The Impacts of the Invasive Emerald Ash Borer (*Agrilus planipennis*) on Ash Trees (*Fraxinus spp.)* in the United States: A Review

The emerald ash borer (EAB) (*Agrilus planipennis*) is an invasive insect that has caused the death of millions of ash trees (Fraxinus spp.) in Detroit, Michigan and has since spread into other areas of Michigan, isolated locations in Indiana, Ohio, Maryland, and Virginia, and nearby Windsor, Ontario in Canada (MacFarlene, 2005). In addition to this, 48 U.S. counties have populations of EAB and several counties in southern Michigan, Ohio, and Indiana have quarantined to regulate the movement of live ash trees and products (MacFarlene, 2005). If EAB populations are not contained and eventually eradicated, the North American ash resource could be depleted. Ash trees are widely distributed across the eastern U.S. and portions of southeastern Canada and are one of the more widely planted trees in urban and suburban areas (Fig. 1).

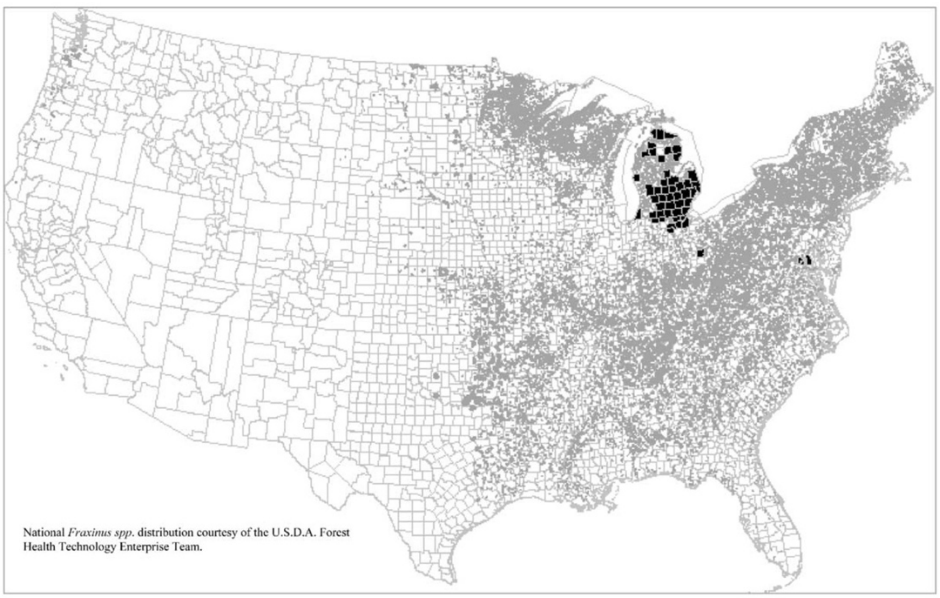

Fig. 1. Distribution of *Fraxinus* species in the U.S. (gray shaded areas). Populations of emerald ash borer (EAB) (*Agrilus planipennis*) have been discovered in 48 U.S. counties as of 2005 (black shaded areas), as well as Windsor, Ontario, Canada (not pictured). Adapted from MacFarlene et al. (2005).

There are approximately 16-17 species of *Fraxinus* depending on phenotypic and genetic relationships amongst ash species. Harlow et al. (1991) lists white ash and green ash as being taxonomically important species of ash in the U.S. but also lists a number of species of lesser importance, including black ash (*F. nigra*), Carolina ash (*F. caroliniana*), pumpkin ash (*F. profunda*), blue ash (*F. quadrangulata*), Oregon ash (*F. latifolia*), and single-leaf ash (*F. anomala*). Stewart and Krajicek et al. (1973) lists six of these species: white, pumpkin, blue, black, green, and Oregon as commercially important. Preliminary testing of host preference in

MacFarlene et al. (2005) suggests that all eastern North American ash species are susceptible to EAB.

White ash (*Fraxinus americana*) and green ash (*Fraxinus pennsylvanica*) have been listed as taxonomically important species of ash in the U.S. White ash is best suited to nutrient rich upland soils with plenty of moisture, also called mesic sites. These sites are often found in areas that collect water, nutrients, and organic matter, such as coves and the base of hills. In addition to this, white ash rarely grows in pure strands but is a rather common component of northern hardwood forests, and grows along sugar maple, yellow birch, American beech, hemlock, and red spruce (Catanzaro, 2023). White ash is also primarily characteristic of early and intermediate stages of succession, and the seedlings are shade tolerant but can also establish in full sun. Mature white ash are shade intolerant, and after persisting for a few years in moderately dense shade, trees developing inside closed strands reach the overstory by responding quickly in the canopy (USDA).

Green ash can tolerate more water than white ash and are often found in riparian and low-lying areas. Unlike white ash, green ash is often the dominant species in lowland settings, particularly in riparian forests, because it is well-adapted to areas with high water levels. Because of this, green ash is often found within forest types composed of other tree species well-adapted to wet conditions, such as ash-elm-maple and elm-ash-cottonwood forests (USDA).

