Emerald Ash Borer Incidence and Infestation at McMaster Forest Teaching and Research Facility

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SUMMARY

The emerald ash borer (EAB), *Agrilus planipennis*, poses great risk to Canada's ash trees (*Fraxinus* spp.); it threatens forested areas, urban shade trees, and manufacturing and shipping industries. EAB interferes with interactions of native species and have the potential to initiate ecosystem-wide cascades. This study assesses the current state of EAB infestation at McMaster Forest Teaching and Research Facility and attempts to elucidate relationships between EAB incidence and ecological factors. Ash trees were selected using stratified random sampling within pre-existing habitat classes. Selected trees were surveyed for evidence of EAB infestation. In addition, tree location, diameter at breast height (DBH), height of lowest exit holes, and visual assessments of tree health were recorded. Results do not indicate a clear effect of ecological land classification on EAB infestation across the McMaster Forest. Evidence of EAB activity is prevalent throughout the Forest and across all surveyed land classes: deciduous forest, deciduous woodland, mixed plantation, mixed forest, and deciduous shrub thicket. Data suggest that insect-foraging bird damage may be a useful indicator for future assessment of EAB infestation. The results of this study highlight the current state of EAB infestation in McMaster Forest, solidify some principles of the visual techniques used to assess EAB infestation, and provide insight into EAB distribution in relation to several ecological factors.

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INTRODUCTION

Ash trees have great ecological, economic, and aesthetic value in Canada. They are not only extremely widespread in forested areas, but also frequently planted as urban shade trees (Poland and McCullough, 2006). These trees increase property value, cool urban environments, take up storm water, and reduce airborne pollutants. Ash wood is also used in the manufacture and shipping of many products (Timms, et al., 2006). Unfortunately, the Asia-native emerald ash borer (EAB), *Agrilus planipennis*, has decimated millions of North America's ash trees since its introduction presumably around 2002 (Poland and McCullough, 2006).

Shipping infested wooden pallets or crates likely facilitated international migration of the flat-headed, wood-boring EAB. While this infestation was initially detected in Michigan and Ontario, EAB has since spread to 21 US states and two Canadian provinces (Xie, et al., 2004). It is considered the most costly biological invasion by a forest insect in North American history (Herms and McCullough, 2014). In addition to economic impacts, EAB infestation has immense and potentially cascading ecological effects. These beetles produce canopy gaps, increase coarse woody debris, and alter delicate understory environments and nutrient cycling. Over 40 North American arthropod species feed on ash and are now at risk of local extinction as ash populations decline (Herms and McCullough, 2014).

The invasive ability of EAB is partially a result of stratified dispersal; by guerrilla strategy, the beetle invades new areas by flying to different sections of canopy, but also covers large distances via human transport of infested wood (Lopez, Acosta and Serrano, 1994). This allows small populations to be established at great distances from the initial infestation and accelerates radial spread (Liebhold and Tobin, 2008).

Initially, EAB infests the ash tree canopy. Lower regions are affected only later on, as tree health declines (Cappaert, et al., 2005). EAB activity is usually greatest in June and July, during which time adults feed for approximately 1 week before mating. Within their short 3–6-week lifespan, females lay between 50 and 90 cream-coloured eggs in bark crevices (Poland and McCullough, 2006). Within a few days, eggs darken to reddish-brown (Cappaert, et al., 2005). Larvae emerge from eggs within 2 weeks and begin to feed on phloem. As the larvae feed, they carve out winding galleries that become filled with sawdust-like frass. Eventually, this tunnelling becomes so extensive that it disrupts tree nutrient transport mechanisms (Poland and McCullough, 2006). Under such stress, trees may develop epicormic shoots: new branch or leaf growths below the point of infestation. Infested ash trees are eventually unable to circulate water and nutrients, and usually die within 1–3 years (Poland and McCullough, 2006).

EAB overwinters within ash trees as either pre-pupae or young larvae; the latter require a second year of development before emergence as adults. In spring, the adult EAB chews through bark to emerge from the tree. This occurs once temperatures stabilize above approximately 10°C. They leave behind D-shaped exit holes, about 3–4 mm in width (Poland and McCullough, 2006). These are easily distinguishable from exit holes of native wood-borers (**Figure 1**), such as the ash bark beetle, red-headed ash borer, and banded ash borer. Native borers leave behind much rounder holes which tend to be substantially larger or smaller than those caused by EAB (Burns and Honkala, 1990; Fuester, et al., 2007; Stepanek, 2014). Native borers typically only infest stressed trees and thus do not cause anywhere near as much devastation to ash populations. Similarly, in Asia, EAB attacks unhealthy trees. In North America, however, EAB infests even healthy ash trees (Herms and McCullough, 2014).

