Twenty Million Ash Trees Later: Current Status of Emerald Ash Borer in Michigan

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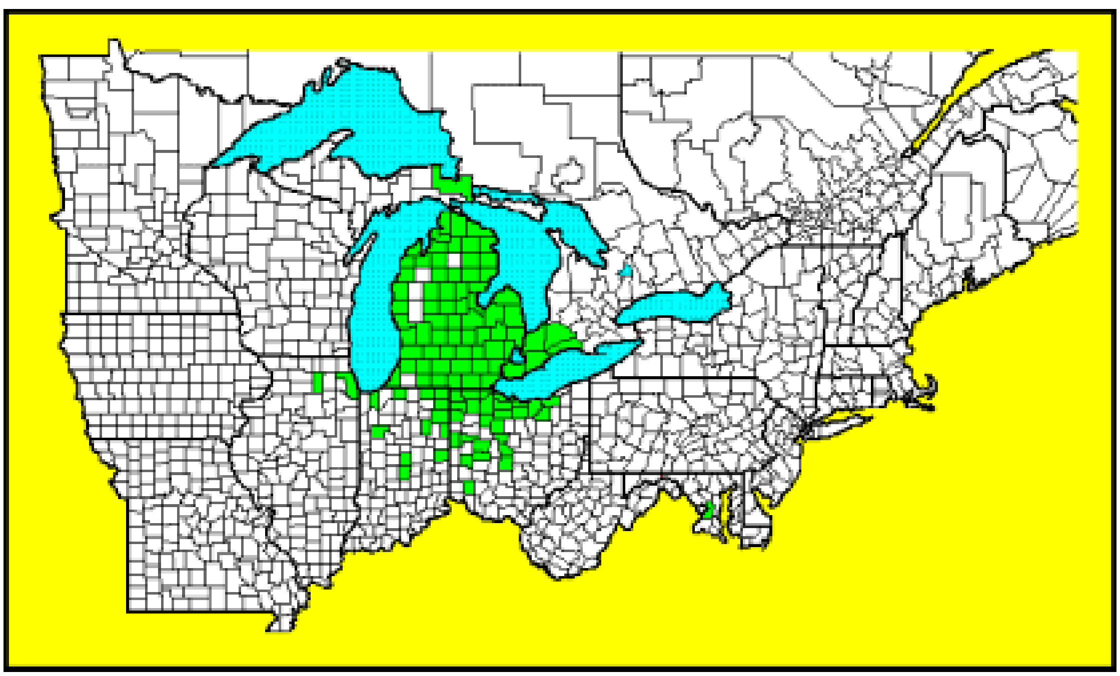
Since its discovery in 2002, the emerald ash borer (EAB), *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), appears to be living up to expectations and predictions about its potential spread and destruction of ash trees, *Fraxinus* spp., in North America. The initial discovery and identification process took several months and little was known about this relatively obscure Asian woodborer at the time (Haack et al., 2002). In the Asian literature, there were species descriptions and two brief accounts with general information about its biology in China (Chinese Academy of Science 1986, Yu 1992). Once EAB had been identified, regulatory agencies, resource managers, and research scientists quickly took action. Scientists began to study attack patterns and signs and symptoms of infestation in dead and dying trees. Based on visual symptoms, damage and delimitation surveys were conducted by personnel from natural resource and regulatory agencies from throughout the Upper Midwest. Initial results suggested that roughly 5 to 7 million ash trees in forests, woodlots and urban settings were dead or dying as a result of EAB infestation in a six-county area of southeastern Michigan. It appeared that EAB could spread throughout the range of ash in North America and cause considerable economic and environmental damage. Thus, a quarantine was quickly enacted by the Michigan Department of Agriculture restricting movement of ash from the six infested counties (Haack et al. 2002).

