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Effectiveness of Emerald Ash Borer (Agrilus planipennis) trap placement in relation to forest edges

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EFFECTIVENESS OF EMERALD ASH BORER (*AGRILUS PLANIPENNIS*) TRAP PLACEMENT IN RELATION TO FOREST EDGES

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Report Abstract

Agrilus planipennis, Fairmaire (Order Coleoptera: Family Burprestidae), an invasive insect to North America has caused mortality and decline of millions of *Fraxinus* trees since its discovery in 2002. A study to evaluate purple prism trap effectiveness in low-to-moderate beetle densities in relation to road proximity and basal area of *Fraxinus* species was conducted in northern Michigan in 2013 and 2014. Transects of traps were established at set distances from roads during *A. planipennis* flight season. Analysis indicated a significant relationship between road proximity and trap effectiveness, with traps established on the road edge out-performing traps established in the forest interior. As early detection is critical to slowing the spread of this invasive pest, using this method in conjunction with the national detection survey may reduce the time between beetle establishment, detection, and management.

Chapter 1: Emerald Ash Borer Overview

Introduction

In the spring of 2002, an unknown buprestid was discovered in Detroit, Michigan and identified as *Agrilus planipennis,* Fairmaire (Order Coleoptera: Family Burprestidae) and given the common name emerald ash borer (EAB). Soon after the positive identification, other *A. planipennis* populations were discovered in Ontario, Canada in 2002 (Haack et al 2002, Poland and McCullough 2006). *Agrilus planipennis* is native to China, Mongolia, Korean, Japan, Taiwan and eastern Russia (Yu 1992, Haack et al 2002, Cappaert et al 2005), where it is not known to be a serious forest pest (Yu 1992). In North America, EAB has caused significant mortality and decline of millions of *Fraxinus* (ash) species across the landscape (Aukema et al 2011, Marshall et al 2013, Herms and McCullough 2014). Apparently established in North America since the mid-1990's (Siegert et al 2014), the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) and the United States Department of Agriculture Forest Service (USDA FS) believe the beetle was introduced to North America in solid wood packing materials (Aukema et al 2011). As EAB had not previously been identified outside its native range (Cappaert et al 2005), much of its ecology and behavior was unknown. Since its discovery, research has focused on developing information concerning EAB's lifecycle, morphology, ecology, behavior, spread and management (Herms and McCullough 2014). By 2015, infestations of EAB had been reported in 25 states and two Canadian provinces (EAB.info 2015, USDA-APHIS 2015c).

Biology of Emerald Ash Borer

Research focused on understanding phenological events of the EAB lifecycle, as very little literature was available (Herms and McCullough 2014). Information concerning egg, larvae, and adult development, in addition to overwintering behavior and adult activity in forest canopies was critical to understanding population dynamics, and to develop management strategies (Cappaert et al 2005). Eggs are oblate-shaped, approximately 1.0 mm in size, white-yellow when laid, turning amber-brown when mature (Yu 2002, Wei et al 2007, Wang et al 2010). Larvae are flat and broad, white in color. The largest instar larvae are 26 to 32 mm long. The head of the larva is small with only mouth parts visible. The abdomen is divided into 10 legless segments, with the last segment containing a pincer shaped urogomphi appendage (Wei et al 2007, Wang et al 2010). Pupae are 10 to 13 mm long, and white in color. Adults are 10 mm to 13 mm long, elongate, cylindrical shaped and copper metallic green. The emerald ash borer is the only *Agrilus* species in North America found to have a red purplish metallic dorsal abdominal color which is concealed by the elytra (Parsons 2008).

In southern regions EAB has one generation per year, but larvae require two years to complete a single generation in more northern regions of the United States and Canada (Yu 1992, Cappaert et al 2005, Wei et al 2007, Siegert et al 2010). A two year life cycle also occurs in areas with low EAB density and low tree vigor rating (low canopy decline) (Tluczek et al 2011). Eggs are individually laid by adult beetles in host bark crevices in sunny locations in the summer months (Yu 1992, Wei et al 2007, Wang et al 2010). One female can lay between 50 and 90 eggs during her lifespan (Haack et al 2002, Cappaert et al 2005). Eggs hatch within 7 to 14 days and larvae develop through four instars, all of which consume phloem and cambium tissue (Haack et al 2002, Wang et al 2010). Larvae create serpentine S-shaped galleries as they feed on host tissue during the late summer and fall months. The larval stage is the most destructive life stage, as the host's ability to transport nutrients and water is reduced (Wang et al 2010). Mature larvae overwinter in prepupal chambers located approximately 1.0 cm deep in host sapwood, and pupation occurs the following spring (Cappaert et al 2005, Poland and McCullough 2006). Immature larvae, not fully developed by the end of fall, require a second year of development. Immature larvae will overwinter in the cambium, continue to feed the following spring, and overwinter as prepupae the second winter before emerging as adults in the spring (Yu 1992, Wei et al 2007, Siegert et al 2010). When adults complete development they emerge, creating D-shaped exit holes as they chew through outer bark layers. Emergence occurs when approximately 450 grown degree days (base 50°F) has been reached (USDA APHIS PPQ 2015). Adults are most active during the spring months especially on warm, sunny days feeding in tree canopies (Wang et al 2010, Cappaert et al 2005). Both female and male adults can consume 0.5 cm^2 to 1.0 cm^2 foliage per day. Beetles continue to feed and mate throughout their lifespan of approximately two to three weeks (Haack et al 2002, Wei et al 2007, Wang et al 2010).

Hosts – *Fraxinus* Species

All North America ash species (*Fraxinus* spp.) are susceptible to infestation by EAB. Beetles have been observed readily attacking and killing white ash (*F. americana* Linnaeus), green ash (*F. pennsylvanica* Marshall), and black ash (*F. nigra* Marshall) (Haack et al 2002, Wang et al 2010) and lower amounts of blue ash (*F. quadrangulata* Michx.*)* (Pureswaran and Poland 2009). North American ash species (Family: Oleaceae), range from Nova Scotia to northern Florida, and northwest as far as Alberta, Canada extending south through Montana, Wyoming toward the Texas Gulf coast. Ash can be found on a wide range of soils, from poorly drained peat soils to upland well drained fertile soils (Burns et al 1990, Little 1977).

External symptoms of EAB are rarely observed during initial infestations, as low larval populations typically do not cause significant visible host damage (Haack et al 2002, Cappaert et al 2005, Poland and McCullough 2006, Wang et al 2010). As population densities increase, the heavy consumption of tissue disrupts nutrient and water transportation leading to diminished health, and eventual death of hosts (Haack et al 2002, Cappaert et al 2005, Wang et al 2010). Infestations can be visually observed by external signs of epicormic branching, reduced host vigor, canopy dieback, bark splits along the trunk, D-shaped exit holes, water sprouts at the tree base, and woodpecker activity (Haack et al 2002, Cappaert et al 2005). Bark splits apparently result from the defensive response of the host producing callous tissue around larval galleries. Epicormic branching and the production of water sprouts at the tree base is a result of extreme distress, as the host produces photosynthetic material needed for survival (Haack et al 2002). In areas of one-year EAB life cycles, host death may occur within two or three years (Haack et al 2002, Cappaert et al 2005, Wang et al 2010).

Laboratory studies to determine EAB host preference were conducted using green, white, black, blue, Manchurian (*Fraxinus mandshurica* Rupr.) and European ash (*Fraxinus excelsior* L.). Beetles were observed to most prefer green ash, followed by black, white, European, and Manchurian ash (Anulewicz et al 2008, Pureswaran and Poland 2009). Larvae and adults were observed feeding on all ash offered to them, with Manchurian and blue ash being least preferred (Pureswaran and Poland 2009). Manchurian ash, which co-evolved with EAB in its native range, may have developed natural defenses which limit beetle consumption and development (Rebek et al 2006, Pureswaran and Poland 2009). Blue ash, less preferred by EAB, may also have physical and chemical properties that cause lower fitness of feeding adults and developing larvae. Both Manchurian and blue ash may produce higher amounts of host volatiles that result in lower beetle preference (Pureswaran and Poland 2009, Cipollini et al 2011). As EAB is reported to only infest stressed hosts in its native range (Yu 1992), it is likely Asian ash species have developed resistance mechanisms through co-evolution with EAB. This co-evolution has resulted in no widespread ash mortality in the native range of EAB (Yu 1992, Rebek et al 2006, Rebek et al 2008).

Emerald ash borer has been shown to complete development on white fringetree (*Chionanthus virginicus* L.) (Cipollini 2015). The white fringetree native to southeastern United States, is in the same family, Oleaceae, as other North America ash vulnerable to EAB. Several white fringetrees examined in Dayton, Ohio were discovered having multiple generations of larvae and adult activity (Cipollini 2015). EAB has been reported to land and oviposit on other non-ash species in no-choice studies (Anulewicz et al 2008). Larvae attempted to feed on black walnut (*Juglans nigra* L.), Japanese tree lilac (*Syringa reticulate (Blume H. Hara)*, American elm (*Ulmus americana* L.) and hackberry (*Celtis occidentalis* L.), but were unsuccessful as failed first instar larvae galleries were observed (Anulewicz et al 2006, Anulewicz et al 2008). Although eggs matured and hatched, failed first year larvae were observed. No larvae were successful on non-ash species in no-choice studies (Anulewicz et al 2006, Anulewicz et al 2008).

Spread and Impact of Emerald Ash Borer

As of February 2015, EAB populations have been reported in 25 states and two provinces in Canada; Arkansas, Colorado, Connecticut, Georgia, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Hampshire, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin, and Ontario and Quebec, Canada (EAB.info 2015, USDA-APHIS 2015c, USDA-APHIS 2016). After the initial introduction of EAB, likely in the mid-1990's based on dendrochronological analysis (Siegert et al 2014), dispersal of EAB has occurred through long-range transport of infested wood products and natural dispersal mechanisms (Cappaert et al 2005, Kovacs et al 2011). Evaluation of EAB flight performance was conducted using flight mills in laboratory settings. The median corrected distance flown by mated females was greater than 3 km, while one percent of EAB were recorded flying greater than 20 km (Taylor et al 2010). Isolated infestations like those found in Quebec, Canada and Calumet, Michigan in 2008 are clearly anthropogenic. The steady range expansion from these isolated sites, and other sites are likely due to natural dispersal capabilities of EAB (Siegert et al 2010).

