acer	negundo
Burr Oak	QUMA	Quercus	macrocarpa
Common Elderberry	SACA	Sambucus	canadensis
Cottonwood	PODE	Populus	deltoides
Dogwood	COSP	Cornus	species
E. Burning Bush	EUSP	Euonymus	species
Eastern Redbud	CECA	Cercis	canadensis
Green Ash	FRPE	Fraxinus	pennsylvanica
Hackberry	CEOC	Celtis	occidentalis
Hawthorn	CRSP	Crataegus	species
Hickory	CASP	Carya	species
Honey Locust	GLTR	Gleditsia	triacanthos
Honeysuckle	LOMA	Lonicera	maackii
Ironwood/hornbeem	CACA	Carpinus	caroliniana
Mulberry	MOSP	Morus	species
N red Oak	QURU	Quercus	rubra
Black-Haw	VIPR	Viburnum	prunifolium
Oak	QUSP	Quercus	species
Ohio Buckeye	AEGL	Aesculus	glabra
Osage Orange	MAPO	Maclura	pomifera
PawPaw	ASTR	Asimina	triloba
Pin Oak	QUPA	Quercus	palustris
Prickly Ash	XAAM	Xanthoxylum	americanum
Pumpkin Ash	FRPR	Fraxinus	profunda
Red Maple	ACRU	Acer	rubrum
Russian Olive	ELAN	Elaeagnus	angustifolia
Shagbark Hickory	CAOV	Carya	ovata
Shellbark Hickory	CALA	Carya	laciniosa
Silver Maple	ACSA2	Acer	Saccharinum
Spicebush	LIBE	Lindera	benzoin
Sugar Maple	ACSA1	Acer	saccharum
Swamp White Oak	QUBI	Quercus	bicolor
Unknown	UNKN	Unidentified	species
White Ash	FRAM	Fraxinus	americana
White Oak	QUAL	Quercus	alba

RELATIVE IMPORTANCE

Understory composition was analyzed by finding the relative density, relative basal area, and relative frequency of the understory woody species (Fig. 1).

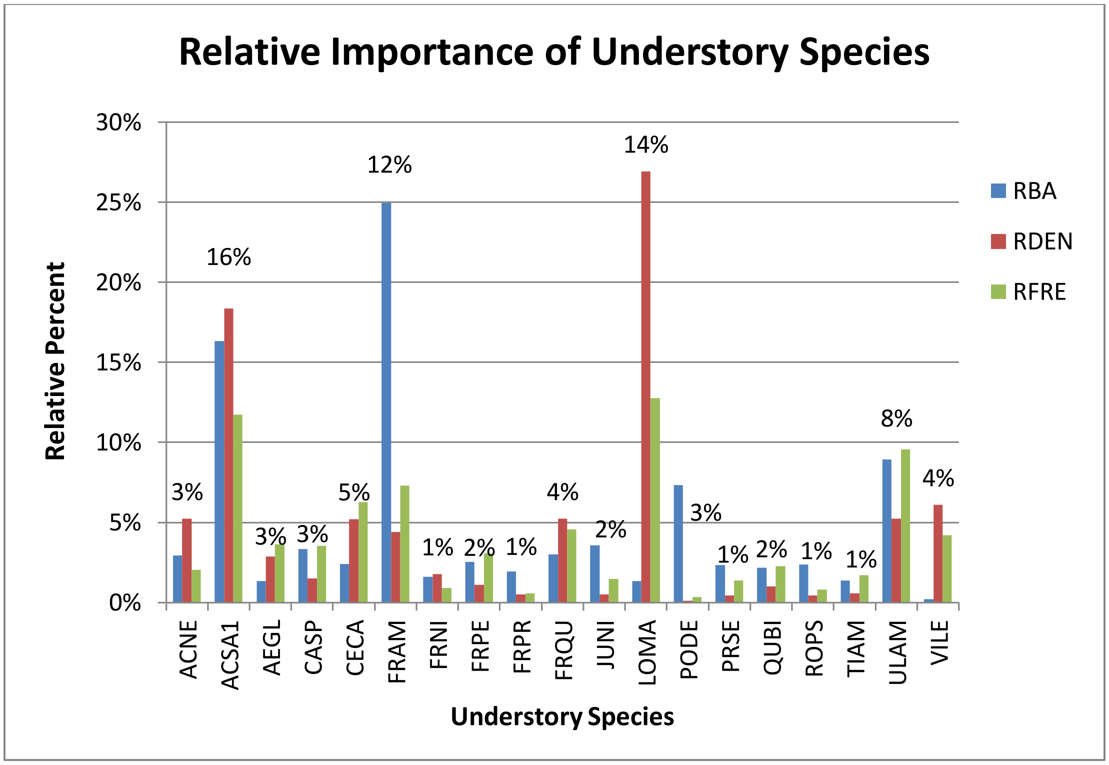


Figure 1: Relative importance of species based on relative density (RDEN), relative basal area (RBA), and relative frequency (RFRE) for species with an overall importance value greater than 1% for all plots. Overall importance values are given above each species in the figure

The most important species was *Acer saccharum* (sugar maple, ACSA1) with a 16% of a possible 100%. Sugar maple did not have the highest value in any of the categories (RBA,RDEN, or RFRE) but was the second most important in all three. Sugar maple had a large basal area, was relatively dense, and found frequently within the plots. The second most important species was *Lonicera maackii* (bush honeysuckle, LOMA) with a 14% relative importance. Bush honeysuckle was the most frequent and dense of all sampled species but had very little basal area. Honeysuckle tends to have many small stems rather than a few large stems. Only the largest stem was sampled for each cluster of honeysuckle which decreases the overall quantity of the relative basal area. The third most important was *Fraxinus americana* (white ash, FRAM) with a 12% relative importance. White ash dominated the relative basal area and accounted for 25% of all sampled species. Other important species included *Ulmus americana* (American elm, ULAM), *Cercis canadensis* (eastern redbud, CECA), *Fraxinus quadrangulata* (blue ash, FRQU), and *Viburnum prunifolium* (black-haw, VIPR). Out of the top 7 most important species, only four are capable of reaching the canopy: sugar maple, white ash, American elm, and blue ash. The other three species contain shorter crown heights, making it nearly impossible to reach crown level height, even in the most ideal situations. Honeysuckle is a bush and only grows in the understory and has no potential to reach the canopy. Honeysuckle does however have the ability to outcompete native species of woody stems. Eastern redbud has an adult height ranging from 8-15m (25 to 50 feet) which is far less than average canopy height (Sullivan 1994). Therefore, eastern redbuds do not have the ability to fill canopy gaps. Black-haw is a tree-like shrub that only reaches heights of 4 meters.

The importance of understory species varied according to the central ash species (Table 5). Sugar maple dominated under most species except for black ash and pumpkin ash which were found in swampy areas. Sugar maple did not grow well in those conditions. American elm also shows high importance, in particular, under blue ash. Honeysuckle appears to be important, and like sugar maple, was common except under the swampy conditions that favored black and pumpkin ash.

ANOVA with Tukey's was used to show significant differences among understory species with respect to the central ash (Table 5). All five ash species were significantly associated with themselves. For example, white ash was found most under white ash and blue ash was found most under blue ash. Ash species may have some tendency to replace themselves as long as EAB does not destroy all trees of reproductive age. Spicebush was one in particular species that was only found in the wetter sites near black and pumpkin ash. This was the same trend for common elderberry; found only under black ash. Ohio buckeye showed strong association with blue ash but not with any of the other ashes. Boxelder was not considered significant but it did show a strong relationship with green ash (13% overall importance). Some of the green ash plots were very dense with boxelder, but were not found very frequently.

Table 5: Importance value under each ash species with relative basal area, relative density, and relative frequency in parenthesis for all plots. Significant values based on the average of relative basal area and density. Asterisks indicate significance and Tukey letters denote similarity between ash species

Importance Value (rba,rden,rfreq in parentheses)					
	FRAM	**FRPE**	**FRQU**	**FRPR**	**FRNI**
Sugar maple	18 (19,23,12)	9 (8,11,10)	17 (22,14,14)	8 (10,5,9)	4 (3,5,4)
Honeysuckle *	13 (1,25,12) [ab]	19 (25,0,17)[c]	17 (2,35,14)[a]	2 (0,4,3) [ab]	4 (0,2,9) [b]
White ash *	16 (33,6,10) [a]	10 (21,3,6) [ab]	3 (6,1,3) [b]	3 (2,4,3) [ab]	12 (27,5,4) [ab]
American elm	8 (8,6,10)	4 (2,4,8)	13 (22,5,11)	6 (2,6,9)	8 (11,5,9)
Eastern redbud	5 (3,6,7)	5 (3,6,5)	4 (1,6,6)	0 (0,0,0)	1 (0,2,2)
Blue ash *	3 (2,4,4) [b]	2 (0,2,3) [b]	11 (12,12,9) [a]	0 (0,0,0) [a b]	3 (2,3,4) [a b]
Black-Haw	4 (0,8,5)	1 (0,1,1)	1 (0,1,1)	7 (0,13,6)	9 (0,14,11)
Boxelder	2 (1,4,1)	13 (13,19,6)	1 (1,0,1)	2 (0,1,3)	1 (0,1,2)
Hickory *	2 (2,1,4) [b]	1 (1,0,2) [b]	0 (0,0,1) [b]	19 (33,11,13)[a]	8 (6,6,11) [a]
Ohio Buckeye *	2 (1,2,4) [a]	0 (0,0,0) [a]	7 (6,8,7) [b]	0 (0,0,0) [ab]	1 (0,1,2) [ab]
Green ash *	1 (1,1,2) [b]	8 (12,3,8) [a]	1 (0,1,2) [b]	0 (0,0,0) [ab]	1 (0,1,2) [ab]
Black walnut	3 (5,1,2)	0 (0,0,0)	0 (0,0,0)	0 (0,0,0)	7 (15,1,4)
Swamp white oak	1 (1,1,2)	0 (0,0,1)	5 (9,2,4)	4 (1,5,6)	3 (1,2,4)
Black ash *	0 (0,0,0) [c]	0 (0,0,0) [c]	0 (0,0,0) [c]	11 (14,11,9) [b]	21 (27,26,9)[a]
American basswood	1 (2,1,2)	2 (0,2,5)	0 (0,0,0)	0 (0,0,0)	2 (2,1,2)
Black locust	2 (4,0,1)	1 (0,1,1)	0 (0,0,0)	0 (0,0,0)	2 (0,4,2)
Pumpkin ash *	0 (0,0,0) [a]	0 (0,0,0) [a]	0 (0,0,0) [a]	22 (37,13,16)[b]	2 (2,2,2) [a]
Pawpaw	0 (0,1,1)	1 (0,1,1)	2 (0,5,1)	0 (0,0,0)	1 (0,1,2)
Spicebush *	0 (0,0,0) [a]	0 (0,0,1) [a]	0 (0,0,0) [a]	11 (0,26,6) [b]	5 (0,12,2) [a]
Common elderberry*	0 (0,1,0) [abc]	0 (0,0,0) [bc]	0 (0,0,0) [bc]	0 (0,0,0) [abc]	4 (0,7,4) [a]
Chinkapin oak *	0 (0,0,0) [b]	0 (0,0,0) [b]	0 (0,0,0) [b]	0 (0,0,0) [b]	2 (3,1,2) [a]

LARGEST STEM

The largest stem can be used to predict likely successors in the forest turnover cycle (Table 6). Sugar maple was found to be the largest stem in 18% of the plots, followed by American elm (7%), boxelder (4%), redbud (4%), black walnut (4%), and American basswood (4%).