Over the subsequent four-and-a-half years, considerable progress has been made by research scientists studying the biology, impact, and management of EAB and enormous efforts have been invested in detection surveys and containment activities. Federal quarantines were imposed by the Canadian Food Inspection Agency (CFIA) in Canada in 2002 and by the USDA Animal and Plant Health Inspection Service (APHIS) in the US in 2003. In both countries, quarantines regulate movement of ash logs and ash nursery stock. In the case of firewood, all hardwood species are regulated because inspectors cannot easily identify the species of tree that was cut. In addition infested states imposed internal quarantines that further restrict within-state movement of ash. Nevertheless, EAB has continued to spread naturally and new outlier infestations, many of which resulted from human-assisted movement of infested material prior to the quarantine, have been detected each year.

Current Status of Infestations. Currently, the generally infested "core" area includes 21 counties in Southeast Michigan and extends into Ohio and Ontario, Canada. In addition, numerous outlier infestations have been found throughout Michigan's Lower Peninsula, Ohio, Indiana, and Ontario. An outlier in Maryland that originated from infested Michigan nursery stock was first detected in 2003 and is still under eradication. Isolated infestations were detected in two counties in the Chicago area of Illinois in the summer of 2006. As of 1 December 2006, APHIS revised the federal quarantine to include the entire states of Ohio, Indiana, and Illinois, in addition to the Lower Peninsula of Michigan (APHIS 2007). The 21 Michigan counties in the core infested area are regulated under a state level I Quarantine based on the general presence of EAB. The remainder of the Lower Peninsula is under level II Quarantine based on several isolated occurrences of EAB in a contiguous area. Movement of ash is restricted from the entire Lower Peninsula (i.e., both level I and level II Quarantine areas) and is further restricted within Michigan from level I areas to level II areas (MDA 2007). In Ohio, the state quarantine regulates 22 entire counties and portions of 4 others. Infested ash tree materials and hardwood firewood can move within but cannot leave contiguous quarantined areas (ODA 2007). The State of Indiana has a three-layered quarantine: Level I regulates the entire county in which EAB is found, Level II further regulates movement of ash within a county from townships in which living specimens of EAB are found, and Level III regulates movement of ash into and out of the entire state. There are currently 12 counties under Level I quarantine in Indiana



Counties in Illinois, Indiana, Maryland, Michigan, and Ontario where EAB has been found as of 21 January 2007.

(Purdue University 2007). In Illinois, a state quarantine regulates all of Kane County, infested portions of Cook County, and any other areas of the state where the presence of EAB is confirmed in the future (IDA 2007).

The area infested with EAB now exceeds 40,000 square miles in Michigan, Ohio, Indiana and Ontario and it is estimated that the beetle has killed more than 20 million ash trees in the core infested area of the US (EAB Info 2007). Attacked trees include green ash (*F. pennsylvanica*), white ash (*F. americana*), black ash *(F. nigra*), blue ash (*F. quadrangulata*), and pumpkin ash (*F. profunda)*. Blue ash appears to be less preferred by EAB but is attacked as other nearby ash species succumb (Agius et al. 2005). Although stressed trees may initially be preferred or less resistant to EAB attack, once beetle densities build, even the healthiest ash trees are attacked and killed. Large ash trees may die within 3 to 4 years of initial infestation and saplings or small trees may die after a single year. Estimates derived from USDA Forest Service Forest Inventory and Analysis data indicate that nearly 850 million ash trees in forests and riparian areas are threatened by EAB in Michigan alone. Projected loss of the ash resource in Michigan, based on stumpage value, would likely exceed $1.7 billion (Federal Register 2003).

Containment Activities. The national Emerald Ash Borer Science Advisory Panel recommended implementation of a long term program to contain EAB, reduce population densities, and eventually eradicate this exotic invasive pest (EAB SAP 2002, 2004, 2005, 2006). Federal, state and provincial regulatory and natural resource agencies implemented programs that focus on preventing artificial movement of EAB, detecting and eradicating outlier populations and containing the major infestations in Michigan and Ontario. These programs emphasize education and enforcement of quarantine regulations to prevent artificial spread of EAB. In Michigan, mandatory inspections are carried out at the Mackinac Bridge, a key transportation gateway between Michigan's Upper Peninsula and the quarantined areas of the Lower Peninsula. Material in violation of the quarantine is confiscated and destroyed. In addition, random firewood inspection blitzes are carried out along targeted major thoroughfares. Detection and delimitation surveys are also major components of federal and state regulatory programs. Initially, surveys relied on visual signs and symptoms of attack including D-shaped exit holes made by EAB adults chewing out of the tree, branch dieback, and epicormic shoots. More recently, based on research demonstrating that girdled ash trees are significantly more attractive than healthy ash trees (Poland et al. 2004, 2005), Michigan, Ohio and Indiana have implemented the use of girdled trap trees to aid in statewide detection surveys.