Millions of ash trees have died or are dying as a result of EAB infestations (Marshall et al 2013). Ash resources, in forests and urban settings in the United States, are valued at more than $282 billion (USDA FS 2009). Whereas the annual ash nursey stock is valued at approximately $140 million (USDA APHIS ARS FS 2015). Federal and state managers have spent on average $29.5 million per year to manage EAB populations (USDA APHIS ARS FS 2015). Removal of dead and infested trees, treating infested trees, and replanting is estimated to cost $10.7 billion over a 10 year period (Kovacs et al 2010). Ash saplings as small as approximately 6 cm in diameter have been reported to be vulnerable to EAB attack (McCullough and Katovich 2008). Impacts in areas of high ash mortality include reduced landscape and aesthetic value, changes in forest composition, reduced wildlife habitat, and changes in hydrological cycles

(Hausman and Jaeger 2010, Sydnor et al 2007). The fate of white, green, black and blue ash species is largely dependent on the success of established seedlings and saplings (Klooster et al 2014) in addition to discovered surviving ash (Knight et al 2012, Tanis and McCullough 2012, Marshall et al 2013, Robinett et al 2014). In areas of high ash mortality, individual surviving healthy ash have been discovered (Knight et al 2012, Tanis and McCullough 2012, Marshall et al 2013, Robinett et al 2014). Surviving white ash have been discovered in areas infested for over six years (Robinett et al 2014). The potential survival of these trees may be influence by bark roughness and other factors (Knight et al 2012, Marshall et al 2013).

Trap Development

As little literature existed on EAB before the first infestation in North America, it was unknown if beetles used long-range pheromones, visual cues, tactile cues or host volatiles to locate host trees and potential mates. Much of the early focus of detecting EAB populations involved using girdled trap trees. Girdled trap trees were established by removing a section of phloem and bark around the circumference of the tree. Field crews established girdled traps prior to EAB flight season and returned to fell and peel the tree to confirm infestation through larvae presence (Marshall et al 2009, Marshall et al 2010, McCullough et al 2009b, Tluczek et al 2011, Foelker et al 2013). Although reliable, peeling trees is expensive and labor intensive and cannot be widely used in urban settings (Mercader et al 2013, Poland and McCullough 2014). In addition, sticky bands were frequently placed around girdled trees to traps adults landing on the tree (Marshall et al 2010).

Sticky traps had previously been developed to capture flatheaded borers in the buprestid family. Traps made of multiple colors of heavy wallpaper covered with insect glue where used to simulate sapling tree silhouettes. Green, gray and red sticky traps captured the most buprestids, confirming buprestid sensitivity to colors (Oliver et al 2002). Retinal sensitivity was examined using electroretinogram recordings from the compound eye of adult EAB. Recordings measured wavelengths across the 300 to 700 nm spectrum. Peak recordings showed beetle sensitivity in the UV 340nm, violet 420 to 430 nm, blue 460nm, green 540 to 560 nm and red 640 to 670 nm regions of the spectrum (Crook et al 2009). Additionally, buprestids were found to be more attracted to the colors in the violet range of 400 to 420 nm (Francese et al 2005).

Further trapping studies evaluating color and design of traps were conducted. Purple panels were shown to capture significantly more adult beetles than any other color (Francese et al 2005). Traps constructed of a single color (purple, white or red) of corrugated plastic were evaluated at set distances from an ash woodlot in 2004. Traps were established on the edge of the woodlot, inside the woodlot, and in adjacent fields. Purple traps captured more beetles, while edge traps captured significantly more beetles than inside woodlots (Francese et al 2008). Four panel box traps, single panel, three panel prism, and crossvane traps were compared in 2006. Box traps caught more beetles than crossvane traps, while the three panel prism trap did not significantly differ from any other trap design (Francese et al 2008). In 2008, 2010 and 2011, purple double decker traps, consisting of two purple prism traps attached to a PVC pipe (McCullough et a 2011, Poland and McCullough 2014), were compared to purple prism canopy traps. Double decker traps captured higher amounts of female and male beetles (McCullough et al 2011, Poland and McCullough 2014). As purple prism traps were relatively inexpensive, made of a single sheet of corrugated plastic and required less hardware than double decker traps they were more desirable for large scale surveys (Francese et al 2008).

In addition to color, green leaf volatiles emitted by ash species have been shown to attract EAB beetles (Rodriguez-Saona et al 2006, de Groot et al 2008, Crook et al 2008). These green leaf volatiles elicit an antennal response from both female and male EAB. Several green leaf volatiles were identified from green and white ash, with 3-Z-hexenol eliciting the largest response in male beetles (de Groot et al 2008). Two natural oil concentrates, Manuka oil and Phoebe oil have been shown to contain high levels of several active volatiles that also elicit beetle antennal response (Crook et al 2008). Lures containing assorted combinations of Manuka oil, Phoebe oil and 3-Z-hexenol were shown to increase trap success when paired with purple prism traps (Crook et al 2008, de Groot et al 2008, Marshall et al 2010, Silk et al 2011, Crook et al 2014, Poland and McCullough 2014). Since 2008, USDA APHIS has relied on various versions of the baited purple prism canopy traps in national trapping surveys to detect EAB populations across the landscape (Crook et al 2009, USDA-APHIS PPQ 2015).

Management and SLAM Project

Management strategies to detect and reduce the spread of EAB populations include artificial purple prism traps, girdled trees, sinks of girdled trees, insecticide treatments, removal of infested trees, biological control, and quarantines (Poland et al 2010, Mercader et al 2013, Mercader et al 2015). These strategies were combined in the SL.owing A.sh M.ortality pilot project, also known as the SLAM project. The SLAM project was a large-scale program involving universities, state and federal agencies in the Upper Peninsula of Michigan with the objective of protecting ash resources (Mercader et al 2013, McCullough et al 2015, Mercader et al 2015).

Isolated EAB infestations discovered in Moran and St. Ignace, Mackinac County, Michigan in 2007 served as the first SLAM project areas from 2008 to 2010 (Mercader et al 2015). As successful containment of newly infested areas is highly dependent on timely detection of EAB, purple prism traps and girdled trees were established to act as detection tools (Mercader et al 2013, Mercader et al 2015). Population sinks comprised of multiple girdled trees within close proximity, were established to retain beetles in currently infested areas. In addition to retaining EAB, SLAM field crews felled and peeled population sinks to remove the next generation of beetles (Poland et al 2010, McCullough et al 2015).

A systemic insecticide, found to reduce larval densities and cause adult beetle mortality (McCullough et al 2009c), was injected into ash trees to create a buffer zone around infested core areas (Poland et al 2010, Mercader et al 2015). The insecticide was also applied to areas containing population sink trees (McCullough et al 2015) and to individual trees on private lands (Mercader et al 2015). To further reduce the potential production of EAB in SLAM sites independent contractors removed heavily infested trees (Poland et al 2010). Natural enemies *Oobius agrili, Spathius agrili,* and *Tetrastichus planipennisi* found in the native ranges of EAB were released as biological control agents in SLAM sites to aid in controlling EAB populations (USDA APHIS ARS FS 2015). State and federal quarantines were utilized to prevent infested logs, firewood, nursery trees, and other infested materials from being transported into non-infested areas (Poland et al 2010).

In 2008, a SLAM pilot program was established in Houghton and Keweenaw Counties of Michigan after an isolated infestation of EAB was discovered near Calumet, Michigan (Hyslop and Storer 2009). In 2010, an intensive trapping grid was established in northern Houghton and Keweenaw Counties using previous knowledge from the 2008 initial trapping survey. The objective of this intensive grid was to identify new infestation locations and monitor infestation spread, with an emphasis on protecting ash resources. Between 2010 and 2013, girdled trees, purple prism traps, forest health plots, ash inventory plots, biological release plots, and insecticide treatments were established across the Houghton-Keweenaw area.

Hundreds of purple prism traps were established in Houghton, Keweenaw, and Mackinac Counties. In 2008, a lure releasing 50 mg per day of Manuka oil was used, whereas a lure releasing 50 mg per day of an 80:20 mixture of Manuka and Phoebe oil was used in 2009 and 2010 (Mercader et al 2013). Lures containing Manuka and Phoebe oil were shown to increase trap capture rates when paired with purple prism traps (Crook et al 2008, de Groot et al 2008, Marshall et al 2010, Silk et al 2011, Crook et al 2014, Poland and McCullough 2014). Evaluation of traps established in Moran and St. Ignace SLAM project locations indicated that both girdled trees and purple prism traps have a relatively low probability of detecting EAB in areas of low population densities (Mercader et al 2013). The ability implement management strategies to reduce ash mortality across North America largely depends on early detection of EAB populations (Liebhold and Tobin 2008).

National Emerald Ash Borer Survey

In 2012, the national EAB detection survey relied on a computer-generating survey sampling program to produce coordinates to established purple prism traps. The program was developed by APHIS and the United States Forest Service's Forest Health Technology Enterprise Team (USDS FHTET) (USDA APHIS 2012, USDA APHIS PPQ 2013). Geographic locations having the highest probability of detecting EAB populations were pre-selected by the program, and coordinates were produced. Field crews travelled to these locations, which were often difficult and time consuming to reach. Impassable river crossings, bogs, or steep terrain slowed the trap establishment process. In some situations, field crews would pass suitable ash trees to reach the computer coordinates containing no ash species. Cost associated with trapping include; time needed to reach coordinates, time to find suitable trees, establishing traps, and the time needed to negotiate land access permission by field crews or project coordinators prior to trap establishment.

In some areas, suitable trees may be available within the right-of-way of roads, or within visual distance from roads. Permission in these areas are often easier to gain, or are owned by the county, state or federal agencies. Establishing traps closer to roads could decrease the time needed for field crews to identify suitable trees, and establish traps. More importantly establishing traps closer to roads, if determine to increased trap effectiveness, could reduce the time between beetle establishment, detection and management. The research described in this report investigated whether proximity to roads or basal area of ash species influenced trap effectiveness.

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Chapter 2: Purple Prism Transect Evaluation

Abstract

The emerald ash borer (*Agrilus planipennis*) is a destructive invasive pest that has caused mortality of millions of *Fraxinus spp.* trees in North America. The extended interval between insect establishment, detection, and management has allowed this pest to spread to large parts of North America. Purple prism canopy traps are currently used in national detection surveys for this beetle. The effectiveness of purple prism traps at low-to-moderate population densities of EAB in relation to road proximity was evaluated in 2013 and 2014. Transects of traps were established at set distances from roads in northern Michigan near an isolated beetle infestation. It was hypothesized that detection success is influenced by road proximity, and that traps placed closer to roads were more likely to detect emerald ash borer. There was a positive significant relationship between EAB captured and road proximity. Traps established further from roads were no more likely to detect EAB than traps established close to roads. Basal area of non-ash species, EAB population density, vigor rating, EAB population density, tree species, and sampling duration were shown to significantly influence EAB captured on traps.

