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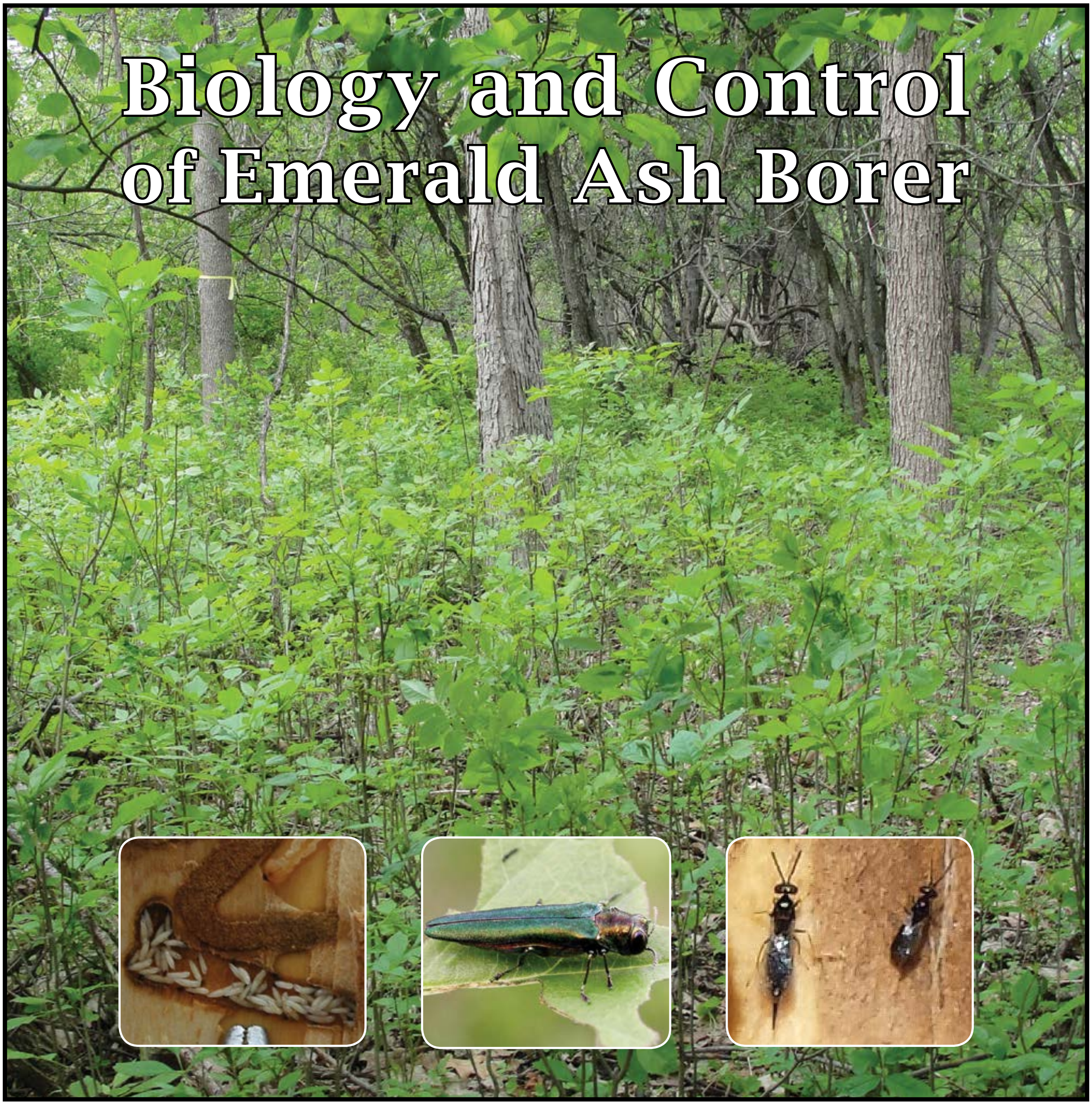
Non-native Pest

Biology and Control of Emerald Ash Borer



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CHAPTER 4: OTHER OPTIONS FOR EMERALD ASH BORER MANAGEMENT: ERADICATION AND CHEMICAL CONTROL

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THE EARLY YEARS — COULD EAB HAVE BEEN CONTAINED OR ERADICATED?

