Predicting the Arrival Time of Emerald Ash Borer to Texas Based on Estimated Speed Dispersal

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Abstract

First reported in North America in 2002, the emerald ash borer (EAB, *Agrilus planipennis*) has been spreading rapidly from its point of invasion in Michigan. This spread has resulted in ash tree mortality in massive amounts on the scale of millions of individual trees. EAB appears to spread at a relatively constant dispersal rate, as over the past 13 years it has moved from southeast Michigan to states that are nearby Texas, including Colorado in 2013, Arkansas in 2014, Kansas and Louisiana in 2015. In this study we examined previous models conducted to estimate EAB invasion such as those conducted at the University of Illinois Urbana. From these studies we found that EAB has a detection lag of 2- 5 years from initial infestation. Our main questions include how fast EAB is spreading, time it will take EAB to reach Travis County, and based estimated speed how long does Travis county have to make plans for this possible invasion. The main goals included producing a time series video indicating current spread and future predicted spread. Estimating current spread of EAB and predicting future spread using 2-5 years of detection lag predicted by several studies. Our study used a dataset that was provided by USDA/APHIS on the EAB county detection per year. Using this data we conducted an analysis using ArcGIS to calculate distance from initial infection to all other infected counties. Once this analysis was complete we used SPSS to project our data as a regression from which we obtained a slope and used this as our factor for speed. Our analysis indicated that EAB spreads 45 km/year and it will reach Travis County in 2039. We also estimated based on the closest county to Texas using the same regression equation, EAB would reach Travis County in 2024. By estimating arrival times and dispersal pathways, our study provides critical information that can be used to slow and/or prevent the invasion before it occurs.

Introduction

Species invasions are a principal component of global change, causing large losses in biodiversity as well as economic damage. Invasion theory attempts to understand and predict invasion success and patterns of spread. However, there is no consensus regarding which species or community attributes enhance invader success or explain spread dynamics (Arim & Abades, 2005). Invasive species have accounted for major environmental losses adding up to about 120 billion dollars per year and an estimated 50,000 foreign species have been identified in North America. Due to such large numbers of invasive species about 42% of the species on the Threatened or Endangered species lists are primarily at risk due to this factor (Pimentel et al., 2006). There are examples of invasive species altering the evolutionary pathway of native species by competitive exclusion, niche displacement, hybridization, introgression, predation, and ultimately extinction. Invaders themselves evolve in response to their interactions with natives, as well as in response to the new abiotic environment. Flexibility in behavior, and mutualistic interactions, can aid in the success of invaders in their new environment (Mooney & Cleland, 2001).

Overview of the role of EAB and dispersal in North America

Forests in North America are being negatively impacted and depleted primarily due to an invasive species known as Emerald Ash Borer *(Agrilus planipennis)*. EAB has been estimated to threaten about 300 billion of Timberlands in the USA (Nowak, 2003)**.** This species has proven detrimental to Ash trees in the U.S., especially along the western side of the country (Pons, 2003). The Emerald Ash Borer (EAB), a native insect of Asia, was first introduced to North America inadvertently by the transport of infested ash trees by humans, unprocessed logs, firewood, and other ash commodities (Emerald Ash Borer Info). The first

encounter with this invasive species occurred in 2002 in southeastern Michigan and Canada. Since 2002 the distribution of Emerald Ash borers broadened infesting several states that include Missouri, Arkansas, Georgia, Connecticut, Massachusetts, Tennessee, West Virginia, Colorado, and several other states located in this general area (Emerald Ash Borer Info). Larval beetles can be transported over long distances in contaminated ash tree products, the combination of local, natural dispersal of adults and human mediated long distance transport of larvae is consistent with stratified diffusion (Hengeveld et al., 1989). EAB poses an enormous threat since its larval stage feeds on the phloem and cambium of the tree. Once this occurs nutrient transport begins to decrease and eventually is completely lost and the tree dies.

Turning attention to Texas

Invasive species should respond in ways that are quantifiable and predictable (Hellmann, 2008). Therefore, once these predictions have been made similar methods could be applied to other invasive species found at Wild Basin. Several studies have been conducted on EAB to find preventative solutions to slow or halt the invasiveness yet little to nothing are known about the

ome the standard for other applications, in order to help examine and predict future dispersion of EAB.

Dispersal is a fundamental component to species distribution and ecology, thus it is and remains one of the most intensively studied fields (Clobert et al., 2001; Bullock et al., 2002; Nathan 2005). Due to this rapid dispersal and detrimental effects of the EAB on ash trees in North America, we want to determine the rate of dispersal, its possible pathways into Texas, and the possible effects the Eme

Attention has been focused on the relative contributions of local and long distance dispersal and their consequences for species ranges, patterns of dispersal, and population persistence (Lewis,

1997; Higgins & Richardson, 1999; Levin et al., 2003; Green & Figuerola, 2005; Trakhtenbrot et al., 2005). Therefore we want to see if we can identify any patterns through our analysis and determine the optimal path ways into Texas. Since little is known on the rate of spread of EAB (Haack et al., 2002) we chose to develop some questions and methods to answer them.

