The Emerald Ash Borer in North America

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The emerald ash borer (*Agrilus planipennis*), or EAB, is an invasive beetle from Asia that appeared in southeast Michigan, USA, and Ontario, Canada in 2002. It rapidly spread to the northern United States and southern Canada and became one of the most destructive invasive species in North America (Haack et al. 2002, McCullough and Mercader 2011). The beetle is specifically native to China, Korea, Mongolia, far eastern Russia, and Taiwan (Haack et al. 2002). While regarded as a pest in their native region, invaded regions have suffered devastation to their species of ash trees. The ash trees are known to be defenseless against the EABs, causing national devastation of one species (Haack et al. 2002, Klooster et al. 2018). The rapid loss of ash trees has enormous effects on the invaded ecosystems, the organisms living in those ecosystems, and the economy. Fortunately, many methods of control to limit environmental and economic strain are available.

The facts of where the invasion first occurred and when are well understood, however the specific mechanism of its initial arrival is only hypothesized. *Agrilus plannipennis* was first reported by the Entomology Department at Michigan State University, which is in central Michigan (Haack et al. 2002). Reconstruction of the emerald ash borer's progression narrows the epicenter of the invasion to Canton Township in Wayne County, located in southeastern Michigan (Siegert et al. 2014). Though the species was first identified in 2002, the earliest that they were found to be responsible for the death of a tree was in 1997 (Haack et al. 2002, Siegert et al. 2014). Because it typically takes up to 3 years for a tree to die from infection, the initial invasion most likely began in the early to mid-1990s (Haack et al. 2002). How they got there is still unknown, however from what is known about other insects similar to the emerald ash borer it can be assumed by the sudden appearance in a location EABs otherwise could not have traveled to on its own that its introduction was human-mediated. It is thought that because solid wood packing material associated with containerized shipping is a high-risk pathway for these types of insects, it is a likely pathway for the emerald ash borer (Siegert et al. 2014).

Early in their invasion, knowing if EABs would be able to use non-ash species as host organisms was paramount, but further studies deduced that it was unlikely that they would find any non-ash species suitable within North America (Anulewicz et al. 2014). Within China, the only host organisms reported are different species of the genus *Fraxinus,* the ash tree. In Japan, the genuses *Pterocarya*, *Juglans*, and *Ulmus* are also hosts (Haack et al. 2002). Though these trees have populations in China as well, the EABs of this region do not use non-ash trees as hosts (Haack et al. 2002). The same stands in North America, where several studies took place that introduced emerald ash borers to multiple species of cut logs, live trees, and even cut logs positioned inside of ash trees (Anulewicz et al. 2014). In all cases, female ash borers repeatedly choose ash to lay their eggs (Anulewicz et al. 2014). The study suggests that female ash borers can differentiate ash trees to choose as their breeding grounds (Anulewicz et al. 2014). The larvae of those that were not able to correctly identify ash rarely lived to adulthood (Anulewicz et al. 2014).

When laid on ash trees, after the eggs hatch, the larvae eat serpentine tunnels through the bark and feed on the phloem (Haack et al. 2002). Once adulthood is reached, they chew their way out of the tree leaving D-shaped holes (Haack et al. 2002). In North America, where ash did not have any selective pressures to build defenses against EABs, the effects were intensely destructive (Siegert et al. 2014). In its native range, the emerald ash borer is nothing more than a pest. The ash trees in these regions are more well-suited to deal with the bug, and so the only viable hosts are stressed or already declining individuals (Siegert et al. 2014). A comparison of phloem chemistry in ash trees from each region showed significant differences (Eyles et al. 2007). North American ash lacked hydroxycoumarins and contained less pinoresinol glucoside and pinoresinol dihexoside, chemicals that are correlated with deterring insect feeding in other plants (Eyles et al. 2007).

Due to the lack of evolutionary defenses in North American ash trees, *A. planipennis* kill their host organism in large quantities, causing dramatic changes to the environments they inhabit. The mortality of infected black, green, and white ash was over 99% by 2009, of which 60% took place over 5 years (Klooster et al. 2018). The seed banks of the ash are depleted and only saplings that are too small to be infested survive in the invaded range (Klooster et al. 2018). The simultaneous appearances of gaps in the canopy left by dead and dying ash allow for intense changes to occur in the understory, such as the spread of plants that would otherwise be shade intolerant and the potential facilitation of invasive woody plant species (Klooster et al. 2018, Schrader et al. 2021). The massive loss of ash trees in the invasion area has also been linked with changes in air quality, enough to suggest that human mortality due to cardiovascular and lower respiratory illnesses increased as a result of emerald ash borer invasion (Schrader et al. 2021, Donovan et al. 2013). Additionally, the loss of ash negatively impacts carbon capture (Schrader et al. 2021). Because of the size difference between old and new trees, even replacing the lost ash will not make up for the loss in air quality long term (Schrader et al. 2021). The emerald ash borer invasion has consequences for the individual species within the ecosystems.