Table 6: largest non-ash stem shown as the percent of the total number of plots sampled.

SPECIES	PERCENT
Sugar maple	18%
American elm	7%
Boxelder	4%
Eastern redbud	4%
Black walnut	4%
American basswood	4%
Black cherry	3%
Black locust	3%
Ohio buckeye	2%
Cottonwood	2%
Burr oak	2%
Hickory	1%

Additional species include: Hawthorn (1%), Honey locust (1%), Osage orange (1%), Mulberry (1%), American sycamore (1%), Pin oak (1%), Swamp white oak (1%).

The largest stem can also be broken down by central ash species (Table 7). Excluding the ash species, sugar maple (ACSA1) was the largest species under white and blue ash. Black walnut (JUNI) was the largest under black ash and hickory (CASP) was the largest under pumpkin. The largest stems under green ash were black cherries.

Table 7: The central ash species showing the percentage of the largest species within the plot including ash species.

FRAM	80	FRNI	5	FRPE	24	FRPR	4	FRQU	24
FRAM	40%	FRAM	40%	FRPE	25%	FRPR	50%	ACSA1	29%
ACSA1	20%	FRNI	40%	FRAM	13%	CASP	25%	ULAM	17%
ULAM	6%	JUNI	20%	PRSE	13%	FRNI	25%	FRQU	13%
JUNI	5%			ACNE	8%			QUMA	13%
CECA	4%			ACSA1	8%			AEGL	8%
ROPS	4%			CECA	8%			FRAM	8%
TIAM	4%			PODE	8%			ACNE	4%
ACNE	3%			TIAM	8%			GLTR	4%
FRQU	3%			ROPS	4%			QUBI	4%
				ULAM	4%				

Numbers following ash abbreviations are the total number of plots for each central species. I.e. FRAM (white ash) had 80 total plots. Largest stems >1% are shown.

NEAREST NEIGHBOR

Table 8: Nearest neighbor in all plots combined.

SPECIES	PERCENT
FRAM	35%
ACSA1	12%
FRPE	9%
JUNI	5%
ULAM	5%
FRQU	4%
PODE	4%
PRSE	4%
QUMA	3%
FRNI	2%
FRPR	2%
QUAL	2%
QUBI	2%

Percentages are given as a total of all plots combined. Species found in more than 1% of the plots are shown.

The most common non-ash neighbor is sugar maple which was found to be the nearest neighbor in 12% of the plots (Table 8). Black walnut and American elm were found in 5% of plots followed by cottonwood (4%), black cherry (4%), burr oak (3%), white oak (2%), and swamp white oak (2%). If ash species are included, white ash was found to be the most common neighbor at 35% of plots. Ash species nearest neighbor percentages will be mainly driven by sample size of each species. Since white ash had the most plots, the nearest neighbor was more likely to be white than black for example. The nearest neighbor species incorporated all plots but did not include the same proportion of ash species as the center ash.

Table 9: Nearest neighbor under each ash species

FRAM	**80**	**FRNI**	**5**	**FRPE**	**24**	**FRPR**	**4**	**FRQU**	**24**
FRAM	53%	CAOV	20%	FRPE	46%	FRPR	75%	FRQU	21%
ACSA1	15%	FRAM	20%	FRAM	13%	FRNI	25%	QUMA	17%
JUNI	5%	FRNI	40%	PODE	13%			ULAM	17%
QUAL	4%	JUNI	20%	PRSE	13%			ACSA1	8%
PLOC	3%			ACSA1	8%			FRAM	8%
PODE	3%			TIAM	4%			JUNI	8%
PRSE	3%			ULAM	4%			QUBI	8%
QUPA	3%							AEGL	4%
ROPS	3%							GLTR	4%
ULAM	3%							TIAM	4%

Ash species with total number of each plot. Nearest neighbor species are shown as percentages of the total number of plots. Includes species found in >1% of plots.

Excluding ash species as a possible replacement, the following species show the largest percentage to neighboring ashes (Table 9). Sugar maple is the most common species near white ash with 15% of the time being the nearest neighbor. Shagbark hickory is found 20% of the time near black ash, cottonwood (13%) is found near green ash, pumpkin ash always had a neighboring ash species, and burr oak was the most common neighbor to blue ash.

GEOGRAPHIC INFORMATION SYSTEM MAP BUILDS

The following figures show the required maps in producing the final IMI. Figure 2 shows each of the four resulting maps that account for moisture content for Carriage Hill; other park maps are similar. Lighter colored areas have a higher affinity for water and therefore, will result in a higher IMI value for that given location. Hillshade (Fig. 2a) accounts for the solar radiation and drying of the surface due to heat. The light area near the left side is a small lake within Carriage Hill MetroPark. Flow accumulation (2b) shows that water flows downhill to theoretical streams. Curvature (2c) probably gives the least information for Carriage Hill, which is primarily a relatively flat area. The curvature map consisted of moisture levels that were more or less the same. Water holding capacity produced a very high resolution map with distinct lines separating moisture contents of the soil. Lighter colored areas contained soil capable of holding lots of water and is able to retain that water for quite some time.

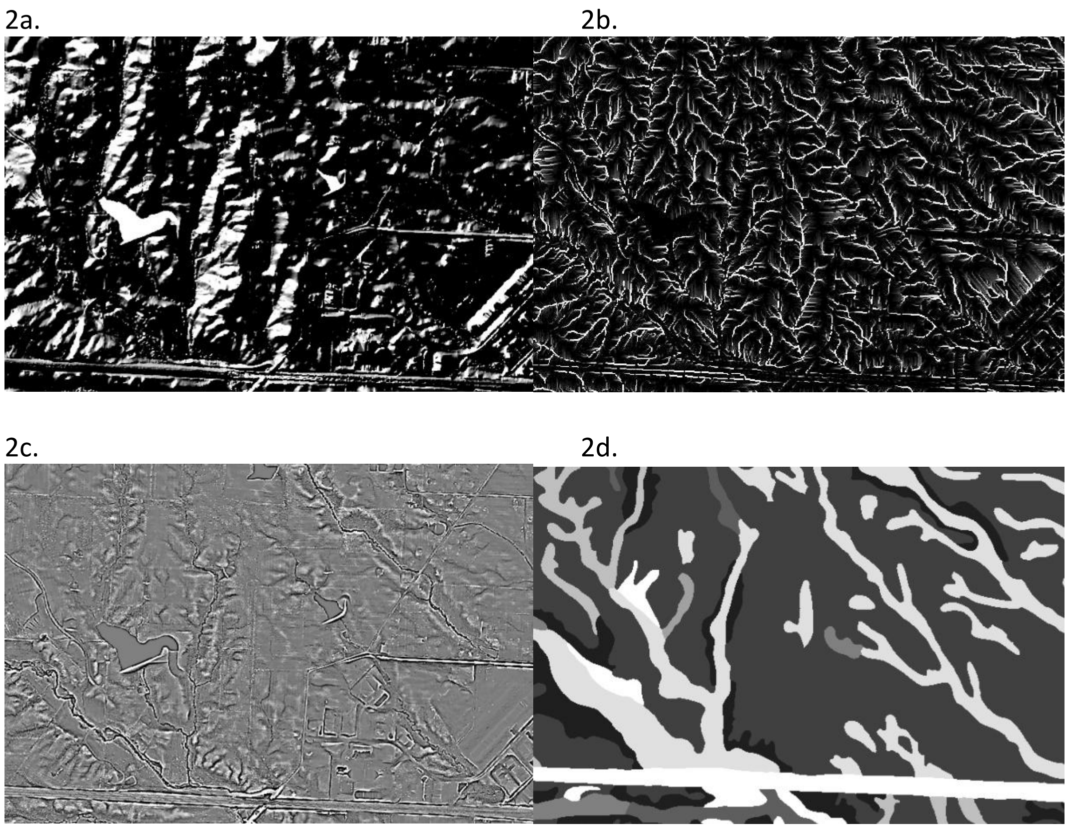


Figure 2: Maps of Carriage Hill showing the hillshade (2a), flow accumulation (2b), curvature (2c), and water holding capacity (2d) which were all used to produce the IMI map. Similar maps were done for each park.

Figure 3 shows the IMI map with varying levels of moisture throughout the entire landscape. Blue areas contain high levels of moisture, whereas low moisture is depicted by a brown color. IMI values for Carriage Hill ranged from 4.9 – 61.8. Highest values were shown to be areas of standing water (i.e. lake, streams) whereas the lowest values were shown on ridge tops that descended down to a small stream.

