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Detection and Landing Behavior of Emerald Ash Borer, *Agrilus planipennis*,
at Low Population Density

By

Melissa J. Porter

A Thesis

Submitted in partial fulfillment of the requirements

for the degree of

MASTER OF SCIENCE IN FOREST ECOLOGY AND MANAGEMENT

MICHIGAN TECHNOLOGICAL UNIVERSITY

2009

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This thesis, “The detection and landing behavior of emerald ash borer, *Agrilus planipennis*, at low population density,” is hereby approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE IN FOREST ECOLOGY AND MANAGEMENT.

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Thesis Abstract

The exotic emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), was first discovered in North America in southeastern Michigan, USA, and Windsor, Ontario, Canada in 2002. Significant ash (*Fraxinus* spp.) mortality has been caused in areas where this insect has become well established, and new infestations continue to be discovered in several states in the United States and in Canada. This beetle is difficult to detect when it invades new areas or occurs at low density. Girdled trap tree and ground surveys have been important tools for detecting emerald ash borer populations, and more recently, purple baited prism traps have been used in detection efforts.

Girdled trap trees were found to be more effective than purple prism traps at detecting emerald ash borer as they acted as sinks for larvae in an area of known low density emerald ash borer infestation. The canopy condition of the trap trees was not predictive of whether they were infested or not, indicating that ground surveys may not be effective for detection in an area of low density emerald ash borer population.

When landing rates of low density emerald ash borer populations were monitored on non-girdled ash trees, landing rates were higher on larger, open grown trees with canopies that contain a few dead branches.

As a result of these studies, we suggest that the threshold for emerald ash borer detection using baited purple prism traps hung at the canopy base of trees is higher than for girdled trap trees. In addition, detection of developing populations of EAB may be possible by selectively placing sticky trapping surfaces on non-girdled trap trees that are the larger and more open grown trees at a site.

Chapter 1

Introduction

The exotic emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (EAB) (Figure 1.1), was first discovered in North America in southeastern Michigan and Windsor, Ontario, Canada in 2002 (Cappaert et al. 2005, Siegert et al. 2007). This insect pest of North American ash (*Fraxinus* spp.) was likely introduced into Michigan from Asia in the 1990s based on dendrochronological evidence (Cappaert et al. 2005). Significant ash mortality has been caused in the introduced range of EAB, with additional infestations being discovered in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, West Virginia, and Wisconsin, USA, and Quebec, Canada (EAB Info 2008). At least 50 million ash trees in southern Michigan, northern Ohio, and northern Indiana alone, have apparently succumbed to or are infested with emerald ash borer (Smith et al. unpublished).

This boring beetle is thought to have arrived from Asia as a stowaway in solid wood packing material (Poland & McCullough 2006), and continues to spread both naturally and from human-assisted movement of ash nursery stock, logs, and firewood. The human-assisted movement results in the initiation of outlier infestations (Poland 2007). In North America, ash species in the genus *Fraxinus* are apparently the only suitable host of EAB, and this tree genus is threatened by the continued spread of this pest (Anulewicz et al. 2008). The species of ash that are affected by EAB include white ash (*Fraxinus americana*), green ash (*F. pennsylvanica*), black ash (*F. nigra*), blue ash

(*F. quadrangulata*), pumpkin ash (*F. profunda*), and several horticultural varieties of ash (McCullough & Katovich 2004).



Figure 1.1. Adult emerald ash borer, *Agrilus planipennis* (actual size range is 7 to 14 mm long) (Photograph taken by Storer).

The life cycle of EAB in North America has been shown to be similar to EAB in China based on two Chinese articles that describe EAB biology (Chinese Academy of Science 1986, Yu 1992). Adult EAB emerge by chewing their way out of the bark of the host in early summer creating D-shaped exit holes (Poland 2007). The flight season of EAB starts in May and goes through August with the timing in this window varying according to climate and latitude. The beetles feed on ash foliage and mate during their remaining 3-6 week life span (Bauer et al. 2004, Lyons et al. 2004). Females deposit eggs individually in bark crevices, the eggs hatch within a week, and the first instar larvae chew through the bark to the cambium layer where they feed on the phloem and

cambium until the fall (Poland 2007). This feeding creates serpentine-shaped galleries that progressively become wider as the larva develops (Figure 1.2). Larval development includes four instars (Haack et al. 2002). The emerald ash borer typically completes its life cycle in one year in warmer climates, but requires two years in colder climates (McCullough & Katovich 2004). A two year life cycle is most common at low EAB densities and on healthy trees whereas a one year life cycle is common on stressed trees (Cappaert et al. 2005). The emerald ash borer overwinters as a prepupa in the outer sapwood or inner bark in a one-year life cycle; in a two-year life cycle, it overwinters for the first winter as a young larva still requiring a second year of development and then as a prepupa during the second winter before it emerges as an adult. In early spring, pupation occurs followed by the emergence of the adult beetle.

This beetle is difficult to detect when it invades new areas or occurs at low density because the eggs are deposited in bark crevices usually beginning in the upper part of the tree, and the larvae feed beneath the bark (Haack et al. 2002). The first sign of an infested tree may be holes excavated by woodpeckers feeding on larvae and prepupae (McCullough & Katovich 2004). After at least one year of infestation, D-shaped exit holes created by the emergence of the adult beetles may be visible on the branches and trunk of a tree. Vertical bark splitting may occur above larval galleries. The serpentine-shaped galleries created by the feeding larvae are visible after the bark is removed from infested trees or behind splits in the bark. The large numbers of serpentine galleries block the transport of water and nutrients within the tree, which results in foliage wilting and canopy dieback. An infested tree may die after 3-4 years (McCullough & Katovich 2004, Poland & McCullough 2006, Poland 2007).

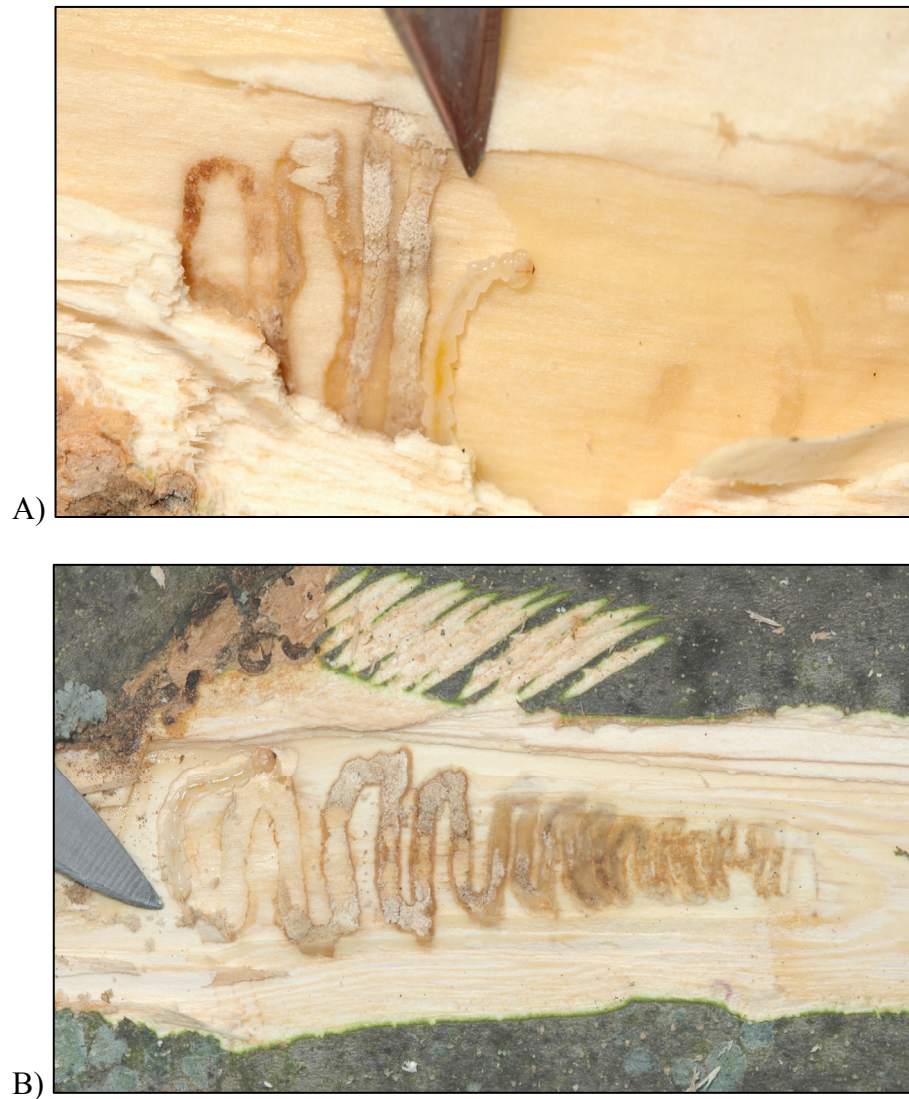


Figure 1.2. Emerald ash borer larvae, *Agrilus planipennis*: A) 1st-2nd instar larvae and B) late instar larvae (Photograph taken by Storer).

Detection of EAB in new areas is critical because it allows for the implementation of management options, such as reducing the ash phloem resources from a site, to aid in slowing the spread (Eberhart 2007, Eberhart et al. 2007). Establishing an effective trap for EAB is difficult since there is apparently not an attractant pheromone for this beetle, at least not at a long range. Methods for detection include girdled trap trees with sticky

bands for trapping adult beetles, firewood surveys, visual surveys, and the peeling of bark to detect larvae (Cappaert et al. 2005, de Groot et al. 2006, Metzger et al. 2007, Storer et al. 2007).

Most beetles of the buprestid family seek hosts that are stressed (Mendel et al. 2003). EAB are attracted to stressed ash trees, and are more likely to lay eggs on trees that are stressed than on trees that are healthy (Cappaert et al. 2005). Since 2004, artificially stressed trap trees have been used as an alternative to visual survey (Storer et al. 2007). Trees were artificially stressed by girdling and removing a band of bark and phloem from around the trunk of the tree. No trap development has been proven to be more effective than a girdled trap tree at detecting EAB, despite efforts to identify colors, host volatiles, and pheromones. Buprestids have been shown to be more attracted to purple hues than to reds, oranges, and browns (Oliver et al. 2002, Francese et al. 2005). In 2008, a large scale survey using purple prism traps baited with lures of manuka oil was carried out in the United States. The purple prism traps were baited with manuka oil because it contains volatile compounds similar to those found in ash bark and wood and is an available cheap alternative to actual ash bark sesquiterpenes (Crook et al. 2006). The effectiveness of these baited purple prism traps hung at the canopy base of trees compared with the effectiveness of girdled trap trees in areas of very low EAB density is unknown and was the focus of one of the studies reported in this thesis.