Eradication cuts have been carried out at several outlier sites in Michigan and Ohio, as well as in Indiana. At these outlier sites, all ash (> 1 in diam.) within 0.5 miles of an infested tree are felled, chipped, and then the chips are burned at an electricity co-generation plant (Poland and McCullough 2006). Stumps are ground or treated with herbicide to prevent sprouting. It has been found that ash trees within 0.5 miles of a known infested tree may contain EAB larvae, despite having no external symptoms of infestation (McCullough et al. 2005a). In 2004 and 2005, MDA conducted statewide detection surveys using over 10,000 girdled trap trees. In 2006, detection trees were concentrated in the Upper Peninsula and in the gateway areas of southwestern Michigan and the northern portion of the Lower Peninsula near the Mackinac Bridge. Eradication activities are currently directed at the Upper Peninsula and at outlying locations located in the gateway area of the Northern Lower Peninsula. In the Lower Peninsula, the eradication and containment program supports voluntary actions of residents and municipalities to apply insecticides, remove infested trees, harvest ash, favor alternate species, develop value added activities, and build markets for utilizing ash materials (MDA 2007).

The Ohio Department of Agriculture is using methods similar to those used in Michigan to manage EAB from Ohio. A statewide survey using girdled detection trees is conducted to locate new infestations. In 2006, over 10,000 detection trees were used in Ohio. Plant pest inspectors and surveyors work to delimit the area of each point infestation and determine and prioritize sites for eradication. In order to effectively destroy the insect at the selected eradication sites, every host tree within 0.5 mile of an infested tree is cut and chipped into small pieces (1-inch diameter or less) before being removed and burned at a power plant in Flint, Michigan. (ODA 2007).

The Indiana Department of Natural Resources (IDNR) conducts surveys throughout Indiana. In 2006, approximately 2,485 detection trees were used for surveys throughout the entire state of Indiana targeting locations within 2 miles of high risk sites such as campgrounds, sawmills, and landsape nurseries. The IDNR supports the efforts of individuals and communities to remove trees, dispose of woody debris and encourages ash wood utilization using portable sawmills (Purdue University 2007).

The Illinois Department of Agriculture (IDA) plans to remove approximately 250 infested trees in parts of Kane and northern Cook Counties. IDA has chosen the strategy to remove only infested trees rather than the more severe and costly measure of cutting all trees within the vicinity because eradication cuts have not been completely effective in the neighboring states of Michigan, Ohio and Indiana where EAB has been repeatedly detected beyond the control zone. It is hoped that removal of the infested trees will help reduce populations and contain the insect's spread while allowing time for development of a scientific remedy that could control EAB without having to cut down all of the ash trees.

With the current expansion of the infested area and limited resources and tools for detection and eradication, it is evident that complete eradication is unlikely under the current program. New tools are critically needed for detection and control and for long-term management should eradication fail.