The purpose of this study is to determine the current state of EAB infestation at McMaster Forest Teaching and Research Facility in Hamilton, Ontario, and to elucidate any potential relationship between EAB distribution and ecological factors. McMaster University purchased the 48-hectare Forest in 1964. It consists of grassland, forest, and wetland regions, and is used as a study site for various biodiversity studies and restoration projects. More specifically, the Forest is divided into 14 different regions, each defined by specific ecological factors (**Figure 2**). Ash trees are very prevalent in the Forest; distributed sparsely in the front, prairie region, and closely aggregated in the forested, rear area. This, alongside the sheer number of ecosystems represented, makes the Forest an extremely useful study site. Its biodiversity is analogous to that of Southern Ontario, and allows this study to make inferences about larger-scale patterns.

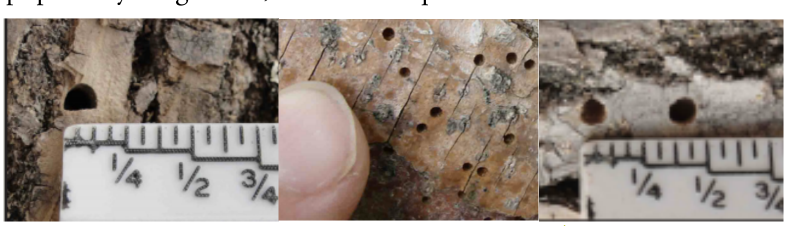

Figure 1: Comparison of D-shaped EAB exit holes (left), round ash bark beetle holes (centre), and round banded ash borer holes (right) (de Groot, et al., 2006; Fuester, et al., 2007; Stepanek, 2014).

METHODS

Data collection took place between mid-January and mid-March, 2016, and included measurements of diameter at breast height (DBH), tree location, height of lowest EAB exit hole or larval gallery above the ground, and visual observations of tree health. Visual observations included dead branches, woodpecker or squirrel damage, and bark cracks or peeling. Standing, dead ash trees were also assessed.

The entire McMaster Forest site is divided into 100-metre grid squares, while the back, forested area is further sub-divided into 20-by-20 metre quadrats. An ongoing census of the Forest has thus far catalogued over 16,000 trees, including data concerning species (in accordance with the Ministry of Natural Resources' vascular plant species list), DBH, and location (x,y coordinates). This study obtained data from the ecological land classifications represented by the rear quadrats. Stratified random sampling was used to select quadrats from each of the land classes in which ash trees grow. Other researchers have conducted EAB surveys using similarly random sampling, such as random transects across the area of study (Smitley, et al., 2008). In this study, data was collected from all trees in 5 random quadrats from each ecological class.

Census data, especially tag numbers, were used to guide data collection. In ecological regions represented by 5 or fewer quadrats, as many quadrats as possible were sampled.