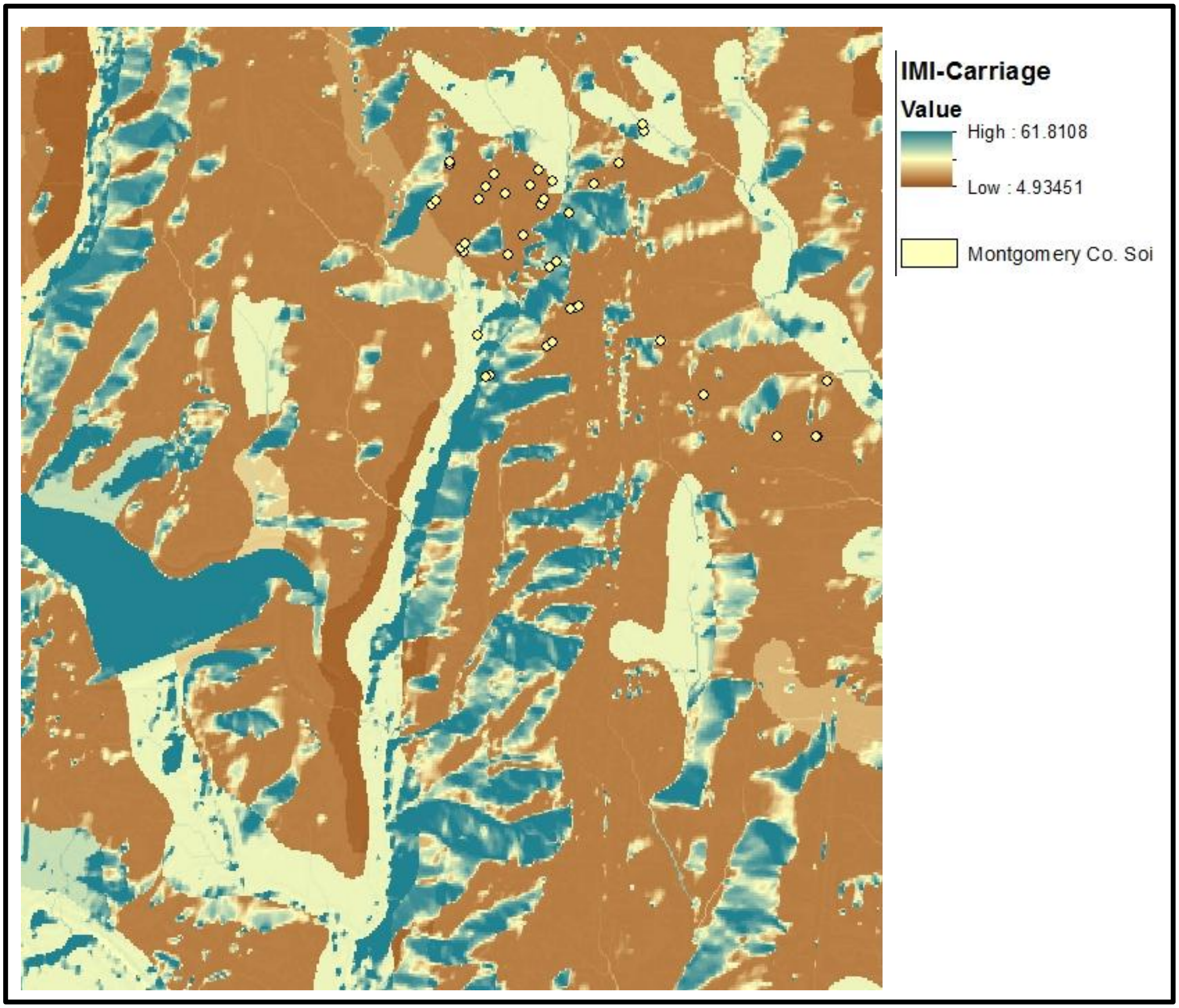


Figure 3: Combination of hillshade, flow accumulation, curvature, and water holding capacity maps to create the IMI map using ArcGIS. Each map has a weighted importance value. Plots are indicated with points on the map.

IMI RANGES

IMI values for each of the four study parks were similar, with much overlap (Table 10). Englewood had both the lowest and the highest IMI values with 1.3 and 90.1 respectively. Englewood is also one of the most diverse parks. Four different ash species were found in Englewood and only two species found in each of the other three parks. Englewood contains areas with large slopes and has the Stillwater River running through the property. Carriage Hill had the lowest range of IMI values (4.9-61.8).

Table 10: IMI ranges for Carriage Hill, Taylorsville, Englewood, and Huffman MetroParks.

PARK	IMI RANGE	COUNTY
Carriage Hill	4.9 – 61.8	Montgomery
Taylorsville	2.0 – 72.0	Montgomery
Englewood	1.3 – 90.1	Montgomery
Huffman	4.3 – 72.3	Greene

Figure 4 shows the IMI ranges for each ash species in all parks combined. Black and pumpkin ash showed the highest IMI values at approximately 60%. White, green, and blue ashes had significantly lower values near 30%. Pumpkin and black ash (FRPR and FRNI respectively) are found in wet-to-very wet sites. The high moisture levels set both pumpkin and black ash apart from the remaining three ash species. The IMI ranges were significantly different between the groups (species) with a p-value of 0.001.

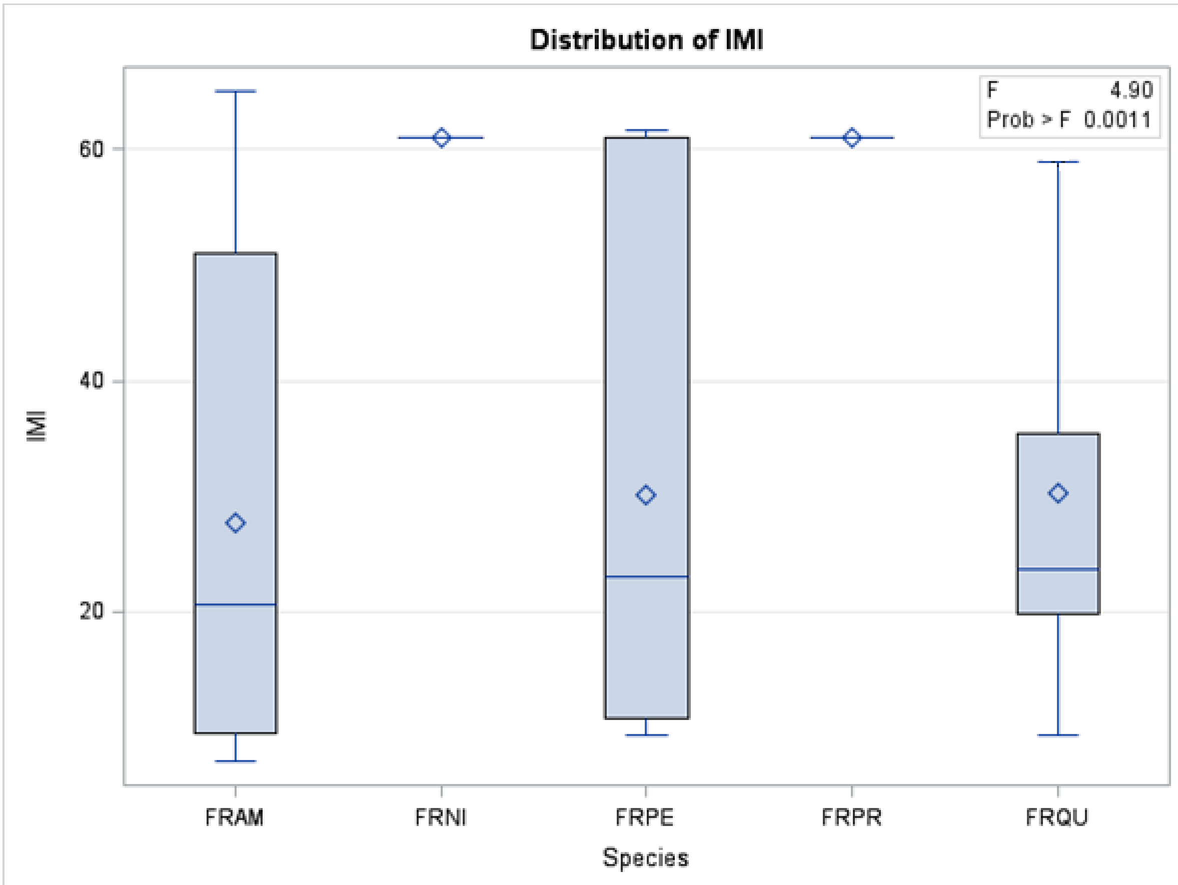


Figure 4: IMI ranges for each ash species in all plots. Ash species with IMI ranges on the y-axis. Species are labeled with the first two letters of both the genus and species. Diamonds indicate the mean with horizontal lines indicating median. The boxes are the IMI ranges (maximum and minimum) with standard deviation indicated by the “whiskers”. The p-value between species was 0.001 with an F value of 4.9.

Table 11: ANOVA with Tukey's between the IMI ranges per ash species.

Groups	***Count, N***	***Mean (IMI)***	***Standard Deviation (IMI)***
FRAM [c]	72	28	21
FRNI [a b]	3	61	0
FRPE [b c]	19	30	20
FRPR [a]	4	61	0
FRQU [b c]	23	30	15
Source of Variation between groups. P-Value = 0.001			

Ash species with same letters are similar whereas those species containing different letters are significantly (0.05) different. FRAM is significantly different than FRPR and FRQU in the IMI values. The sample size, N, is low for FRNI and FRPR making it hard to find significance between other species.

Table 11 shows the number of samples, N, with the mean and standard deviation of the IMI ranges for each ash species. Black ash (FRNI) and pumpkin ash (FRPR) both had low sample sizes whereas white ash (FRAM) had the highest sample size. The low sample size still detected a significant difference between the groups. Letters indicate significance between the species. Table 12 shows the ANOVA with Tukey's for the IMI calculation. The alpha was set to 0.05 with a critical value of 3.92.

Table 12: Tukey's Studentized Range (HSD) Test for IMI.

Alpha	0.05
Error Degrees of Freedom	116
Error Mean Square	364.9494
Critical Value of Studentized Range	3.91900

Tukey's test controls for the type I experimental error.