Introduction

Emerald ash borer (EAB, *Agrilus planipennis* Fairmaire, Coleoptera: Buprestidae) is a destructive invasive pest of North America ash trees (*Fraxinus* spp.). Native to China, Mongolia, Korea and Japan (Yu 1992, Cappaert et al 2005), this invasive pest has caused significant mortality to ash resources across North America (Cappaert et al 2005, Poland and McCullough 2006). Since its discovery, EAB has quickly become the most devastating forest pest resulting in mortality of millions of ash trees across the United States and Canada (Aukema et al 2011, Marshall et al 2013, Herms and McCullough 2014). The beetle was first discovered in Detroit, Michigan in 2002 (Haack et al 2002, Poland and McCullough 2006), and is believed to have been introduced through solid wood packing materials (Aukema et al 2011). In 2005, EAB was discovered approximately 300 miles north of Detroit in Brimley State Park in Chippewa County in Michigan's Upper Peninsula. In 2007, the beetle was found in Mackinac County, Michigan (Storer et al 2008) and in 2008, EAB was confirmed nearly 500 miles north of Detroit, in northern Houghton County, Michigan (Hyslop and Storer 2009). Based on dendrochronological analysis, the beetle was likely in northern Houghton County in Calumet, Michigan for at least six years prior to the first detection in 2008 (Hyslop and Storer 2009). Natural spread of the beetle across the landscape is possible, but long-distance spread is largely facilitated by movement of wood products (Cappaert et al 2005).

Emerald ash borer is a phloem-feeding insect, causing the majority of damage in its larval stage (Haack et al 2002). Larvae create serpentine galleries in the living phloem of the host from summer to late fall as they develop through four stages and feed on host tissue. A one year lifecycle typically occurs where larvae overwinter in pupae chambers and emerge as adults the following spring (Yu 1992, Wei et al 2007, Wang et al 2010). In more northern regions such as Houghton County, larvae require a second year of development and overwinter in the first year as early instars in the phloem. They continue to feed in the summer and overwinter as prepupae the second winter and emerge as adults the following summer. After emergence, adults feed on ash foliage, mate, and oviposit eggs in outer bark crevices (Yu 1992, Cappaert et al 2005, Wei et al 2007, Siegert et al 2010). Ash vulnerable to beetle infestation include all North American species including white (*Fraxinus americanna* Linnaeus), green (*Fraxinus pennsylvanica* Marshall), and black ash (*Fraxinus nigra* Marshall) (Haack et al 2002, Wang et al 2010).

Since 2008, the national EAB detection survey has relied primarily on purple prism traps to monitor and detect EAB populations (Crook et al 2009, USDA-APHIS 2015a). This survey is a collaboration involving United States Department of Agriculture's, Animal and Plant Health Inspection Service (APHIS) and Forest Service (FS) in addition to various State's departments of agriculture and natural resources and Tribal institutions. The national survey uses a computer generated program based on historical data of ash presence and current EAB infestation information to produce GPS locations with the highest probability of detecting EAB. Tens of thousands of traps have been established using this computer generating program, often at significant distances into the forests (USDA APHIS 2012, USDA APHIS 2015b).

The objectives of this study were to (1) determine if EAB detection success is related to road proximity and (2) to determine if detection success is related to ash basal area. The ability to detect EAB populations within close road proximity may reduce the time and associated costs needed to establish artificial traps across the landscape. Including road proximity into current detection surveys may improve the likelihood of detecting EAB and ultimately provide critical information for effective management options.

Materials and Methods

Field Site

In 2010, an intensive EAB detection survey known as the SL.owing A.sh M.ortality (SLAM) project began around the epicenter of a known infestation discovered near Calumet, Michigan (Hyslop and Storer 2009). The SLAM project was a pilot project that aimed to characterize developing EAB populations and implement management strategies to slow the progress of ash mortality (Mercader et al 2013, Mercader et al 2015). Artificial purple prism traps and girdled trap trees were established throughout a 59,000 hectare area in Houghton and Keweenaw Counties. Between 2010 and 2013, over 1800 purple prism and girdled tree traps in addition to forest health plots and ash inventory plots were established in the SLAM study site. The detection of known low-to-moderate EAB populations throughout the SLAM study site provided a suitable location to test objectives concerning artificial trap effectiveness in relation to proximity to roads.

In 2013 and 2014, transects of traps were established in Houghton and Keweenaw counties. These counties are located on the Keweenaw Peninsula of Michigan which extends to Lake Superior. This area has an average annual precipitation of 0.86 m, annual average snow fall of 5.5 m, and an annual mean temperature of 12°C (NOAA 2004). Traps were established on state, federal, and private lands, with a landowner base of over 500 participants. The population of EAB was initially delimited by placing traps along transects radiating outward from the Calumet location to north of Ahmeek, east of Lake Linden, south beyond Houghton, and west toward Liminga (Figure 2.1).

Study Design

Purple prism traps were established along transects in known low-to-moderate EAB population densities. Each transect comprised of three or four traps established at distances from the nearest non-seasonal public paved or non-paved roads. Traps were established by a two-person field crew using GPS units to determine distance from roads. Trap establishment began when approximately 450 growing degree-days was reached throughout the area. Climatological daily temperatures recorded at the Hancock - Houghton County Airport by the National Oceanic & Atmospheric

Administration were used to calculate growing degree-days. Approximately 450 growing degrees days was reached on July 10, 2013 and July 5, 2014 at the study site.

Relatively healthy trees, having vigorous crowns and no signs or symptoms of EAB, were selected for trap establishment. Selection for trap placement was based on, crown class, vigor rating, crown light exposure, diameter at breast height, and signs of EAB infestation of potential trees (USDA APHIS PPQ 2013). Trees having a crown class (position of crown in the forest canopy) of open grown or dominant were preferred for trap placement. In previous artificial trap research, traps placed in the upper and outer canopies of open grown or dominant trees where shown to increase trap success (Poland et al 2005, Marshall et al 2010). Trees having a vigor rating (rate of crown decline) of low decline were preferred in addition to trees having a higher crown light exposure rating (amount of crown exposed to direct sunlight). Potential trees also had a minimum diameter at breast height of 10 cm and no major signs of EAB infestation; exit holes, bark splits, epicormic, woodpecker activity or galleries.

Once suitable trees were identified, GPS locations were recorded, uniquely numbered metal tags were placed at the base of each tree, and flagging was placed at approximately diameter at breast height. Tree health data was recorded at each trap location including; tree species, vigor rating, crown class, crown light exposure, signs and symptoms of EAB, and basal area of ash and non-ash species.

As ash readily hybridize in the study site, accurately discerning between green and white ash in the field proved difficult. Species of ash were assigned into two groups; black ash, and green or white ash. Tree vigor rating was used to assess the amount of dead twigs and branches in the tree canopy recorded on a 1 to 5 scale; 1 = crown with relatively few dead twigs, foliage density and color normal, occasional small dead branches in upper crown and occasional large branch stubs on upper bowl, 2 = crown with occasional large dead branch in upper portion, foliage density below normal, some small dead twigs at top of crown, occasional large branch stubs on upper bole, 3 = crown with moderate dieback, several large dead branches in upper crown, bare twigs beginning to show, several branch stubs on upper and mid bole, 4 = approximately half of crown dead and 5 = over half crown dead (Schomaker et al 2007).

Crown class was used to classify the position of the tree in the stand and was recorded on a 1 to 5 scale; 1 = open grown, 2 = dominant, 3 = co-dominant, 4 = intermediate and 5 = overtopped. Crown light exposure was recorded based on a 0 to 5 scale, to estimate direct sunlight received by the crown; 0 = tree receiving no full light because its shaded by trees, or other vegetation (the tree has no crown by definition), 1 = the tree receives full light from the top or one side, 2 = the tree receives full light from the top and two sides (or two sides without the top), 3 = the tree receives full light from the top and two sides (or three sides without the top), 4 = the tree receives full light from the top and three sides and 5 = tree receiving full light from the top and four sides (Schomaker et al 2007).

Signs and symptoms of EAB indicated by wood pecker activity, bark splits, epicormic shoots or water sprouts, D shaped exit holes and galleries were recorded based on a 0, 1, 2 scale where 0 = None, 1 = Few (< 5) and 2 = Many (5 +) (modified from USDA APHIS 2015a). Signs and symptoms of trees on which traps were placed were assessed during establishment and inspection of each trap. Basal area was measured with a 10-factor prism using a center point adjacent to the suitable tree. The number of ash, live or dead, and the number of live non-ash species was recorded. Tree health and basal area measurements were recorded for both 2013 and 2014 trapping seasons during trap establishment.

Traps used for this project were provided by APHIS (Animal and Plant Health Inspection Service). Traps were constructed of a single sheet of purple corrugated plastic (35.5 cm x 60.9 cm), with pre-glued panels. Assembly of traps into prism shape was accomplished by folding, sticky side out, along pre-folded horizontal groves and placing corresponding tabs into slots. Zip ties were placed into matching pre-punched holes to ensure shape. Metal spreaders were fitted into corresponding pre-punched holes at the top of the prism shape. A metal hanger attached to the metal spreader (USDA APHIS PPQ 2013). The outside panels were pre-covered with Tanglefoot© (The Tanglefoot Company, Grand Rapids, MI). Lure packets were attached to a ring on the metal spreader in the center of the trap. Lures were designed to last for 60 days in the field, emitting volatile compounds at specific rates. Two lures were used on each trap. One emitted an 80:20 mixture of Manuka and Phoebe oil at a rate of 50 mg/day, and the other lure released Z-3-hexenol at a rate of 50 mg/day. Traps were hung in tree canopies using a telescoping pole. In areas where a suitable limb was out of pole reach, a throw line was tossed over a limb and the trap was hoisted into the canopy (USDA APHIS PPQ 2013).

Transects were comprised of traps established at putative set distances from roads at approximately 0 m from the road and 25 m, 50 m and 200 m into the forest. Since suitable ash trees were not available at the exact locations needed on the transects, traps were established within 10 m of the 0 m, 25 m, and 50 m distances, and within 50 m of the 200 m distance. Some transects lacked a fourth trap established at the 200 m distance due to lack of ash resource. Traps were initially established in 2013 in known areas of low-to-moderate EAB population densities in trees showing no major signs or symptoms of EAB, and met preferred suitable tree selection guidelines concerning; crown class, vigor, and DBH ratings (USDA APHIS PPQ 2013). In 2014, traps were re-established in trees used in 2013 where available. Trees showing major signs and symptoms of EAB, or dead were not re-used in the 2014 trapping season. In situations where 2013 trees could not be reused, a suitable tree was located at the distance needed.

