# Introduction

The emerald ash borer (EAB), Agrilus planipennis Fairemaire (Coleoptra: Buprestidae), is an invasive species that has killed millions of ash trees (Fraxinus spp.) since it was first detected in North America in 2002, although it had likely been present since the late 1990’s. Because these beetles spend most of their life as larvae under the bark of ash trees, most of their movement can be attributed to unintentional human transportation of infested wood. As a result, it is difficult to predict where the EAB will move, making early detection nearly impossible. The effort to slow the spread of this pest is headed up at a federal level by the US Department of Agriculture (USDA) Animal Plant Health Inspection Service (APHIS) and typically by the individual state agencies at the state level. The Minnesota Department of Agriculture (MDA) is the lead agency in Minnesota.

#### **Biology and Lifecycle**

The EAB is a member of the order Coleoptera (beetles) and is in the Buprestidae family, which are the wood boring beetles. The life cycle of A. planipennis spans from one to two years, depending upon the temperatures of the infested region. The two-year life cycle is likely in Minnesota, where the larvae will spend a second winter season to mature while feeding on the phloem and cambium in a pre-pupae state through four instar stages (Marshall et al., 2010). The adult form of A. planipennis is small, usually less than ten millimeters long and approximately two millimeters wide. Their bodies are elongated in the shape of a bullet with a bronze abdomen and metallic emerald colored wing covers.

The adult beetles do not cause significant damage to ash trees as they usually feed on the leaves and mate on the bark of the trees. Instead, it is the larvae that effectively girdle the trees during the winter months, essentially cutting of the nutrient supply from the roots to the crown of the tree resulting in the death of a tree. During the mating season, females lay their eggs on the bark and in between crevasses on the outer surface of trees. On average, ach female will lay between 50-90 eggs during her lifecycle (Poland & McCullough, 2006).

After about two weeks, the eggs hatch and the larvae emerge as a creamy white wormlike organism and immediately begin boring into the tree. In the first few months, the instars in their pre-pupae state will form shallow serpentine tunnels in the phloem and cambium of the trees leaving behind a trail of brown woody excrement known as frass. The larvae mature through four instars in their pre-pupae form during the fall, and then move deeper into the sapwood to form overwintering chambers. In the one-year cycle, the larvae will the larvae will transform into sexually mature adults in the spring and emerge from the trees leaving D-shaped exit wounds (Poland & McCullough, 2006).

In colder areas, the larvae will overwinter for a second season before emerging from the tree, which is likely in Minnesota. In the northern parts of the state, EAB larvae cannot survive the extreme winter temperatures, particularly in the USDA Plant Hardiness Zones 3a and 3b (**Figure 1**). When a tree’s inner core reaches extreme temperatures between -20° F and -30° F, EAB larval mortality can be estimated to be around 50%. EAB larval mortality can exceed 90% when the tree’s core dips below -30° F for an extended period of time. It is important, however, to note that wind chill does not affect the larvae (Venette et al., 2014).

#### **EAB Spread in Minnesota**

#### The first confirmed EAB sighting in Minnesota was discovered in the Saint Anthony’s Park area of St Paul in May of 2009. Since then, it has spread to a total of 14 counties in the metro area and the southeastern portion of the state along the Mississippi River. It is likely the EAB is in other portions of the state, but have not yet been discovered. This beetle threatens the ash tree resource in Minnesota where dense populations can result in high levels of ash mortality. In urban settings, tree removal can be very expensive where ash is a common monoculture (MDA, 2016).

The City of Saint Paul has seen firsthand how quickly the EAB can move through urban areas. In 2015 alone, it was estimated that the EAB had spread across 75% of the city, as opposed to 55% in the beginning of the year. These numbers are quite high compared to 2010, when only about 3.5% of the city area had known infestations. There are an estimated 26,000 ash trees in the Right of Way (ROW) on street boulevards, and tens of thousands more in public parks and open land areas. These numbers do not include ash trees on private lands, where tree maintenance is the responsibility the landowner. These dead and dying trees present many hazards within the urban landscape because the branches become weak and break off easily, causing damage to property and parked cars (city of Saint Paul, Minnesota, 2015).