Although there is no evidence of EAB in Texas, we can predict that this invasive species may in fact be found in ash trees in Texas due to its proximity and rapid distribution through human mediated factors.

We hypothesis that the closest entry point for EAB is through Webster, LA or Arkansas and since currently no action is being conducted to quarantine the invasive species in Louisiana, it is likely that EAB will make its way into Texas. Therefore it is important to take preventative action to determine locations where this invasive species might spread and create a variety of prevention plans. In this study we want to calculate the speed of spread and from this speed make future predictions of when EAB will invade other counties in North America and more specifically in Texas. The county we aim to focus on in Texas is Travis County located in Austin, TX. Travis County is home to Wild Basin Wilderness preserve; this preserve does have a presence of Texas ash. Therefore we believe it is important to estimate the time Wild Basin has to make plans or identify other ecological constraints their ash tree population could face.

Methodology

Study Species

During the larvae stage, EAB looks like a caterpillar and is usually 1.1 inches in length. The adult stage if the Emerald Ash Borer is a dark, metallic green in appearance and its approximate size is between an eighth and a half and half an inch in length.

During the larvae stage, the larvae feed on the cambium leaving a series of tracks behind creating a network in the bark. The larvae can only obtain the nutrients in the cambium of older trees. The sap in these trees contains all the nutrients that the larvae need to grow and develop. The larvae feed on both the trunk and major branches in the tree. The Adult stage feeds on the Ash leaves but there is no real impact on the Ash tree.

EAB can have up to a two year life cycle. This is one of the major contributing factors of the rapid distribution rates and spread of EAB. The first adult appears during the second half of May and the peak emergence occurs in late June. Females begin laying eggs about 2 weeks after emergence in early June. The eggs hatch after 2 weeks of incubation. The tiny larvae then bore through the bark and enter the cambium. The cambium is the area where the tree nutrient levels are the highest. It is located between the bark and the wood (which is old cambium). When the larva is in the cambium area, it feeds on the wood sap from July through four stages and can grow to an average size of 1.1 inches. EAB has the ability to protect itself against cold winter months; they overwinter in a small chamber in the outer bark or in the outer inch of wood. The Emerald Ash Borer has its main reproduction event in the spring and once this cycle is over it begins again.

There are many natural predators of the EAB such as predaceous and parasitic insects and insect-pathogenic fungi found in Asia, but few natural predators are found in North America. *Cerceris fumipennis* is an American wasp, which lays its eggs inside the EAB larvae and kills it. The other predators present in America are different species of woodpeckers and nuthatches, but they are not effective enough in reducing the mass numbers of EAB populations.

The Emerald Ash Borer can be found in areas with an annual average temperature of -4°C to 18°C in Asia. In USA, they live in Minnesota with an annual average temperature of

5.1°C until the border of Georgia with an average annual temperature of 17.5°C but we do not

America due to an

average annual increase of 18°C in North America. Therefore it is difficult to know when exactly the EAB population will stabilize.

In the native area, the precipitation is between 1000 ml and 2000 ml per year**.** The average precipitation in the states infested by EAB is between 700 ml and 1300 ml. Thus we can see that the limiting factors are different between the EAB Asian population and the EAB populations found in the US.

Study dataset

Our dataset was provided by USDA/APHIS. This data set is provided to the public through the collaborative effort of Michigan State University and USDA Forest Service. This information is provided to allow a comprehensive, accurate and timely source of information of the emerald ash borer. The data was provided on a monthly basis or as it was updated by USDA and the dataset included the counties and the year EAB was detected.

EAB dispersal

Adults can fly at least half a mile to find another ash tree where they lay their larvae and emerge but this is not their main method of dispersion. The main method of dispersal for EAB involves the movement of infested firewood and treated wood by people hence long distance jumps. According to a study done on the spread of EAB it has spread in North America through a combination of diffusive range extensions, associated with local flights, and by long distance

firewood (Muirhead et al., 2006). The probability of infestation was found to be inversely

related to the distance from borer epicenters but a positive relationship to the size of human population centers. The study determined that 9 of 39 populations first seen in Michigan cannot be accounted to local diffusion; therefore other factors must be at play (Muirhead et al., 2006). Currently the beetle is spreading via stratified diffusion due to human interaction with the species. There are also several factors which we yet to understand about how this species is

-biased (Taylor et al., 2004).