Research Activities. Numerous research scientists from government agencies and universities have been actively involved in research on EAB. Summaries of the research are reported each year at the Emerald Ash Borer Research and Technology Development Meeting and the Proceedings are published annually (Mastro and Reardon 2004, 2005, 2006, 2007). These proceedings highlight the wide range of on-going research in the areas of 1) Behavior and Biology (including genetics, host and mate location, flight capability, spread models, and understanding the 2 yr life cycle); 2) Host Relations (including wound defenses, rural ash resources, models to reduce EAB populations through reducing ash, patterns of mortality and dieback, and changes in forest composition); 3) Chemical Control (including within tree distribution of systemic insecticides, oral ingestion effects on adults, comparison of different insecticides, imidacloprid soil drenches, trunk injection studies over four years, and neo-nicotinoids as trunk sprays); 4) Biopesticides (including *Beauvaria bassiana*, and spinosad); 5) Biological Control (including host preferences of Chinese wasp genera, lab studies with the parasitic wasps *Oobius agrili*, *Tetrastichus planipennisi*, and *Spathius agrili*); 6) Survey (including firewood survey, trap height and design, multistate comparison of different detection tools, multicomponent traps, microhabitat selection patterns, chemical ecology, timing and placement of girdled trees, trap trees with methyl jasmonate or manuka oil, remote sensing, and using nests of *Cerceris fumipennis*, a native wasp that provisions its nests with buprestid beetles, to locate EAB populations); and 7) Regulatory and Outreach (including the use of lethal trap trees, evaluating chipping, debarking, and herbicide treatments, firewood movement and public awareness).

Biology and Life History. Research on the life cycle of EAB in North America demonstrates that it is generally quite similar to that described by Chinese scientists (Chinese Academy of Science 1986, Yu 1992). Adult beetles chew their way out of the tree in early summer leaving D-shaped emergence holes. In southeast Michigan adults begin emergence in mid-May at roughly 230-260 degree days, using a base 10°C threshold (Brown-Rytlewski and Wilson 2005) and adult activity peaks from late June to early July (Cappaert et al. 2005). Beetles feed on ash foliage causing superficial esthetic damage that is not very evident until it is quite extensive. Adults feed for 5-7 days before mating begins and females feed for an additional 5-7 days before beginning to lay eggs in bark crevices. Each female can lay 50 to 90 eggs during her lifetime. Beetles continue to feed and mate during the remainder of their life span, which can last from 3-6 weeks (Bauer et al. 2004; Lyons et al. 2004). Eggs hatch within two weeks and the larvae feed in the phloem and cambium from July through autumn. The larvae create serpentine-shaped galleries or feeding tunnels that are packed with frass. Larvae pass through four instars (Cappaert et al. 2005) and most larvae complete feeding in October or November. Pre-pupae overwinter in cells about 0.5 inches deep in the sapwood or outer bark. Pupation begins in mid-April and continues into May, followed by adult emergence roughly 3 weeks later. Some EAB, however, overwinter as young larvae rather than as prepupae, and then require a second year of development before emerging as adults (Cappaert et al. 2005).

Dispersal and Spread. Dendrochronological research using cross-dating techniques to determine year of initial infestation for cores collected from trees throughout the infested area, has demonstrated that EAB had been established for at least 10 years before detection (Siegert et al. 2007). It appears that tree mortality has advanced through the infested core area at a rate of approximately 10 km/year. At outlier sites, EAB galleries have been found on trees as far as 750 m from trees or logs with emergence holes; however most new attacks were on trees within a 100-200 m (McCullough et al. 2005a). Laboratory studies have been conducted to evaluate EAB flight capability using computer-monitored flight mills with tethered EAB adults. Results indicate that beetles are capable of flying up to 5.2 km in 40 hours and can achieve flight speeds of 3.5 mph. Females flew twice as far as males in 24 hr and mated females flew twice as far as unmated females. The average distance flown by mated females in 24 hrs was 1.7 km (Taylor et al. 2006). More recently, laboratory studies using digital video monitoring of EAB in a free flight room suggest that flight mills may interfere with beetle flight mechanics, reduce potential flight speed, and underestimate flight capability (Taylor et al. 2007). Several research groups have been working on developing models of EAB spread using estimates of natural and artificial spread as well as host inventory data (BenDor et al. 2006, Iverson et al. 2007).