While girdled trap trees have been found to be among the most effective of the traps for EAB, this method is destructive to the host resource. The non-destructive use of ash trees as traps would result in fewer trees being girdled and eventually dying during detection surveys each season. A second study reported in this thesis was conducted to

determine what tree and resource characteristics explain differences in landing rates of emerald ash borer on ash trees that have not been girdled in areas of known low density emerald ash borer infestation.

Effectiveness of baited purple prism traps at detecting a low density EAB population.

Detection surveys of EAB using girdled trap trees have been implemented in the Upper Peninsula of Michigan since 2004 (Storer et al. 2009). The first detection of EAB in the Upper Peninsula was at Brimley State Park, Chippewa County, in 2005. New infestations were discovered near Moran Township and in Straits State Park, both in Mackinac County, in 2007. In 2008, two additional infestations were found through ground survey in Houghton County and in Delta/Schoolcraft counties. Movement of infested ash firewood by campers and landowners is believed to be the reason for the introduction of EAB at these sites.

Straits State Park is located in Mackinac County in St. Ignace, Michigan (MI DNR 2001) (Figure 1.4). The park consists of 181 acres situated on the northern shore of the Straits of Mackinac, which connects Lake Huron and Lake Michigan. Straits State Park was established in 1924 and is governed by the Michigan Department of Natural Resources, Parks Division. The park has 255 campsites and several lookouts for viewing the Mackinac Bridge. Trap trees have been used to survey for EAB at Straits State Park since 2004, and in the fall of 2007 one of the trap trees established in the park was found to contain EAB larvae. All remaining trap trees at the park were cut and peeled, and none of the trees contained larvae. Delimitation surveys that included destructive

sampling of trees by the Michigan Department of Agriculture did not find any other infested trees in the area around the park. Straits State Park was considered an area of very low density EAB infestation because only one infested tree was found. This made the site suitable for a study that was designed to compare the effectiveness of girdled and non-girdled trap trees and baited prism traps hung in trees (Figure 1.3) to detect adults and larvae. In addition, this study determined whether the canopy condition of a tree can be used to predict infestation in an area of known low density EAB infestation.

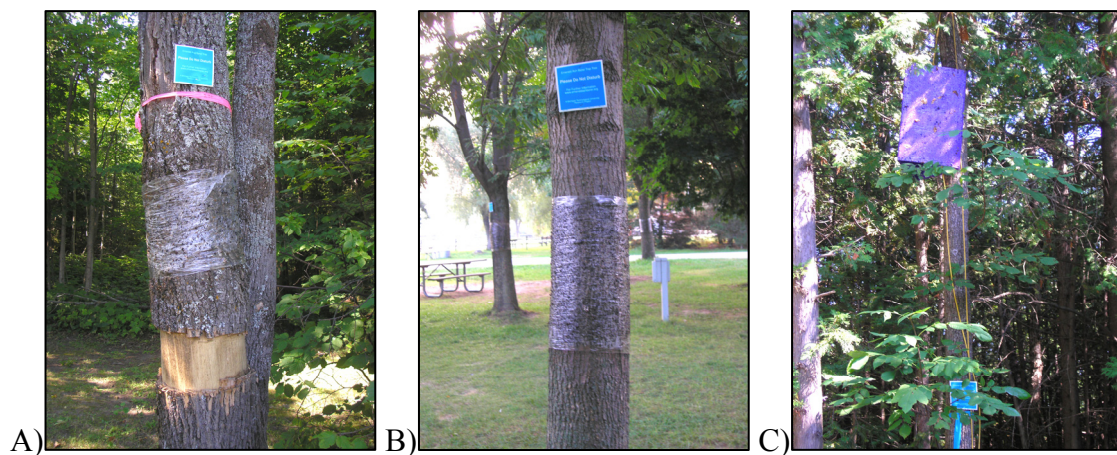


Figure 1.3. The different trap tree types: A) girdled tree, B) non-girdled tree, and C) tree with a purple prism trap hung from the base of the crown (Photographs taken by Porter).

Landing rates of emerald ash borer on non-girdled ash trees in areas of low infestation.

Burt Lake State Park is located in Cheboygan County in Indian River, Michigan (MI DNR 2001). The park consists of 406 acres located on the southeast corner of Burt Lake and is managed by the Michigan Department of Natural Resources. The park has over 300 campsites with modern camping available from May 1st through October 15th.

Harrisville State Park is located in Alcona County in Harrisville, Michigan (MI DNR 2001). The park consists of 107 acres of heavily wooded shoreline along Lake Huron. Harrisville State Park was established in 1921, making it one of the oldest parks in the Michigan State Park system. The park has 229 campsites and is open from April 15th to November 1st.

Tawas Point State Park is located in Iosco County in East Tawas, Michigan (MI DNR 2001). The park consists of 183 acres situated on Tawas Bay off from Lake Huron. Tawas Point State Park is governed by the Michigan Department of Natural Resources. The park has 193 campsites and the Tawas Point Lighthouse is located within the park.

Since movement of infested ash firewood by campers is believed to be a cause of spread of EAB, Burt Lake State Park, Harrisville State Park, and Tawas Point State Park, Michigan, have been sites for a trap tree survey since 2004 (Figure 1.4). EAB adults had been caught in each park, but only at low densities. These three parks are known to be areas of low density EAB infestation, making them suitable sites for a study designed to determine what variables explain differences in landing rates of EAB on non-girdled ash trees in an area of known low density EAB infestation.

The overall goals of the studies reported in this thesis were to improve methodologies for detecting EAB by evaluating the effectiveness of purple prism traps in an area of very low EAB density, and by characterizing the trees that EAB land on when at low density. Previous studies to compare trapping tools and beetle host selection have been conducted in various areas with higher densities of EAB infestation than the sites used in the studies reported here (Francese et al. 2005, Eberhart 2007, Metzger et al. 2007, Marshall et al. 2009a, Marshall et al. 2009b). Better knowledge of the threshold at

which low density populations can be detected is needed to establish effective survey protocols for detecting EAB, which in turn helps to guide environmental policy in response to this exotic insect. Detection of very low density populations will enhance the options available for management to aid in slowing the spread of this insect.

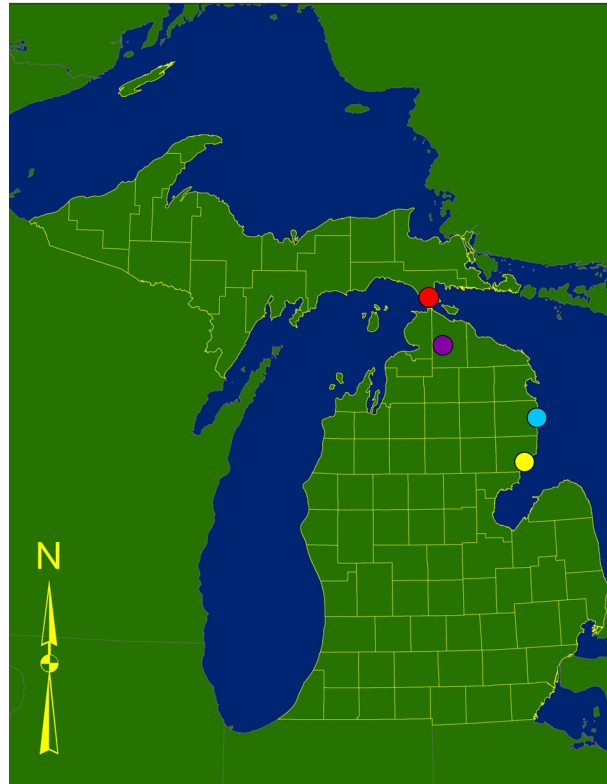


Figure 1.4. Map of the location of A) Straits State Park (red), B) Burt Lake State Park (purple), C) Harrisville State Park (blue), and D) Tawas Point State Park (yellow), in Michigan, USA (ESRI Data & Maps. Adapted by Porter).

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MI DNR, Burt Lake State Park, Harrisville State Park, Straits State Park, and Tawas

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Chapter 2

Detection of a low-density population of emerald ash borer,

Agrilus planipennis

Abstract - The exotic emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), was first discovered in North America in southeastern Michigan in 2002. This beetle has killed millions of ash (*Fraxinus* spp.) trees in several states in the United States and in Canada. This beetle is difficult to detect when it invades new areas or occurs at low density, and for the foreseeable future, girdled trap tree and ground surveys will be important tools for detecting emerald ash borer populations.

A field experiment was established at Straits State Park, St. Ignace, Michigan in 2008 to characterize the effectiveness of different trap types in an area of known low density population of emerald ash borer. This study was designed to compare the effectiveness of girdled and non-girdled trap trees and the baited prism traps to detect adults and larvae of the emerald ash borer. Canopy assessments of trees were carried out to determine if the canopy condition was predictive of whether a tree was infested with emerald ash borer or not.

Adult beetles were not detected using the baited purple prism trap during the trapping survey, and only one adult beetle was caught on a girdled trap tree during the flight season. Eight of the girdled trap trees contained larvae when peeled, and only one tree containing a purple prism trap contained larvae. No non-girdled trap trees were infested. Canopy condition of these trees was not predictive of infestation. Of the girdled trees, infested trees were larger in diameter than non-infested trees. The use of

large girdled trap trees may be the most effective tool for detecting emerald ash borer at low density, whereas baited purple prism traps may be ineffective when the population density of the insect is very low.

Introduction

The exotic emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (EAB), was first discovered in North America in southeastern Michigan, USA, and Windsor, Ontario, Canada in 2002 (Cappaert et al. 2005, Siegert et al. 2007). This insect pest of North American ash (*Fraxinus* spp.) is thought to have been introduced into Michigan from Asia in the 1990s based on recent dendrochronological evidence (Cappaert et al. 2005). It has been estimated that approximately 50 million trees have been infested with EAB in Michigan, northern Ohio, and northern Indiana (Smith et al. unpublished). Infestations are also known to occur in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, West Virginia, and Wisconsin, USA, and Quebec, Canada (EAB Info 2008).