Since the larvae can be transported over a long distance it has affected the ways in which we can control the spread. Populations have also been seen to be established 2-5 years before they are detected (Siegert et al., 2007); therefore all calculations and estimations in arrival time were based on this detection lag. These estimations will then be used to identify ideal management efforts that could potentially be most ideal for Wild Basin and Travis County. In places such as Maryland and Virginia varying types of management have proven successful, but continued expansion of the EAB range continues in the Great Lakes area regardless of the management efforts (Muirhead et al., 2006). Since EAB spread has proven hard to stop several studies will be reviewed to choose optimal strategies.

Calculating speed

Three hypotheses were made for the estimation of speed based on previous data provided by USDA. 1) Speed of EAB follows a linear trend and will remain at a constant speed, 2) speed of EAB follows an exponential trend, therefore overall speed is increasing, and 3) speed will follow a logarithmic trend, therefore speed has decreased over time.

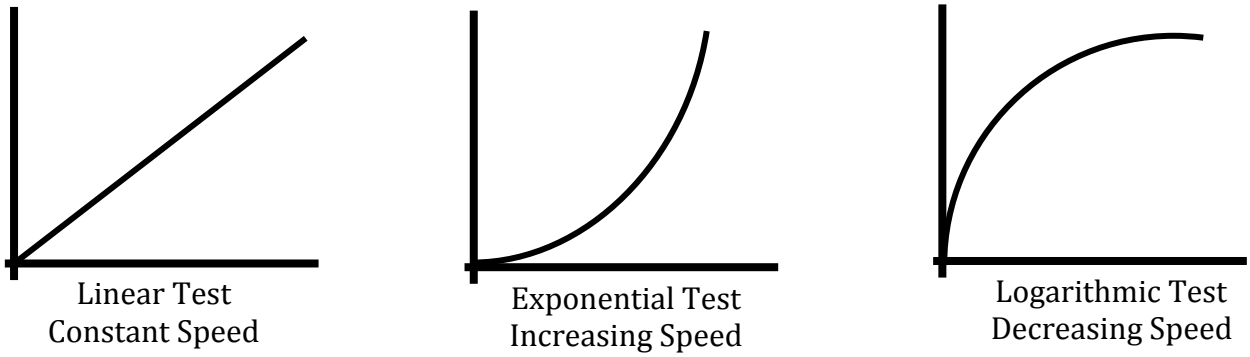


Figure 1: Three possible trends that could be identified in data provided by USDA after speed analysis is conducted.

We used a shapefile from USDA to use it with Arcgis. This file let us create a map with all the counties draw on it and the border for all the states. Lot of data are available in this file: Objectid, Shape, STATEFP, COUNTYNS, AFFGEOID, GEOID, NAME, LSAD, ALAND and AWATER but we used only the GEOID because these data let us to identify each counties with a

We obtained another file from USDA. This file gave use these data: COUNTY_NAME, STATE_NAME, STATE_FIPS, CNTY_FIPS, FIPS, Year_EAB and ORIG_FID but we used only FIPS and Year_EAB. FIPS is exactly the same information than GEOID in the first file so us to know if EAB were detected and if it were detected when it happened.

So we created a file with all the data we cited before. We linked the counties map with the counties detection date. We were able to do that because we use GEOID and FIPS as common point between the both data set. We used colors to underline when the counties has been detected. We got this map:

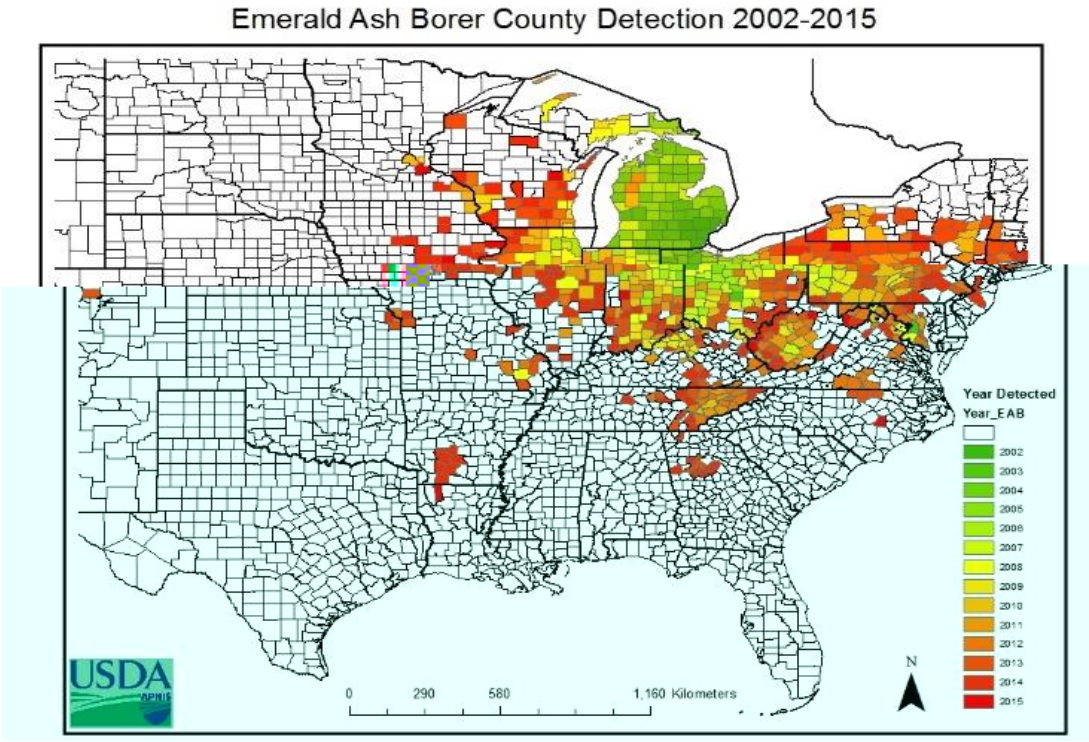


Figure 2: USDA data linked with US counties shapefile. Color coded by year of EAB detection from 2002-2015. This data was updated as of April 1, 2015.

county that we know that they infected. We downloaded the coordinates of each point. These coordinates are GPS coordinates in Decimal degrees. We want to measure the distance between the first county infected and all the others. We had the choice between 6 counties infected in 2002: Wayne, Washtenaw, Macomb, Livingstion, Oakland and Monroe all of them are in Michigan. We choose Wayne, Michigan as first counties infected for two reasons. The first one is because we can assume that EAB has a radial spread and we can see on the map below that Wayne is in the middle of all others counties infected the same year. The second reason is that there is an important port at Detroit, Wayne, Michigan and we know that EAB is native from Asia. We assumed that

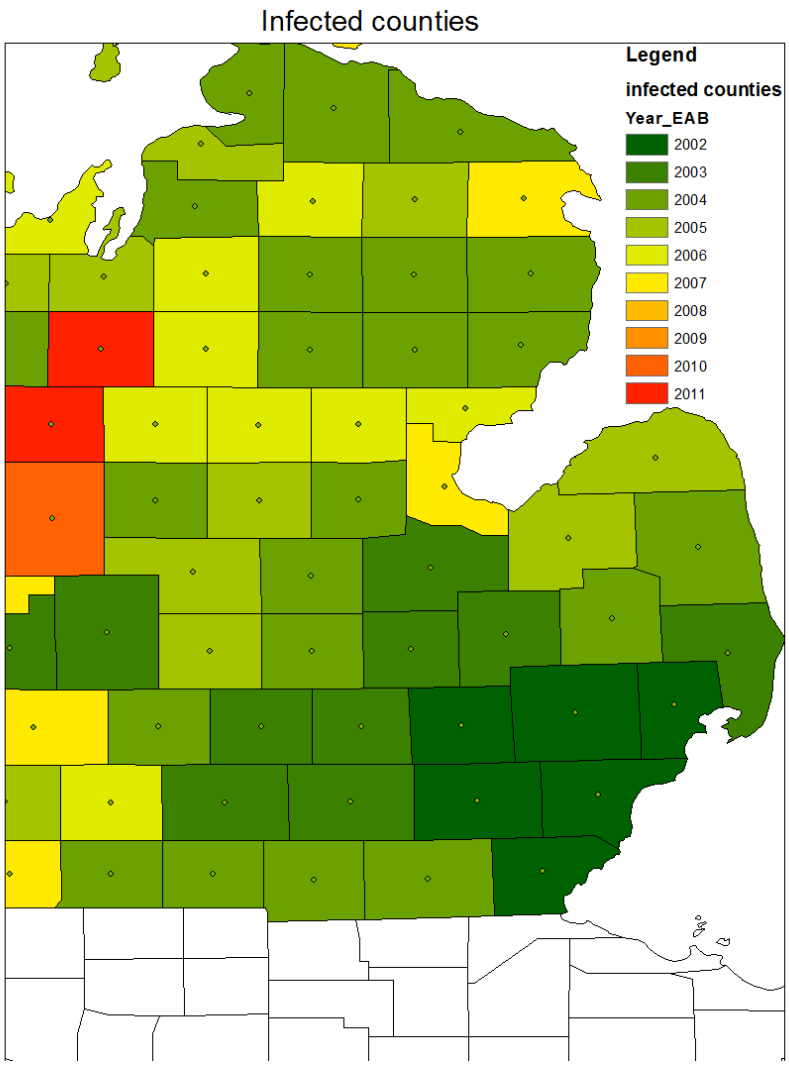


Figure 3: Map showing points added using feature to point function in GIS

We know the start of the invasion and we want to measure the distance between this county and all the others so we computed the distance between Wayne coordinate and the others counties coordinates.