Since suitable ash trees were rarely located at precise locations along transects, four primary distance classifications were used for analysis purposes. Classifications include; edge, edge interior, interior, and forest. The proximity tool in ArcGIS was used to calculate actual trap distances to roads and a Ward's (1963) hierarchical cluster was performed to group traps. In 2013, edge traps ranged from 1 to 19 m from roads, interior edge traps ranged from 22 to 53 m from roads, interior traps ranged from 58 to 114 m from roads, and forest traps ranged from 136 to 262 m from roads. In 2014, edge traps ranged from 1 to 20 m from roads, interior edge traps ranged from 21 to 48 m from roads, interior traps ranged from 50 to 115 m from roads, and forest traps ranged from 136 to 258 m from roads.

Inspection of traps occurred in October of both trapping seasons, after the EAB flight season ended. During inspection, traps were removed from trees using a telescoping pole or rope, and full beetles or pieces (elytra, abdomens, and heads) were carefully removed from the Tanglefoot panels using tweezers. Samples were confirmed as EAB in the field, counted, and placed into vials or small zip lock bags.

Statistical Analysis

As field data contained several traps with zero beetles, a transformation to produce a normal distribution was required for analysis. As transforming count data was not recommended for accurate analysis (Bolker et al 2009), a negative binomial distribution was adopted to suit the overdispersion of the data (O'Hara and Kotze 2010). Two generalized linear models (GLM) with a negative binomial log link were applied to each trapping season to determine if the amount of EAB captured was related to road proximity (distance as a continuous variable) and to compare distance classifications (edge, edge interior, interior, and forest). Chi-squared tests were applied to determine if detection success, catching at least one beetle, was associated with distance classifications or basal area of ash species. Distance classifications, and basal area categories equal to 2.3 square meters per hectare were plotted on the horizontal of the Chi-squared matrix with EAB presences plotted on the vertical. Pearson Chi-squared and Likelihood Ratio were applied appropriately where more or less than 20% cells had expected counts of less than 5 (Martin Andres 2008). The four GLMs, Chi-squared tests, and descriptive statistics of model parameters were produced using SPSS 23 (IPM SPSS Statistics 23), while Ward's (1963) hierarchical clustering was produced in JMP Pro 10 (SAS Institute Inc.).

To produce the best fit GLMs the lowest Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) was used to eliminate parameters (Posada and Buckley 2004, Johnson and Omland 2004, Bolker et al 2009). Parameters included; trap distances from roads, crown class, crown light exposure, sampling time frame, ash basal area, non-ash basal area, ash species in two groups (green or white, and black), EAB population density classes of low, medium, and high determined by wards hierarchical clustering, vigor rating, and diameter at breast height (DBH) classes determine by Ward's hierarchical clustering. All parameters were included before the backward step procedure was applied (Bolker et al 2009).

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Results

A total of 966 adult EAB beetles were captured on traps in 2013, while a total of 6,799 EAB were captured in 2014. There was a significant relationship between the amount of EAB captured on traps and road proximity. Traps established on the edge (close to roads) captured more beetles than traps at interior or forest locations (further from roads) during both seasons. Those traps established further from roads were no more likely to detect EAB than traps established close to roads. Basal area of non-ash species, EAB population density, vigor rating, sampling time frame, and tree species were shown to significantly influence EAB captured on traps. As basal area of non-ash species increased at trap locations, significantly fewer EAB were captured. An increase in EAB captured on traps occurred as EAB population density, vigor rating, and sampling time frame increased during both trapping seasons. Results of analyses are presented by the year in which traps were established (2013 and 2014), and indicate traps established closer to roads outperform traps established further into forests.

2013 Trapping Season

The best fit generalized linear model in 2013 contained; Distance + Crown Class + Density + Species + Sampling Time Frame + Ash Basal Area + Non-ash Basal Area with an AIC value of 658 (Table 2.1). Parameters of distance, sample time frame, and basal area were treated as continuous covariates to reduce group variance. Density, species, and crown class were treated as categorical factor variables. A total of 126 traps were established in 36 transects across three EAB retroactively classified population densities; low (0 to 14 EAB per transect), medium (23 to 52 EAB per transect), and high (103 to 115 EAB per transect). Thirty-six traps were established at the edge, 45 traps at the edge interior, 26 traps at the interior, and 19 traps at the forest classification.

The generalized linear model for the 2013 trapping season showed a significant relationship between EAB captured and road proximity, density class, trap sampling duration, and basal area of non-ash species. As distance from roads increased, the amount of EAB captured significantly decreased, (χ^2 = 4.5, d.f. 1, p = 0.033) (Table 2.2, Figure 2.2). Traps established in the edge captured significantly more EAB than; edge interior traps (χ^2 = 5.2, d.f. 1, p = 0.022), all interior traps (combining edge interior and interior traps) (χ^2 = 5.9, d.f. 1, p = 0.015), and forest traps (χ^2 = 15.4, d.f. 1, p < 0.001) (Table 2.3, Figure 2.2). Mean beetle counts decreased with increased distance from the edge. Traps established in the edge had a mean of 12 beetles (SE = 3.5), while edge interior had a mean of 7 beetles (SE = 2.1), all interior had a mean of 7 beetles (SE = 1.5), and forest had a mean of 3 beetles (SE = 1.3) (Table 2.4). Chi-squared analysis indicated that detecting at least one adult beetle was no more likely in the forest than on the edge, (χ^2 = 0.66, d.f. 3, p = 0.881) (Table 2.5). Population density of EAB significantly influenced trap EAB captures, as less EAB were captured in low density transects, (χ^2 = 17.5, d.f. 1, p < 0.001) (Table 2.2). Transects were grouped into three density classes; 85 traps were established in low density with a mean of 3 beetles (SE = 1.1), 31 traps in medium density with a mean of 13 beetles (SE = 2.4), and 10 traps in high density with a mean of 29 beetles (SE = 9.9) (Table 2.6) Since density classifications were retroactively based on the number of beetles captured, significant differences were expected between density classes.

Traps were established in the field between 10 to 14 weeks in 2013. As trap sampling duration increased, significantly more EAB were captured on traps, ($\chi^2 = 7.6$, d.f. 1, $p = 0.006$) (Table 2.2). The largest EAB mean count was observed on traps established for 14 weeks with a mean of 12 beetles (SE = 4.0) (Table 2.8). As basal area of non-ash species increased the amount of EAB captured on traps significantly decreased, ($\chi^2 = 16.1$, d.f. 1, $p < 0.001$) (Table 2.2). Basal area measurements of non-ash species ranged from zero to 45.9 meter^2/hectare at trap locations (Table 2.9, Figure 2.3). There was no relationship between detecting at least one beetle and basal area of ash species. EAB was no more likely to be detected in areas with higher ash basal area than in areas with lower ash basal area, (Likelihood ratio: $\chi^2 = 15.6$, d.f. 9, $p = 0.075$) (Table 2.10).

2014 Trapping Season

The best fit generalized linear model in 2014 contained; Distance + Vigor + Density + Species + Sampling Time Frame + Ash Basal Area + Non-ash Basal Area + DBH Class with an AIC value of 1472 (Table 2.1). Parameters of distance, sampling duration, basal area, and DBH class were treated as continuous covariate to reduce group variance. Vigor, density, and species were treated as categorical factor variables. A total of 181 traps were established in 48 transects across three retroactively classified EAB population density classes; low (0 to 66 EAB per transect), medium (87 to 160 EAB per transect) and high (212 to 508 EAB per transect). Forty-seven traps were established at the edge, 60 traps at the edge interior, 38 traps at the interior, and 36 traps at the forest classification.

The generalized linear model for the 2014 trapping season showed a significant relationship between EAB captured and road proximity, vigor rating, density class, species of ash, sampling duration, and basal area of non-ash species. As distance from road increased the amount of EAB captured on traps significantly decreased ($\chi^2 = 7.1$, d.f. 1, $p = 0.008$) (Table 2.11, Figure 2.4). Analysis of distance classifications indicated a significant difference between edge traps and all other classifications; edge interior, interior, all interior and forest. Edge traps captured significantly more EAB than; edge interior traps ($\chi^2 = 5.2$, d.f. 1, $p = 0.022$), interior traps ($\chi^2 = 4.1$, d.f. 1, $p = 0.041$), all interior traps ($\chi^2 = 6.3$, d.f. 1, $p < 0.001$), and forest traps ($\chi^2 = 18.0$, d.f. 1, $p < 0.001$) (Table 2.11, Figure 2.4). Of the 181 traps established in 2014, 47 were established in the edge with a mean of 55 beetles (SE = 10.2), 60 traps were established in the edge interior with a mean of 35 beetles (SE = 5.6), 38 traps were established in the interior with a mean of 35 beetles (SE = 7.3), 98 were established in the all interior (interior combined with edge interior) with a mean of 35 beetles (SE = 4.4), and 36 traps established in the forest with a mean of 21 beetles (SE = 5.3) (Table 2.4). Chi-squared analysis indicated detecting at least one EAB adult is no more likely further into the forest than on the edge, (Likelihood Ratio = 4.4, df 3, p = 0.213) (Table 2.5).

Significantly fewer EAB were trapped on trees with a vigor rating of 1 (less canopy decline) than trees with a vigor rating of 5 (high canopy decline), ($\chi^2 = 4.7$, d.f. 1, $p = 0.029$) (Table 2.11). Significantly fewer EAB were captured in the low and medium EAB density classes than high EAB density, ($\chi^2 = 65.1$, d.f. 1, $p < 0.001$) and ($\chi^2 = 6.7$, d.f. 1, $p = 0.009$) respectively (Table 2.11). The high density class had a mean of 86 beetles (SE = 8.7), while the medium had a mean of 34 beetles (SE = 4.0), and the low had a mean of 9 beetles (SE = 2.0) (Table 2.6). Significantly more EAB were captured on black ash than green and white ash combined ($\chi^2 = 8.5$, d.f. 1, $p = 0.004$) (Table 2.11). Sixty-seven traps were established in black ash trees with a mean of 55 beetles (SE = 6.7), and 114 traps were established in green or white ash trees with a mean of 27 beetles (SE = 4.3) (Table 2.7).

Traps were established in the field between 10 to 16 weeks. A significant increase in EAB was observed as trap sampling time frame increased, ($\chi^2 = 13.8$, d.f. 1, $p < 0.001$) (Table 2.11). The highest mean beetle catch was observed on traps established for 13 weeks, with a mean of 66 beetles (SE = 9.9) (Table 2.8). As basal area of non-ash species increased a significant decrease in EAB captured occurred, ($\chi^2 = 1.7$, d.f. 1, $p = 0.182$) (Table 2.11, Figure 2.5). Basal area measurements for non-ash species ranged from zero to 39 meters^2/hectare (Table 2.9). Detecting at least one EAB adult is no more likely in areas of higher ash species basal than areas of lower ash species basal area (likelihood Ratio = 13.2, d.f. 8, p = 0.104) (Table 2.10).