This boring beetle is thought to have arrived from Asia as a stowaway in solid wood packing material (Poland & McCullough 2006), and continues to spread both naturally and from human-assisted movement of ash nursery stock, logs, and firewood, initiating outlier infestations (Poland 2007). In North America, ash species in the genus *Fraxinus* are the only suitable host of EAB, and are threatened by the continued spread of this pest (Anulewicz et al. 2008).

Adult EAB flight starts in May and goes through August with the timing in this window varying according to location. After emerging from the host, the beetles feed on

ash foliage, mate, and deposit eggs (Bauer et al. 2004, Lyons et al. 2004). The eggs hatch, and the first instar larvae chew through the bark to the cambium layer where they feed on the phloem and cambium until the fall (Poland 2007). Larval development includes four instars (Haack et al. 2002). EAB typically complete their life cycle in one year in warmer climates, but may require two years in colder climates (McCullough & Katovich 2004). In early spring, pupation occurs followed by the emergence of the adult beetle.

This beetle is difficult to detect when it invades new areas or occurs at low density. Detection of EAB in new areas is critical because it allows for the implementation of management options, such as reducing the ash phloem resources from a site, to aid in slowing the spread (Eberhart 2007, Eberhart et al. 2007). Methods for detection include girdled trap trees with sticky bands for trapping adult beetles, firewood surveys, visual surveys, and peeling of bark to detect larvae (Cappaert et al. 2005, de Groot et al. 2006, Metzger et al. 2007, Storer et al. 2007). EAB is attracted to ash trees that are stressed (Cappaert et al. 2005), and artificially stressed girdled trap trees have been used extensively as an alternative to visual survey (Storer et al. 2007). No trap development has been proven to be more effective than a girdled trap tree at detecting EAB, despite efforts to identify colors, host volatiles, and pheromones that may be useful. Buprestids are attracted in larger numbers to purple hues than to reds, oranges, and browns (Francese et al. 2005). In 2008, a large scale survey was implemented in the United States using purple prism traps baited with manuka oil, which contains volatile compounds similar to those found in ash bark and wood (Crook et al. 2006). However,

the effectiveness of baited purple traps compared with trap trees in areas with low EAB populations is unclear.

The objectives of this study were to (1) characterize the effectiveness of girdled and non-girdled trap trees and baited prism traps to detect adults and larvae of EAB and (2) determine if the canopy condition is predictive of whether a tree is infested or not infested in an area of known low density EAB infestation.

Materials and Methods

Field Data Collection

The study was carried out at Straits State Park, St. Ignace, Michigan. EAB was discovered at this site in 2007 as larvae in a single infested girdled trap tree (Storer et al. 2009). No other trap trees ($n = 22$) were found to be infested in 2007, and the site was therefore classified as having a very low density of EAB. The ash resources at the park were mapped using a Global Positioning System in fall 2007, and the diameter was recorded of each tree at breast height (dbh).

In May 2008, 60 ash trees were randomly selected and assigned to one of three treatments: girdled trap tree wrapped with a sticky band, non-girdled tree with a purple prism trap baited with manuka oil hung at base of canopy, and non-girdled trap tree wrapped with a sticky band (Figure 2.1). Most ash trees occurred in the campground areas of the park (upper campground in the north, lower campground in the south, and group campground to the east). Trap trees were located at least 10 m apart. Trap trees were established by removing a 30 cm wide band of bark and phloem approximately 1 m above the ground. Pallet wrap measuring 0.5 m wide was wrapped around the tree

centered at breast height (1.3 m) and covered with Tangle-Trap Insect Trap Coating (The Tanglefoot Co., Grand Rapids, Michigan). Purple prism traps were hung at the canopy base of non-girdled trees using a rope pulley system. The purple prism traps were also covered with Tangle-Trap Insect Trap Coating (The Tanglefoot Co.) and were baited with a manuka oil lure with a release rate of 50 mg/day (Crook et al. 2008). Non-girdled trap trees were set up the same as the girdled trap trees but without being girdled.

Traps were checked every 2 weeks for adult beetles throughout the EAB flight season, from late June through August in northern Michigan. Adult beetles were removed from the trapping surface. Canopy assessments were made of the trap trees in mid July. The attributes assessed included: crown light exposure, tree vigor, crown dieback, uncompacted live crown ratio, crown class and position, crown density, and foliage transparency. The USDA Forest Service rating system within the Forest Inventory and Analysis protocol was used for assessing all of the attributes and are briefly described here (USDA 2005). Crown light exposure was measured by dividing the tree canopy into four equal sides and estimating the number of sides that would receive direct sunlight, ranking the tree from 0 to 5 (receives no light to receives full light). A tree rated as a 5 receives light on all four sides of the canopy plus on the top of the canopy. Tree vigor and condition estimated the amount of dead twigs and branches in the crown on a scale from 1 to 8, where 1 is relatively few dead twigs and 8 is a dead tree. Crown dieback is the percent of the live crown that has dieback. Uncompacted live crown ratio (ULCR) is the percentage of the total height of the tree that is live crown. Crown class and position rates the crown of the tree in relation to other trees and ranges from open grown (rated 1) to overtopped (rated 5). Crown density is the percent of light

blocked from showing through the crown canopy which takes into consideration both the live and dead parts of the crown. Foliage transparency measures the amount of light that shines through the live crown as a percent of visible light that would show through if it were not blocked by the crown while disregarding dead parts of the crown when taking the measurement.

In October and November of 2008, all the trap trees were cut and fully peeled using drawknives. The data that was recorded included: height (m) of tree, number of D-shaped exit holes, number of woodpecker attacks, number and instar of EAB larvae, and height (m) and diameter (cm) on the tree where EAB larvae were found. Larval stages were recorded as first-second instar, third instar, fourth instar, and prepupae. Surface area (m^2) was calculated using the model presented by Eberhart (2007), which was then used to calculate larval density per unit area of phloem (larvae/m^2).

Data Analysis

A G-test was conducted to test whether infestation of trees was dependent on trap type ($\alpha = 0.05$). A one-way analysis of variance (ANOVA) was used to test for differences in canopy attributes and tree diameter between infested ($n = 8$) and non-infested ($n = 12$) girdled trap trees. For these tests, α was set at 0.1 due to the low sample size. Differences in canopy attributes and tree diameter between girdled trap trees ($n = 20$), non-girdled trap trees ($n = 16$), and non-girdled trees ($n = 18$) that purple prism traps hung from were tested for using a one-way analysis of variance ($\alpha = 0.05$). Pearson Correlations were used to characterize relationships between the different canopy attributes ($\alpha = 0.05$). To normalize the crown dieback data, an arcsine transformation

was used. The mean height where larvae were found on trees and the mean diameter of trees where larvae were found was reported along with 95% confidence intervals.

Statistix 8.0 (2003) was used for all of the statistical tests.

Results

In summer 2008, only one adult female beetle was trapped during the flight season. This individual was trapped on a girdled trap tree located in the upper campground. No adult beetles were trapped on purple prism traps or on non-girdled trap trees. Larvae were found in 8 of the girdled trap trees and in one of the non-girdled trees with purple prism traps. No exit holes were observed on any trees in the study. The distribution of infested and non-infested trees in the park is shown in Figure 2.2. Infested trees were widely distributed throughout the park with locations in both the upper and lower campgrounds of the park.

Infested and Non-infested Girdled Trap Trees

A limited amount of woodpecker damage was evident on one girdled trap tree. When peeled, this tree contained 107 larvae. Of the 20 girdled trap trees, 8 contained early instar larvae (range 1-107 individuals) (Table 2.1). Most of the infested girdled trap trees were located in the upper campground (Figure 2.2). Infested trees ranged from 17.5 cm to 25.2 cm dbh and from 5.2 m to 14.6 m in height (Table 2.1). The overall mean diameter where larvae were found was 10.5 cm (95% confidence range 10.0 cm - 11.1 cm), and the overall mean height where larvae were found was 4.4 m (95% confidence range 4.2 m - 4.6 m).

Comparison of Infested and Non-infested Girdled Trap Trees

Infested girdled trap trees had a mean diameter of 21.9 cm which was significantly different from the diameter of 16.9 cm for the non-infested girdled trap trees ($p = 0.09$) (Table 2.2). Also, the mean ULCR for infested girdled trap trees of 67.5% differed significantly from the mean ULCR of 53.8% for non-infested girdled trap trees ($p = 0.09$) (Table 2.2). None of the other canopy attributes differed significantly between infested and non-infested girdled trap trees (Table 2.2).

Comparison of Trap Types

Of girdled trap trees, 40.0% ($n = 20$) were infested compared with 5.6% ($n = 18$) of non-girdled trees with a purple prism trap hung in them ($G = 6.57$, d.f. = 1, $p = 0.01$) and 0.0% ($n = 16$) of non-girdled trees without purple traps ($G = 8.25$, d.f. = 1, $p < 0.01$). A one-way analysis of variance was used to test the significance of differences in canopy attributes between girdled trap trees, non-girdled trap trees, and non-girdled trees with purple prism traps. Foliage transparency was higher for girdled trees than for both non-girdled trees and non-girdled trees with purple prism traps (Figure 2.3). The mean foliage transparency of the non-girdled trees with purple prism traps did not significantly differ from the mean of the non-girdled trees. Girdled trees had significantly lower mean tree vigor (indicated by higher vigor rating values) than the non-girdled ash without purple traps. The non-girdled trees with purple prism traps did not differ in mean vigor rating from either of the other trap types (Figure 2.4). Other comparisons of canopy attributes between trap types did not reveal significant differences.

Correlations among crown canopy variables

Pearson correlations showed numerous positive and negative correlations between different trap tree attributes, many of which would be anticipated (Table 2.3). Crown class and position was negatively correlated with larval density and with total larvae found indicating that larval density and number was higher for an open grown tree than for an overtopped tree. Crown class and position was negatively correlated with crown density, ULCR, and crown light exposure, and positively correlated with foliage transparency and crown dieback, which indicates that an open grown tree tends to receive more direct sunlight and have a larger and denser live canopy with fewer dead branches and less skylight shining through than an overtopped tree. Also, foliage transparency was positively correlated with larval density indicating that larval density was higher for trees with canopies with more light shining through. Foliage transparency is negatively correlated with crown density, ULCR, and crown light exposure, and positively correlated with crown class and position, tree vigor rating, and crown dieback indicating that a tree that lets more light shine through its canopy tends to be an overtopped low vigor tree with a smaller and less dense canopy containing more dead branches than a tree that does not let much light through its canopy. UCLR, which differed significantly between infested and non-infested girdled trees, was negatively correlated with crown class and position, foliage transparency, and tree vigor, and positively correlated with crown density, which indicates that a tree that has a larger live crown tends to be a more dominant tree with fewer dead branches and less light shining through the canopy.