ORDINATIONS

Nonmetric multidimensional scaling (NMS) and detrended correspondence analysis (DCA) both were used to plot the five ash species versus IMI values in a two-dimensional space. Ash species present are based on stems in the understory surrounding the central ash. NMS and DCA showed the same ordination patterns. DCA adequately separated the five ash species and was therefore used in further analyses. Figure 5 (NMS) and Figure 6 (DCA) show axis 1 versus axis 2 and the relationship between the understory species importance in a two-dimensional ordinal space.

NMS

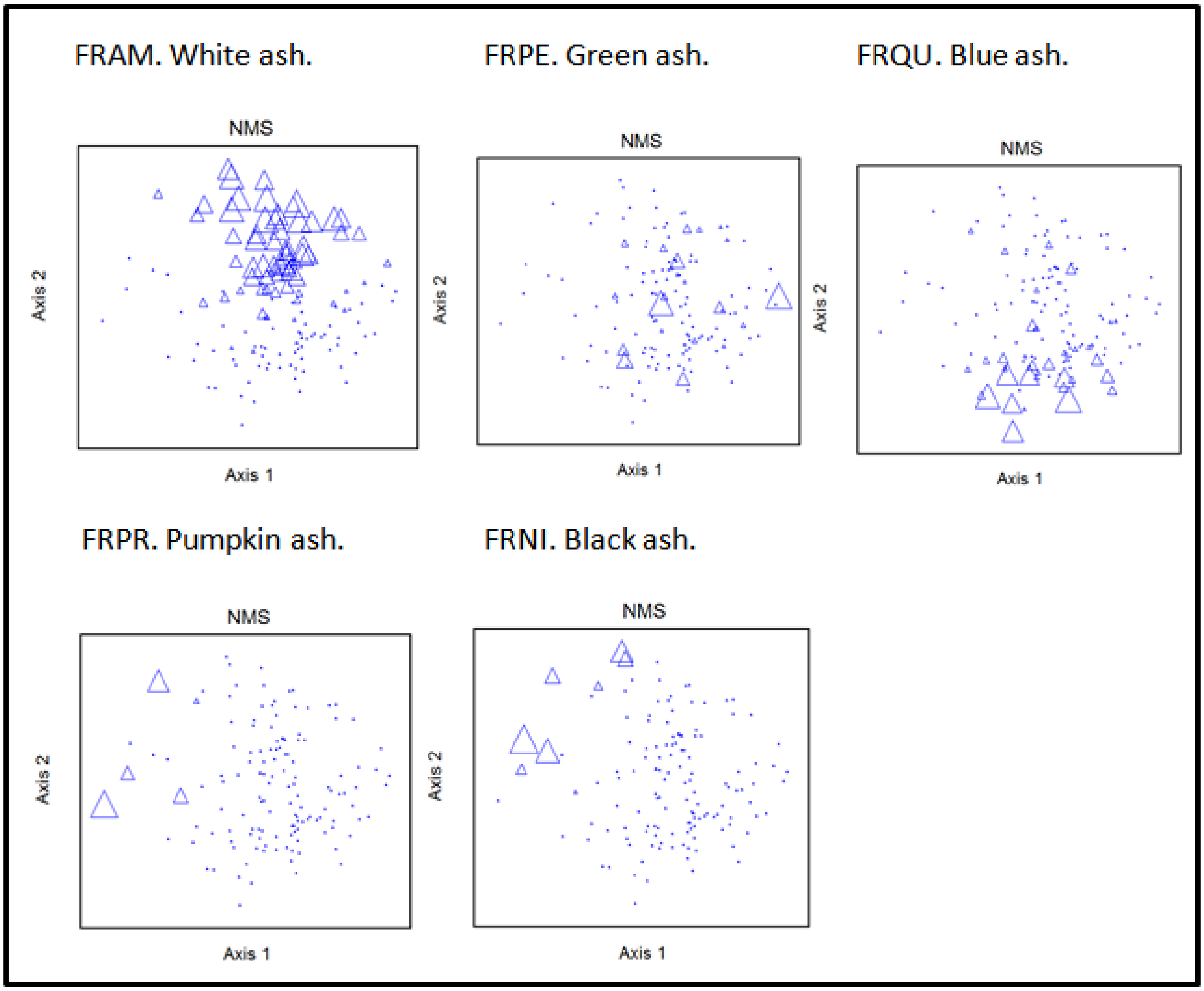


Figure 5: NMS ordination of 5 ash species in all plots. The relationship between understory species importance and IMI (moisture) values on a two-dimensional space. Groupings indicate similarities among species

DCA

The different ash species showed different distribution patterns in the ordination space using DCA. For example, pumpkin and black ashes are grouped in similar locations (left side), possibly related to their joint occurrence in wet, moist soils, found in flat upland areas. White ash shows a scattering throughout the ordination with the strongest clustering near the center. Blue ash is plotted on the bottom near axis 1 and could be separated from the rest of the ashes due to its typical dry upland locations. Green ash is also found in wet areas but not swampy areas like black and pumpkin. Therefore, green ash is found in a different ordination space, located on the right side of the graph. Table 13 shows the eigenvalues for each DCA axes. The values decrease as axes are added to the ordination.

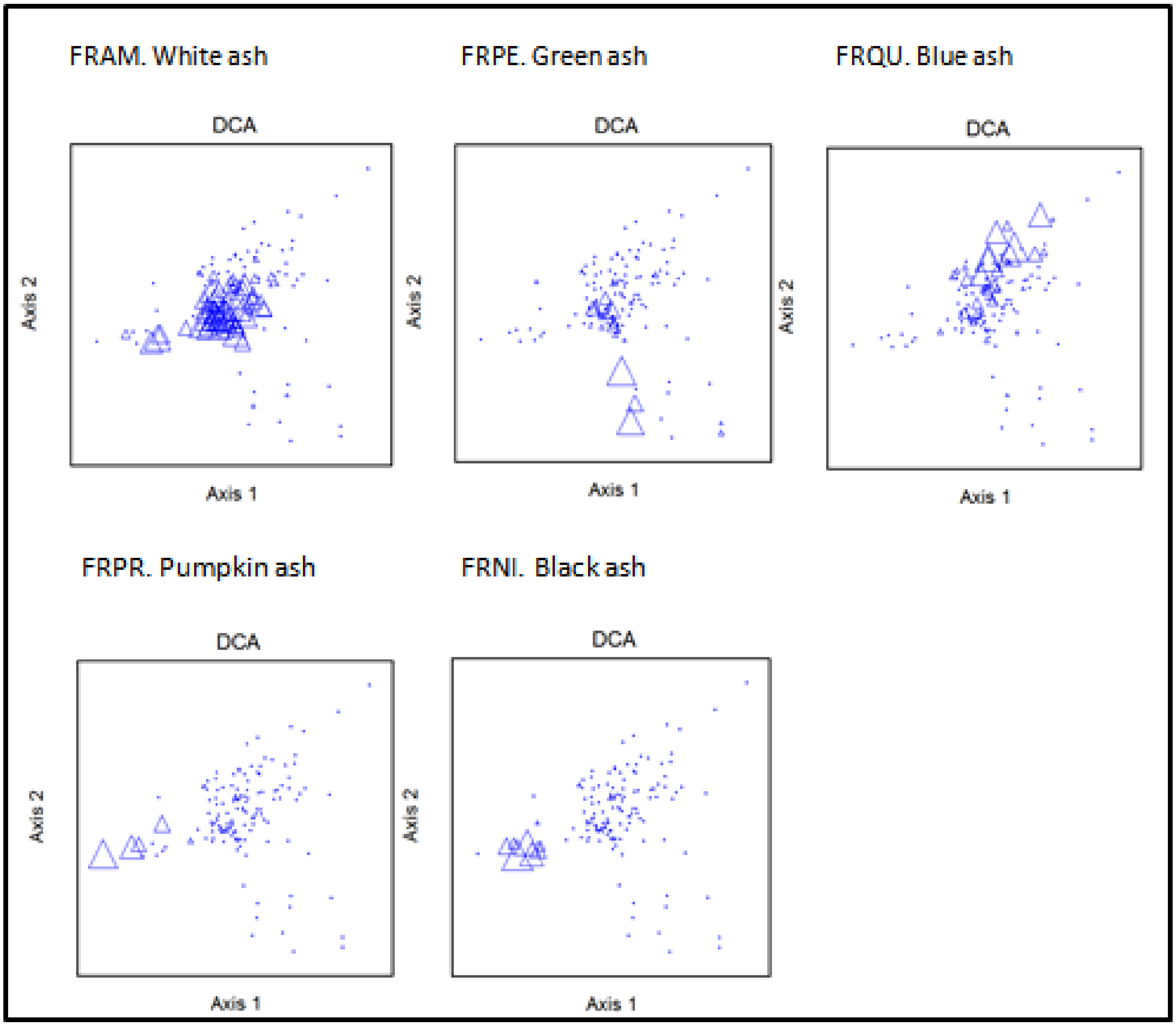


Figure 6: DCA ordination of 5 ash species in all plots. The relationship between understory species importance and IMI (moisture) values on a two-dimensional space. Groupings indicate similarities among species

Table 13: The three axes with associated eigenvalues.

```
AXIS SUMMARY TABLE
-----------------------------
                     Gradient
Axis    Eigenvalue    Length
   1       0.69528     5.284
   2       0.53716     3.305
   3       0.41343     3.643
-----------------------------
```

Table 14: Significance between ash species related to the first and second axes of DCA.

Species	**N**	**DCA1**			**DCA2**	
		Mean	**Std Dev**		**Mean**	**Std Dev**
White ash (FRAM) [b]	80	235.241626	56.6377800	**FRAM** [a b]	232.220817	66.9063428
Black ash (FRNI) [c]	5	125.136440	69.0376214	**FRNI** [a]	187.746702	33.0084318
Green ash (FRPE) [a]	25	282.880430	68.9966418	**FRPE** [b]	203.142776	96.6359824
Pumpkin ash (FRPR) [c]	4	52.203865	40.9292190	**FRPR** [a]	185.376965	22.2218069
Blue ash (FRQU) [a b]	23	237.861981	47.1990348	**FRQU** [a]	272.377952	63.1306642

Ash species with same letters are similar whereas those species containing different letters are significantly (0.05) different.