Discussion

Our primary objective was to determine if establishing purple prism traps closer to roadways improved trap effectiveness. The ability to establish traps close to roadways allows field crews to visually identify suitable trees, place traps, and move to their next location saving both time and costs. Our second objective was to determine if basal area of ash species was related to trap effectiveness. Our results indicate those traps established closer to roads outperformed traps established further into forests. Basal area of ash species was not found to significantly influence EAB captured. These findings could improve the national trapping survey, and provide forest managers ample time to implement management strategies before EAB populations increase or spread.

Emerald ash borer is expected to continue to spread throughout North America to new populations of non-infested, healthy hosts (Herms & McCullough 2014). In locations of early infestation and low EAB populations, external symptoms on ash trees are rarely visible (Haack et al 2002, Cappaert et al 2005, Poland and McCullough 2006). In such locations, relying on visual surveys conducted by field crews is difficult as signs and symptoms are only visible in the upper portion of the canopy (Cappaert et al 2005). Trapping methods utilizing girdled trap trees and artificial traps have been shown to detect EAB infestations, and have been used in several research projects (Francese et al

2008, Marshall et al 2009, Marshall et al 2010, McCullough et al 2009b, Tluczek et al 2011, Foelker et al 2013).

Results for the transect study indicate increased amounts of EAB are captured on traps established closer to roads. Beetles have been observed using natural corridors to disperse (McCullough et al 2003) and may be using roads to disperse as well. Based on our analysis, EAB detection surveys would benefit from including proximity to roads as a factor to determine trap placement. Of the four distance classifications, traps placed in the edge (between one and 20 m from roads) outperformed traps in all other classifications (between 20 and 262 m) in terms of beetles captured. Additionally, detection success (capturing at least one beetle) is no more likely at traps established in the forest than those traps established on the edge. This knowledge could save on trapping survey costs, and provide managers a higher likelihood of early detection and therefore an earlier opportunity to implement management or prepare quarantine regulations. Basal area of ash species did not influence detection success, however, an inverse relationship was observed between basal area of ash species and the amount of EAB captured on traps. This suggests lure and trap combination may be more important than volatiles emitted by surrounding stressed trees (Marshall et al 2009).

Density of EAB populations, ash species, sampling time frame, and vigor rating were found to have a significant influence on the amount of EAB captured on traps. Throughout the Houghton and Keweenaw County study site, EAB population densities have fluctuated between transects and seasons. A total of 966 beetles were recovered in 2013, while 6,799 beetles were recovered in 2014. This increases is likely a result of the two-year life cycle observed in the study area. A single introduction time of EAB may result in alternating years of larvae and beetles population densities, and result in observed beetle counts. Traps placed in areas of higher EAB densities outperformed (in terms of EAB captured) traps placed in lower densities, as also indicated in multiple studies (Marshall et al 2009, Mercader et al 2013, Poland and McCullough 2014). In the higher EAB population densities in 2014, traps established in black ash captured significantly more EAB than traps in green or white ash. Preference for ash species was not observed in previous low EAB density study areas (Marshall et al 2010), but have been observed in previous high EAB density areas (Marshall et al 2009). Volatile emissions and bark roughness have also been linked to host mortality rates and larval densities (Anulewicz et al 2008, Pureswaran and Poland 2009, Marshall et al 2013).

Traps established in the field for longer periods captured more EAB. The sample time frame of all traps in 2013 and 2014 surpassed the 60 day, 8.5 week lure expiration. Recommended lure replacement (USDA APHIS PPQ 2013) was not implemented as trap inspections occurred at flight season end. The largest mean counts of EAB were observed on traps with longer sampling time frames. Vigor rating was found to be significantly related to EAB captured in 2014. During both trapping seasons more overall EAB were captured on traps established in trees with a vigor rating of three (moderate crown dieback). In a previous study conducted in low EAB density in 2010, lure and trap combination had a greater influence on trap catch than tree vigor (Marshall et al 2010).

In 2013, crown class, and in 2014, DBH class were included in the GLM, but were not shown to significantly influence EAB capture rates. Several studies have shown crown class to be important in EAB capture rates (Poland et al 2005, McCullough et al 2009a, Marshall et al 2010). Dominant trees, have been shown to capture some of the highest rates of EAB per day (Marshall et al 2010), and have been shown to be more attractive to EAB (Poland et al 2005, McCullough et al 2009a, Marshall et al 2010). Analysis indicate diameter of breast height had a direct relationship with EAB captured, as found in previous studies in high and low EAB density (Marshall et al 2008, Marshall et 2009). Crown light exposure did not have a significant influence on trap catch in our analysis, although it has been shown to have a weak significant relationship to EAB capture rates on purple prism and double-decker traps (Marshall et al 2010, McCullough et al 2011).

The ability to detect EAB populations before ash decline begins is critical to effectively slowing the spread of this invasive beetle. As EAB has caused significant mortality to ash resources across North America and continues to spread, it is desirable to protect non-infested regions of ash to, at a minimum, preserve current ecosystem functions. Identifying new infestations as early as possible provides land managers, landowners, and the public more time to implement strategies and slow infestation spread. Establishing purple prism traps closer to roads was shown to significantly improve trap effectiveness in terms of beetles captured, but not in terms of detecting at least one adult beetle. Including this knowledge will help to improve effectiveness and efficiency of current detection surveys.

Map of Field Site

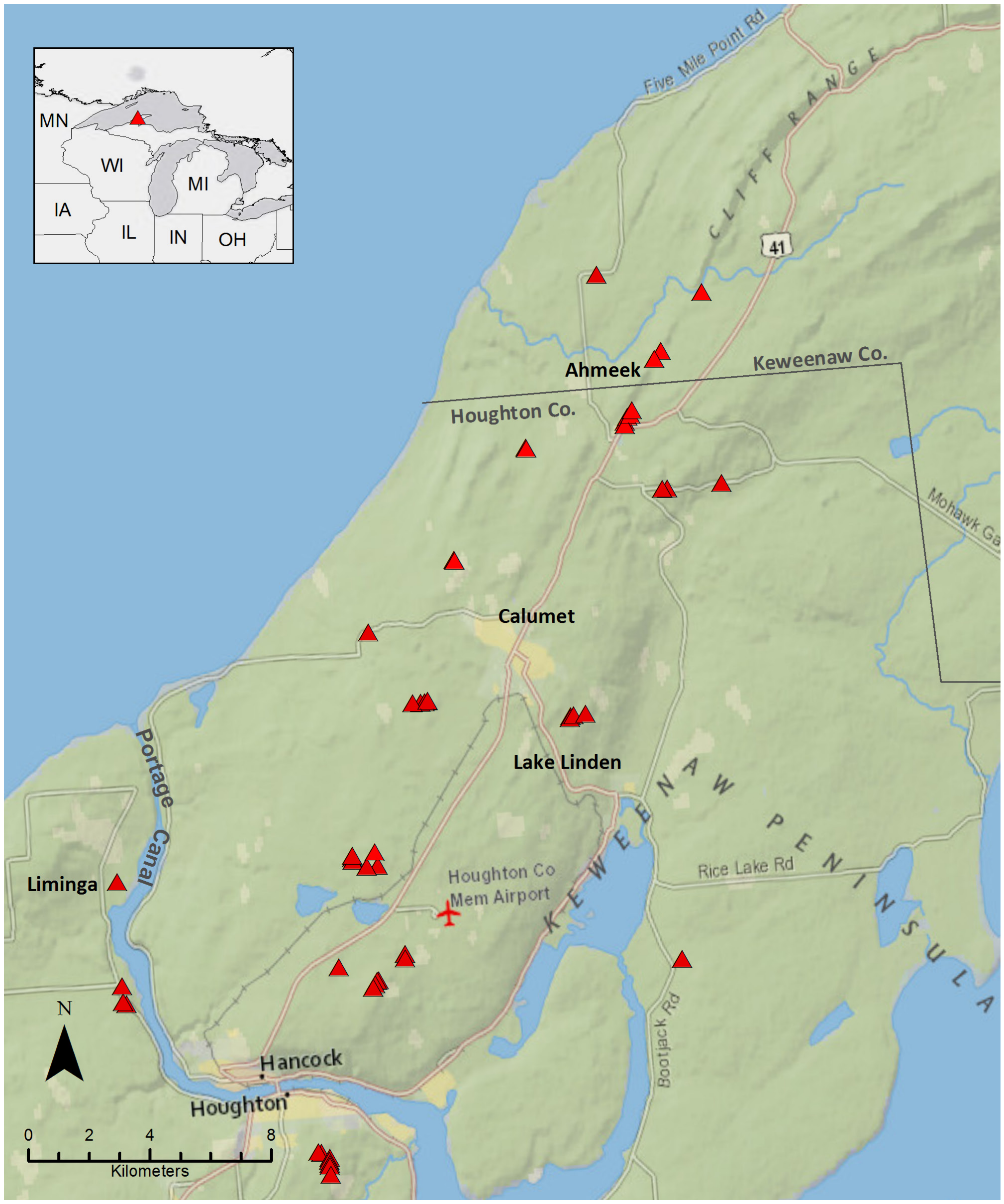
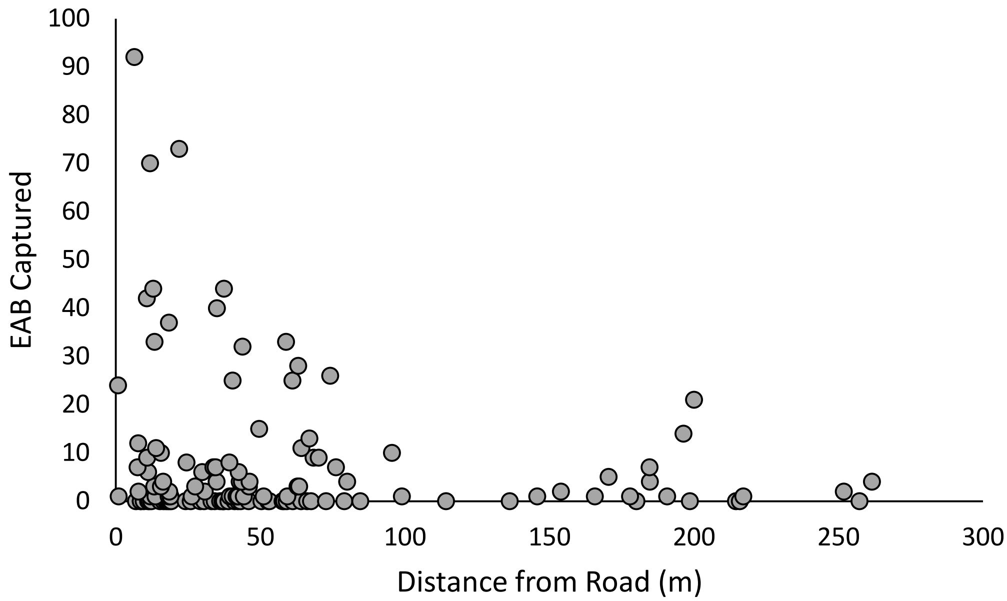


Figure 2.1. Study site of the effect of EAB trapping effectiveness in Houghton and Keweenaw County, Michigan in 2013 and 2014. Red triangles represent established purple prism transects. This map was created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license. Copyright© Esri. All rights reserved. For more information please visit www. esri.com. Map sources: National Geographic, Esri, DeLorme, HERE, UNEP-WCMC, USGS, NASA, METI, NRCAN, GEBCO, NOAA, increment P Corp.