Following identification of emerald ash borer (*Agrilus planipennis* Fairmaire) (EAB) (Coleop.: Buprestidae) in Michigan in July 2002, state and federal regulatory officials began surveys to delimit the infestated area in the greater Detroit area (Cappaert et al., 2005; Herms and McCullough, 2014). It rapidly became clear that EAB was causing substantial ash mortality and decline, but there was little information available on even basic aspects of EAB biology. No species of *Agrilus* beetles were known to produce long range sex or aggregation pheromones, and there were certainly no traps or lures available for EAB surveys. A high proportion of ash in the suburban municipalities northwest of Detroit was dead or dying, so regulatory personnel conducted visual surveys along transects radiating out from the known infestation. Survey crews checked ash trees for symptoms such as canopy dieback, bark cracks (revealing EAB larval galleries), and epicormic sprouts on large branches or the trunks of infested trees. By autumn 2003, six counties in southeast Michigan were quarantined and at the time, regulatory officials believed the quarantine boundaries extended well beyond the actual infestation (Cappaert et al., 2005; Poland and McCullough, 2006; Siegert et al., 2014).

Along with visual surveys, officials in Michigan initiated trace-backs and trace forwards in 2002 and 2003 to track ash nursery trees shipped from the infested area. Ash, primarily cultivars of green ash (*Fraxinus pennsylvanica* Marshall) and white ash (*F. americana* L.) were abundant in most commercial nurseries in southeast Michigan when EAB was identified. Ash species were popular because they tolerate the often stressful conditions found in urban environments (Schoon, 1993; MacFarlane and Meyer, 2005; Poland and McCullough, 2006) and were commonly planted in commercial landscapes, along roads and highways, as well as on private residential property. Ash trees near sawmills that processed ash logs, along with ash in campgrounds and tourist destinations likely to attract people with firewood, were also intensively surveyed.

Eradication of EAB within the six counties in southeast Michigan was never considered a realistic option, given the millions of ash trees in urban, residential, and forested areas and the geographic extent of the infestation. Landscapers had begun treating some declining ash trees in the Detroit area with insecticides even before EAB was identified in 2002. Treatment efficacy varied but none provided 100% control (McCullough et al., 2005, 2006; Herms et al. 2014). Moreover, there were no practical or economically feasible means to treat the millions of ash trees growing in the affected areas (Cappaert et al., 2005; Herms and McCullough, 2014).

It was clear, however, that continued spread of EAB would threaten more than 8 billion ash in U.S. forests along with millions of ash in urban landscapes. A strategy similar to that applied to large wildfires was proposed by scientists and regulatory officials appointed to the EAB Science Advisory Panel. Nearly complete mortality of ash within the infested area, which was already underway, would eventually lead to a substantial drop in EAB density in the core of the infestation and over time, the severely affected area would expand. If the advancing front of the infestation could be contained or at least slowed below the rate at which the core expanded, the EAB population would presumably collapse as fewer and fewer host trees became available. Regulations to restrict transport of ash trees, logs, firewood, and related materials out of the quarantined area were part of the effort to contain the infestation (Federal Register, 2003; Herms and McCullough, 2014).

Officials initially considered removing ash trees in a 5-10 km band around the infested area to deplete potential hosts for dispersing EAB adults. This strategy, referred to as a firebreak or an ash-free zone (Herms and McCullough, 2014), was never attempted in the United States. As surveys continued, the extent of the main EAB infestation in southeast Michigan and northwest Ohio became apparent. Officials realized that the inability to accurately delineate the infestation, the logistical problems of establishing an ash-free band, and the costs of creating such a band were insurmountable. Canadian officials did attempt to establish an ash-free zone in Ontario in 2004, but infested trees were soon found beyond this zone and the firebreak idea was abandoned.