Discussion

Adult EAB were not detected using the baited purple prism trap in this study. Only one beetle was caught on a girdled trap tree during the flight season. The baited purple prism trap failed to detect adult EAB at this low population density, and the threshold at which it detects populations remains to be determined.

Girdled trap trees acted as sinks for larvae at this low density site since larvae were found in 8 of the 20 girdled trap trees, none of the 16 non-girdled trees, and only one of the 18 non-girdled trees with purple prism traps. The fact that more larvae were found in artificially stressed girdled trap trees is consistent with the finding that EAB is more attracted to ash trees that are stressed than to healthy ash trees (Cappaert et al. 2005).

The mean height of the larvae locations of the eight infested girdled trees is consistent with the finding that traps should not be placed at ground level (Francese et al. 2008). Most of the mean heights of the larvae locations of the eight infested girdled trees were above the crown base (Table 2.1). That means traps should be placed in the canopy above the crown base rather than below the crown base. Other studies have found traps placed below the crown base to be effective (Marshall et al. 2009a). The mean height where larvae were found was 4.4 m, which is consistent with the finding that within-tree gallery distributions generally fall below 7 m (Timms et al. 2006). The mean diameters of the locations where larvae were found of the eight infested girdled trees shows that survey teams should initiate searches in sections of the tree that are approximately 7 cm and larger in diameter, which is consistent with the finding from the study by Timms et al. (2006) though the latter study utilized host trees that were younger and smaller than

those used here. The mean diameter and 95% confidence interval describing the host diameter where larvae are found are consistent with those reported for other studies in areas with low EAB density (Marshall et al. 2009b).

Canopy condition of girdled trees was not predictive of whether trees were infested or not. Girdled trap trees had higher foliage transparency and lower tree vigor than both non-girdled trap trees and non-girdled trees with purple prism traps. Since the canopy attributes did not differ significantly between infested and non-infested girdled trap trees, the cause of these differences between girdled and non-girdled trees is likely a result of the girdling rather than EAB infestation. Since the canopy condition of girdled trees was not predictive of whether trees were infested or not, ground surveys would likely not be effective at detecting a very low density population of EAB.

Of the girdled trees, infested trees were larger in diameter than the non-infested trees, and this is consistent with previous reports that large ash trees are preferentially attacked in newly established EAB populations (Eberhart 2007, Marshall et al. 2009a). Infested girdled trap trees also had larger crowns than non-infested girdled trap trees. Based on these two findings, trees with large diameters and large crowns would be good candidates as girdled trap trees.

There were numerous correlations, positive and negative, found between the different trap tree attributes. Larval density was higher on a more dominant or open grown tree than for an overtopped tree suggesting that open grown trees are more likely to become infested in the early stages of an infestation. The positive correlation between larval density and foliage transparency suggests that EAB are more attracted to stressed trees or that the stress may have been caused by the infestation of EAB. These findings

are consistent with previously reported preferences for open grown trees as girdled trap trees (Chinese Academy of Science 1986, Haack et al. 2002) and the preference of EAB for trees that are stressed (Cappaert et al. 2005).

In this study, the effectiveness of different trap types in an area of known low density EAB infestation was characterized. Girdled trap trees, non-girdled trap trees, and purple prism traps hung in ash trees differed in their ability to detect a known EAB infestation. Girdled trap trees were more effective at detecting EAB larvae, and acted as better sinks for EAB larvae than non-girdled trap trees and non-girdled trees with purple prism traps in a low density EAB population. Canopy assessments of ash trees did not provide reliable indication of whether a tree was infested or not with EAB.

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Table 2.1. Descriptive statistics for the emerald ash borer infested girdled trap trees and a single infested non-girdled tree with a purple prism trap hung at the canopy base at Straits State Park, St. Ignace, Michigan, in 2008.

Tree Number	Tree DBH (cm)	Tree Height (m)	Tree Crown Base (m)	Total Larvae	Larval Density (larvae/m²)	Mean Height of Larvae (m)	95% Confidence Range of Heights (m)	Mean Diameter of Where Larvae Found (cm)	95% Confidence Range of Diameters (cm)
850	29.2	14.6	8.1	1	0.1	7.6	7.6	19.8	19.8
856	19.8	9.4	4.7	11	1.3	3.9	1.9 - 8.8	17.5	14.0 - 20.1
862	20.8	11.3	1.1	7	0.8	7.5	5.9 - 9.1	12.7	9.9 - 15.5
870	21.6	5.9	1.8	1	0.1	3.7	3.7	8.1	8.1
875	17.5	9.7	3.4	19	2.6	4.6	2.8 - 6.5	13.1	11.4 - 14.5
883	25.7	7.9	1.6	45	3.5	5.7	3.3 - 7.5	9.8	4.1 - 15.0
892	22.9	8.5	1.8	107	9.9	4.1	1.2 - 7.3	10.4	4.3 - 23.9
893	18.0	5.2	2.1	46	6.1	3.4	1.7 - 7.5	8.2	3.8 - 21.3
846*	16.5	6.0	3.0	15	2.3	5.0	4.6 - 5.4	5.6	4.8 - 6.5

* The infested non-girdled trap tree with a purple prism trap hung at the canopy base.

Table 2.2. Comparisons of attributes of infested and non-infested girdled trap trees at Straits State Park, St. Ignace, Michigan, in 2008.

Attribute	Mean	S.E.	Mean	S.E.	F	d.f.	P
	Girdled trees infested with		Girdled trees not infested with				
	emerald ash borer (n=8)		emerald ash borer (n=12)				
Crown Class/Position	1.9	0.39	2.7	0.32	2.51	1,19	0.13
Crown Density (%)	51.9	5.54	56.7	4.52	0.45	1,19	0.51
Crown Dieback Transformed (%)	0.4	0.06	0.3	0.05	1.81	1,19	0.20
Crown Dieback Transformed Back (%)	0.2	+0.04, -0.05	0.1	+0.03, -0.03	1.81	1,19	0.20
Foliage Transparency (%)	25.6	2.35	22.1	1.92	1.36	1,19	0.26
Tree Vigor	1.9	0.31	1.5	0.25	0.88	1,19	0.36
Tree Diameter (dbh, cm)	21.9	2.14	16.9	1.75	3.28	1,19	0.09
Crown Light Exposure	4.3	0.49	3.4	0.40	1.74	1,19	0.20
Uncompacted Live Crown Ratio (%)	67.5	5.87	53.8	4.79	3.30	1,19	0.09

Table 2.3. Pearson correlations matrix of the coefficient of correlation (r) and p-value between trap tree attributes (n=53) at Straits State Park, St. Ignace, Michigan, in 2008. Significant p-values are shown in bold.

	Crown Class and Position	Crown Density (%)	Foliage Transparency (%)	Tree Vigor	Uncompacted Live Crown Ratio	Crown Light Exposure	Tree Diameter (dbh, cm)	Crown Dieback (%) Transformed	Larval Density (larvae/m ²)
Crown Density (%)	r = -0.550 p-value = <0.001								
Foliage Transparency (%)	0.284 0.040	-0.539 <0.001							
Tree Vigor	0.259 0.061	-0.653 <0.001	0.347 0.011						
Uncompacted Live Crown Ratio (%)	-0.502 <0.001	0.388 0.004	-0.359 0.008	-0.301 0.029					
Crown Light Exposure	-0.791 <0.001	0.521 <0.001	-0.306 0.026	-0.300 0.029	0.369 0.007				
Tree Diameter (dbh, cm)	-0.089 0.526	-0.025 0.857	-0.072 0.610	0.154 0.272	0.099 0.482	0.097 0.491			
Crown Dieback (%) Transformed	0.278 0.044	-0.624 <0.001	0.298 0.030	0.891 <0.001	-0.290 0.035	-0.269 0.051	0.181 0.194		
Larval Density (larvae/m ²)	-0.278 0.044	-0.022 0.874	0.286 0.038	-0.015 0.915	0.174 0.214	0.214 0.124	0.135 0.334	-0.032 0.821	
Total Larvae	-0.273 0.048	-0.017 0.906	0.259 0.061	-0.009 0.950	0.187 0.179	0.211 0.129	0.160 0.253	-0.034 0.812	0.983 <0.001