#### **Tracking the EAB in Minnesota**

The lifecycle of the EAB presents an interesting mitigation challenge for the MDA. Trees often do not show signs of stress until it is too late because most of the damage occurs under the bark. The MDA has several methods for searching for EAB infestations in new areas. Thousands of purple prism traps have been placed around the state (**Figure 2**) to capture and detect adult beetles. In addition to periodically checking the traps, field crews are also sent to perform branch sampling in high risk areas. The MDA uses a risk area map based on criteria such as ash population densities, campgrounds, and sawmills to estimate where new infestations may be so traps can be effectively placed (**Figure 3**).

The MDA staff rely on visual cues such as crown dieback, epicormic shoots, bark splits, D-shaped exit holes, and flecking as a result of woodpecker feeding (also known as blonding) in high risk areas. The woodpecker damage can be a sign of a dense infestation within a tree because they peel back the bark while looking for larvae. If these signs are present, they will perform branch sampling by collecting at least 35 branches within a forest stand and checking under the bark to search for larval galleries. There are several wood boring beetles that can be found in Minnesota, but the EAB create distinct S-shaped galleries (P. Walrath, personal communication, February 17, 2016).

### **Quarantines and Firewood Regulations**

In order to slow and prevent the spread of wood boring pests, the USDA APHIS Plant Protection and Quarantine (PPQ) institutes an emergency quarantine when EAB are found in a new area. This puts strict regulations put in place to prevent wood products from being moved or sold outside of the quarantined area. The MDA defines wood products as: 1) logs and green lumber; 2) nursery stock, scion and bud wood; 3) chips and mulch, either composted or uncomposted; 4) stumps, roots, and branches. In order to avoid having the entire state of Minnesota being part of the federal quarantine, the MDA has agreed to enforce the USDA APHIS quarantine within the state, usually at the county level. By the Minnesota Statues Section 18G.06 (2008), the Commissioner of the MDA has the authority to declare that a county is under quarantine (Minnesota Department of Agriculture, 2016).

Some firewood can be moved under the quarantine laws if it has been heat treated first. There are two different types of wood that can be moved legally in Minnesota. The first type is the DNR approved firewood. This wood may not be pest-free and therefore cannot be moved outside of a quarantine. This wood is allowed on any DNR administered lands or within 50 miles of the harvest location as long as it does not go outside of a quarantine. By far the safest wood to move is the MDA/USDA approved firewood which can be moved outside of quarantine boundaries within the state. This wood has been heat treated in a USDA APHIS approved dry kiln facility where the core of the wood is required to maintain an internal temperature of at least 60° C (140° F) for a period of at least 60 minutes. Also required when moving MDA/USDA certified wood out of a quarantined area is a signed Compliance Agreement (CA) with the MDA for interstate movements, or with both the MDA and USDA APHIS PPQ for transporting outside of the state. The CA requires the business or individual to comply with the methods, conditions, and procedures for handling ash wood, pursuant to the quarantine laws. Any violation related to transporting untreated wood outside of a quarantine can result in daily fines up to $7,500 (Minnesota Department of Agriculture, 2016).

### **Web GIS and VGI**

Early detection of EAB in new areas is extremely valuable to the MDA because the sooner they take action against an EAB population, the better their chances for slowing it down. This presents a perfect scenario where volunteered geographic information (VGI) can be leveraged to use humans as sensors. VGI is defined by Michael Goodchild as using technology to “create, assemble, and disseminate geographic information provided voluntarily by individuals” (2007). VGI is extremely useful in early warning systems and post catastrophic events as people familiar with the area are able to provide accurate geographic observations in real time. The main catalyst that made VGI possible was evolution of the Web 2.0. VGI is even more powerful now with rapid advances in technology and easy access to smart phones. Citizens become sensors themselves as they are each “an intelligent synthesizer and interpreter of local information” (Goodchild, 2007).

Web GIS is a huge part of what makes VGI a viable option for collecting large amounts of geographic data through client to server interaction. Countless GIS databases are stored in the cloud and can be shown in the context of rich basemaps available from different sources. These datasets often have full editing capabilities allowing the user to create, update, or delete data. Once this data is exposed as a web service, it can be consumed by any client that can make HTTP requests, without the end user needing to install any additional software.