Survey and Detection. Numerous research studies have been conducted to evaluate various trapping techniques and attractants for detection of EAB. The number of EAB adults captured by sticky bands and the density of larvae were compared on large (6 ft long) ash trap logs and on healthy and girdled ash trees as well as trees treated with herbicide, various lures and baits including ethanol and manuka oil, or with the stress-eliciting hormone methyl jasmonate. Studies have been conducted at numerous sites over a four-year period. Girdled (stressed) trap trees were consistently and significantly more attractive than healthy trees or cut logs (Poland et al. 2004, 2005). Although trap trees have proven to be useful in detecting previously unknown EAB infestations, they are not ideal for large-scale survey efforts. Locating suitable trees can be difficult in some areas, girdling and peeling trees is labor-intensive, and the attractive radius of a trap tree is unknown. An effective lure and trap would be much more practical for EAB detection programs. EAB adults respond to olfactory cues such as blends of ash volatiles (Poland et al. 2004, 2005) and to color or other visual stimulants (Francese et al. 2005a, 2005b, 2005c). Researchers are continuing to work on the development of traps and attractive lures (Crook et al. 2005; Francese et al. 2004, 2005a; Otis et al. 2005; Poland et al. 2005).

Insecticidal Control. Research is also underway to develop and evaluate other critically-needed management tools to help suppress populations as part of the containment effort. Insecticides appear to be a viable option to reduce EAB populations and protect high-value urban and shade trees within the quarantined areas. Recent studies have demonstrated that widely available insecticides including cover sprays and trunk and soil injected products can substantially reduce EAB larval density compared with untreated trees. Effectiveness varies depending on insecticide product, injection method, timing, tree size and the extent of previous EAB injury (McCullough et al. 2003, 2005; Smitley et al. 2005). While none of the products tested provided 100% control of EAB, ash trees are relatively resilient and can tolerate minor damage from EAB. However, in areas where EAB population pressure is sustained and high, annual treatment would be necessary and still might not provide guaranteed control.

Biological and Microbial Control. In woodlots and forested areas, insecticidal control is neither economically viable nor environmentally desirable. Chinese or indigenous natural enemies and control with pathogens or microbial insecticides may have potential for suppressing populations of EAB in woodlots and natural areas. Studies in Michigan have revealed extremely low rates (< 1%) of parasitism by native natural enemies (Bauer et al. 2005). Explorations in China, however, revealed significant parasitism by three species of parasitic wasps: the previously known *Spathius agrili* (Gould et al. 2005), and two newly discovered species, *Tetrastichus planipennisi* and *Oobius agrili* (Liu et al. 2003, Bauer et al. 2005). Parasitism by the latter two species accounted for approximately 60% mortality of EAB at a field site in China (Bauer et al. 2007). Methods have been developed for laboratory rearing of all three species of Chinese parasitoids, and their efficacy against EAB and impacts on non-target species have been evaluated in the laboratory (Bauer et al. 2007; Liu et al. 2007, Gould et al. 2007). Plans are underway to evaluate controlled field releases of these parasitoids pending approval of release permits.

The microbial insecticide Botanigard, formulated with the fungus *Beauvaria bassiana,* has been evaluated in laboratory and field studies. It has been found to be highly virulent against EAB in standardized laboratory trials. Pre-emergent trunk sprays resulted in >80% mortality due to infection of adults as they attempted to chew out of the trees (Liu et al. 2005). Trees sprayed with Botanigard also had significantly lower larval densities and crown dieback (Liu et al. 2006). Similarly, mortality was significantly higher for adults fed leaves collected from sprayed trees compared to unsprayed trees. New research will test specific strains and toxins of the insect pathogenic bacterium, *Bacillus thuringiensis*, against EAB.

Future Outlook. Restoration programs have been initiated in Michigan, Ohio, and Indiana to assist communities and property owners affected by EAB. Grants are available to municipalities within the quarantined counties to assist in planting non-host trees. While these efforts help, only a fraction of the dead urban ash trees in southeastern Michigan have been replaced.

The scope of EAB damage in Michigan indicates that successful containment of EAB will be necessary to protect ash in urban and forested settings across North America. This task is especially difficult given the scale of the infestation and the lack of effective tools for detection and control. Public education and outreach activities help to prevent artificial spread of EAB and build support for containment and control efforts. Sustained operational programs and outreach will be required to help contain and slow the spread of this pest. Long-term management using widespread regional control will be required if the North American ash resource is to be protected from EAB. Restoration programs that emphasize a variety of trees will minimize the impact that a particular insect or disease may have on the landscape and could mitigate the threat of future invasive species.

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