Figures



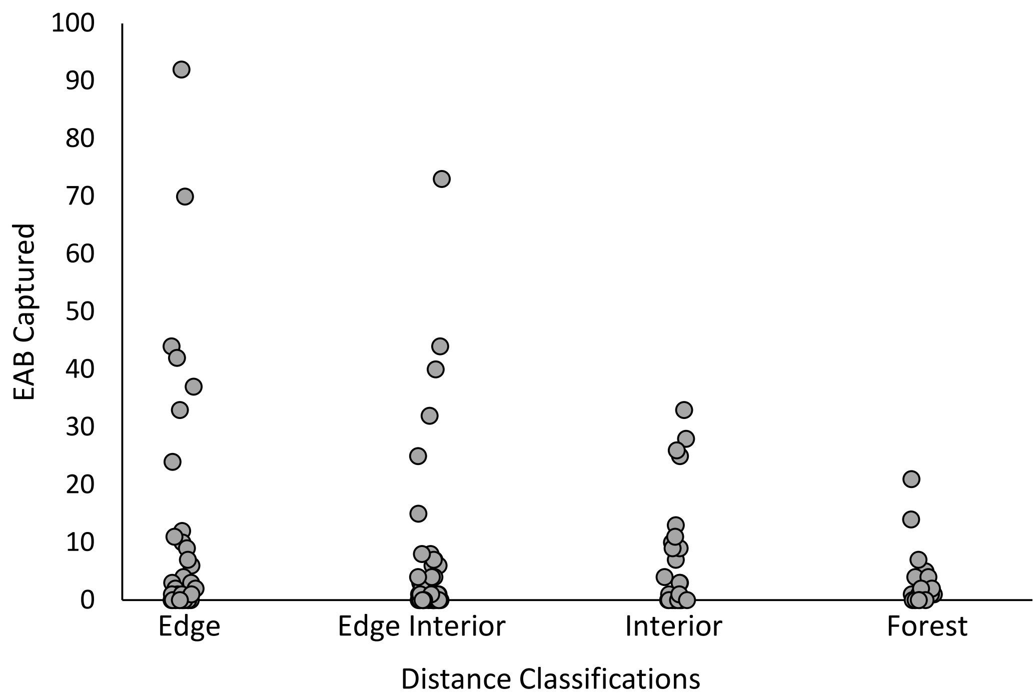
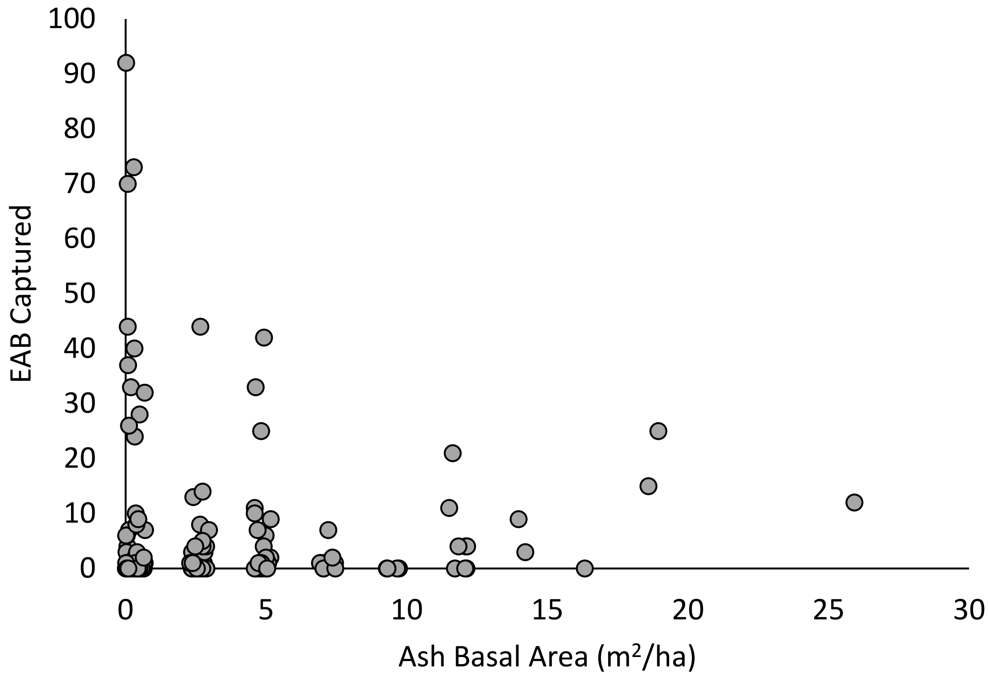


Figure 2.2. EAB captured in 2013. Top, actual distance (m) from road way. Bottom, retroactive distance classifications. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014.



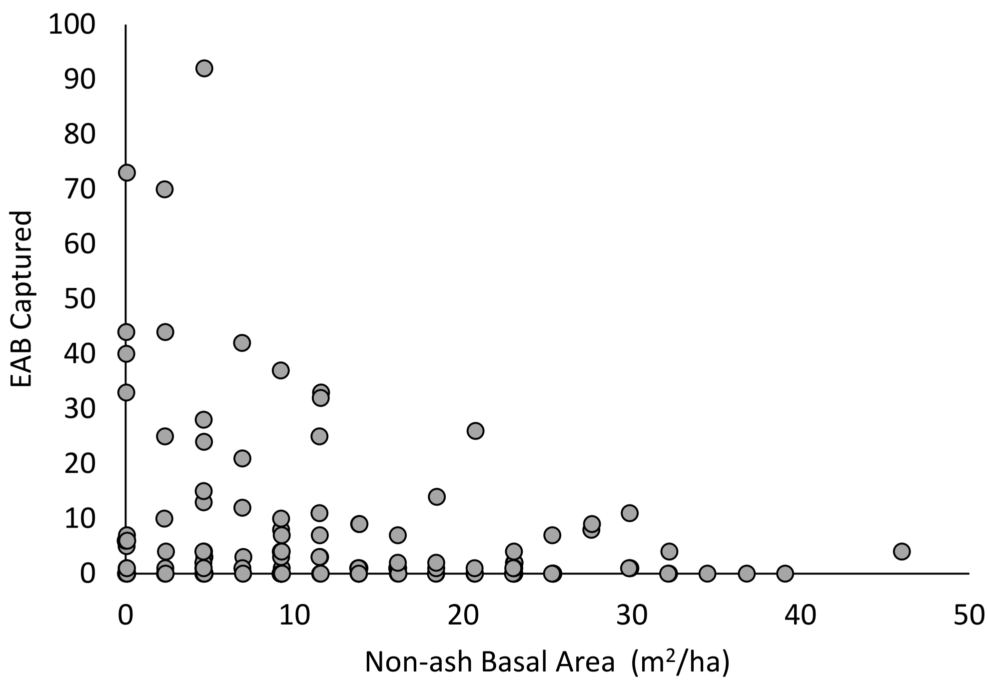


Figure 2.3. 2013 basal area of ash and non-ash species. Top, Ash basal area. Bottom, Non-ash basal area. Basal area expressed in categories of 2.3 m^2 basal area per hectare. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014.

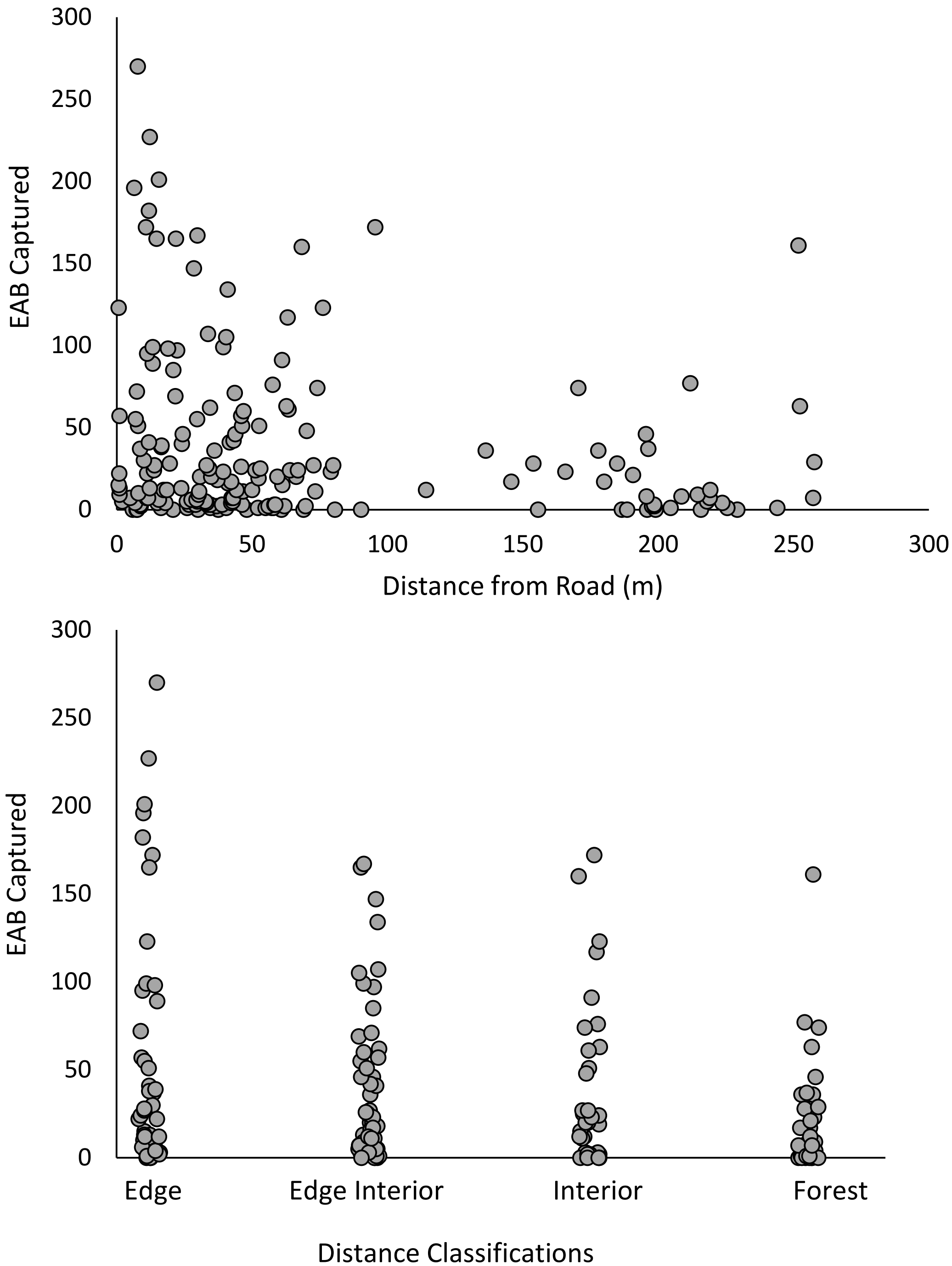


Figure 2.4. EAB captured in 2014. Top, actual distance (m) from road way. Bottom, retroactive distance classifications. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014.