According to MacFarlene et al. (2005), preliminary investigation suggests that the EAB is found on Chinese ash (*F. chinensis*), Manchurian ash (*F. mandshurica*), and some North American *Fraxinus* species in its native range, which includes most of China, Korea, and Japan and parts of Russia and Mongolia. Across China, ash species are found in a wide variety of climates and in all provinces except for Xinjiang and Tibet. However, they are much less abundant and geographically isolated compared to North American ash species. In North America, ash species are widely distributed across many interconnected forested ecosystems (MacFarlene, 2005).

Little was known about the EAB when it was first discovered in North America in 2002, but substantial advances in understanding EAB biology, ecology, and management have occurred since. In North America, the EAB completes its life cycle in one or two years. In Ohio and Michigan, adult emergence generally begins between early May (southern Ohio) and mid-June (central Michigan), and peaks from mid-June to early July. Adult emergence is typically complete by early August (Herms, 2013). Adults, which can live approximately three to six weeks, require one week of maturation feeding on the margins of ash leaves before mating begins, but cause insignificant defoliation, or the premature removal of ash leaves (Herms, 2013).

On average, females produce between 40 and 70 eggs, with long-lived females capable of producing more than 200 eggs. Eggs are individually laid within bark crevices or beneath bark flakes. The eggs then hatch within about two weeks. Upper portions of the canopy of large ash trees are usually colonized before the main trunk, which makes it difficult to detect early infestations (Herms, 2013). Neonate larvae bore through the outer bark and feed in galleries in the phloem and cambium. Serpentine galleries disrupt the ability of ash trees to transport nutrients and water, which eventually cuts through, or girdles, the branches and the trunk. As the larval density builds up within a tree, canopy thinning and branch dieback become noticeable. Once this happens, ash trees will typically die within two to four years (Herms, 2013). According to Herms et al. (2013), to date, all North American ash species encountered by EAB are susceptible to varying degrees. Specifically, black, green, and white ash are highly vulnerable, although white ash is less preferred. EAB adults are typically attracted to trees stressed by factors such as girdling, but healthy trees are colonized as well. Larval density and growth rate are typically higher on stressed trees as well (Herms, 2013). For all three tree species, mortality of trees ≥ 2.5 cm in diameter exceed 99% by 2010 in certain sites near the infestation epicenter in Michigan, and the signature of this mortality is apparent in large-scale forest inventory data (Herms, 2013). According to the same study, blue ash seems to be the most resistant North American ash species encountered by the EAB.

In addition to this, there is strong evidence that ash species are the only hosts of EAB in North America. In Herms et al. (2013), it was found that EAB adults landed on green ash almost exclusively, and field and laboratory studies showed that EAB larvae were unable to develop on species other than ash. As of twelve years ago when this paper was published, there had been no observations, even in heavily infested sites, of EAB colonizing non-ash species.

The EAB has detrimental impacts on forests across the eastern U.S. According to Poland and McCullough et al. (2006), surveys in southeastern Michigan in 2004 suggested that roughly 15 million ash trees in forested and urban areas were dead or dying as a result of the EAB, including green ash, white ash, and black ash. Blue ash also appeared to be less preferred by the EAB in this study. Estimates derived from the U.S. Department of Agriculture's Forest Inventory and Analysis (USDA FIA) database indicate that approximately 850 million ash trees in forests and riparian areas are threatened by the EAB in Michigan alone, and the projected loss of the resource in the state, based on stumpage value, would likely exceed $1.7 billion (Poland and McCullough, 2006). However, it is important to note that this data is nineteen years old as of 2025.

Continued spread of the EAB through North America threatens at least 16 endemic ash species, with at least six of these species being commercially important in terms of their wood, which is used for numerous products including tool handles, baseball bats, furniture, cabinets, crating, cardboard, and paper. In the eastern U.S., ash comprises nearly 7.5% of the volume of hardwood sawtimber, with an undiscounted stumpage value estimate to be at least $25.1 billion. Over eight billion ash trees occur across the U.S., and 40% of those trees fall into large-diameter classes with the undiscounted compensatory value of forest ash in the U.S. estimated to be approximately $282.3 billion (Poland and McCullough, 2006).

Economic impacts associated with the EAB also include the loss of ash from both urban and suburban landscapes. As mentioned, ash has been a popular choice for urban plantings since the 1940s. According to Poland and McCullough et al. (2006), in sample of nine cities in Southeastern Michigan conducted before the discovery of the EAB, ash cultivators comprised an average of 12% of all street trees. Further, data collected from seven U.S. cities (Atlanta, Baltimore, Chicago, New York, Oakland, Syracuse, and Philadelphia) showed that ash trees made up 14% of the total leaf area in the cities, with an estimated value of $565 million (Poland and McCullough, 2006). According to the same study, impacts of the EAB on urban trees could be even greater in north central states and areas of the western U.S., where ash has been widely planted. The undiscounted potential loss of all urban ash trees in the U.S. was estimated at $20-$60 billion in 2006, a figure that represents only cost of removal not replacement.