Table 14 shows the significance between ash species relating IMI with species. Axis 1 separates black and pumpkin ash from the others and finds a significant difference between white ash and green ash. Blue ash is found to be similar to both green and white ash. Axis 2 did not show as strong of patterns as in the first axis. Axis 2 indicated that green and white ash were similar to one another but green was different than the rest of the ashes. The similarity between green and blue ash from axis 1 was pulled apart and differentiated in the second axis.

Figures 7 and 8 show both the first and the second axes of DCA. Figure 7 shows pumpkin and black ash being pulled away from the other ash species. The figures are box and whisker plots with the standard deviation displayed as vertical lines and the median as the horizontal line. The diamond shows the averages for each species. The F value and the P-value associated with the F value are shown in the top right of the figures.

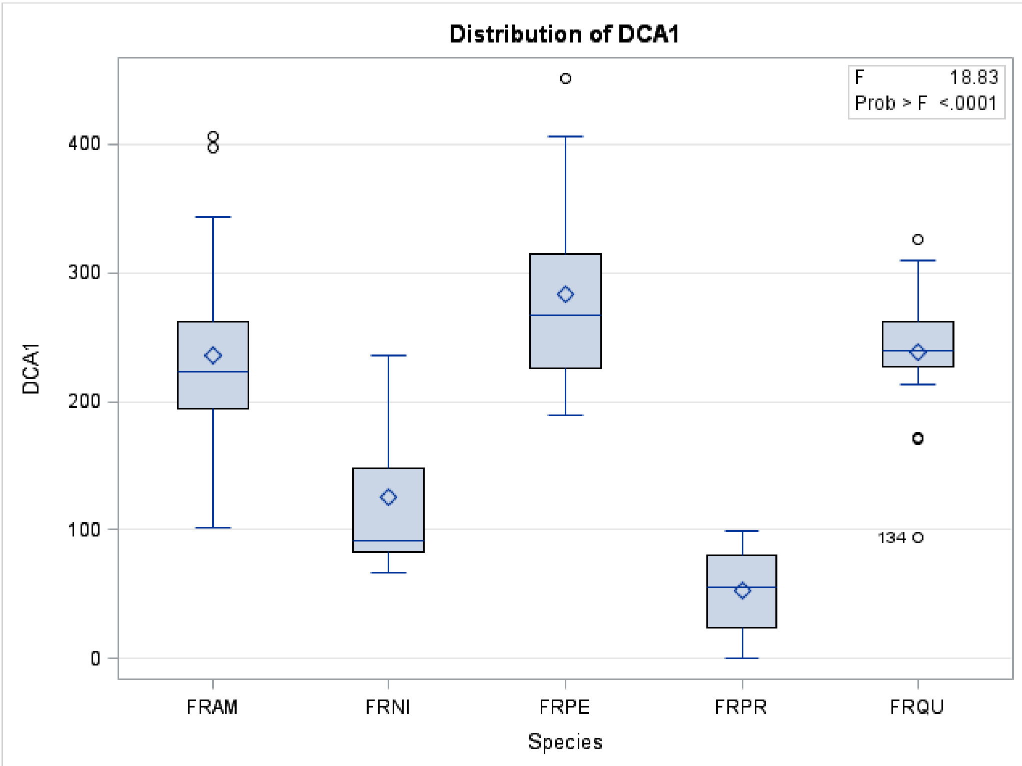


Figure 7: Distribution of ash species on the first DCA axis.

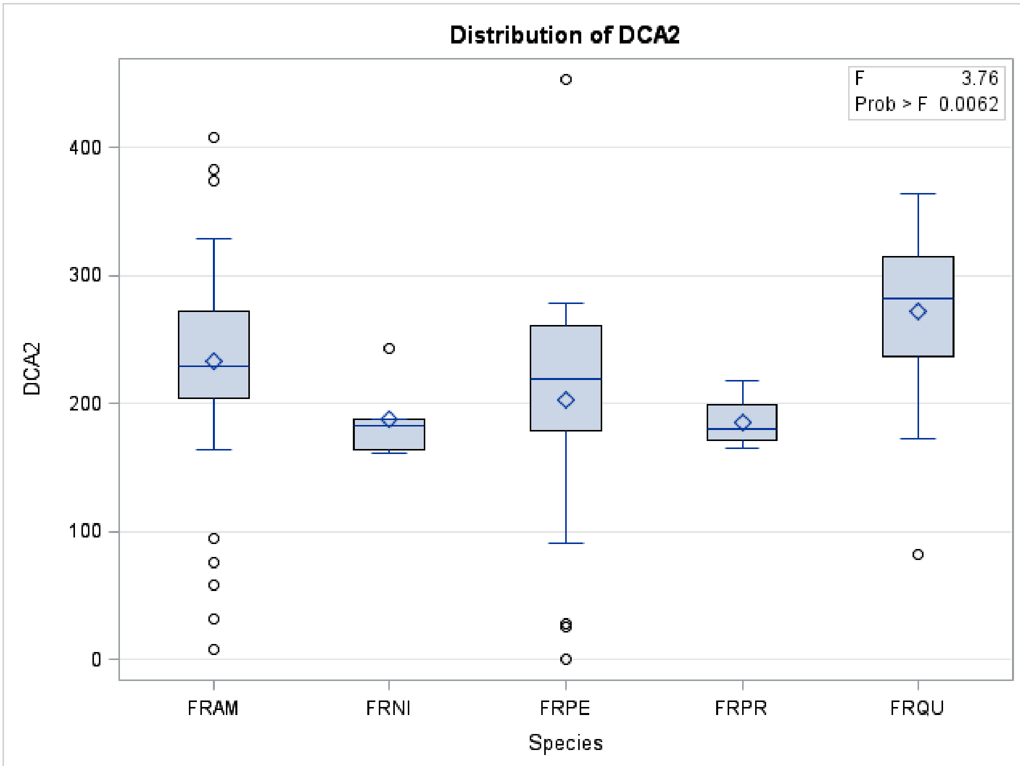


Figure 8: Distribution of ash species on the second DCA axis.

Both NMS and DCA show the same patterns in grouping and organizing the different ash species, but there are some slight variations in the locations of each species in the graphs. For example, DCA shows green ash pulled down near axis 1 instead of to the right and blue ash is grouped near the top instead of the bottom (as in NMS).

CORRELATIONS

Pearson and Spearman correlations were calculated between six selected variables: IMI, ordination scores for the first two axes in DCA (DCA1 and DCA2), DBH (center ash), NDBH (neighbor-DBH), and BA (basal area of plot). Table 15 shows a summary of the simple statistics for each variable. The table includes the number of samples, N, mean, standard deviation (Std Dev), median, minimum, and maximum.

Table 15: Correlations between 6 selected variables.

Simple Statistics						
Variable	**N**	**Mean**	**Std Dev**	**Median**	**Minimum**	**Maximum**
IMI	121	30	20	23	7	65
DCA1	137	235	71	230	0	451
DCA2	137	231	74	233	0	453
DBH	139	41	14	39	12	87
NDBH	137	38	16	33	12	95
BA	137	1893	1666	1552	0.34000	13135

IMI=integrated moisture index, DCA1 = detrended correspondence analysis –axis 1, DCA2 = detrended correspondence analysis – axis 2, DBH = diameter at breast height of center ash, NDBH= neighbor DBH, and BA= basal area of all species in plot. Each cell contains three values. The top is the correlation coefficient, the middle is the probability, and the third (bottom) is the number of observations. The tables are in the form of a matrix. Significant values are indicated with an asterisk.

Tables 16 and 17 below show the Pearson and Spearman coefficients respectively. Both coefficients found significant correlations between IMI and both DBH and NDBH. These results indicate that higher IMI value result in larger trees. As IMI increased, the diameters of the trees increased. The first axis (DCA1) showed higher values when compared to DCA2. High DCA1 scores may be associated with one of two things: a successional gradient or an environmental variable. High scores in the first axis are associated with large diameter trees. This trend could indicate a successional pattern, with older, larger, trees on the right. The variation in DCA scores could also indicate an environmental gradient, such as moisture. Trees on the left (pumpkin ash and black ash) may be stunted by the high moisture content resulting in smaller trees.

Table 16: Pearson Correlation between variables.

	IMI	DCA1	DCA2	DBH	NDBH	BA
IMI	1.00					
	121					
DCA1	-0.08	1.00				
	0.39					
	119	137				
DCA2	-0.12	0.12	1.00			
	0.18	0.18				
	119	137	137			
DBH	0.22	0.18	-0.12	1.00		
	0.01*	0.04*	0.15			
	121	137	137	139		
NDBH	0.32	0.28	-0.12	0.33	1.00	
	0.00*	0.00*	0.18	0.00*		
	120	135	135	137	137	
BA	-0.05	0.05	-0.16	-0.05	0.27	1.00
	0.56	0.58	0.06	0.58	0.00*	
	119	136	136	137	135	137

Each cell contains three values. The top is the correlation coefficient, the middle is the probability, and the third (bottom) is the number of observations.

Table 17: Spearman correlation coefficients between variables.

	IMI	DCA1	DCA2	DBH	NDBH	BA
IMI	1.00					
	121					
DCA1	0.01	1.00				
	0.95					
	119	137				
DCA2	-0.03	0.24	1.00			
	0.73	0.00*				
	119	137	137			
DBH	0.21	0.15	-0.00	1.00		
	0.02*	0.09	0.96			
	121	137	137	139		
NDBH	0.31	0.19	0.018	0.42	1.00	
	0.00*	0.03*	0.84	0.00*		
	120	135	135	137	137	
BA	-0.11	-0.16	-0.05	-0.05	0.12	1.00
	0.25	0.06	0.56	0.58	0.16	
	119	136	136	137	135	137

Each cell contains three values. The top is the correlation coefficient, the middle is the probability, and the third (bottom) is the number of observations.

SUCCESSIONAL PATTERNS

Understory species importance for each plot was related to the ordination scores for axes 1 and 2 (Table 18). The axes scores were produced from the detrended correspondence analysis.

Table 18: Relationship between ordination scores and understory species overall importance of the most important species.