We have some things to do before to be able to compute the distance. First step is to convert Decimals degree in Degree minutes seconds then use these data to compute the radians for each of them. Below an example of what we did.

Example

Decimal degree: Y: -83,282181 ➔ Degree: = Tronc(-83.282181)= -83

➔Minutes : = Tronc(Decimale value (83.82181)*60) = 16.93086

➔Secondes: Tronc(Decimale value (16.93086)*60) = 55.8516

Degree minutes seconds: Y : -83.1655

- We used this formula to compute the Radians of X and Y:
  - = Radians((Degree*3600+Minutes*60+Seconds)/3600)

Example:

Y: -83.1655 (Degree Minute seconds)

= Radians ((-83*3600+16*60+55)/3600) = -1.4437

We used all these data to compute the distance between Wayne which has the coordinate (X1:Y1) and the other counties which have the coordinates (Xx:Yx) and x is the rank of the county. We computed the distance in using this formula With (X1:Y1) coordinate for Wayne and (X2:Y2) the coordinates for the counties infected with the second rank:

Distance (in nautical miles)= ACOS(SIN(X1)*SIN(X2)+COS(X1)*COS(X2)*COS(Y2-Y1))*180/PI()*60

Example :

Y1 : -1.4437 X1 : 0.737954

Y2 : -1.41495 X2 : 0.745197

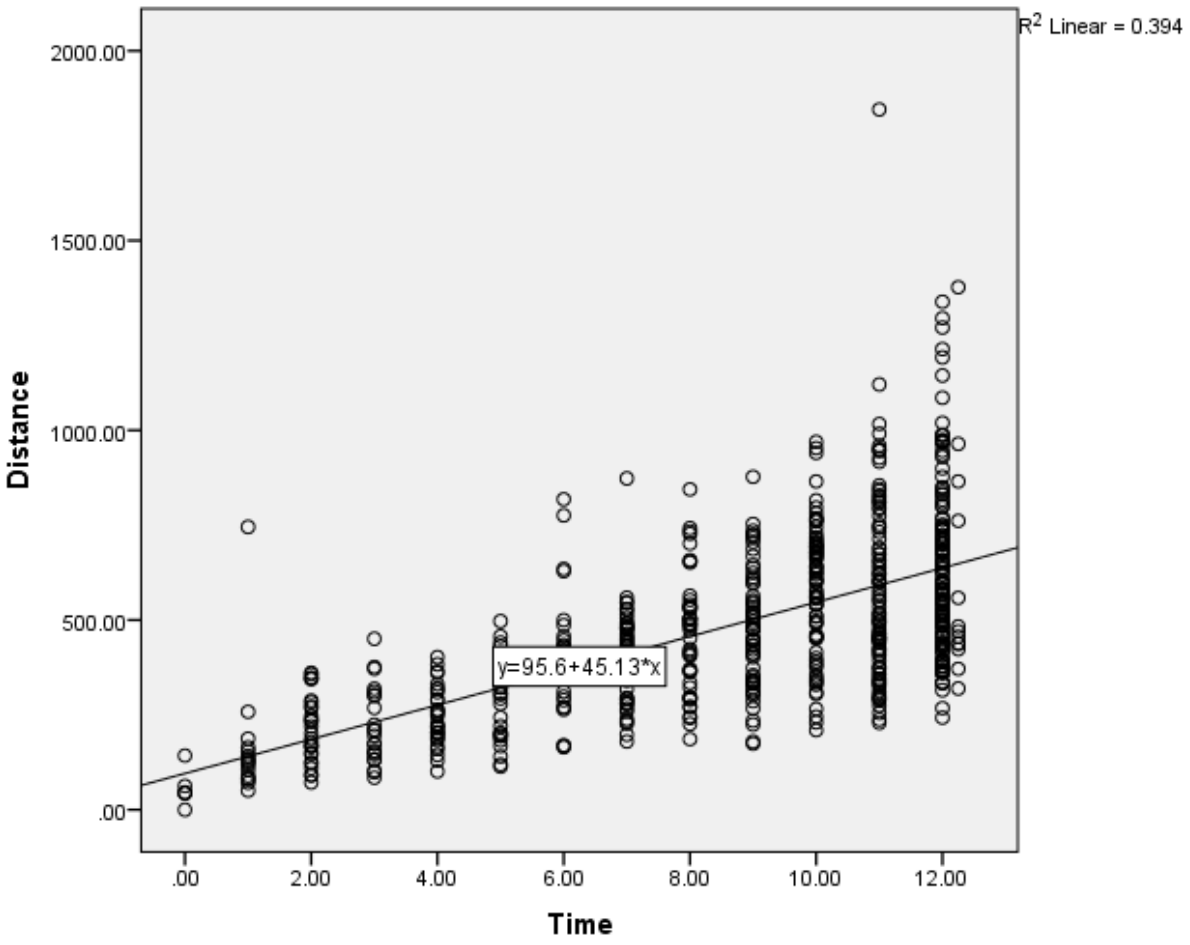
ACOS(SIN(0.737954)*SIN(0.745197)+COS(0.737954)*COS(0.745197)*COS(-1.41495-(-1.4437))*180/PI()*60 = 77.02646579