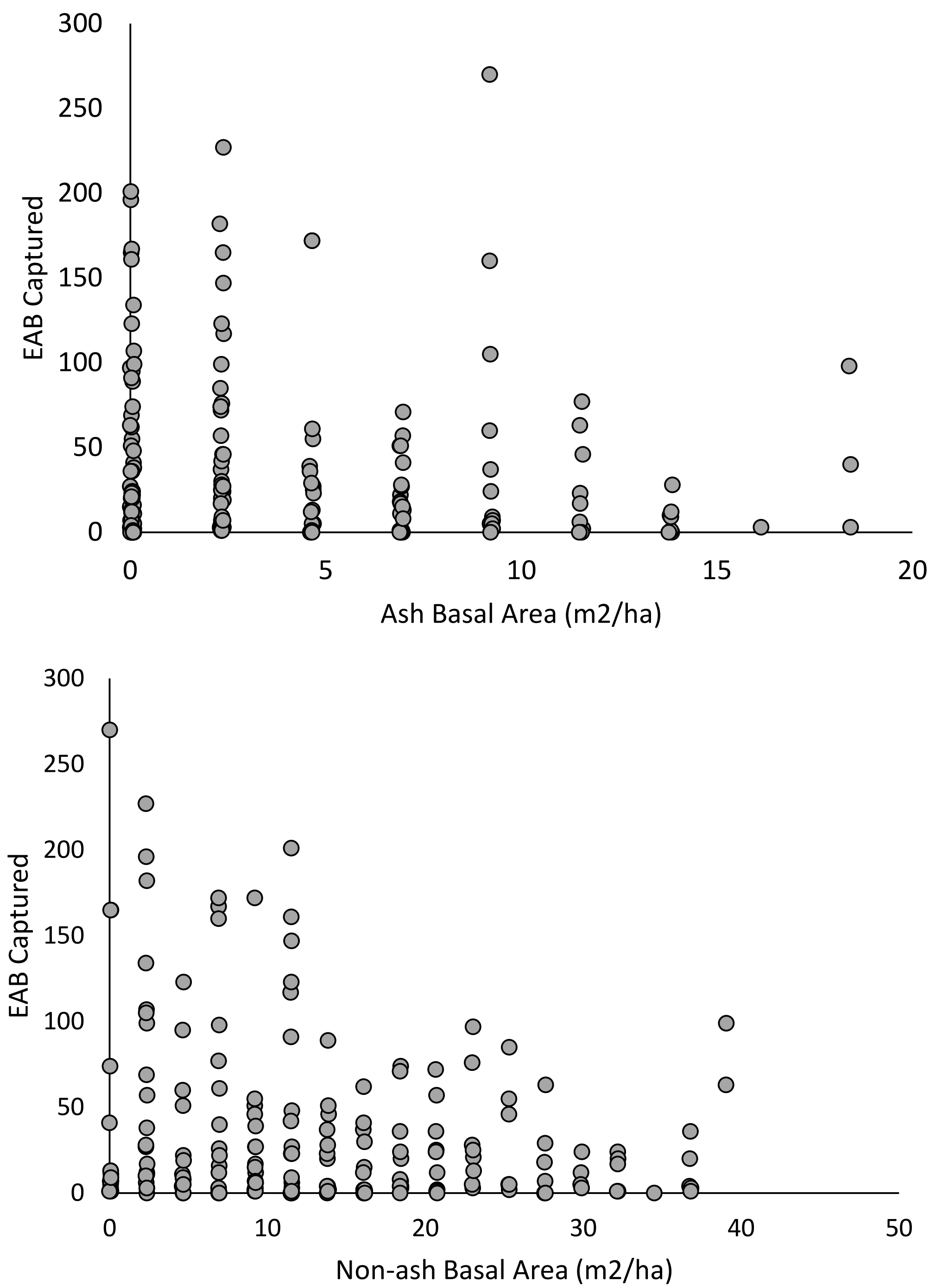


Figure 2.5. 2014 basal area of ash and non-ash species. Top, Ash basal area. Bottom, Non-ash basal area. Basal area expressed in categories of 2.3 m^2 basal area per hectare. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014.

Tables

Table 2.1. Generalized linear model parameters for 2013 and 2014 trapping seasons. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Parameters: Dis = distance, CC = crown class, CL = crown light exposure, Den = density, Spp = species, Est. T = trap established time, Ash BA = basal area of ash species, Non BA = basal area of non-ash species, DBH = diameter at breast height classes. *ΔAIC value < 2 was used for data analysis.

	Parameters	AIC	BIC	ΔAIC (AIC_i - min AIC)
2013	Dis + CC + CL + V + Den + Spp + SD + Ash BA + Non BA + DBH	670.2	727.0	13.7
	Dis + CC + CL + V + Den + Spp + SD + Ash BA + Non BA	668.3	722.2	11.8
	Dis + CC + V + Den + Spp + SD + Ash BA + Non BA	663.3	705.8	6.8
	***Dis + CC + Den + Spp + SD + Ash BA + Non BA**	**657.9**	**689.1**	***1.4**
	Dis + CC + Den + SD + Ash BA + Non BA	657.0	685.3	0.4
	Dis + CC + Den + SD + Non BA	656.5	682.0	0.0
2014	Dis + CC + CL + V + Den + Spp + SD + Ash BA + Non BA + DBH	1486.1	1556.5	14.7
	Dis + CL + V + Den + Spp + SD + Ash BA + Non BA + DBH	1479.0	1536.6	7.6
	***Dis + V + Den + Spp + SD + Ash BA + Non BA + DBH**	**1472.3**	**1513.9**	***0.9**
	Dis + V + Den + Spp + SD + Ash BA + Non BA	1472.0	1510.3	0.5
	Dis + V + Den + Spp + SD + Non BA	1471.4	1506.6	0.0
	Dis + Den + Spp + SD + Non BA	1476.6	1496.0	5.1

Table 2.2. Generalized linear model for 2013 trapping season. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Parameters include continuous trap distance from road, crown class, EAB population density, tree species (B = black, G&W = green and white), sampling time, and basal area of ash and non-ash species. (*Significant at 0.05 level).

			Hypothesis Test			
Parameters	B	Error	Wald Chi-Squared	df	p value	Exp(B)
(Intercept)	-0.051	1.914	0.001	0	0.979	0.950
Distance	-0.004	0.002	4.524	1	0.033*	0.996
Crown Class 2	0.603	1.266	0.226	1	0.634	1.827
Crown Class 3	-0.459	1.253	0.134	1	0.714	0.632
Crown Class 4	-0.487	1.329	0.134	1	0.714	0.614
Crown Class 5	0[a]	.	.	.	.	1
Density Low	-1.699	0.406	17.520	1	0.000*	0.183
Density Med	0.038	0.446	0.007	1	0.931	1.039
Density High	0[a]	.	.	.	.	1
Species B	0.258	0.253	1.043	1	0.307	1.295
Species G&W	0[a]	.	.	.	.	1
Sampling Duration	0.302	0.109	7.691	1	0.006*	1.352
Non-ash BA	-0.012	0.003	16.127	1	0.000*	0.988
Ash BA	-0.008	0.006	1.573	1	0.210	0.992

Table 2.3. Generalized liner model for 2013 distance classifications. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Edge include traps established a 1 to 19 meters from roads, edge interior includes 22 to 53 meters from road, interior includes 58 to 114 meters from roads, all interior includes 22 to 114 meters, and forest includes 136 to 262 meters from roads. (*Significance at the 0.05 level).

			Hypothesis Test			
Parameters	B	Error	Wald Chi-Squared	df	p value	Exp(B)
(Intercept)	2.447	0.174	198.420	1	0.000	11.556
Forest	-1.233	0.313	15.437	1	0.000*	0.291
All Interior	-0.524	0.215	5.919	1	0.015*	0.592
Interior	-0.496	0.272	3.317	1	0.069	0.609
Edge Interior	-0.540	0.236	5.237	1	0.022*	0.583
Edge	0[a]	.	.	.	.	.

Table 2.4. Descriptive statistics of distance classifications. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prism traps, where N equals the number of traps established.

	Distance	N	Mean	Std. Error	% (EAB sum)	Total EAB Captured
2013	Edge	36	11.6	3.5	28.6	416
	Edge Interior	45	6.7	2.1	35.7	303
	Interior	26	7.0	2.0	20.6	183
	All Interior	71	6.9	1.5	50.3	486
	Forest	19	3.4	1.3	15.1	64
	Total	126				966
2014	Edge	47	55.2	10.2	38.2	2594
	Edge Interior	60	35.1	5.6	31.0	2107
	Interior	38	35.1	7.3	19.6	1335
	All Interior	98	35.1	4.4	50.6	3442
	Forest	36	21.2	5.3	11.2	763
	Total	181				6799

Table 2.5. Chi-squared test for distance classifications. To determine likelihood of adult beetles detection. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. (Person Chi-value for 2013: 0.667, df 3, p = 0.881. Likelihood Ratio for 2014: 4.494, df 3, p = 0.213). Dependent variable is capturing at least one adult beetle.

	EAB ≥ 1	Distance classification: Edge	Interior Edge	Interior	Forest
2013	Yes	23(22)	27(28)	15(16)	13(12)
	No	13(14)	18(17)	11(10)	6(7)
	Total	26	45	26	19
2014	Yes	44(42)	56(54)	34(34)	29(32)
	No	3(5)	4(6)	4(4)	7(4)
	Total	47	60	38	36

Table 2.6. Descriptive statistics for EAB population density. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prims traps, where N equals the number of traps established.

	EAB Density	N	Mean	Std. Error	% (EAB sum)
2013	Low	85	3.3	1.1	28.9
	Medium	31	12.9	2.4	41.5
	High	10	28.6	9.9	29.6
	Total	126			
2014	Low	85	8.5	2.0	10.6
	Medium	42	33.7	4.0	20.8
	High	54	86.4	8.7	68.6
	Total	181			

Table 2.7. Descriptive statistics for tree species. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prims traps, where N equals the number of traps established.