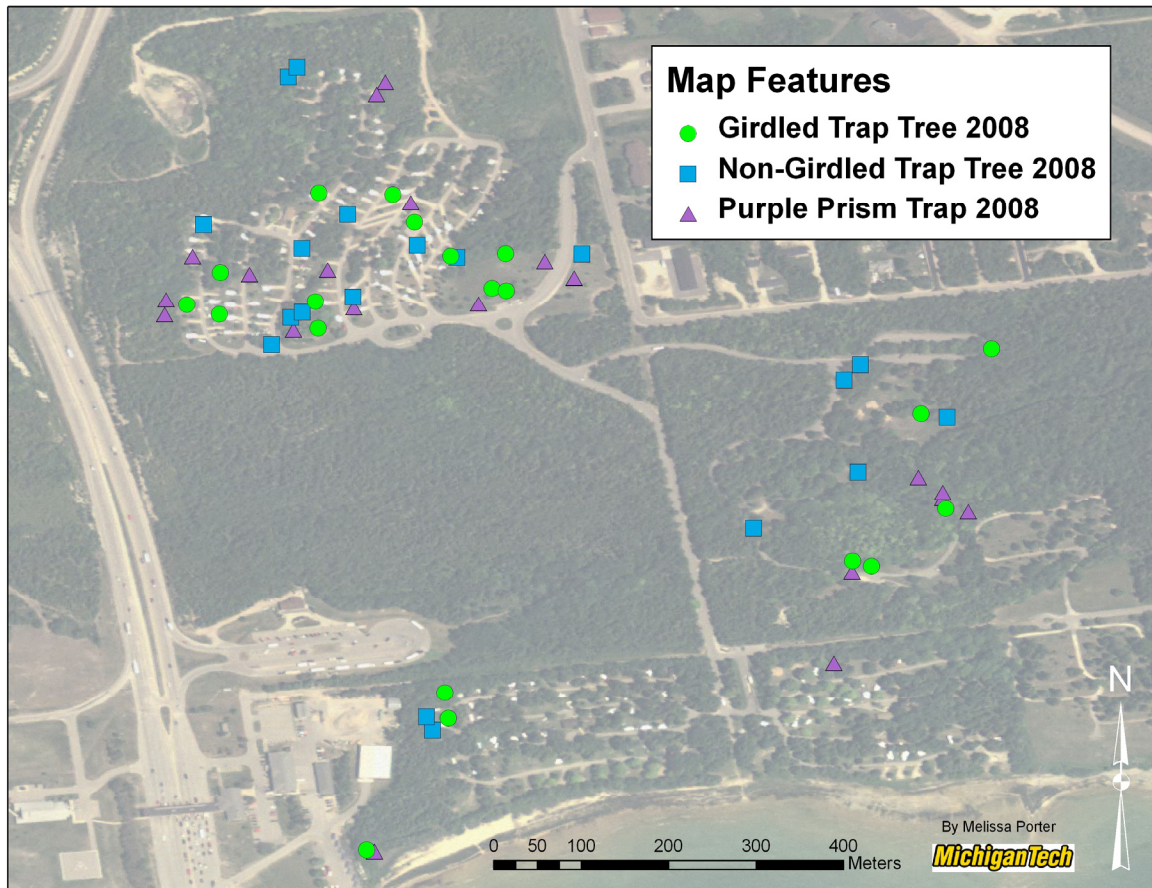


Figure 2.1. Map of the location of the different emerald ash borer trap tree types at Straits State Park, St. Ignace, Michigan, in 2008 (<http://www.mcgi.state.mi.us/mgdl/>). Adapted by Porter from files created by Hyslop).

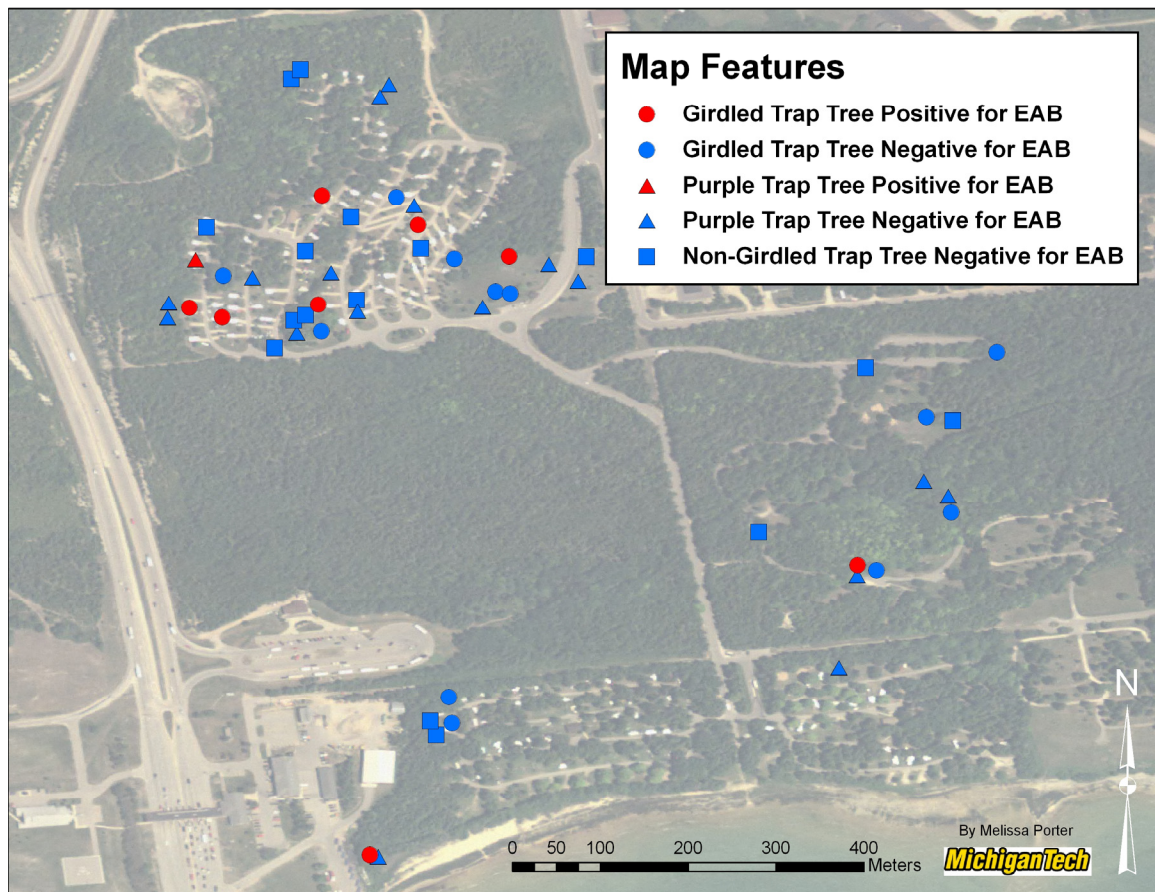


Figure 2.2. Map of the location of traps of different types that were positive and negative for emerald ash borer adults and larvae at Straits State Park, St. Ignace, Michigan, in 2008 (<http://www.mcgi.state.mi.us/mgdl/>). Adapted by Porter from files created by Hyslop).

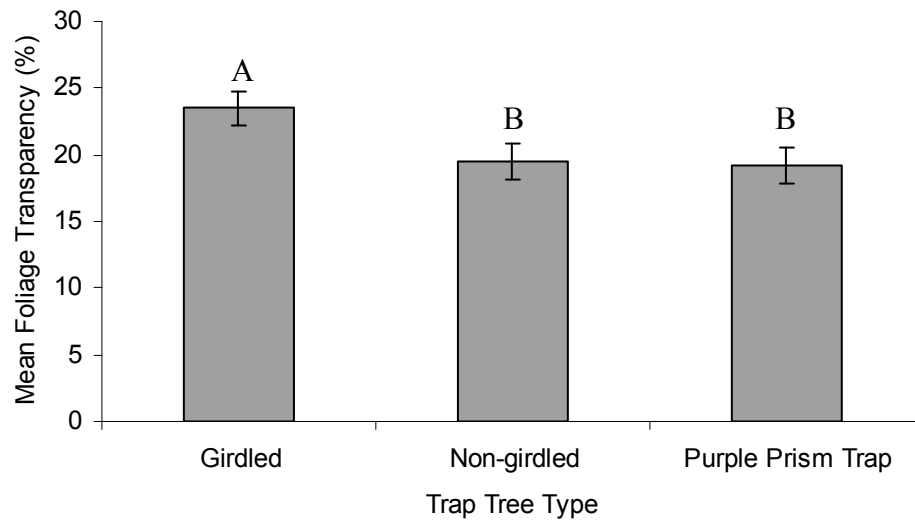


Figure 2.3. Mean foliage transparency of girdled trap trees ($n = 20$), non-girdled trap trees ($n = 16$), and non-girdled trees with purple prism traps ($n = 18$) at Straits State Park, St. Ignace, Michigan in 2008. Bars with different uppercase letters are significantly different (analysis of variance followed by least significant difference test, $p < 0.05$).

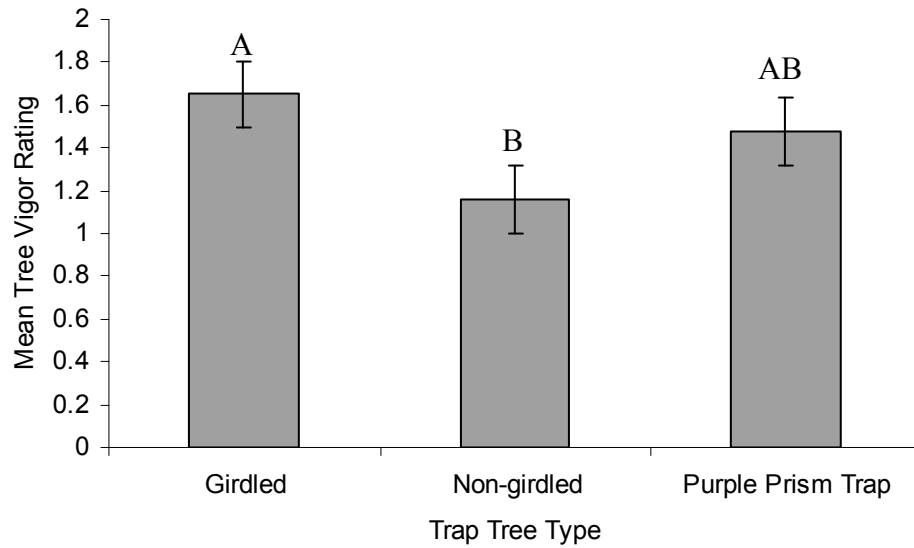


Figure 2.4. Mean tree vigor of girdled trap trees (n = 20), non-girdled trap trees (n = 16), and non-girdled trees with purple prism traps (n = 18) at Straits State Park, St. Ignace, Michigan in 2008. Bars with different uppercase letters are significantly different (analysis of variance followed by least significant difference test, $p < 0.05$).

Chapter 3

Landing behavior of emerald ash borer, *Agrilus planipennis*, at low population density

Abstract - The exotic emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (EAB), was first discovered in North America in southeastern Michigan, USA, and Windsor, Ontario, Canada in 2002. Significant ash (*Fraxinus* spp.) mortality has been caused in areas where this insect has become well established, and new infestations continue to be discovered in several states in the United States and in Canada. This beetle is difficult to detect when it invades new areas or occurs at low density. Girdled trap tree surveys have been important tools for detecting emerald ash borer populations to aid in slowing the spread and management of this pest. However, the girdling of trees is destructive to the host resource, and this has limited use of this technique in areas with low density emerald ash borer populations. The goal of the studies reported here was to evaluate landing behavior of EAB on non-girdled ash trees when at low density.

In 2007 and 2008, a field experiment was conducted at three state parks located in the northern lower peninsula of Michigan. A trapping survey and canopy assessments were conducted during the flight season of the emerald ash borer at each of the parks to determine if the tree size, tree canopy condition, and the position of the tree in the forest influenced the landing behavior of the beetle on non-girdled trees in low density populations.