In general, long-term ecological impacts of the EAB are difficult to quantify but could be profound because ash species grow on a variety of soil sites across much of the eastern U.S. and are at risk of infestation by the EAB. Ash trees provide browse, thermal cover, and protection for a variety of wildlife species, and animals such as beavers, rabbits, and porcupines feed on the bark of young trees. Seeds, which are often produced in large amounts, are consumed by ducks, song and game birds, small mammals, and insects (Poland and McCullough, 2006).

Current management of the EAB seems to be focused on biological control, insecticide protection of high-value trees, and integrated efforts to slow ash mortality. Once efforts to completely eradicate the EAB were stopped, classical biological control methods came into focus. According to Herms et al. (2013), three species were being mass reared and released. These species included an egg parasitoid (*Oobius agrili*), a larval endoparasitoid (*Tetrastichus planipennisi*), and a larval ectoparasitoid (*Spathius agrili*). Asian parasitoids were released at certain sites in southeastern Michigan in 2007, and production increased annually and in 2012, over 350,000 wasps were released in 14 states. Several releases seemed to be successful in establishment. In addition to this, other studies have suggested that *T. planipennisi* may be successful at sites with young ash trees (Herms, 2013).

Insecticide trials conducted in the first few years following the discovery of the EAB in North American generated inconsistent results. Systemic insecticides used to control EAB included products that were either applied as soil injections or drenches, injected into the base of the trunk, or sprayed on the basal 1.5 m of the trunk (Herms, 2013). According to Herms et al. (2013), one product with the active ingredient emamectin benzoate provided up to three years of approximately 100% EAB control in some trials.

In addition to this, a pilot project, called SLAM, or Slow Ash Mortality, was initiated in 2008 to develop, implement, and evaluate an integrated strategy for EAB management. SLAM focused on slowing EAB population growth, which in turn slowed the ash tree mortality rate. Some management options included destroying EAB life stages before adults could reproduce, concentrating and eliminating adult EAB and their offspring, and reducing the amount of available food, otherwise known as ash phloem, available for the development of the EAB larvae (Herms, 2013). This integrated effort is not expected to completely eradicate an EAB infestation or terminate ash mortality; it instead allows managers and property owners to develop a long-term approach, rather than having to reach to huge numbers of dying, dead, and often hazardous trees.

There are also a number of public forest management and ash preservation strategies, as highlighted in Catanzaro et al. (2023), which provides more recent research on this issue. The first strategy is to know what you have to protect (or lose) by identifying ash in your forest and monitoring it for signs of EAB. Although millions of ash trees across the U.S. have succumbed to the EAB, trees are genetically rich organisms, and there may be individual ash trees across the landscape that express a genetic resistance to EAB, which are known as "lingering ash." By identifying and encouraging the regeneration of these lingering ash, such as through seed collection efforts, it may help provide a long-term solution to maintaining ash trees in U.S. forests. In addition to this, identifying female ash trees is also important. Only female trees produce seeds, which will happen once every three to five years. However, it is believed the females make up a relatively low number of the ash population, perhaps even less than 20 percent. To identify these trees, look for ash seeds, which can be found in the canopy of the tree and in the area around its base. Once a female ash tree has been identified, mark it with flagging or paint (Catanzaro, 2023).

Identifying preservation patches is also a strategy that has been used to protect ash trees. To do this, identify groups of twelve to fifteen ash trees within 1 to 3 acres of forest. Establishing preservation patches will increase pollination between trees and create a concentrated seed bank. These preservation patches should include a variety of diameters, ranging from 12-30+ inches, and be located on sites that ash prefer. Make sure to select trees with high vigor and full crowns in a dominant or co-dominant crown position in the main canopy forest and be sure to include a minimum of 60-75 percent of females within the selected group (Catanzaro, 2023).

However, preservation patches are likely to succumb to the EAB without insecticide treatment. Since treating all ash trees with an insecticide can be cost-prohibitive, treating preservation patches will maximize the value of these patches for preserving ash trees. Work with a forester, a certified arborist, or a person with a pesticide applicator license to apply direct stem injections of emamectin benzoate before the tree loses 50 percent of its crown. These treatments are weather dependent and should occur between May and July and are effective for up to four years (Catanzaro, 2023).

Finally, reach out to others within your area, such as neighboring landowners, public land managers, and conservation organizations, to communicate the efforts you are undertaking and encourage them to take on ash forest management and preservation practices. In addition to this, seek out Indigenous partnerships, as Indigenous communities have been particularly focused on maintaining ash because of the importance of the trees to their culture (Catanzaro, 2023). The efforts of Indigenous peoples and other organizations have provided inspiration and a road map for applying strategies to sustain ash for future generations.

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