SPECIES	PEARSON		SPEARMAN		DCA1	DCA1^2	DCA2	DCA2^2
	DCA1	DCA2	DCA1	DCA2				
Sugar Maple	0.01	0.17*	-0.03	0.19*	1.1E-3	-2.4E-6	3.7E-4	3.6E-7
Honeysuckle	0.10	-0.01	0.14	0.01	2.1E-3*	-3.9E-6*	5.8E-4	-1.4E-6
White Ash	-0.14	0.01	-0.18*	-0.07	3.7E-4	-1.4E-6	8.2E-4	-1.9E-6
American Elm	0.06	0.03	-0.01	0.02	3.5E-5	-1.1E-7	-3.5E-4	9.2E-7
Eastern Redbud	0.06	-0.09	0.07	0.06	5.5E-4	-9.9E-7	-3.3E-4	5.0E-7
Blue Ash	-0.10	0.08	-0.06	0.21*	2.0E-4	-6.8E-7	2.7E-4	-4.1E-7
Black-haw	-0.11	-0.07	-0.12	-0.13	5.9E-5	-3.4E-7	4.3E-4	-1.2E-6*
Boxelder	0.15	-0.31*	0.25*	-0.22*	-8.1E-4	2.6E-6	-2.9E-3*	5.3E-6*
Hickory Species	-0.35*	-0.08	-0.22*	-0.10	-1.8E-3*	2.8E-6*	3.7E-4	-1.1E-6
Ohio Buckeye	0.02	0.17	0.06	0.39*	2.0E-4	-4.0E-7	-1.5E-4	6.9E-7
Cottonwood	-0.10	-0.05	-0.13	-0.09	-9.0E-5	6.9E-8	5.0E-5	-1.8E-7

The two ordination scores (axis 1 and 2) are squared. Pearson and Spearman correlations were used to detect significance. Asterisks indicate significance.

Pearson and Spearman correlations were performed to compare ordination scores and understory species importance. DCA1 did not show a strong relationship with any species except for hickory at low values (Table 18). DCA2 showed a gradient from boxelder at low values (-0.31 and -0.22) to sugar maple at high values (0.17 and 0.19). The gradient indicates boxelder being associated with floodplains and sugar maple associated with uplands. Boxelder showed a strong positive negative trend for DCA1 and DCA2 respectively. Plotting a positive value for axis 1 and a negative value for axis 2 would group the boxelder with the green ash (Fig. 5). This puts boxelder near wetter sites primarily dominated by green ash and even pumpkin and black ash. Sugar maple had the opposite trend showing a negative positive relationship. Sugar maple was found in the drier sites, similar to that of blue and white ash.

IV. DISCUSSION

ASH REPLACEMENT

The study focused on the replacement of ash species post emerald ash borer. I wanted to answer the following question: what species will replace ash? Three methods were used to predict likely successors to replace ash. Relative importance, largest stem, and nearest neighbor were all calculated to give the best indication of possible replacement species. Figure 1 showed that sugar maple had the highest importance value followed by honeysuckle, white ash, and American elm. If all ashes are eliminated, then white ash no longer is a viable option. Honeysuckle is a low growing woody shrub that will never make it to the canopy height. Therefore, sugar maple and American elm are the two most likely species to increase. Previous research has shown that the likely successors will be ash (if EAB are eliminated), maple, or elm (Knight et al. 2010). Although elm was shown to have high importance in many of the plots, it may not be able to reach canopy height due to the Dutch elm disease. The disease will usually infect trees before they reach full maturity, eliminating elm as a possible replacement. If young ash saplings tend to replace the dying ash, this may facilitate a longer exposure time to the EAB and prolong the effects. However, if maple or elm species replace the dying ash, the borer may deplete its food source and die out. Previously studied ash centered plots found a relatively low density of invasive woody species (Knight et al.

2010) but my plots were more likely to contain invasive species. The species composition may transition into a more invasive-friendly space as more ash trees tend to die and create a higher light availability. Ash species were shown to have a mortality rate near 100% (Knight et al. 2007). The ash seed bank is disappearing as shown in a four year study (Knight et al. 2007, Herms et al. 2009). The decreasing seed bank may pose a problem for the future of ash trees to be replenished. Seedling and saplings remain unaffected by the borer but once trees reach a certain size, (>2.54cm.) they are vulnerable to attacks (Kashian and Witter 2011). Saplings are being attacked before they reach their mature, reproductive age (approximately 20 years for white ash), posing a threat to the seed bank (Burns and Honkala 1990). Seedlings declined significantly from 2007 to 2009 in a study near the introduction point (Kashian and Witter 2011).

The largest stem was also used to predict replacement and Table 6 shows that sugar maple and American elm were found to be the largest stem most often. Next in importance were boxelder, eastern redbud, and black walnut. The third measurement included the nearest canopy-height neighbor. Once a canopy tree dies, it leaves a gap in canopy, increasing the available light. The added light allows for shade intolerant species to grow and fill the gap. The closest tree to a gap is a likely candidate for replacement due to its proximity and ability to grow rapidly, and close the gap. The nearest neighbor species from most frequent to least were white ash, sugar maple, green ash, black walnut, and American elm. Both white and green ash are eliminated which leaves sugar maple, black walnut, and American elm. The three methods for determining replacement showed similar results. In all cases sugar maple was the most dominant followed by American elm and then black walnut. Flowers et al. (2013) found that when looking at basal area post EAB attacks, maples and elms responded the most; followed by cottonwoods, tulip poplar, and oaks. The mentioned species all showed significant increases in basal area in response to the declining ash population. These results indicate that ash species are likely to be replaced by maples and possibly by elms. Elm are less likely to reach the canopy due to a reduce lifespan caused by the Dutch elm disease (Barnes 1976).

REPLACEMENT BY ASH SPECIES AND TOPOGRAPHY

Replacement species vary with ash species and topographical position. Canopy ash may be interacting with the understory species creating a relationship with nearby species. Five different ash species were separated and the three tests (importance value, largest stem, and nearest neighbor) were performed on each ash species and compared. Table 5 showed the importance values for the five ashes and the understory species. Ash species were highly associated with themselves, showing possible replacement. Ash located in wet sites may have a more difficult time becoming established due to the stress and environmental conditions. Upland ash may be able to become established more easily due to better soil conditions. In either case, it is typical to see a high rate of mortality in seedlings, especially germinates (Burns and Honkala 1990). There was a trend showing ash species related to species with similar moisture requirements (i.e. pumpkin ash and spicebush) A similar trend is apparent with white ash being the dominant species under white ash and blue ash (after eliminating honeysuckle). Green ash was associated with some of the wetter species such as boxelder and cottonwood. Pumpkin and black ash picked up hickories, spicebush, and American elm. Separating the ashes allows for patterns in the distribution to be more apparent.

To test whether topography had an influence on species, a map was built in ArcGIS to map moisture levels across the landscape. Moisture tends to drive species location due to the tolerance levels of different species. Beatley (1959) stated that the most important variable driving species composition is moisture levels. Moisture levels can vary based on local climate, soil type, or elevation (Whittaker 1956). Studies have shown that position on a slope is important in determining species occurrences. Runkle and Whitney (1987) studied 18 plots with varying degrees of topography in southeastern Ohio. They found that topography had an effect on the soil moisture and nutrient content. These two variables showed strong patterns when comparing upland versus lowland sites. Uplands were dominated by oaks whereas lowlands had high numbers of elm and sycamore. Slope not only separates species, but has been found to cause higher mortality on white ash at higher elevations. A higher position on slopes leads to increased rates of dieback and poor crown development (Royo and Knight 2012).

Species can be grouped based on specific locations (i.e. moisture levels, nutrient content) in the landscape. The grouping of species can be seen by ordinations run in PC-ORD showing patterns of distribution (Figures 5 and 6; NMS and DCA respectively). The two-dimensional ordinations show clear separation in species, especially dividing black and pumpkin ash from the rest of the ashes. Pumpkin ash is found in flooded bottomlands with black ash found in bogs, swamps, and poorly drained soils with high water tables (Stewart and Krajicek 1973, Fowells 1965). Moisture levels were much higher for pumpkin and black (Figure 4; Table 14) than for the other ashes. White ash showed IMI levels that ranged from approximately 7-48% which is similar to a study by White (2011) which found white ash IMI values of 20-48%. White ash is sensitive to droughts (Woodcock et al. 1993) and is found in upland, moderately drained soils (Burns and Honkala 1990). Varying moisture levels are associated with differing understory species that can withstand certain conditions. Ordinations have been used in other studies to determine stand similarity based on environmental variables (Runkle and Whitney 1987; Bell 1978). Bell (1978) and White (2011) used the available moisture levels and determined that sugar maple dominated mesic, wet sites, and oaks dominated the xeric, dry sites. Zimmerman and Runkle (2010) used topography and found oaks on dry sites and sycamore and cottonwoods in wet sites.

UNDERSTORY SPECIES VIA ASH SPECIES AND TOPOGRAPHY

The understory species are related to the center ash species and moisture levels. Species adapt to varying moisture levels and are more likely to be found in favorable conditions. Black and pumpkin ash had hickories, black-haw, and spicebush. These two ash species had the least amount of sugar maple whereas other ash species were dominated by it. The forest is in a constant change, shifting from shade intolerant species to more shade tolerant species. Hardwood mesophytic forests are shifting from forests primarily dominated by oak and hickory to those dominated by maple and tulip poplar (Iverson et al. 1997). Ash decline may accelerate the maple and poplar takeover that is already occurring in the region. DCA2 (Table 18) DCA2 showed a gradient from box elder at low values, indicating floodplains, to sugar maple at high values, indicating uplands. Boxelder showed trends toward wetter sites primarily dominated by green ash. Sugar maple had the opposite trend and was found in the drier sites, similar to that of blue and white ash. Table 5 indicated that central ash species had understory compositions similar to the central ash. For example, white ash was more likely to be found in a plot with a white ash tree as the center.

Subsequent years will be important in showing trends over time between the two sample groups. The emerald ash borer was recently found in the area and will probably take a couple years before any sort of pattern is discovered. Some ash trees appear to have some resistance to EAB attacks and survive while nearby neighbors are killed. These “lingering ash” are being studied by Kathleen Knight for possible resistance. The surviving ash trees can be replicated through grafting to potential restore ash populations (Knight et al. 2013).