### **Engaging the public**

In the spirit of VGI, the MDA is currently trying to educate as many citizens as possible to assist in identifying and reporting EAB sightings in new locations. Workshops are held to train citizens how to spot signs of an EAB attack on live ash trees, paying particular attention the most helpful visual cues such as woodpecker damage. They also show attendees how to properly identify an EAB in both the larval and adult stages as well as some of the common look-a-like insects that are often mistaken for an EAB. One thing that is stressed at these workshops is that the MDA truly needs the help from public volunteers (P. Walrath, personal communication, February 17, 2016).

The MDA does not have enough staff to patrol the entire state and are therefore welcome the public to report new sightings through their “Arrest the Pest” website (<http://www.mda.state.mn.us/arrestthepest)>. They ask that if you see an EAB, you should take a picture and try to describe exactly where it was spotted and get a sample if possible. If you are able to provide the MDA with a sample or photograph of the sighting, it can help them determine if the sighting presents a legitimate EAB threat, and therefore an inspection crew can be sent to the site for verification.

One way to facilitate reporting EAB sightings in Minnesota through VGI is to provide a mobile application that can collect information in real time. With virtually every adult resident owning a smart phone, a mobile application is a great way to empower the public to accurately report new sightings. The device GPS can be used to log the location while the camera allows the user to provide photographic evidence so the proper agencies can determine whether or not the site needs to be visited for field verification. Additional attribute information can also be collected from the user through a form with drop-down domain values and text boxes feeding into a cloud based GIS database. In order to leverage ArcGIS technology in native mobile applications, the ArcGIS Runtime Software Development Kits (SDKs) must be used. The application for this project is currently being built separately for iOS and Android using the ArcGIS Runtime SDK for iOS and ArcGIS Runtime SDK for Android, respectively. The Android and iOS platforms were chosen because collectively they make up 93.95% of the mobile market share as of June 2016, with Android taking 70.85% and iOS taking 23.1% (Epstein 2016).

### **The ArcGIS Runtime**

The ArcGIS Runtime exposes ArcGIS functionality natively to Desktop, mobile, and embedded devices. It is based on a small, cross platform high performance C++ Runtime Core with its own geometry engine. The ArcGIS Runtime also allows for a faster display via GPU Acceleration with OpenGL or DirectX, depending on which platform is being used. ESRI provides Runtime SDKs to support virtually all platforms in the desktop and mobile environments, and each Application Programming Interface (API) has its own bindings to the Runtime Core (ESRI 2015).

### **Study Area and Data**

This study will focus on Minnesota, particularly in the counties within the predicted risk areas where there have been no prior EAB infestations discovered. However, information on EAB infestations collected anywhere in the state will be useful. Figure X shows the web GIS map hosted by the MDA showing the areas currently quarantined. A county boundary shapefile was downloaded from the Minnesota GeoCommons website, which will serve as one of the basemap layers for the mobile application to help track existing quarantines as well as counties that could have infestations based on data collected by citizens. Other GIS data that is used in the app comes from the MDA’s own web GIS map service for the EAB in Minnesota. This service includes locations of known EAB infestations, release of biocontrol agents such as various species of wasps to prey on the EAB, and counties with their respected quarantine status.

## **Methods**

### **GIS Data Preparation**

A file geodatabase was set up with a point feature class to track individual sightings and a polygon feature class to track counties with their respected quarantine status and was published to ArcGIS Online as a hosted feature service. Attribute domains were created with helpful description aliases so that even users unfamiliar with the EAB can record detailed information about the sighting. The attribute domains allow the user to describe the type of sighting such as adult beetle, visible larvae, D-shaped exit holes, and S-shaped galleries. Another field tracks information about any visible tree stress such as crown dieback, epicormic shoots, and bark splitting. For purposes of checking data integrity and reliability of the user, another field was added to get a sense of the user’s knowledge level of the EAB with options such as that user being a biologist or entomologist, environmental scientist or similar, or not having much knowledge of the beetle. Other fields that user could fill in were site descriptions, comments, and their name and email. Some attributes are automatically populated by app such as latitude and longitude as well as an address provided by reverse geocoding the input point.

The county polygons are much simpler with the only important attribute other than the county name being the current quarantine status. There are three options for the application: currently quarantined, no positive sightings, and needs to be considered for quarantine. The sighting points and county data were published to ArcGIS Online as a hosted Feature Service with editing capabilities.