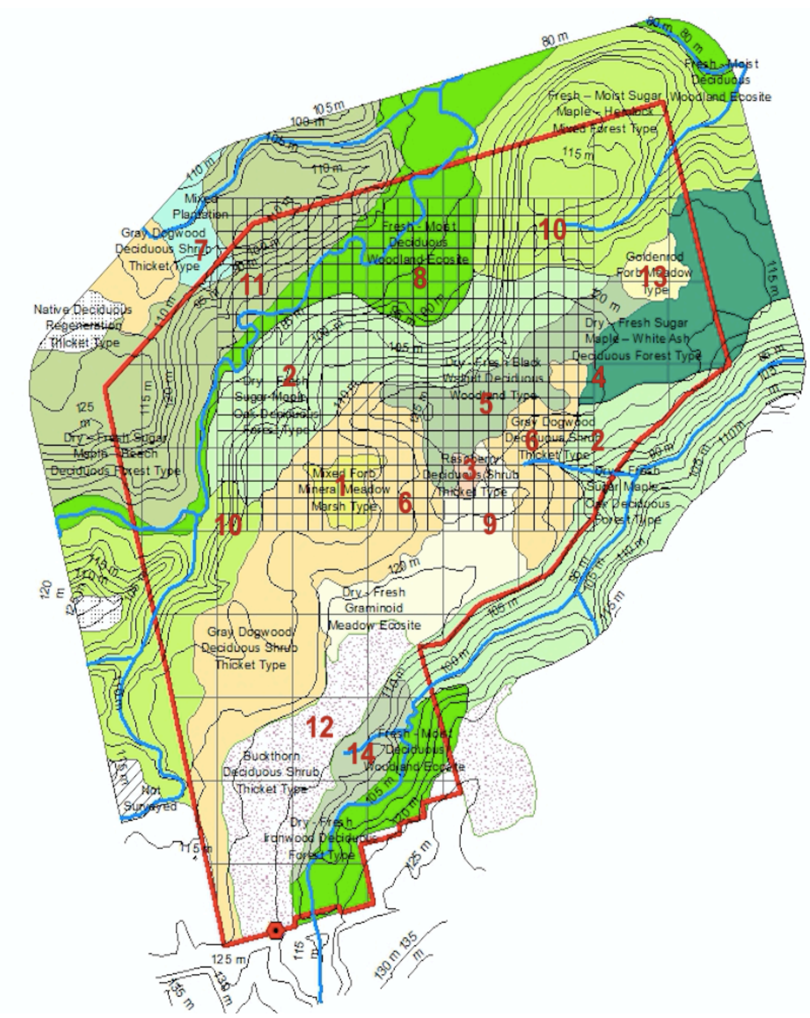

Figure 2: Ecological regions of McMaster Forest. 1) Mixed forb mineral meadow marsh, 2) Dry fresh sugar maple oak deciduous forest, 3) Raspberry deciduous shrub thicket, 4) Dry fresh sugar maple white ash deciduous forest, 5) Dry fresh black walnut deciduous woodland type, 6) Gray dogwood deciduous shrub thicket, 7) Mixed plantation, 8) Fresh moist deciduous woodland ecosite, 9) Dry fresh graminoid meadow ecosite, 10) Fresh moist sugar maple hemlock mixed forest, 11) Dry fresh sugar maple beech deciduous forest, 12) Buckthorn deciduous shrub thicket, 13) Goldenrod forb meadow, 14) Dry fresh ironwood deciduous forest.

SYMPTOMS OF EAB INFESTATION

Visual assessment techniques largely detect only later-stage EAB infestation (Ryall, et al., 2011). Dendrochronological data has shown that EAB in Michigan remained undetected for a decade, likely because native borers produce similar symptoms in affected trees (Cappaert, 2005). This study acknowledged such limitations, but continued to utilize non-destructive, visual observation techniques to provide a preliminary assessment of EAB infestation in the McMaster Forest.

More specifically, this assessment involved close binocular examination of ash trees, which has been effective in previous studies (Smitley, et al., 2008). EAB is also more likely to attack trees infested by other beetles, likely because it is attracted by stress-induced pheromone production (Cappaert, 2005). Thus, evidence of other beetle activity, including round exit holes, were considered to be indicative of tree vulnerability to infestation. Similarly, while woodpecker damage or bark peeling by squirrels could be due to feeding on many boring insects, these patterns could also be associated with EAB infestation (de Groot, et al., 2006). So, any observed drill-like woodpecker marks or ragged bark were noted.

As infestation occurs first in the canopy and progresses downward, the height of the lowest exit hole or larval gallery above the ground was recorded for each infested tree. This provided an approximate measure of the stage of infestation. Regions below cracked bark were closely observed for larval galleries. EAB seldom infests trees less than a certain diameter. This is likely because it requires substantial bark thickness to provide nutrition and protection from desiccation and temperature extremes (Timms, et al., 2006). Thus, ash trees of DBH 5 cm or greater were surveyed in each of the randomly selected quadrats.

Table 1: Proportion of ash trees infested in each land class.

Land Class	Proportion of Ash Infested
Mixed plantation	0.667
Fresh moist sugar maple hemlock mixed forest	0.619
Dry fresh sugar maple white ash deciduous forest	0.571
Dry fresh sugar maple oak deciduous forest	0.452
Fresh moist deciduous woodland ecosite	0.419
Dry fresh sugar maple beech deciduous forest	0.4
Dry fresh black walnut deciduous woodland type	0.333
Gray dogwood deciduous shrub thicket	0.031

Censused regions of the McMaster Forest already associated species names with tag numbers; this information guided data collection. Some ash trees were missing tags, and had to successfully be distinguished from other species. In these cases, ash were distinguished from other tree species by their opposite branching, "braided" bark, highly veined leaf scars, stout twigs, and "scaly" buds (Lyons, et al., 2007). As data collection took place during the winter, tree identification was carried out without observation of leaf shape.