FUTURE WORK

Post-EAB studies will be very important in tracking the changes of the forest composition and turnover. A change in forest dynamics of this amplitude would drastically change the forest composition and could potentially eliminate a number of animal and plant species that currently reside in those areas. Continued research would help reduce the impacts on the valuable Midwest forests. Future studies could look at the ash saplings and determine to what extent they are affected by EAB. The beetle may sweep through the area and allow the open gap spaces to be filled by the young ash or species found of importance in the sampled plots. On the other hand, EAB could make a second pass through and kill the ash saplings as well. Knight (2010b), from the US Forest

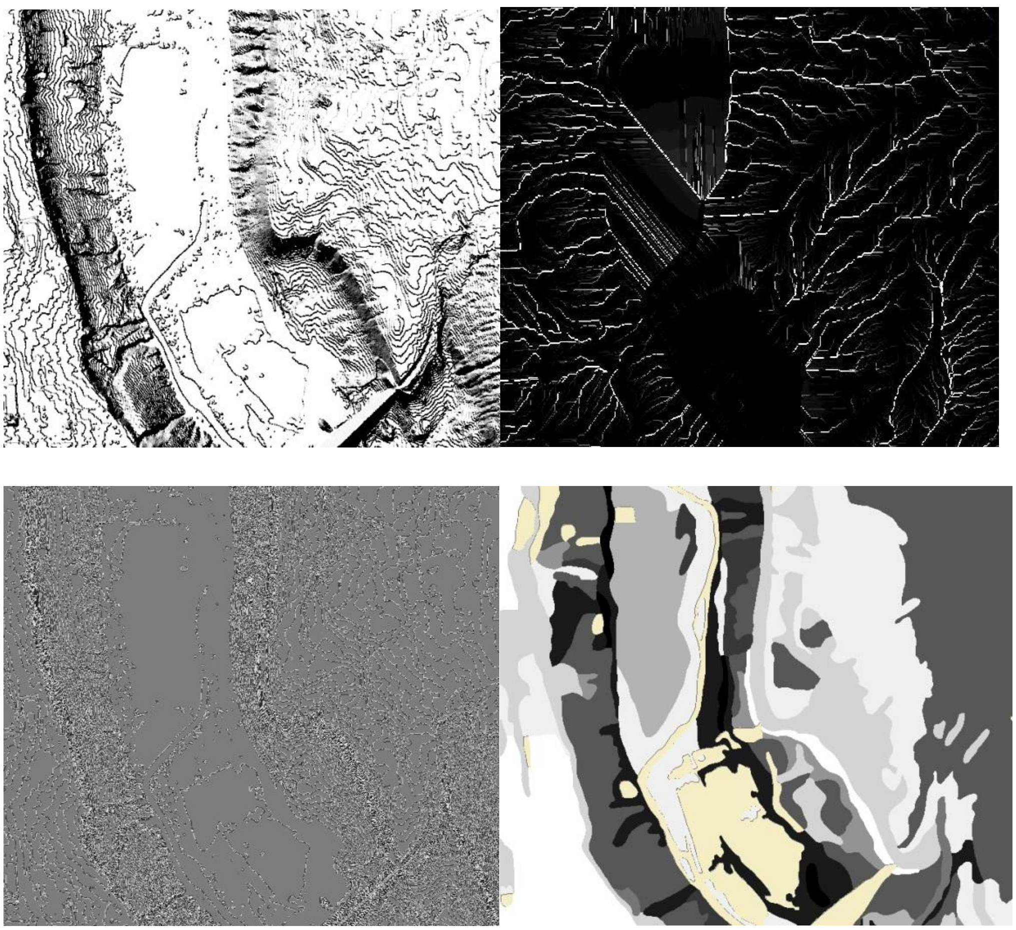
Service, is monitoring over 4,500 ash seedlings and saplings to determine decline and mortality. Yearly monitoring began in 2004 and shows that nearly all ash are destroyed with no relationship to ash density, size, habitat, or diversity. A forest can transition from being totally healthy to all ash trees being dead in a matter of 6 years (Knight et al. 2010b). EAB populations initially increase very quickly, peak, then are reduced to a very low density, at which they can persist for some time feeding on saplings and other small ash seedlings when they reach a susceptible size of 3 cm DBH (Knight et al. 2010b).

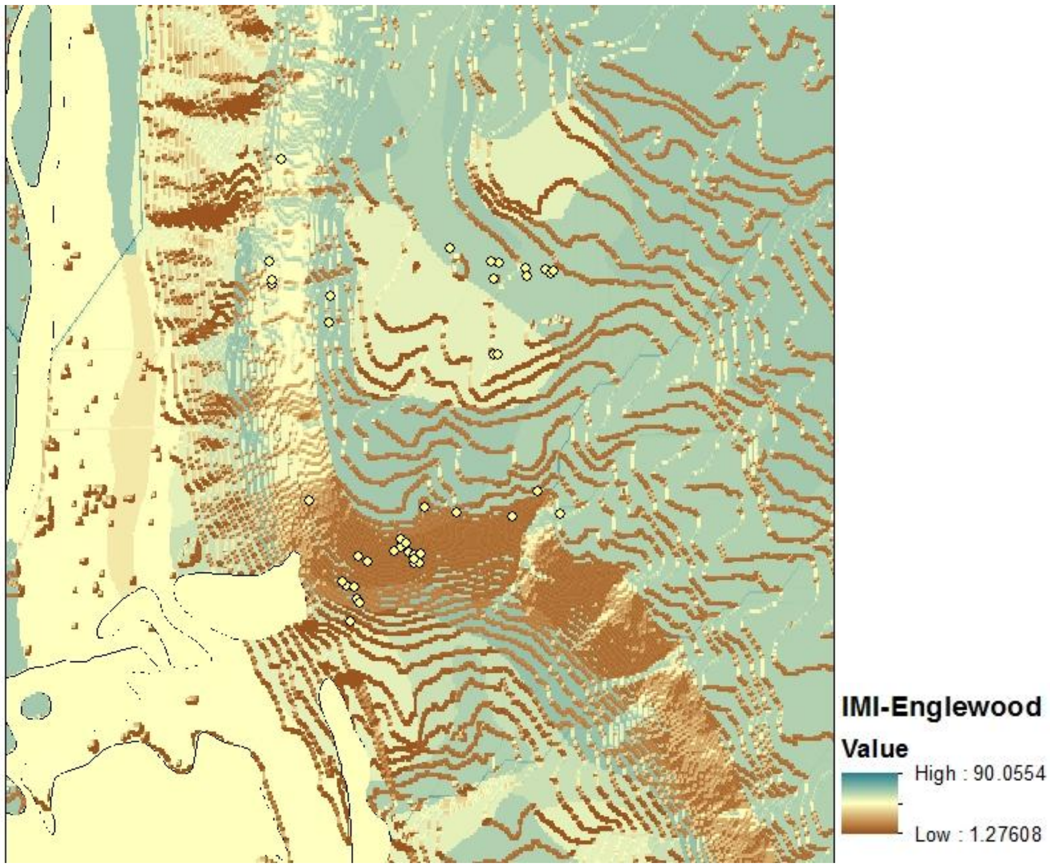
Plots around treated ash will be the starting point for others to determine whether treatments are effective or whether the ash population is declining. Comparative studies 3, 5, or even 10 years down the road can monitor the changes in ash plot understory. The future of ash trees does not look good. This may be the last chance in history to obtain information on the way that ash species structure their forests.

