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Evaluation of the potential use of a systemic insecticide and girdled trees in area wide management of the emerald ash borer

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ABSTRACT

Emerald ash borer, *Agrilus planipennis* Fairmaire, has become the most destructive forest insect to invade North America. Unfortunately, tactics to manage *A. planipennis* are limited and difficult to evaluate, primarily because of the difficulty of detecting and delineating new infestations. Here we use data from a unique resource, the SL.ow A.sh M.ortality (SLAM) pilot project, to assess whether treating a small proportion of trees with a highly effective systemic insecticide or girdling ash (*Fraxinus* spp.) trees to serve as *A. planipennis* population sinks can result in discernable effects on *A. planipennis* population growth or ash mortality. Components of the SLAM pilot project included an extensive inventory of ash abundance across a heterogenous area encompassing >390 km^2, treatment of 587 ash trees with a highly effective systemic insecticide, and girdling 2658 ash trees from 2009 to 2012. Fixed radius plots were established to monitor the condition of >1000 untreated ash trees throughout the area from 2010 to 2012. While only a very small proportion of ash trees in the project area were either treated with insecticide or girdled, both tactics led to detectable reductions of *A. planipennis* densities and protected ash trees in areas surrounding the treatments. The number of trees treated with the systemic insecticide reduced larval abundance in subsequent years. In contrast, the area of phloem in the insecticide-treated trees had no discernable effect on *A. planipennis* population growth, indicating that the number of treated trees was more important than the size of treated trees. Significant interactions among girdled trees, larval density, and the local abundance of ash phloem indicate girdling trees has a positive, but complex potential as a management tactic.

1. Introduction

The emerald ash borer, *Agrilus planipennis* Fairmaire, a phloem-feeding insect native to Asia, has become the most destructive forest insect to ever invade North America (Aukema et al., 2011; Herms and McCullough, 2014). Recent evidence has shown this pest became established in southeast Michigan by at least the early 1990s (Siegert et al., 2014) but it was not identified as the cause of ash (*Fraxinus* spp.) decline and mortality until 2002 (Cappaert et al., 2005). Ash mortality rates of >85% were recorded in plots in southeast Michigan and Ohio (Marshall et al., 2013; Burr and McCullough, 2014; Klooster et al., 2014, Knight et al., 2014) and to date, hundreds of millions of ash trees in the U.S. and eastern Canada have been killed by *A. planipennis*. In addition to natural dispersal, inadvertent human transport of infested ash trees, logs or firewood have spread *A. planipennis* long distances and infestations have been found in at least 24 U.S. states and two Canadian provinces (EAB.info, 2015). More than 8 billion ash (*Fraxinus* spp.) trees growing in forests plus millions of ash trees planted in landscapes are threatened by *A. planipennis* in the U.S. (Poland and McCullough, 2006). Economic costs of replacing or treating even half of the landscape ash trees likely to be affected by EAB in urban areas between 2009 to 2019 were projected to exceed 10 billion USD and if surrounding suburbs were included, expected costs doubled (Kovacs et al., 2010). These economic cost

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projections do not include lost ecological services such as stormwater capture in urban areas or effects of widespread ash mortality on nutrient cycling, biodiversity, and forest productivity (Gandhi and Herms, 2010; Burr and McCullough, 2014; Klooster et al., 2014; Flower et al., 2014). Moreover, loss of urban ash in U.S. cities such as Detroit, Michigan was linked to increased human mortality associated with cardiovascular and lower-respiratory-tract illness (Donovan et al., 2013).

Current and potential impacts of *A. planipennis* have elicited strong interest in development of practical and effective management options, particularly in areas with relatively new infestations. Eradication of *A. planipennis* was originally considered following the initial identification of this phloem-boring insect in southeast Michigan, but was abandoned as the extent of the EAB footprint became apparent (Herms and McCullough, 2014). Attention then turned to options for containing or minimally, slowing the spread of EAB populations. Successful containment or management of invasive forest pests, however, is generally dependent upon the timely detection and delineation of newly established infestations (Myers et al., 2000; Liebhold and Tobin, 2008). For example, strategies to slow the spread of gypsy moth (*Lymantria dispar* L) are based on grids of highly effective pheromone traps to detect and delineate small, isolated populations soon after establishment (Sharov et al., 2002; Liebhold and Tobin, 2008). These infestations can then be targeted for mass trapping, mating disruption, microbial insecticide application, or other appropriate tactics (Suckling et al., 2012; Blackwood et al., 2012; Epanchin-Niell et al., 2012; Tobin et al., 2013) to limit population growth and spread.