RESULTS

While this preliminary survey did not include all land classes in the McMaster Forest, it provided a comprehensive assessment of the state of infestation at the research site. Evidence of EAB infestation was found in all 8 surveyed land classes, in the proportions shown in **Table 1**.

Initially, observation of EAB activity at the front of the Forest prompted a wider investigation of the extent of infestation. This resultant survey found that EAB infestation was not limited to the front region, and had actually spread to affect trees across the entire site (**Figure 3**). Infested ash trees were observed to often also display extensive woodpecker damage; almost 83% of infested trees also showed considerable bark mutilation by woodpeckers. In future surveys, this could serve as a useful indicator for potential EAB infestation.

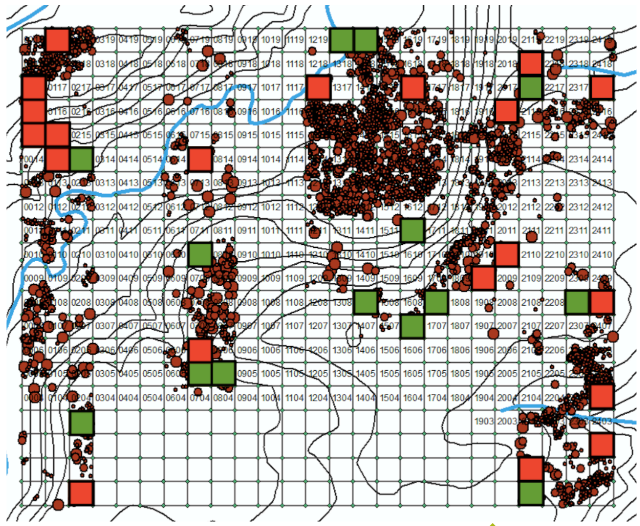

Figure 3: Red circles on map indicate censused ash trees (radii proportional to measured DBH). Quadrats indicated by coloured squares were selected randomly and surveyed. Red quadrats contained trees that exhibited signs of EAB infestation, while green quadrats did not.

A logistic regression was performed in order to determine any potential relationship between land class and EAB incidence. While a significant effect of land class on infestation was observed ($p = 0.00266$), a post-hoc Tukey's test revealed that only one land class was significantly less infested than any others (**Figure 4**). One land class, "gray dogwood deciduous shrub thicket", remained relatively uninfested, while all other surveyed quadrats displayed 33% or greater infestation rates. These results, while preliminary, suggest that ecological factors do not play a great role in EAB infestation pattern. However, it is possible that the gray dogwood thicket region has several characteristics, including lower tree density, that make its ash trees less susceptible to infestation.

Regional characteristics did not seem to greatly affect EAB distribution in the Forest. However, some properties of ash trees appeared to affect EAB incidence. Previous studies have not found infestation to be limited to trees within a certain DBH range (Cappaert, et al., 2005). While this survey did not find evidence directly to the contrary, it appears that EAB tended to infest ash trees with mature, braided bark.

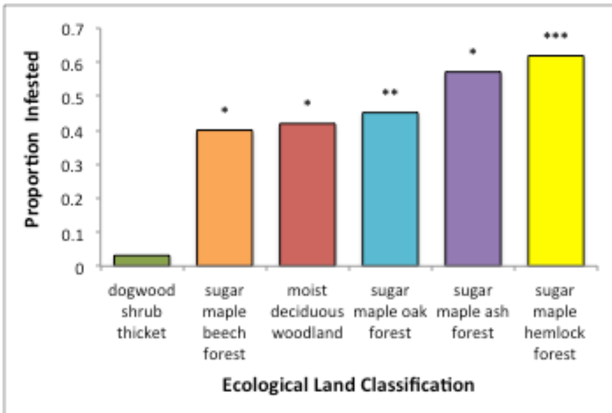

Figure 4: Significant differences between proportions of infested trees in various land classes (p-value < 0.001 represented by "***", p < 0.01 represented by "**", p < 0.05 represented by "*"). The only significant differences were found between gray dogwood thicket and several other highly infested land classes, suggesting little association between ecological factors and EAB infestation patterns.