A web map was also created in ArcGIS Online to store some configurations for the mobile applications. It is advantageous to reference a web map in an ArcGIS Runtime app because the web map specification contains popup attributes and layer definitions for the ArcGIS web services and can be transferred into the app. This is very convenient because the web map specification is represented in JavaScript Object Notation (JSON) which is queried by the web app ID when the app is loaded to get all the layer and popup information, meaning that the application’s source code does not need to be modified when additional layers are added. When an ArcGIS online web map is not used, the programmer is responsible for initializing all layers and popups programmatically in the source code. It is also possible to create a JSON structure that mimics that of a web map to handle the layer and popup configurations to be used in a Runtime app as well. It is important to note that because the ArcGIS Runtime has its own display engine, the layers from the web app are not viewed through a browser, instead they are rendered on the device natively with OpenGL GPU acceleration.

#### **Mobile Phone Applications**

Despite the application being developed for two different platforms, the capabilities and functionality will accomplish the same goals: 1) incorporate a map view where new sightings of EAB are reported using the device GPS and stored in an ESRI Geodatabase, 2) allow users to identify/view sightings and Web GIS Services provided by the MDA for traps, biocontrols, and confirmed sightings, 3) provide the user with information on how to identify Ash trees and the EAB, 4) send an email to the the MDA when a new sighting has been logged, 5) send out push notifications to everyone who has the app when a new sighting has been logged, and 6) send out an email to the MDA’s “Arrest the Pest” email account.

#### **iOS Application Setup**

The iOS application was developed using the new Swift programming language created by Apple. Swift offers many benefits over the traditional Apple development language of Objective-C with features such as automatic memory management, dynamic library support, and optional variable unwrapping. All Swift coding was done within the Xcode Integrated Development Environment (IDE). The first step in this application was to enable the ArcGIS functionality required for the app. Because the ArcGIS Runtime SDK for iOS is a third party library provided by ESRI, it needed to be referenced in the app as a dependency. This was added to the EAB Tracker app by using CocoaPods, which is a dependency manager for Swift and Objective-C projects. A podfile was set up and used to install the ArcGIS API version 10.2.5 locally within the project so it could be compiled with the application’s source code (Figure X).

There are also some application security settings that needed to be managed within the project as well. Because this application will be working with ArcGIS Web Services, the device will need to have appropriate permissions set to make web requests. Exception domains for accessing ArcGIS Online and the Google Maps Geocoding API were added to the application’s information properly list. Also stored in the information property list is the prompt to ask the user if they will allow this application to have access to their location services. The final permission necessary for the application is the use of the device camera, which the prompt text was set in the app source code.

**Android Application Setup**

The Android application was developed using the Java programming language and the Android Studio IDE, and the permissions set up was similar to iOS. The ArcGIS Runtime SDK (version 10.2.7) for Android was added to the project as a dependency by using Gradle, which can be used to install third party libraries for Java/Android (Figure X). All user permissions were set within the “AndroidManifest.xml” file, which included internet access, camera, and GPS location. One additional permission that had to be explicitly set in the Android application was the use of the OpenGL graphics library, which is what the ArcGIS Runtime Core uses to display 2D and 3D graphics.

**Expected Results**

The mobile application can provide an effective means of tracking new sightings and promote early detection of new infestations. Each year, the MDA provides workshops to train citizens on how to identify and report new EAB infestations. This mobile application could serve as a complimentary tool to quickly report new sightings in a consistent manner with coordinate information and photographic evidence. Because the app will be using push notifications, MDA staff who use the app will be notified immediately when a new sighting is reported, and can hopefully promptly visit the site to validate and take any necessary actions.

The most difficult task will be engaging the public and getting volunteers to submit new sightings. One major challenge is letting people know that the app exists in the first place. Social media could be used for advertising, but picking the best venues to distribute this information will not be easy. Another important aspect is to ensure that the app is designed in a way that is visually appealing, intuitive, and easy to use. A poorly designed app will likely not get much use or provide any tangible value to aid in early detection of the EAB.

**Conclusion**

I believe that this tool could make a difference in early detection and swift mitigation strategies if enough people use the app.