Unfortunately, detecting and delineating low density *A. planipennis* populations remains challenging. Like its native congeners, *A. planipennis* does not appear to produce effective long range pheromones that could be used as attractants for detection traps, mating disruption or mass trapping. Visual surveys to identify infested trees are also problematic. Larvae in newly infested and relatively healthy trees often require two years to develop (Siegert et al., 2010; Tluczek et al., 2011) and trees exhibit few, if any, external symptoms of infestation until larval densities have increased to moderate or even high levels (Cappaert et al., 2005; Poland and McCullough, 2006; Anulewicz et al., 2007). Some municipalities have attempted to identify infested landscape ash trees by debarking two branches, often accessed with bucket trucks, to assess larval presence (Ryall et al., 2011). This survey method is rarely used in rural or forested areas, however, and the efficacy of the method compared to artificial traps or girdled trees is unknown. Most operational detection programs currently rely on artificial traps in specific shades of green or purple that are suspended in the canopy of ash trees and baited with host volatiles to attract adult beetles with visual and olfactory cues (e.g., Crook and Mastro, 2010; Poland and McCullough, 2014). Field studies, however, have consistently shown the baited canopy traps are not highly effective at low *A. planipennis* densities (McCullough et al., 2011a; Mercader et al., 2012, 2013; Poland and McCullough, 2014). Girdling ash trees in spring then debarking trees in fall or winter to assess larval presence remains the most effective detection method (Rauscher, 2006; Hunt, 2007; McCullough et al., 2011a; Mercader et al., 2013), but is labor-intensive and trees suitable for girdling may not be available. Conventional insecticides cannot be applied in forests or over large areas and while microbial insecticides for *A. planipennis* control continue to be studied (Lyons et al., 2012), they have not been used operationally because of problems with persistence, distribution and efficacy (Herms and McCullough, 2014). Federal agencies in the U.S. have expended considerable efforts in classical biological control with Asian parasitoids (USDA, 2007; Duan et al., 2012, 2014) and native parasitoids and woodpecker predation can account for substantial local mortality of *A. planipennis* larvae (Lindell et al., 2008; Cappaert and McCullough, 2009; Duan et al., 2014; Flower et al., 2014). To date, however, there is no clear evidence that introduced or native natural enemies can regulate *A. planipennis* populations or alter rates of ash mortality in North America.

Given these difficulties and the impacts of unchecked *A. planipennis* infestations, a management approach focused on slowing the progression of widespread ash mortality at the local level by reducing the growth rate of *A. planipennis* populations was proposed (Poland and McCullough, 2010; McCullough and Mercader, 2012). This approach, termed SL.ow A.sh M.ortality, or SLAM, could also potentially slow ash mortality rates at a regional level by reducing *A. planipennis* spread from localized infestations. Kovacs et al. (2011) showed that containing localized *A. planipennis* infestations near urban areas, particularly those distant to the primary infestation, could save or delay millions of USD in economic costs. Simulation models based on empirical data from numerous field studies indicated two tactics, application of a highly effective systemic insecticide and the use of girdled trees as population sinks, were most likely to affect *A. planipennis* population growth (Mercader et al., 2011a, 2011b; McCullough and Mercader, 2012; Kovacs et al., 2014).

Effective protection of individual landscape trees with systemic insecticides applied via trunk injection has advanced considerably since the discovery of *A. planipennis* in North America (Herms and McCullough, 2014; Herms et al., 2014). A systemic product with the active ingredient emamectin benzoate registered in 2010 and sold in the U.S. as TREE-äge® (ArborJet Inc., Woburn, MA) consistently provided at least two and up to three years of nearly complete protection in field studies (Smitley et al., 2010; McCullough et al., 2011b; Herms et al., 2014). This product is injected into the base of the trunk in spring, then translocated in xylem to canopy branches and leaves (Mota-Sanchez et al., 2009; Tanis et al., 2012). Results from laboratory bioassays and extensive field studies have shown *A. planipennis* beetles do not avoid trees treated with TREE-äge® or distinguish between treated and untreated trees (McCullough et al., 2011b). Adult beetles typically die after only one or two bites of a leaf from a tree treated with this product and few, if any, live larvae were recorded when treated ash trees were debarked one to two years post-injection (McCullough et al., 2011b).

Whether applications of a highly effective systemic insecticide, such as TREE-äge®, could affect *A. planipennis* population growth, however, remained to be determined. Results from simulations showed treating trees with this insecticide could slow progression of ash decline and mortality in a local area over time, but effects varied, depending on assumptions about the number and distribution of treated trees (Mercader et al., 2011a; McCullough and Mercader, 2012). When treated trees were assumed to affect only *A. planipennis* larval mortality, simulations suggested a relatively high proportion of trees would need to be treated to significantly reduce ash mortality rates (Mercader et al., 2011a). However, adult *A. planipennis* must feed on ash foliage throughout their 3–6 wk life span and die quickly if they feed on leaves of trees treated with TREE-äge® (McCullough et al., 2011b; Herms et al., 2014). Adjusting models to incorporate adult beetle mortality, along with the multi-year efficacy of the TREE-äge® treatment, yielded significant protection for local ash trees (Mercader et al., 2011a; McCullough and Mercader, 2012).

Girdling ash trees in spring or early summer involves removing a band of outer bark and phloem from around the circumference of the trunk, exposing the sapwood. This causes trees to slowly decline over the course of the season, altering volatile profiles (Rodriguez-Saona et al., 2006) and possibly visual cues associated with hyperspectral signatures of stressed trees (Bartels et al., 2008). Adult *A. planipennis* are attracted to and females preferentially oviposit on ash trees stressed by girdling (Yu, 1992;