Younger, smaller ash with smooth bark tended not to exhibit as many signs of infestation. This supports the theory that EAB prefer bark of a certain thickness for its protective capabilities (Timms, et al., 2006). Furthermore, older, larger ash with extremely ridged bark tended to also exhibit less signs of infestation. Future studies could investigate the potential for such lower and upper DBH limits, within which EAB infestation might be most likely.

DISCUSSION

FUTURE DIRECTIONS

MCMASTER FOREST: Ideally, a more in-depth survey of the McMaster Forest would be carried out to better estimate the effects of ecological factors on EAB infestation. The limited sample size of this study makes accurate prediction of such relationships difficult, especially over larger spatial scales. A larger survey would help to elucidate any relationship, or the lack of any relationship, between EAB infestation and ecological factors, both of which would be extremely informative. This information could then be scaled up to larger geographical scales, where it could influence regional policy development.

As this preliminary survey indicates, EAB infestation is widespread across the McMaster Forest. Ash trees make up a significant fraction of the species in this study site, and their rapid decline will undoubtedly cause significant ecosystem impacts. Furthermore, infestation has the potential to spread from the Forest site as adult beetles emerge and fly to new host trees. McMaster faces a difficult decision in the near future, both ethically and financially. As a preliminary measure, it may be best to place the Forest site under local quarantine in the near future. Site users, including hikers, should be informed and urged not to transport wood into or out of the site.

Subsequently, more drastic measures may have to be employed, including pheromone or insecticide treatments, or even large-scale ash tree removal. Such measures should be implemented prior to adult emergence in late spring in order to prevent further spread.

Several insecticides effective against EAB are publicly available, but cannot protect trees already in late stages of infestation. These are most commonly applied as trunk or soil injections, or as spray directly onto the tree (Herms, et al., 2014). These methods are both labour-intensive and costly, as they require precise application to each and every ash tree. Furthermore, these compounds are toxic and can spread through soil and groundwater to affect flora and fauna in much larger areas (Hahn, Herms and McCullough, 2011). Ash bark volatiles have also been shown to effectively lure EAB into traps (Crook, et al., 2008). While this research is preliminary, perhaps in the future, such traps could be used to combat EAB infestation while also having a lesser impact on the surrounding ecosystem, as they would employ compounds endogenous to the ecosystem. As a last resort, the University could endeavour to physically remove all ash trees with mature, braided bark, or above a certain DBH. The wood material would then have to be burned on-site, to prevent any further spread of infestation.

Southern Ontario: On a larger scale, it would be prudent to implement pheromone traps across Southern Ontario to detect early stages of infestation (Abell, et al., 2015). Perhaps more urgently, these traps should be implemented in dense, urban ash monocultures, where EAB has the potential to wipe out many trees in a concentrated area.

Should future surveys indicate that certain ecological factors impact patterns of EAB infestation, these principles could be used to mimic such ecosystem characteristics and enhance resilience. However, until such results come to light, preventative measures must be implemented across all ecosystem types, with a focus on urban forests.

Further investigation of trunk injection efficacy against EAB infestations of varying severity would allow for more effective use of treatments such as TreeAzin®. Preliminary studies suggest that TreeAzin would be comparably effective in ash trees regardless of infestation severity, should greatly infested trees be treated more frequently (Herms et al., 2014).

Findings could then inform the introduction of an insecticide efficacy term into models of human-forest interactions and EAB spread. Such models demonstrate the importance of considering human involvement in stratified invasive species dispersal (*e.g.,* Ali, et al., 2015; Barlow, et al., 2014). Ideally, quantitative field results of an insecticide efficacy study, combined with conceptual representation of insecticide interference with EAB's stratified dispersal, would lead to implementation of more effective control strategies, especially in urban areas with many at-risk ash trees.

CONCLUSION

The emerald ash borer continues to pose great risks to biodiversity, industry, and property values in North America. The McMaster Forest site, with its diverse ecological composition and abundance of ash trees, provides a unique study environment for the extent and effects of this pest. This survey sheds light on EAB incidence in the McMaster Forest, as well as potential patterns for its distribution in Southern Ontario, through the observation of analogous ecosystems.

Measures should be implemented prior to late-spring emergence of adult beetles so as to prevent further spread of infestation and preserve remaining ash populations. These may include quarantines, insecticide application, or even large-scale ash tree removal.

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