Because we want this distance in kilometers we converted it with this factor: 1km = 0.539612 Nautical mile. Then we used SPSS to create a graphic. This graphic show the distance between Wayne and the county X in function of the time that EAB needed to reach the county X if we take 2002 as t = 0. We calculated the trend for this graphic. We tried linear trend, exponential trend and logarithmic trend and the linear one was the most accuracy. Then with the same software we computed the trend equation, the regression analysis, the correlation coefficient between distance and time and some descriptive statistics.

The second main step in our project was to estimate the EAB future spread. We used the file we have already used to know the distance between all the non-infected counties and Wayne. Because we have the distance between the origin of the infection and these counties and we have an estimation of the equation which show the speed. So it means if we have the distance we can have the time and if we know the time we can have the distance. In our case we have the distance and we want to know the time so we used this equation x = (Y-95. 6)/45. 13 (x is the time and Y the distance) to compute when EAB will reach this county.

We used this formula to get a year of infection: Time of infection = Tronc(x). We got the year when EAB would reach each the non-infected counties. Then we created a map with these new data and created an animation of the data in ArcGIS.

Results



**. Correlation is significant at the 0.01 level (1-tailed).

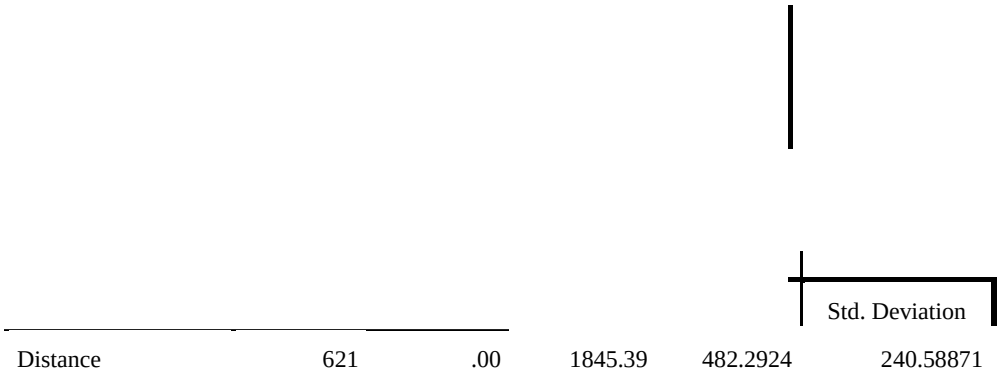
Figure 4: Linear regression graph created by using estimated speed

We computed the first equation for two reasons. The first reason is to know the average

45km/year. The

second reason is to be able to estimate the future spread. Also we know that the correlation between distance and time is R=0.628 (Pearson correlation) R^2=0.394 and the test is significant with a P-value=0.001. So it means that the correlation between these two variables is good but

not perfect and if we want to have a more accuracy model we have to find the other variables which impact the EAB spread speed. We estimated when EAB will reach Travis County and we found out that EAB could reach Travis County in 2039 if we use Wayne as origin of the infection but if we use the closest county infected and our model we found out that EAB could