	Tree Species	N	Mean	Std. Error	% (EAB sum)	Total EAB Captured
2013	Black	57	7.4	1.6	43.9	424
	Green/White	69	7.9	2.1	56.1	542
	Total	126				966
2014	Black	67	55.3	6.7	54.5	3706
	Green/White	114	27.1	4.3	45.5	3093
	Total	181				6799

Table 2.8. Descriptive statistics of trap sampling duration. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prims traps, where N equals the number of traps established. Sampling duration is the number of weeks traps were established.

	Sampling Duration	N	Mean	Std. Error	% (EAB sum)
2013	10	14	3.7	2.3	5.4
	11	27	5.5	2.3	15.3
	12	53	8.6	2.3	46.9
	13	8	2.1	0.8	1.8
	14	24	12.3	4.0	30.6
	Total	126			
2014	10	30	4.1	4.1	1.8
	11	6	17.3	8.3	1.5
	12	22	3.5	0.8	1.1
	13	40	66.5	9.9	39.1
	14	67	54.6	6.5	53.8
	15	4	31.8	22.6	1.9
	16	12	4.0	1.2	0.7
	Total	181			

Table 2.9. Descriptive statistics of basal area of non-ash species. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prims traps, where N equals the number of traps established. Basal area expressed in categories of 2.3m^2 basal area per hectare.

	Non-ash BA (m^2/ha)	N	Mean	Std. Error	% (EAB sum)
2013	0.0	15	14.8	5.7	23.0
	2.3	9	17.1	8.2	15.9
	4.6	16	11.8	5.7	19.7
	6.9	7	11.2	5.9	8.2
	9.2	16	4.6	2.3	7.7
	11.5	9	12.6	4.5	11.8
	13.8	10	2.1	1.1	2.2
	16.1	7	1.7	0.9	1.2
	18.4	5	3.4	2.6	1.8
	20.7	5	5.4	5.1	2.8
	23.0	9	1.1	0.4	1.0
	25.3	5	1.4	1.4	0.7
	27.5	2	8.5	0.5	1.8
	29.8	4	3.5	2.5	1.4
	32.1	3	1.3	1.3	0.4
	34.4	1	0.0	0.0	0.0
	36.7	1	0.0	0.0	0.0
	39.0	1	0.0	0.0	0.0
	45.9	1	0.0	0.0	0.0
	Total	126			
2014	0.0	16	49.5	20.0	11.6
	2.3	20	66.5	15.9	19.6
	4.6	13	31.3	10.9	6.0
	6.9	15	56.9	16.4	12.6
	9.2	17	28.7	9.9	7.2
	11.5	18	56.7	15.4	15.0
	13.8	12	25.4	7.7	4.5
	16.1	13	15.6	5.6	3.0
	18.4	11	22.8	8.0	3.7
	20.7	9	25.4	8.5	3.4
	23.0	8	33.5	12.1	3.9
	25.3	6	33.0	14.0	2.9
	27.5	6	19.5	9.8	1.7
	29.8	4	11.0	4.7	0.6
	32.1	5	12.6	4.8	0.9
	34.4	1	0.0	0.0	0.0
	36.7	5	12.8	6.7	0.9
	39.0	2	81.0	18.0	2.4
	Total	181			

Table 2.10. Chi-squared test for basal area of ash species. To determine likelihood of adult beetles detection. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. (Likelihood Ratio for 2013: 15.616, df 9, p = 0.075, Likelihood Ratio for 2014: 13.227, df 8, p = 0.104). Dependent variable is capturing at least one adult beetle. Basal area expressed in categories of 2.3m^2 basal area per hectare.

	EAB ≥ 1	Basal Area (m^2/ha)									
		0.0	2.3	4.6	6.9	9.2	11.5	13.8	16.1	18.4	25.3
2013	Yes	31(33)	16(15)	14(12)	7(6)	0(3)	5(5)	2(1)	0(.6)	2(1)	1(.6)
	No	22(20)	9(10)	6(8)	3(4)	4(1)	3(3)	0(1)	1(.4)	0(1)	0(.4)
	Total	53	25	20	10	4	8	2	1	2	1
2014	Yes	63(64)	41(37)	15(15)	17(18)	11(11)	7(8)	5(6)	1(1)	3(3)	
	No	8(7)	0(4)	2(2)	3(2)	1(1)	2(1)	2(1)	0(1)	0(1)	
	Total	71	41	17	20	12	9	7	1	3	

Table 2.11. Generalized linear model for 2014 trapping season. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Parameters include continuous trap distance from road, vigor rating, EAB population density, tree species (B = black, G&W = green and white), sampling time, and basal area of ash and non-ash species, and DBH class. (*Significant at 0.05 level).

Parameters	B	Error	Hypothesis Test Wald Chi-Squared	df	p value	Exp(B)
(Intercept)	1.983	0.951	4.346	1	0.037	7.262
Distance	-0.003	0.001	7.132	1	0.008*	0.997
Vigor 1	-0.794	0.363	4.781	1	0.029*	0.452
Vigor 2	-0.268	0.420	0.407	1	0.524	0.765
Vigor 3	-0.103	0.542	0.036	1	0.849	0.902
Vigor 4	-1.035	0.683	2.297	1	0.130	0.355
Vigor 5	0[a]	.	.	.	.	1
Density Low	-1.786	0.221	65.178	1	0.000*	0.168
Density Med	-0.581	0.223	6.789	1	0.009*	0.559
Density High	0[a]	.	.	.	.	1
Species B	0.512	0.175	8.506	1	0.004*	1.668
Species G&W	0[a]	.	.	.	.	1
Sampling Duration	0.229	0.062	13.853	1	0.000*	1.257
Non-ash BA	-0.006	0.004	1.778	1	0.182	0.994
Ash BA	-0.008	0.002	16.389	1	0.000*	0.992
DBH Class	0.095	0.076	1.595	1	0.207	1.100

Table 2.12. Generalized liner model for 2014 distance classifications. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Edge include traps established a 1 to 20 meters from roads, edge interior includes 21 to 48 meters from road, interior includes 50 to 114 meters from roads, all interior includes 21 to 114 meters, and forest includes 136 to 258 meters from roads. (*Significance at the 0.05 level).

Parameters	B	Error	Hypothesis test Wald Chi-Squared	df	p value	Exp(B)
(Intercept)	4.011	0.147	742.614	1	0.000	55.191
Forest	-0.957	0.225	18.049	1	0.000*	0.394
All Interior	-0.452	0.179	6.352	1	0.000*	0.636
Interior	-0.452	0.220	4.187	1	0.041*	0.637
Edge Interior	-0.452	0.197	5.268	1	0.022*	0.636
Edge	0[a]	.	.	.	.	.

Table 2.13. Descriptive statistics for basal area of ash species. In a study of the effect of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014. Dependent variable is the number of EAB captured on purple prims traps, where N equals the number of traps established. Basal area expressed in categories of 2.3m^2 basal area per hectare.

	Ash Basal Area (m^2/ha)	N	Mean	Std. Error	% (EAB sum)
2013	0.0	53	10.8	2.8	59.4
	2.3	25	4.6	1.8	12.0
	4.6	20	7.7	2.7	15.9
	6.9	10	1.4	0.6	1.4
	9.2	4	0.0	0.0	0.0
	11.5	8	5.5	2.5	4.6
	13.8	2	6.0	3.0	1.2
	16.1	1	0.0	0.0	0.0
	18.4	2	20.0	5.0	4.1
	23.0	1	12.0	0.0	1.2
	Total	126			
2014	0.0	16	49.5	20.0	11.6
	2.3	20	66.5	15.9	19.6
	4.6	13	31.3	10.9	6.0
	6.9	15	56.9	16.4	12.6
	9.2	17	28.7	9.9	7.2
	11.5	18	56.7	15.4	15.0
	13.8	12	25.4	7.7	4.5
	16.1	13	15.6	5.6	3.0
	18.4	11	22.8	8.0	3.7
	20.7	9	25.4	8.5	3.4
	23.0	8	33.5	12.1	3.9
	25.3	6	33.0	14.0	2.9
	27.5	6	19.5	9.8	1.7
	29.8	4	11.0	4.7	0.6
	32.1	5	12.6	4.8	0.9
	34.4	14	0.0	0.0	0.0
	36.7	5	12.8	6.7	0.9
	39.0	2	81.0	18.0	2.4
	Total	181			

Table 2.14. Transect study conclusions and associated literature. Study of EAB trapping effectiveness in relation to roads in Houghton and Keweenaw County, Michigan in 2013 and 2014.

Parameters	Transect Results	Literature
Basal Area	Significantly fewer EAB as basal area increase	No relation between detecting EAB and site ash basal area measurement (Marshall et al 2009)
Crown Class	No significant relationship	Open grown trees captured more EAB (McCullough et al 2009a, Marshall et al 2010) Traps in open canopy more attractive to EAB (Poland et al 2005) Dominate trees capture some of the highest EAB rates/day (Marshall et al 2010)
Crown Light	No significant relationship	Sun exposure had weak relation to trap success (Marshall et al 2010, McCullough et al 2011)
DBH	No significant relationship	No significant relationship between EAB detection and DBH (Marshall et al 2009) Size of trap tree is important, large trees capture more EAB/day (Marshall et al 2008)
Sample Duration	Significantly more EAB captured as time increase	Sample duration not always clear. Duration part or all of trapping season.
Population Density	Significantly more EAB captured in areas of higher density than low density	Traps in low density captured less EAB than traps in high density (Marshall et al 2009) EAB density within sites can increase markedly from year to year (Tluczek et al 2011) Probability of detecting EAB improved as density increased (Mercader et al 2013) Amount of EAB increase in canopy traps as density level increases (Poland & McCullough 2014)
Species	Green ash captured significantly more than White ash trees	No significant relationship between ash species and mean EAB/day (Marshall et al 2009 and 2010) Female beetles have strong preference for rougher barked trees (Cappaert et al 2005) Bark texture of ash species seemed to be related to EAB larval density (Anulewicz et al 2008) Trees killed by EAB has significantly rougher bark (Marshall et al 2013).
Trap Distance	Road proximity significantly related to EAB captured. No more likely to detect EAB at forest than edge distance classifications	Most beetles captured along edge than wooded areas (Francese et al 2008) Thermophilic buprestids mainly captured in open land areas (Wermelinger et al 2007)
Vigor Rating	Significantly more EAB at high vigor rating	No relation between mean beetle catch per day and vigor (Marshall et al 2010) Vigor and health may not be as important as lure and trap combination (Marshall et al 2010)

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