The mean tree diameter was larger for trees with emerald ash borer than for trees without emerald ash borer; trees with emerald ash borer contained more dead branches in the canopy than trees without emerald ash borer; and the majority of trees with emerald ash borer were dominant trees having their crowns extend above the general level of crown canopy compared to the majority of trees without emerald ash borer being co-dominant with their crowns at the general level of the crown canopy. The mean distance from the nearest tree regardless of species was greater for trees with emerald ash borer than for trees without emerald ash borer. Based on these findings, it is recommended that in areas where ground survey does not detect emerald ash borer, sticky bands should be placed on trees with dieback that are large and open grown if girdling and peeling of trees is not an option.

Introduction

The exotic emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) (EAB), named for its color, host preference, and feeding habits, is thought to have been attacking North American ash (*Fraxinus* spp.) since the 1990s based on recent dendrochronological evidence (Cappaert et al. 2005, Siegert et al. 2007). This beetle was first discovered in North America in southeastern Michigan, USA, and Windsor, Ontario, Canada in 2002. Significant ash mortality has been caused in areas where this insect has become well established. New infestations continue to be found and have been discovered in Illinois, Indiana, Maryland, Michigan, Missouri, Ohio, Pennsylvania, Virginia, West Virginia, and Wisconsin, USA, and Quebec, Canada (EAB Info 2008).

This wood-boring beetle is thought to have been introduced from Asia in solid wood packing material (Poland & McCullough 2006), and is continually spreading and initiating outlier infestations both naturally and from human-assisted movement of ash nursery stock, logs, and firewood (Poland 2007). Ash species in the genus *Fraxinus* have been found to be the only suitable host of EAB, and are continually threatened by the spread of this phloem-feeding pest (Anulewicz et al. 2008). The species of ash that are affected by EAB include white ash (*Fraxinus americana*), green ash (*F. pennsylvanica*), black ash (*F. nigra*), blue ash (*F. quadrangulata*), pumpkin ash (*F. profunda*), and several horticultural varieties of ash (McCullough & Katovich 2004).

The EAB flight season length depends on the region, but the range begins in May and continues through August. After emerging from the host, the beetles feed, mate, and deposit eggs in crevices on ash bark (Bauer et al. 2004, Lyons et al. 2004). The eggs hatch, and the first instar larvae bore through the bark to the cambium layer where they feed until the fall (Poland 2007). Larvae develop through four instars (Cappaert et al. 2005). EAB may complete their life cycle in 1-2 years; one year in warmer climates and two years in colder climates (McCullough & Katovich 2004). Pupation occurs in early spring and is followed by emergence of the adult beetle.

Approximately 50 million ash trees have already been attacked by EAB with numerous infestations still being detected (Smith et al. unpublished). The borer is difficult to detect in newly infested trees because the larvae feed and grow beneath the bark (Haack et al. 2002). Adults are difficult to detect as they do not appear to have a long range aggregation or sex pheromone that would aid in trapping efforts. In order to initiate management to slow the spread of EAB, such as reducing the ash phloem

resources from an area, early detection of infestations is crucial (Eberhart 2007, Eberhart et al. 2007). Girdled trap trees, ground surveys, firewood inspections, and the peeling of bark to detect larvae are all methods of detection (Cappaert et al. 2005, de Groot et al. 2006, Metzger et al. 2007, Storer et al. 2007). An important tool for detecting EAB infestations and populations in the future will be trap tree surveys. Artificially stressed trap trees have been used as an alternative to visual survey based on the finding that EAB is attracted to stressed ash trees (Cappaert et al. 2005, Storer et al. 2007). Numerous studies were and are being conducted to test for preferred colors, host volatiles, and pheromones (Poland et al. 2004, Francese et al. 2005, Crook et al. 2006). Purple hues were observed to be more attractive to buprestids than were reds, oranges, and browns (Francese et al. 2005). Based on this finding, a large scale survey using baited purple prism traps was carried out in the United States. The effectiveness of these purple traps is unclear (e.g. Marshall et al. 2009). Girdled trap trees have been found to be the most effective of all the traps developed thus far; however, the trap tree method still needs to be refined. The use of girdled trees is destructive to the host resource, and the setting of more effective non-destructive traps will result in fewer trees being girdled and eventually dying each season.

The objective of this study was to determine what variables, specifically the amount of ash resource in the area, tree size, canopy conditions, and position of the tree in the forest, explain differences in landing behavior of EAB on non-girdled ash trees in an area of known low density EAB infestation.

Materials and Methods

Field Data Collection

In the spring of 2007, field sites were established at Burt Lake State Park, Indian River, Michigan; Harrisville State Park, Harrisville, Michigan; and Tawas Point State Park, East Tawas, Michigan, which were all known to have low density EAB infestation based on detection surveys using girdled trap trees that had been conducted since 2004. Study plots ranged in size from 2 to 7 hectares and included areas at each park where ash occurred. All of the ash trees within the plots were wrapped with 0.5 m wide pallet wrap at breast height and covered with Tangle-Trap Insect Trap Coating (The Tanglefoot Co., Grand Rapids, Michigan). The sticky traps were monitored and checked biweekly throughout the beetle flight season from late June through August. All EAB beetles caught were counted and collected, and the aspect (north, south, east, or west) on each tree was recorded.

In mid summer, canopy assessments of all detection trees were conducted at each park. The attributes assessed in 2007 included: crown light exposure, tree vigor, crown dieback, uncompact live crown ratio, and crown class and position. The USDA Forest Service rating system within the Forest Inventory and Analysis protocol was used for assessing all of the attributes and are briefly described here (USDA 2005). Crown light exposure was measured by dividing the tree canopy into four equal sides and estimating the number of sides that would receive direct sunlight, ranking the tree from 0 to 5 (receives no light to receives full light). A tree rated as a 5 receives light on all four sides of the canopy plus on the top of the canopy. Tree vigor and condition estimated the amount of dead twigs and branches in the crown on a scale from 1 to 8, where 1 is

relatively few dead twigs and 8 is a dead tree. Crown dieback is the percent of the live crown that has dieback. Uncompacted live crown ratio (ULCR) is the percentage of the total height of the tree that is live crown. Crown class and position rates the crown of the tree in relation to other trees and ranges from open grown (rated 1) to overtopped (rated 5).

In 2008, sticky bands were reestablished on the trees at all three state parks. The sticky traps were again monitored and checked for EAB every two weeks, and canopy assessments were carried out in midsummer. The tree attributes assessed were the same as in 2007 with the addition of crown density and foliage transparency. Crown density is the percent of light blocked from showing through the crown canopy, which takes into consideration both the live and dead parts of the crown (USDA 2005). Foliage transparency measures the amount of light that shines through the live crown as a percent of visible light that would show through if it was not blocked by the crown while disregarding dead parts of the crown when taking the measurement.

A stem map was produced of Burt Lake State Park in 2007 so that the distance of each ash tree from other ash trees and from other trees regardless of species could be assessed. Burt Lake was selected for the stem mapping part of the experiment because it was more heavily infested than the two other sites, and therefore was expected to yield useful results. To produce the map, reference trees were chosen to take coordinate positions using a Trimble GPS system, and from those reference trees, the distance and azimuth of each visible tree were recorded using a laser rangefinder and a line running compass. When no more trees could easily be measured from that tree, another reference tree was chosen and used to measure all the trees that could be seen from that location.

This procedure was repeated until all of the trees in the study plot were measured and recorded. Diameter at breast height (dbh) and tree species were recorded for all the trees in the plot. Using ArcMap Version 9.3 and the near tool, the stem map of Burt Lake State Park was used to determine the distance from each detection tree to the nearest ash tree and also to the nearest tree regardless of species.

Data Analysis

A one-way analysis of variance (ANOVA) was used to test for differences in tree and canopy attributes between detection trees with and without EAB at each park ($\alpha = 0.05$). Multiple regression was used to investigate the relationship between the number of beetles caught on the trapping surface and the various tree attributes at each park ($\alpha = 0.05$). All analyses were conducted using Statistix 8.0 (2003).

Results

The tree species composition differed between the parks, but ash stems made up between 26 and 41% of the trees (Table 3.1). White ash (*Fraxinus Americana*) was the most prevalent tree species at all three of the state parks. The second most prevalent species differed at each park, with red maple (*Acer rubrum*) the next most prevalent at Burt Lake State Park, white cedar (*Thuja occidentalis*) at Harrisville State Park, and red oak (*Quercus rubra*) at Tawas Point State Park.

In summer 2007, 32 adult beetles were caught on 10 of 270 trap trees at Burt Lake State Park; however, no adult beetles were caught on trap trees at Harrisville State Park or at Tawas Point State Park. In summer 2008, 196 adult beetles were caught on 37 of

271 trap trees at Burt Lake State Park, 15 adult beetles were caught on 11 of 115 trap trees at Harrisville State Park, and again no beetles were caught on 101 trap trees at Tawas Point State Park.

Landing rates of adult beetles were not dependent on the aspect of the tree where they were trapped. More beetles were trapped on the south side of the trees at Burt Lake State Park in 2007 and at Harrisville State Park in 2008 and on the west side of the trees at Burt Lake State Park in 2008, but the differences in the proportion and number of beetles trapped on each side did not differ significantly.

Comparison of detection trees with and without EAB

Differences in tree attributes between detection trees with and without EAB were tested using one-way analysis of variance. At Burt Lake State Park in 2007, the mean tree diameter for trees with EAB was 33.2 cm which was significantly different from the mean diameter of 18.5 cm for trees without EAB ($p = <0.01$, $n = 270$). The mean tree vigor rating for trees with EAB was 2.5 which was significantly different from the mean tree vigor rating of 1.6 for trees without EAB indicating that the trees with EAB had lower vigor than the trees without EAB ($p = 0.01$, $n = 270$). Also, the mean crown dieback for trees with EAB was 31.0% which was significantly different from the mean crown dieback of 12.2% for trees without EAB indicating that the trees with EAB contained more dead branches in the canopy than the trees without EAB ($p = <0.01$, $n = 270$). Differences in the crown class and position rating between detection trees with and without EAB were not significant. Differences in distances from the nearest ash tree or

nearest tree regardless of species between detection trees with and without EAB were also not significant.