Along with efforts to contain or slow expansion of the main EAB infestation, officials determined that localized “outlier” infestations beyond the quarantine zone would be aggressively treated with the goal of eradication. These satellite populations of EAB, often referred to as “outliers,” originated from long distance transport of infested ash nursery trees, logs, or firewood. Large scale field studies that involved systematically felling and debarking ash trees around a known origin showed that while EAB females laid eggs on trees at least 750 m from their emergence point, most eggs were laid within 100 m of the adult beetles’ emergence point (Mercader et al., 2009; Siegert et al., 2010). Regulatory officials determined that eradication projects would encompass an area bounded by a perimeter 800 m beyond the furthest ash tree known to be infested. This distance represented a compromise between the need to eliminate infested but non-symptomatic trees and logistical and economic constraints associated with such a substantial undertaking (Herms and McCullough, 2014). Within the eradication project area, every ash tree greater than 2.5 cm in diameter was felled, sectioned and transported to a disposal yard where the material could be chipped. Numerous outlier sites, primarily in Michigan, Ohio, and Indiana, were targets for eradication between 2003 and 2006 (Cappaert et al., 2005; Herms and McCullough, 2014). The most extensive EAB eradication project occurred in Maryland, where more than 42,000 ash trees were removed between 2003 and 2009 across an area that eventually encompassed nearly 70 km^2 (MD-DNR, 2014).

Eradication efforts, with the exception of Maryland, were abandoned in 2006, in part because funds for eradication, surveys, and related activities were decreasing, but also because outlier populations of EAB continued to be found well beyond the quarantine boundaries (GAO, 2006; Herms and McCullough, 2014). Between 2004-2006, state regulatory officials in Michigan, Indiana and Ohio established grids of small (≈ 15 cm diameter) ash detection trees, typically in right-of-ways along highways and roads (Rauscher, 2006; Hunt, 2007). These trees were girdled in spring, making them highly attractive to adult EAB during the summer, then were debarked in autumn or winter to determine if larvae were present (McCullough et al., 2009). Using girdled trees, along with increased public awareness of EAB, led to the identification of several previously unknown EAB infestations.

As scientists learned more about EAB, it became clear that visual surveys to identify infested trees for detection or to delineate an infestation were inadequate. External evidence of EAB infestation is not apparent until larval densities reach moderate or high levels, while recently infested trees with low larval densities exhibit few, if any, symptoms (Poland and McCullough, 2006; Poland et al., 2011). Moreover, in relatively healthy trees, most EAB larvae require two years to complete development (Siegert et al., 2010; Tluczek et al., 2011). Therefore, trees are usually infested for at least 3-4 years before any external symptoms become apparent. More recent evidence also suggests a small proportion of mature, mated females likely disperse relatively long distances, despite an abundance of suitable host trees in the local vicinity (McCullough et al., 2011a; Mercader et al., 2012), contributing to the difficulty of delineating or detecting new infestations. Eradication activities undoubtedly eliminated a very high proportion of infested trees and developing larvae, but it remains unclear as to whether any projects were successful. Infestations near eradication areas could represent reproduction by EAB that had already dispersed beyond the boundaries of a project area or may reflect subsequent expansion or immigration of beetles from other populations (Herms and McCullough, 2014).

SYSTEMIC INSECTICIDES, EAB, AND ASH TREES

Once eradication efforts ceased, landowners and residents were left to deal with ash trees and EAB on their own. Early studies soon after EAB was identified in North America showed spraying the foliage and upper canopy of landscape trees with relatively persistent insecticides (e.g., bifenthrin, cyfluthrin) could effectively control adult EAB and protect trees (McCullough et al., 2005, Herms et al., 2014). Sprays were not popular, however, because of problems such as drift and possible environmental contamination, potential effects on non-target organisms such as pollinators and beneficial predatory insects, and possible applicator exposure. In addition, adequate coverage of the upper canopy of large trees was difficult and trees in many locations could not be reached with spray equipment.