V. APPENDIX

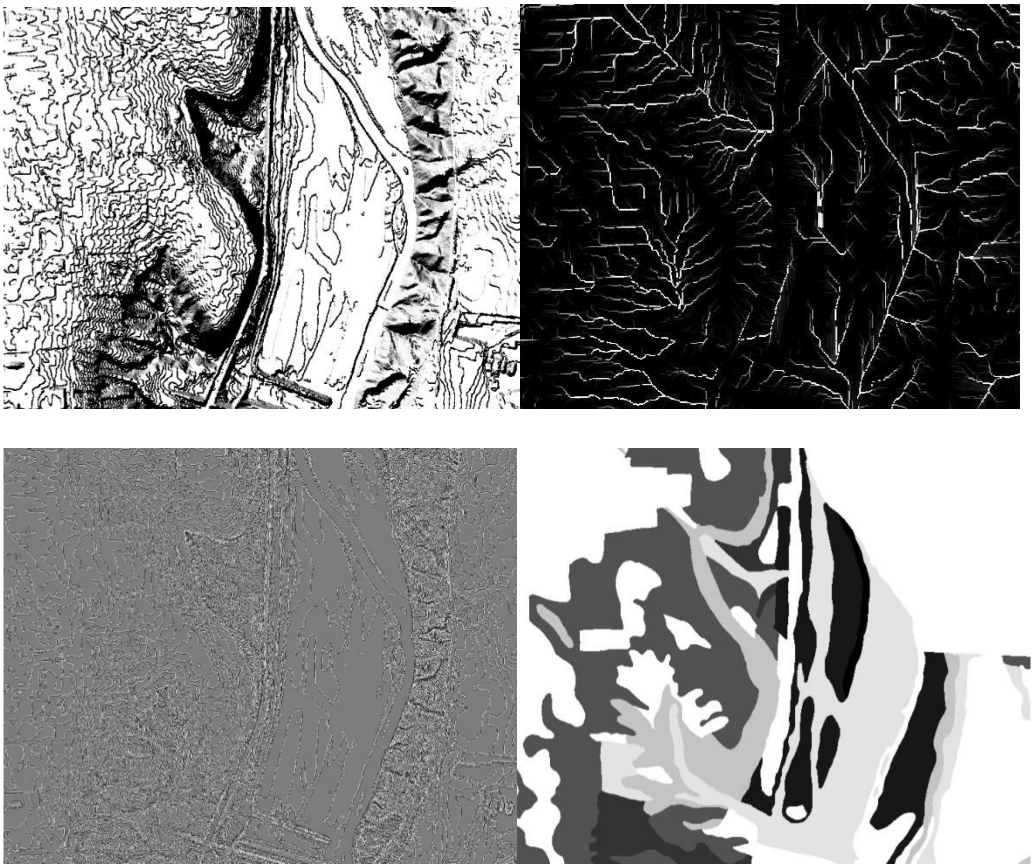
IMI MAPS OF ADDITIONAL PARKS

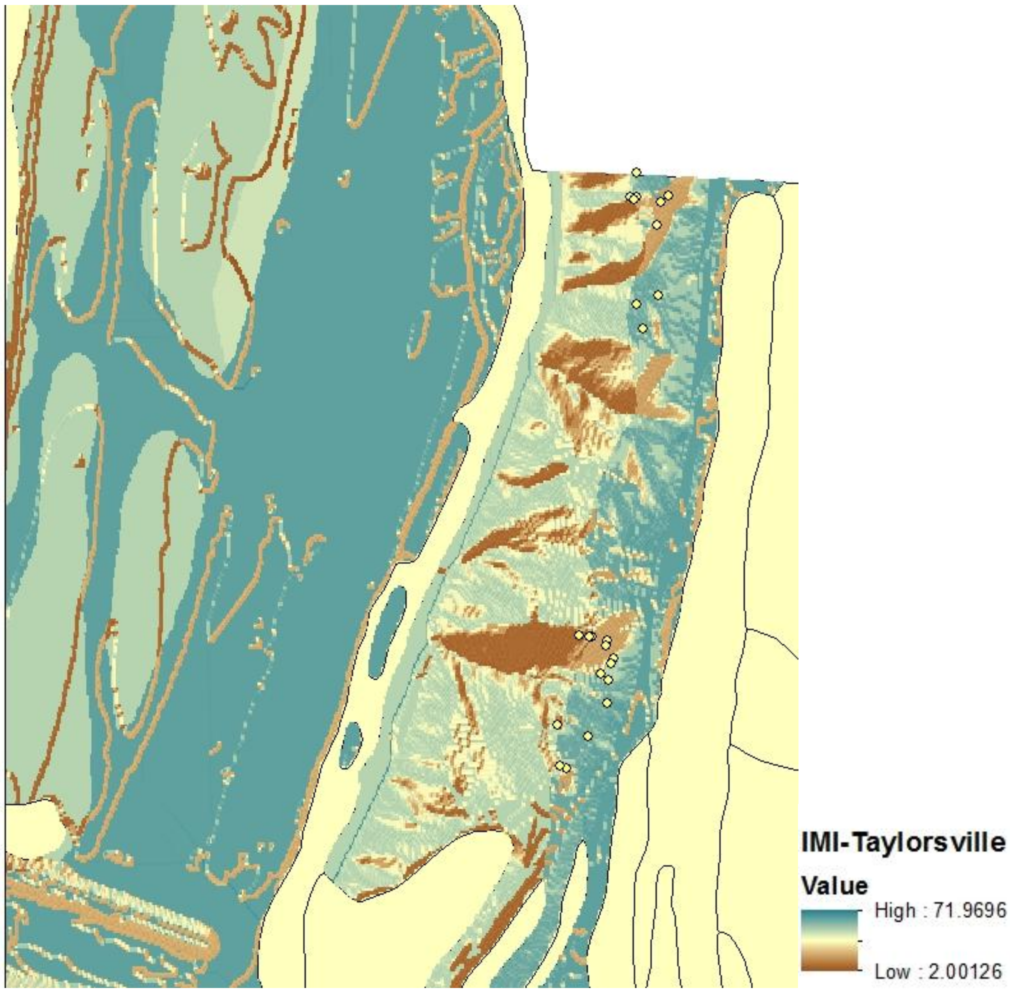
Englewood



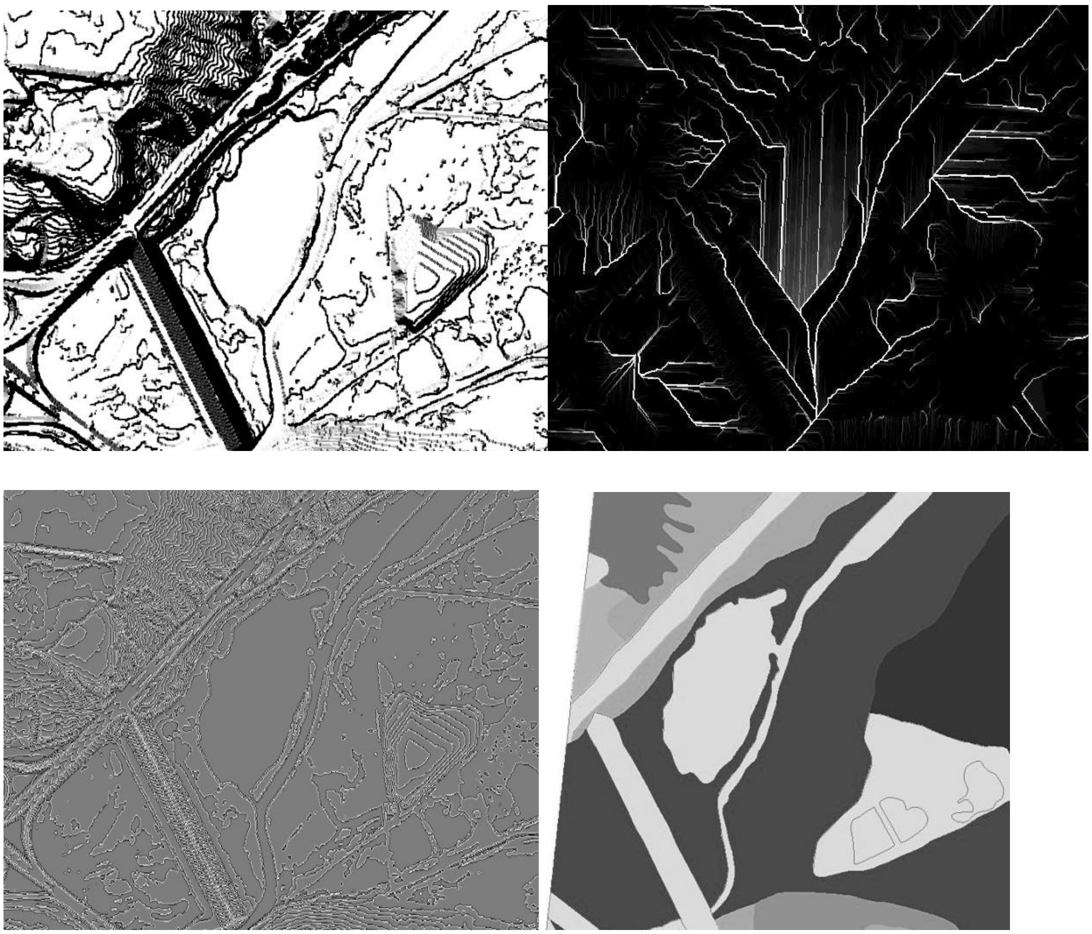

IMI-Englewood
Value
High : 90.0554
Low : 1.27608

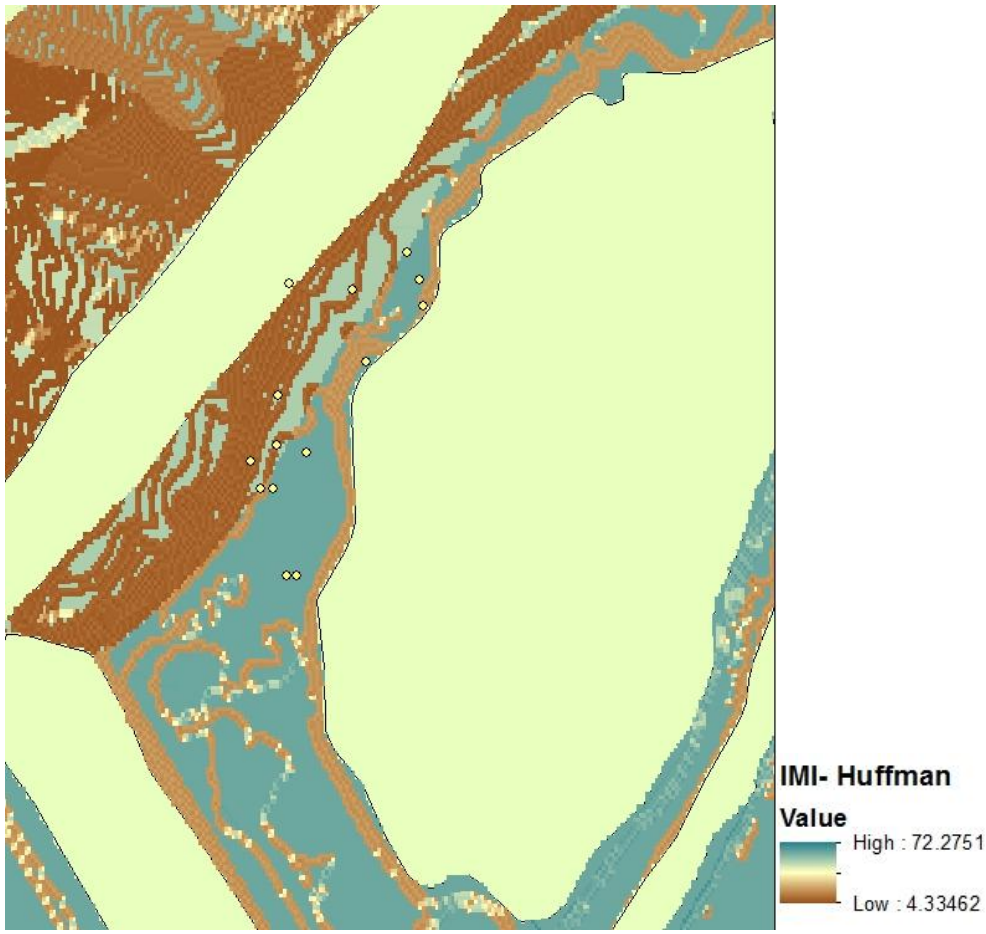
Taylorsville




IMI-Taylorsville
Value
High : 71.9696
Low : 2.00126

Huffman




IMI- Huffman
Value
High : 72.2751
Low : 4.33462

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