Populations inhabiting invaded regions can be affected either by a relationship to the emerald ash borer or its host organism. For example, several species of insectivorous birds saw an increase in numbers following the EAB invasion (Koenig et al. 2012). It is theorized that this is a result of a relationship between both the insect and the host, as they experienced an increase in food resources in the form of the emerald ash borer and nesting materials in the form of ash substrate (Koenig et al. 2012). Additionally, as *A. planipennis*'s populations increased, native monophagous arthropods in the region saw a spike in population due to the presence of now weakened host trees that they could colonize easier (Gandhi and Herms 2010). This spike was followed by a decline in populations after the trees reached advanced decay and were no longer suitable (Gandhi and Herms 2010). Multiple studies agree with the conclusion that there is a general decline in arthropod richness in infested areas as a result of the invasion (Gandhi et al. 2014, Ulyshen et al. 2011, Jennings et al. 2016).

Funding for small- and large-scale damage treatment, preventative treatment and research, and other indirect effects of emerald ash borer invasion have severe negative impacts on the economy. In 2010 it was estimated that the treatment, removal, and replacement of ash trees would cost 10.7 billion dollars (Kovacs et al. 2010). In 2023, the same methodology was used to estimate that the US Army Corps of Engineers would spend 112 million dollars from 2006-2026 on the 12.5 million acres that they are responsible for (Kovacs et al. 2010, Pfisterer et al. 2023). The municipal forest budget doubled during the peak years of the EAB invasion, 5-8 years after confirmation per state (Hauer and Peterson 2017). The budget nearly tripled around year eight (Hauer and Peterson 2017). Resources that would have otherwise gone towards pruning, watering, fertilization, and safety training were diverted towards costs of EAB, most notably the doubled tree and stump removal costs caused by the invasion (Hauer and Peterson 2017). The labor market also saw negative effects associated with EAB invasions (Jones 2020). It is estimated that there was an average drop of 1% in wage earnings following EAB detection for a total loss of 11.8 billion in US labor earnings over 10 years (Jones 2020).

To cut economic losses due to the emerald ash borer, resource management must be prioritized (Vannatta et al. 2012). Short-term and long-term considerations must be made to find the combination of methods that will lead to the most economically effective course of action (Vannatta et al. 2012). Many policymakers look at mortality rates of infested ash and give up on treatment, opting to wait to remove dead ash or preemptively remove non-infested ash and replace it with non-ash (McCullough 2020). Economic analysis concludes that preemptive removal of ash may be a strong option for some areas, however, removal is certainly not the best option in all areas; tree health and cost-benefit analysis should be done first to decide what level of treatment is best for the individual circumstances (Vannatta et al. 2012). Buying time for the gradual replacement of ash and the development

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of control methods is the most considered economically practical approach, and while that may include preemptive removal, more passive approaches are discouraged (McCullough 2020). It is recommended that in most cases preventative measures are taken regardless of low invasion probability and/or predicted effects, specifically when the emerald ash borer has been detected within 10-15 miles (Berry et al. 2017, Vannatta et al. 2012).

Besides preemptive removal and replacement, the most notable preventative measures include specialized insecticide treatments which can be applied at the base of the tree or directly into the trunk. Trunk injections of the insecticide emamectin benzoate have been found to reduce EAB larvae found in trees by almost 100% and can protect the tree for two years before another injection is needed, though these often require a labor charge as special equipment is required for trunk injections (Smitley et al. 2010). Imidacloprid is a basal drench that is absorbed through the roots and is a good alternative for homeowners who do not have the equipment available to inject insecticide directly into the trunk (Smitley et al. 2010b). If an infestation is treated within the first year of establishment, only 10% of trees in the area need to be treated to effectively slow ash mortality (McCullough and Mercader 2011). Using this model, detection is one of the greatest factors in the cost-benefit of insecticide treatments (McCullough and Mercader 2011).

Infestations do not show external signs until two years after establishment, and most are not detected until about 4 years later when ash mortality begins to rise. Therefore alternative methods of detection are required (McCullough 2020). If treatment is started four years after establishment, the most economically advantageous level of treatment is 20% of trees in the area, double what would have been used had the infestation been detected sooner (McCullough and Mercader 2011). The main methods of detection include girdled tree traps, peeling, and canopy traps (Marshall et al. 2009). Girdled trap trees are ash trees that have a section of bark removed around the circumference of the tree (McCullough 2020). Because they target weakened trees in their native range, girdled trees are especially attractive to ovipositing EAB females (Siegert 2014, McCullough 2020). Peeling is a labor-intensive process of randomly removing sections of ash trees and peeling back thin layers to detect EAB larvae (Marshall et al. 2009). Canopy traps are any traps that are hung from trees that are baited with a combination of chemicals intended to attract adult emerald ash borers (McCullough 2020). Results of different trap tests conclude that while girdling trees vary in effectiveness depending on region and species of ash, canopy traps are effective in all regions (Marshall et al. 2009). As such, a focus on detecting adults using canopy traps is recommended, with multiple girdled trap trees at each site to ensure that overall detection is not hindered (Marshall et al. 2009). Early detection using these methods will allow for the most effective preventative measures to be taken in the infested areas, leading to the best course of action overall.

Despite the emerald ash borer's relatively short history in North America, it has made quite an impact. Massive amounts of research have been done to attempt to catalog its history including its initial spread, cumulative effects, and the most cost-effective methods of control (Haack 2002, Klooster 2018, McCullough 2020). It is responsible for economic and environmental strain, all of which can be traced back to a single point in southeastern Michigan (Haack 2002, Klooster 2018). Though it is unlikely its spread will be stopped, control methods aid in softening the environmental and economic blows that it will bring in the future (McCullough 2020).

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