Fortunately, options for protecting landscape ash trees in urban areas from EAB have progressed substantially in the past decade. Systemic insecticides are now used to treat the vast majority of ash trees in urban areas where EAB is present. These products are applied by injecting the insecticide into the outer sapwood (xylem) around the base of the trunk of the tree (e.g., emamectin benzoate, imidacloprid, azadiractin) or applying it to the soil around the base of the tree for uptake by roots (e.g., dinotefuran, imidacloprid) (Herms et al., 2014). Products with dinotefuran, a highly soluble compound, can also be applied as a basal trunk spray (McCullough et al., 2011b; Herms et al., 2014). Trees transport the insecticide in xylem tissue from the base of the tree up to branches and foliage in the canopy (Sur and Stork, 2003; Mota-Sanchez et al., 2009; Tanis et al., 2012). Systemic products eliminate most problems associated with cover sprays of insecticides. They must be applied, however, before high densities of EAB larvae injure the vascular system of an ash tree (Herms et al., 2014).

When EAB was first identified, only a few systemic insecticide products were available. Imidacloprid was the active ingredient in most of those products and was applied either as a soil drench or by injecting the product into the base of the tree. Field trials with these products, however, yielded inconsistent results (McCullough et al., 2006; Herms et al., 2014). Products protected trees from EAB injury in some sites, but in other sites, the same treatments were not effective. In some studies, EAB damage continued to increase, despite annual insecticide applications. Treated trees sometimes lived a few years longer than untreated trees, but still succumbed to EAB, despite the investment in treatment (McCullough et al., 2006).

Research continued and new systemic insecticides became available, application technology improved, and our understanding of how to optimize these treatments advanced considerably. A product with the active ingredient emamectin benzoate, first registered in the United States in 2010, is the most effective systemic insecticide currently available for EAB control (Smitley et al., 2010; McCullough et al., 2011b; Herms et al., 2014). Many field trials showed that emamectin benzoate consistently provided 2-3 years of nearly complete EAB control, even when local EAB densities were high (Smitley et al. , 2010; McCullough et al., 2011b; Herms et al., 2014). Many cities in the United States, as well as private landowners, are now protecting valuable ash trees from EAB with this product. Economic analyses showed costs of protecting landscape trees with the emamectin benzoate product to be substantially lower over time than the costs of removing trees killed by EAB (McCullough and Mercader, 2012; Van Atta et al., 2012). Treating a portion of the trees may also slow the rate of EAB population growth in a localized area (Mercader et al., 2011a,b; McCullough and Mercader, 2012). Insecticides with azadirachtin, a compound derived from the neem tree (*Azadirachta indica* A. Juss.) as the active ingredient, have recently become available for EAB control (McKenzie et al., 2010; Herms et al., 2014) in the United States and Canada and provide 1-2 years of protection, depending on local EAB density. Unlike other insecticides, which are toxic to EAB adults and larvae, azadirachtin products affect EAB reproduction and development of young larvae (McKenzie et al., 2010; Kreutzweiser et al. 2011, DGM, unpubl. data). Basal trunk sprays of dinotefuran, a highly soluble "new generation" neonicointoid product, are effective if applied annually and are popular among arborists, especially when many small trees require treatment (McCullough et al., 2011b; Herms et al., 2014). Dinotefuran sprayed on the trunk moves through the outer bark and into the xylem, where it is then transported to the canopy. Imidacloprid insecticides, which also must be applied annually, continue to be used for EAB control, although effectiveness of these products varies considerably (Herms et al., 2014).