At Burt Lake State Park in 2008, the mean tree diameter for trees with EAB was 24.3 cm which was significantly different from the 18.2 cm for trees without EAB ($p = <0.01$, $n = 262$). The mean tree vigor rating for trees with EAB was 2.5 which was significantly different from the 1.7 for trees without EAB indicating that the trees with EAB had lower vigor than the trees without EAB ($p = <0.01$, $n = 271$). The mean crown dieback for trees with EAB was 31.4% which was significantly different from the mean crown dieback of 14.1% for trees without EAB indicating that the trees with EAB contained more dead branches in the canopy than the trees without EAB ($p = <0.01$, $n = 271$). The mean crown light exposure rating was 3.1 for trees with EAB which was significantly different from the mean rating of 2.3 for trees without EAB indicating that the trees with EAB received more direct sunlight than the trees without EAB ($p = <0.01$, $n = 271$). The mean crown class and position rating was 2.1 for trees with EAB which was significantly different from the mean rating of 3.0 for trees without EAB indicating that trees with EAB were less crowded by other trees and received more direct sunlight than the trees without EAB ($p = <0.01$, $n = 271$). There was no significant difference in distance from the nearest ash tree between detection trees with and without EAB; however, the mean distance from the nearest tree regardless of species for trees with EAB was 5.1 m which was significantly different from the 3.9 m for trees without EAB ($p = 0.04$).

At Harrisville State Park in 2008, the mean tree diameter for trees with EAB was 32.7 cm which was significantly different from the mean diameter of 17.3 cm for trees

without EAB ($p = <0.01$, $n = 115$). The mean tree vigor rating for trees with EAB was 1.8 which was significantly different from the mean tree vigor rating of 1.3 for trees without EAB ($p = <0.01$, $n = 115$). Trees with EAB had significantly lower mean tree vigor (indicated by higher vigor rating values) than the trees without EAB. The mean crown dieback did not significantly differ between detection trees with and without EAB. The mean crown light exposure rating was 4.2 for trees with EAB which was significantly different from the mean rating of 2.8 for trees without EAB ($p = <0.01$, $n = 115$). Trees with EAB received more direct sunlight than the trees without EAB. The mean crown class and position rating was 2.4 for trees with EAB which was significantly different from the mean rating of 3.1 for trees without EAB indicating that trees with EAB were less crowded by other trees and received more direct sunlight than the trees without EAB ($p = 0.01$, $n = 115$).

Regression Analysis

Multiple regression was used to investigate the relationship between the total number of EAB caught at each park and the different detection tree attributes (Table 3.2). At Burt Lake State Park in 2007, the total number of EAB caught increased as tree diameter increased, crown dieback increased, and crown light exposure rating decreased (Table 3.3). At Burt Lake State Park in 2008, the total number of EAB caught increased as tree diameter increased, crown dieback increased, crown class and position rating increased, crown density increased, and the distance to the nearest tree decreased. At Harrisville State Park in 2008, the total number of EAB caught increased as crown

dieback decreased, foliage transparency increased, tree vigor rating increased, and crown light exposure rating increased.

Multiple regressions were also used to investigate the relationship between the density of EAB caught at each park and the different detection tree attributes (Table 3.2). At Burt Lake State Park in 2007, the density of EAB caught increased as tree diameter increased and crown dieback increased (Table 3.3). At Burt Lake State Park in 2008, the density of EAB caught increased as tree diameter increased, crown dieback increased, and crown class and position rating increased. At Harrisville State Park in 2008, the density of EAB caught increased as crown density decreased, crown light exposure rating increased, and tree diameter decreased.

Discussion

The trapping survey was conducted at Burt Lake State Park, Harrisville State Park, and Tawas Point State Park for the EAB flight seasons in 2007 and in 2008. EAB beetles were detected on trees for both flight seasons at Burt Lake State Park and in the second flight season at Harrisville State Park. Tree attributes that differed between detection trees with and without EAB varied between the sites, likely due to differences in the level of EAB infestation at each park. Burt Lake State Park was more heavily infested than the other two parks, and Tawas Point State Park had a low level of infestation that was not detected during this study. Forest composition of the parks may also have affected the results. Burt Lake was more open and the trees are more spread out, Harrisville was heavily wooded with very few open spaces and contained more cedar trees and swampy conditions, whereas Tawas Point contained fewer trees that were more

spread out. This study was conducted to determine which tree attributes are more attractive to the beetle so more effective non-destructive traps can be established to detect EAB.

Tree size appears to influence landing behavior. The mean tree diameter was larger for trees with EAB than for trees without EAB at Burt Lake State Park in 2007 and 2008 and at Harrisville State Park in 2008. Trees with larger diameters at Burt Lake State Park trapped more EAB adults and a higher density of EAB adults in 2007 and 2008. However, the opposite was true for beetle density at Harrisville State Park in 2008. The results at Harrisville may differ because only a small number of EAB were caught. The attraction of EAB to larger trees at Burt Lake State Park may be because there is more resource in the form of food and oviposition sites on larger trees. It could also be that the sticky traps on larger trees have more surface area to catch the beetles. Either way, larger diameter trees make more successful detection trees. This supports the finding that large ash trees are preferentially attacked in newly established EAB populations (Eberhart 2007, Marshall et al. 2009).

Other canopy conditions were important in influencing EAB landing behavior. The mean tree vigor rating for trees with EAB was higher than for trees without EAB at Burt Lake State Park in 2007 and 2008 and at Harrisville in 2008. As higher vigor ratings reflect lower tree vigor, this indicated that trees landed on by EAB were less vigorous on this scale and this indicates more dead wood in the crowns of the less vigorous trees. The infestation of EAB could have caused the dead branches in the tree or the dead branches could be a sign of stress which resulted in attraction of EAB to the tree. The mean crown dieback for trees with EAB was higher than for trees without EAB

at Burt Lake in 2007 and 2008. A tree with a high tree vigor rating (i.e. lower tree vigor) also contains high crown dieback. As the total number of EAB adults caught and the density of EAB increased, the crown dieback increased at Burt Lake State Park in 2007 and 2008, whereas crown dieback decreased as the total number of EAB adults caught increased at Harrisville State Park in 2008. At Burt Lake State Park in 2008, total EAB adults caught increased as crown density increased, whereas at Harrisville State Park in 2008, density of EAB increased as crown density decreased. At Harrisville State Park in 2008, the total number of EAB adults caught increased as foliage transparency increased and as tree vigor rating increased. The results at Harrisville may differ from the results at Burt Lake because only 15 beetles were caught on 11 trees meaning there were only 1 or 2 beetles on each tree with EAB. Based on these findings, trees that have larger diameters and canopies with some dead branches are good candidates for detection trees.

Position in the forest appeared to influence landing behavior. Based on the mean crown class and position ratings at Burt Lake State Park and at Harrisville State Park in 2008, trees with EAB were dominant and less crowded by other trees than trees without EAB. Both of these conditions were affected greatly by the tree's position in the forest. The mean distance from the nearest tree regardless of species was farther for trees with EAB than for trees without EAB in Burt Lake State Park in 2008. As the total number of EAB adults caught increased, the crown class and position rating increased at Burt Lake State Park in 2008, whereas the density of EAB increased as the crown class and position rating increased at Harrisville State Park in 2008. As the total number of EAB adults caught increased, the crown light exposure rating decreased at Burt Lake State Park in 2007, whereas the crown light exposure rating increased as the total number of EAB

adults caught and the density of EAB increased at Harrisville State Park in 2008. The differences in the results may be explained by the few number of beetles caught on few trees at Burt Lake State Park in 2007 and at Harrisville in 2008. Also, as the total number of EAB adults caught increased, the distance to the nearest tree regardless of species increased at Burt Lake State Park in 2008. Based on these findings, trees that are open grown are successful detection trees. Open grown trees have previously been reported to make better detection trees, likely due to preference of adult beetles for warmer sunny canopies.

In developing recommendations for deploying non-girdled ash trees as traps for adult EAB detection surveys, the variability of the results needs to be taken into consideration. The results over two years at Burt Lake State Park appear to reflect the preference for larger open grown trees and trees with dieback in the canopy or lower vigor. The selection of trees with these attributes at Harrisville is consistent with this when detection trees with and without EAB are compared. The outcome of the multiple regression analysis for Harrisville State Park suggests some deviation from this trend, but this is likely a result of the very low numbers of trapped insects at that site. The mean number of adults trapped per tree with EAB at Harrisville was very low, and the analyses comparing trap trees with and without EAB are likely more informative than the multiple regression analyses. Based on these studies, sticky bands should be placed on trees with dieback that are large and open grown where ground surveys have not been able to detect emerald ash borer and girdling and peeling of trees is not an option.

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Table 3.1. Tree species composition at Burt Lake State Park, Indian River, Michigan; Harrisville State Park, Harrisville, Michigan; and Tawas Point State Park, East Tawas, Michigan. The top five tree species are listed.

Burt Lake State Park	Harrisville State Park	Tawas Point State Park
26% white ash (<i>Fraxinus americana</i>)	28% white ash (<i>Fraxinus americana</i>)	31% white ash (<i>Fraxinus americana</i>)
22% red maple (<i>Acer rubrum</i>)	28% white cedar (<i>Thuja occidentalis</i>)	27% red oak (<i>Quercus rubra</i>)
16% white cedar (<i>Thuja occidentalis</i>)	13% black ash (<i>Fraxinus nigra</i>)	8% jack pine (<i>Pinus banksiana</i>)
16% white pine (<i>Pinus strobus</i>)	6% sugar maple (<i>Acer saccharum</i>)	6% willow (<i>Salix</i> spp.)
4% white spruce (<i>Picea glauca</i>)	5% paper birch (<i>Betula papyrifera</i>)	4% red maple (<i>Acer rubrum</i>)

Table 3.2. Relationships of attributes with the total number of emerald ash borer caught and emerald ash borer density at Burt Lake State Park, Indian River, Michigan, in 2007 and 2008 and at Harrisville State Park, Harrisville, Michigan, in 2008. Significant factors ($p < 0.05$) in multiple regression analysis are reported as positive or negative when related to total EAB trapped or EAB density. N/a indicates that attributes are not available for inclusion in the analysis for the site and date combination. N.s. indicates that the factors were not significant.