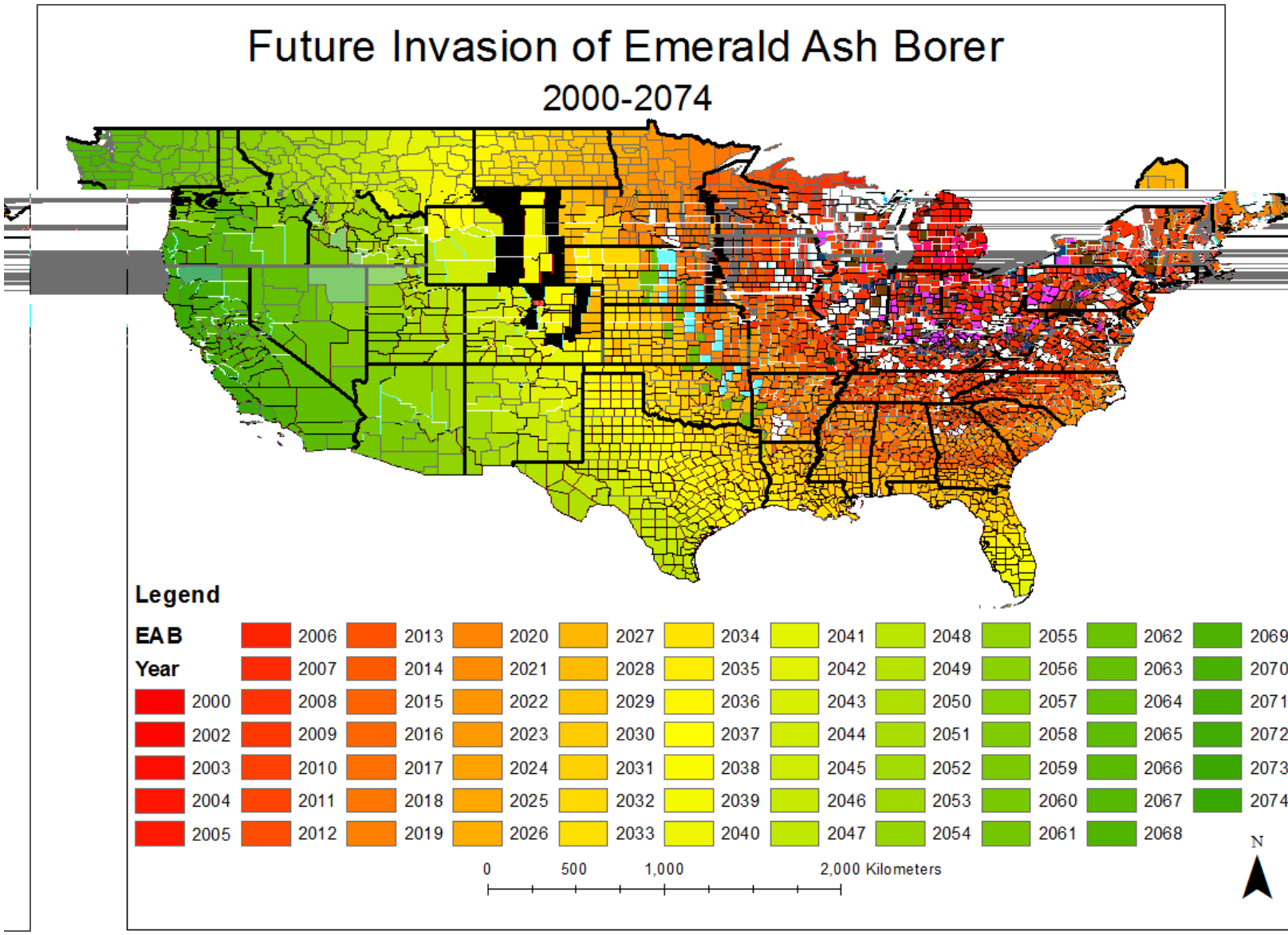


Figure 5: This map includes the speed previous data calculated using data provided by USDA with our speed predictions overlaid using Wayne, MI as the initial detection point. Travis County is invaded in 2039.

More specifically we calculated the estimated arrival time to Travis County, when using Wayne, MI as the initial point and we estimated a year of 2039. Then using the newest detection point in Webster, IL, by shortening the distance over time value we estimated a year of 2024.

Discussion

Variation in spread rate

Based on the three tests run to determine trend, the best fit linear function proved the most significance. Therefore we determined that overall speed of EAB based on our analysis has remained constant. The few outliers we do have in our data which include the counties in Arkansas and Louisiana can therefore be attribute

and Webster, IL

we can see a significant difference for the amount of preparation time to stop or slow the spread of EAB.

A previous study conducted in Ohio states that EAB spreads from ~4km to 20km with human activity (Prasad, 2010). Our estimate was a speed of 45km/year, and based on our future predictions it would reach Travis County in 2039. Even more alarming as stated above when using Webster, IL as the initial point of invasion shortens the estimated time to 2024. We have a range of about 4-16 years based on our model to plan and implement optimal strategies for Texas and more importantly Wild Basin in Travis County. Even though there is such a large window of time, EAB could arrive as early as the year 2019 if not already present in Texas due to the 2-5 year detection lag previously mentioned in the methods. This means it is very important for Texas to begin making such plans to prepare for future invasion or to help slow the spread of EAB to any other states in North America. More importantly based on our estimates Wild Basin has about 5 years to begin planning and identifying methods they would like to implement to protect the park and its ash resources. Texas ash is the main ash species found at Wild Basin and it provides many resources to the park. Some of which include shelter, food source, and

ecosystem services. The threat that EAB would have on Wild Basin is both ecological and economic.