INTEGRATING SYSTEMIC INSECTICIDES AND BIOLOGICAL CONTROL

It is important to note that biological control and systemic insecticides are not mutually exclusive and in combination may yield additive or even synergistic (e.g., superadditive) effects on EAB population growth (Barclay and Li, 1991; Berec et al., 2007; Suckling et al., 2012). Simulations have shown that decreasing pest density with a density-independent tactic such as systemic insecticides may enhance the effectiveness of density-dependent tactics, including biological control, particularly if a parasitoid displays nonrandom searching behavior (Barclay and Li, 1991; Suckling et al., 2012). Larval parasitoids and woodpeckers will not attack dead EAB larvae. Thus, unlike cover sprays, which are likely to affect a wide range of natural enemies, systemic products should have negligible effects on populations of native or introduced parasitoids (or predators) of EAB. Minimally, an additive effect should occur because systemic insecticides and biological control agents target different life stages of EAB. Systemic insecticides affect adult beetles as they feed on leaves and control newly hatched, neonate larvae, whereas native and introduced EAB parasitoids attack EAB eggs or late instar larvae. A synergistic effect may occur if untreated trees near trees treated with the emamectin benzoate product benefit from lower local EAB populations (McCullough and Mercader, 2012). Such trees would provide a consistent, multi-year source of EAB eggs and larvae to retain and support parasitoids. A similar interaction may occur in areas where the native ash species demonstrate some level of resistance to EAB. Black ash (*Fraxinus nigra* Marshall) and green ash, for example, are highly attractive and vulnerable hosts for EAB, white ash is intermediate, but healthy blue ash (*Fraxinus quadrangulata* Michx.) trees do exhibit resistance (Cappaert et al., 2005; Anulewicz et al., 2007; Limback, 2010; Tanis and McCullough, 2012). Interactions between parasitoids and EAB in areas where a portion of ash trees are protected with effective systemic insecticides or in sites with relatively resistant ash species remain to be determined.

FEWER OPTIONS TO PROTECT ASH TREES IN FORESTS

While landscape trees can now be effectively treated with systemic insecticides, these products are not practical options for ash trees in forests, woodlots, riparian zones, or other natural areas. In part, this reflects the substantially higher economic value of individual urban landscape trees compared to forest trees. Many practical and environmental concerns also limit the use of chemical insecticides, including systemic products, in forests and natural areas.

Options for managing EAB in forests may someday include microbial insecticides or perhaps entomopathogenic products. In the United States and many other countries, populations of foliar feeding Lepidoptera are commonly suppressed (or even eradicated) with aerial applications of Bt products (*Bacillus thuringiensis* var. *kurstaki*) (Tobin and Blackburn, 2007; Hajek and Tobin, 2011; Suckling et al., 2012; Tobin et al., 2014). However, there are as yet no effective microbial insecticides for EAB that can be applied in forested settings or across large areas. Researchers from federal agencies, along with private companies, continue to investigate Bt strains that could potentially be used to control adult EAB beetles (Bauer et al., 2012). Aerial applications of Spinosad (*Saccharopolyspora spinosa* Mertz and Yao) in woodlots with EAB infestations have been evaluated on a trial basis (Lewis and Smitley, 2012). Spinosad is a microbial product that affects a broad range of plant-feeding insects, but may be less likely to harm predatory insects or parasitoids. Other research has focused on entomopathogens, such as the generalist fungal pathogen *Beauveria bassiana* (Bals.-Criv.) Vuill., and efficient methods to infect EAB or enhance efficacy or persistence of these products (Liu and Bauer, 2006; Lyons et al., 2012).

Bioinsecticides could eventually play a role in integrated management programs for EAB in forests, if they can be economically produced, effectively applied, and can suppress EAB without harming a wide range of other invertebrates. Life history traits, however, suggest EAB may be less amenable to control via aerial application of Bt or related products than Lepidopteran forest pests like gypsy moth (*Lymantria dispar* L). Individual EAB adults have a relatively long life span and in a given area, adult EAB may be active for at least 10 to 12 weeks during the summer. In addition, EAB adults, particularly mature females, spend considerable time on branches or the trunk. Aerially applied products will likely, therefore, need to penetrate the canopy of overstory trees, which can be challenging during the summer. Whether aerially applied microbial insecticides can persist long enough and reach foliage where most adult EAB are feeding under operational conditions remains to be determined. Given these problems, effective biological control of EAB, whether by native natural enemies or introduced parasitoids, may be critical for preventing the functional loss of many ash species in forest ecosystems across North America (Burr and McCullough, 2014; Klooster et al., 2014; Knight et al., 2013).

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