Attribute	Burt Lake State Park 2007		Burt Lake State Park 2008		Harrisville State Park 2008	
	Total EAB	EAB Density	Total EAB	EAB Density	Total EAB	EAB Density
Crown Class and Position	n.s.	n.s.	Positive	Positive	n.s.	n.s.
Crown Dieback (%)	Positive	Positive	Positive	Positive	Negative	n.s.
Uncompacted Live Crown Ratio (%)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tree Vigor	n.s.	n.s.	n.s.	n.s.	Positive	n.s.
Crown Light Exposure	Negative	n.s.	n.s.	n.s.	Positive	Positive
Foliage Transparency (%)	n/a	n/a	n.s.	n.s.	Positive	n.s.
Crown Density (%)	n/a	n/a	Positive	n.s.	n.s.	Negative
Diameter (dbh, cm)	Positive	Positive	Positive	Positive	n.s.	Negative
Distance to Nearest Ash Tree (m)	n.s.	n.s.	n.s.	n.s.	n/a	n/a
Distance to Nearest Non-ash Tree (m)	n.s.	n.s.	n.s.	n.s.	n/a	n/a
Distance to Nearest Tree Regardless of Species (m)	n.s.	n.s.	Negative	n.s.	n/a	n/a

Table 3.3. Outcome of multiple regression analysis to relate tree attributes with the total number of emerald ash borer caught and emerald ash borer density at A) Burt Lake State Park, Indian River, Michigan, in 2007 and 2008 and at B) Harrisville State Park, Harrisville, Michigan, in 2008.

A)

Attribute	Total emerald ash borer caught				Density of emerald ash borer caught			
	t-value	P-value	d.f.	Variance inflation factor (VIF)	t-value	P-value	d.f.	Variance inflation factor (VIF)
Burt Lake State Park 2007								
Crown Dieback (%)	3.70	<0.01	257	1.0	3.52	<0.01	258	1.0
Crown Light Exposure	-3.03	<0.01	257	1.9	n.s.	n.s.	n.s.	n.s.
Diameter (dbh, cm)	5.68	<0.01	257	1.9	3.74	<0.01	258	1.0
Burt Lake State Park 2008								
Crown Class and Position	4.83	<0.01	256	2.2	4.17	<0.01	258	2.0
Crown Dieback (%)	3.30	<0.01	256	2.1	5.15	<0.01	258	1.0
Crown Density (%)	2.29	0.02	256	2.4	n.s.	n.s.	n.s.	n.s.
Diameter (dbh, cm)	7.59	<0.01	256	2.1	6.00	<0.01	258	2.0
Distance to Nearest Tree Regardless of Species (m)	-2.25	0.03	256	1.5	n.s.	n.s.	n.s.	n.s.

B)

Attribute	Total emerald ash borer caught				Density of emerald ash borer caught			
	t-value	P-value	d.f.	Variance inflation factor (VIF)	t-value	P-value	d.f.	Variance inflation factor (VIF)
Harrisville State Park 2008								
Crown Dieback (%)	-2.65	<0.01	110	4.6	n.s.	n.s.	n.s.	n.s.
Tree Vigor	3.81	<0.01	110	4.5	n.s.	n.s.	n.s.	n.s.
Crown Light Exposure	3.63	<0.01	110	1.0	3.32	<0.01	111	1.5
Foliage Transparency (%)	2.17	0.03	110	1.1	n.s.	n.s.	n.s.	n.s.
Crown Density (%)	n.s.	n.s.	n.s.	n.s.	-3.54	<0.01	111	1.1
Diameter (dbh, cm)	n.s.	n.s.	n.s.	n.s.	-2.06	0.04	111	1.4

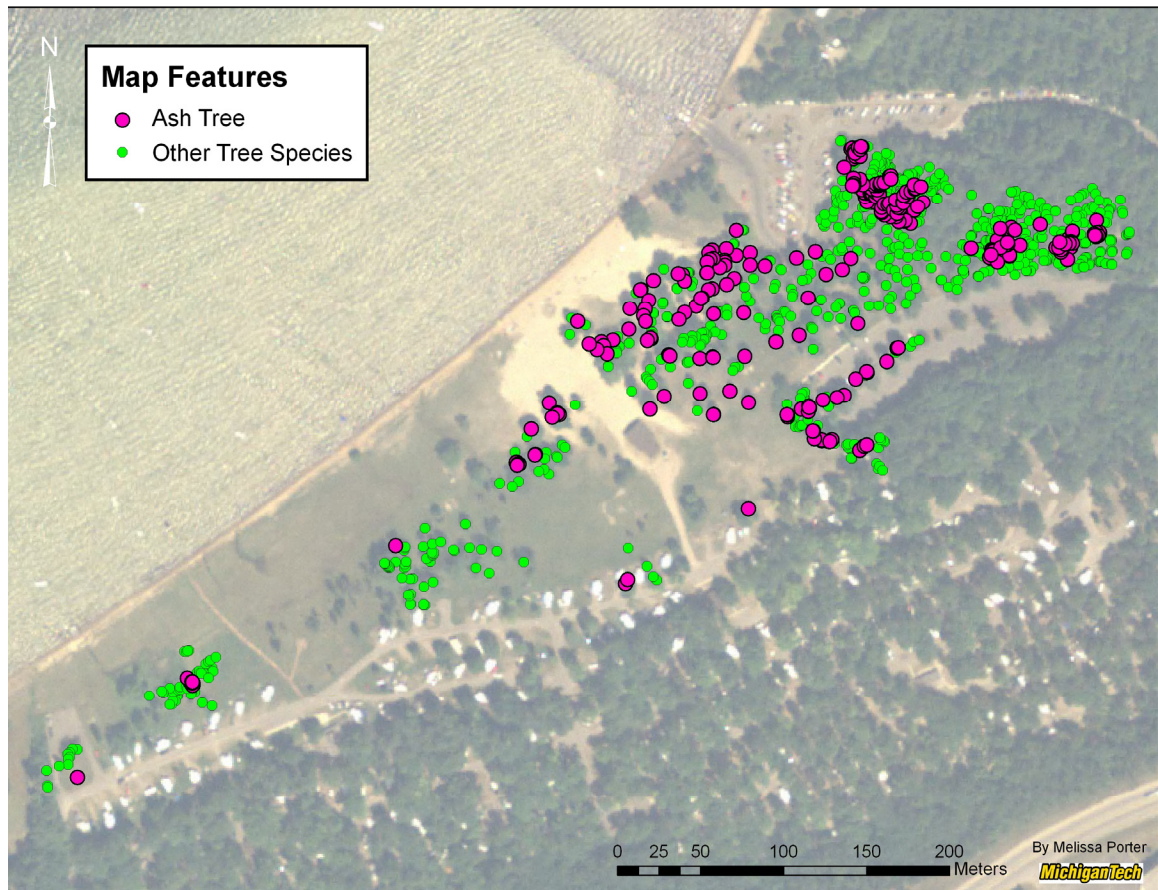


Figure 3.1. Stem map showing the location of the emerald ash borer detection ash trees and trees regardless of species in the study plot at Burt Lake State Park, Indian River, Michigan, in 2007 and 2008. (<http://www.mcgi.state.mi.us/mgdl/>. Adapted by Porter from files created by Hyslop).

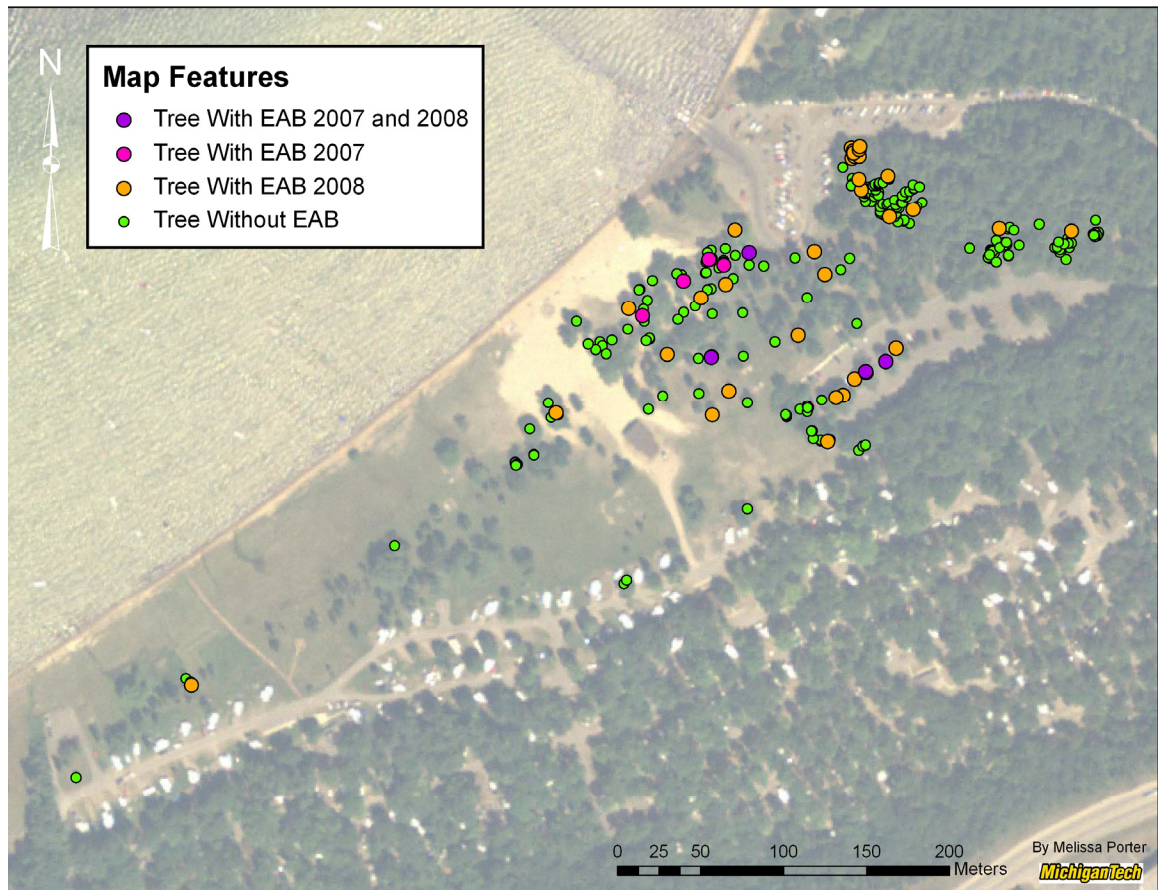


Figure 3.2. Stem map showing the location of the detection trees with and without emerald ash borer at Burt Lake State Park, Indian River, Michigan, in 2007 and 2008. (<http://www.mcgi.state.mi.us/mgdl/>. Adapted by Porter from files created by Hyslop).

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