Recommended prevention Strategies

Dispersal characteristics and geographical distribution of EAB affects the choice of control strategies be it suppression, containment, or eradication (Moody & Mack, 1988; Sharov, 2004; Taylor &Hastings, 2004). Based on our estimates we have identified several key strategies to prevent and or slow the rapid spread of EAB for Wild Basin.

Several states have placed regulations in place in order to slow the spread of EAB once it has been detected. Some of these regulations include quarantine zones and quarantine borders along the state line. This helped slow the spread of EAB to some extent but making strict regulations in states that are not yet infected would prove to be beneficial. Putting stronger regulations on the transport of ash products such as firewood from states positively identified for EAB would possibly slow and eliminate the transfer of infested wood. This would have to be conducted at a state level but could also be done at a local level if the city were to partner with local natural parks. In order for these regulations to be successful the public must be informed about the threat of EAB. Some efforts have been made to increase awareness of EAB such as Texasinvasives.org. Although currently no regulations have been made for Texas websites like this help keep people informed and updated on any new information on EAB.

Based on several studies on lures and attraction to certain colors and semiochemicals, the purple box method has proved to attract more female and male emerald ash borers than any other traps (Francese, 2008; Poland, 2007). It has also been studied that placement of these traps is most ideal on the outlying borders rather than in the center of the woodlot, and on an intermediate height (Francese, 2007; McCullough 2005). Traps placed at the center of the tree

attract more ash borers. This is the most non-invasive method that could potentially be best suited for areas such as Wild Basin Wilderness Preserve. It is costly and effective since EAB has not yet been detected these traps could significantly slow or stop the spread of EAB into Wild Basin.

Another method that has been studied and proven to show significant results is girdling ash trees to attract ovipositing female beetles and then destroying the trees before larvae complete development. Several studies have shown that the girdled bark emits monoterpenes and sesquiterpenes these compounds were seen to give strong antennal responses on both male and female EAB adults (Crook & Mastro, 2010; Crook 2008). Although this is a more invasive method its benefits outweigh the cost. Girdling does cause stress on the host tree but it allows for rapid deceleration of spread (Fraser, 2005). Once eggs are deposited on the exposed tree they can be easily destroyed or the tree can be cut down or burned. It has reduces radial spread by 15%, and reduces the amount of phloem fed on outside the treated area by 20%. This method would be most beneficial in a newly infested area since some trees will be removed, allowing for quick eradication of EAB without removing all ash trees in an area.

Applying a highly effective systemic insecticide has also been seen to slow the spread of EAB. This method is aimed to killing the adult beetle. Applying insecticide into the bark over several years 300m around the origin of infestation has been deemed effective. It reduced radial spread by 30% and reduced the amount of phloem fed on outside the treated area by 40% (Herms & McCullough, 2014).

The final method is early eradication or removing ash trees to reduce available host phloem in the infested area. The aim is to reduce the quantity of food available for the emerald ash borer in its larvae stage. This effort has an effect on the actual larvae that are in the tree once

it has been infected but it has little to no effect on the radial spread or population size outside of the treated area. This method is also beneficial in areas where EAB is present and has been positively identified.

Implications to ecology and future work

EAB has been seen to induce ash tree mortality in a course of a few years (Klooster et al., 2013), this then leads to a synchronous and widespread pattern of dead ash trees. This affect causes severe cascading effects on the forest community makeup and the ecosystem processes present (Gandhi et al., 2010). Some of these effects seen include changed understory environment, and changing nutrient cycles. Since ash is the most widely distributed tree genera in North America the effects caused by EAB will be experienced on a grand scale.

Although our model looks at the US as a homogenous environment, future studies could add variation in order to improve the predictions. Variables could include ash tree distribution, habitat variation, and human assisted dispersal pathways.

Establishing an accurate ash tree density map would be of great use to develop accurate speed predictions across North America where ash trees are present. This would allow for areas to focus on specific areas for protection and prevention therefore maximizing efforts against EAB.

If EAB populations are not contained and or eventually eradicated the ash resource in the U.S could be devastated (MacFarlane & Meyer, 2003). Ash trees are not only resistant to many factors making them great for urban landscaping, but they are in fact the most widely planted trees in urban areas (Ottman & Kielbaso, 1976; Giedriatis & Kielbaso, 1982). Therefore continued efforts on predicting and estimating invasion should be pursued in future studies and years to come.

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