Modeling Emerald Ash Borer Establishment and Spread Using GIS

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Abstract

Within the last decade, Geographical Information Systems (GIS) have emerged to the forefront in computer modeling of invasive species. The invasive Emerald Ash Borer (EAB) has become a major research inquiry because of its drastic impact in such a short time. Spreading is primarily caused through human vectors (i.e. campgrounds, nurseries, and sawmills), although natural spread does occur through flight. This paper will introduce the aspect of density relating to three human vectors to predict high risk areas of new EAB spread holding all other variables constant.

Introduction

Geographical Information Systems (GIS) has emerged as an exceedingly robust tool that is being used to analyze risks in many different areas of research (Holcombe et al 2007). The utilization of GIS allows users to collect, manage, and analyze large amounts of data that can be linked to spatial locations geographically (Ward & Johnson 2007). Currently, GIS is being involved with solving numerous environmental problems such as invasive, or exotic, species and natural disasters. One invasive species, in particular, is the Emerald Ash Borer (*Agrilis planipennis, Fairmaire*). Emerald ash borer (EAB) was introduced sometime in the mid 1990's in Detroit, Michigan (Siegart et al 2008) and first reported in July 2002 (Poland & McCullough 2006). Since that time, EAB has spread to several states throughout the upper Mid-West and Mid-Atlantic regions (USDA Animal and Plant Health Inspection Service 2008). The EAB is documented to be spread primarily by movement of firewood, infested nursery stock, and wood producers with natural spreading through flight. This project will attempt to identify areas of high risk due to those accumulating factors using GIS. Features such as campgrounds, nurseries,

and sawmills (includes firewood dealers) will be assessed and density maps will determine the concentration of features within a given radius.

Since GIS is extremely useful in modeling and prediction of spatial problems, this project will be using point features to develop density grids for six states (OH, PA, WV, MD, DE, NJ) in the Mid-Atlantic region of the United States. Ultimately, this will provide insight of how each attribute is spatially distributed within the study area and how each layer will interact or is interconnected to the other. Combining the layers will result in a predicted output of those areas of high risk due to the presence of campgrounds, nurseries, and wood producers. Upon conclusion, the following questions can be answered: 1) How is each layer represented spatially; 2) Do they interact with human population centers; 3)Will this be useful for treatment strategies, and 4) Is this data actually useful for other types of projects dealing with invasive insects.

Background

Regarded as one of the most important invasive pests in North America, emerald ash borer has quickly made a profound impact on the United States (Haack et al 2002; Cappaert et al 2005; Poland & McCullough 2006; Mastro et al 2007; Wei et al 2007). The native Asian beetle has been a fast moving invasive insect that is spreading across parts of the continent very rapidly. Within the first five years of inception (estimated 1998 to 2003), the core area of infestation by the emerald ash borer had increased 170-fold (Siegart et al 2008). Even EAB outlier populations have spread more rapidly than first predicted (Cappaert et al 2005; Iverson et al 2006; Heimlich et al 2008). Currently, in the United States, EAB infestation has resulted in rapid mortality of ash (Fraxinus sp.) of various sizes and habitats (Pontius et al 2007). While EAB has had adverse impacts on our forest biodiversity, it also creates problems in our urban ecosystems because ash resources are not only widely distributed in forested ecosystems but also planted as shade trees and ornamentals (Lui & Bauer 2008).

With the emerald ash borer being a relatively new occurrence in the United States, researchers are frantically studying effects of its presence. Studies ranging from biocontrol treatments to risk modeling have been ongoing to learn as much as possible about this curious new insect and the outcomes associated with the pest outbreaks. In China, the emerald ash borer is only considered a minor pest due to the presence natural enemies (Lui et al 2008). EAB is also found elsewhere in the surrounding countries of Taiwan, Korea, Russia, Mongolia and Japan where it is a minor pest as well (Haack et al 2002; Smith et al 2003).

Common signs left by EAB are serpentine galleries beneath the surface of the bark, eggs in deep bark crevices, presence of larvae, and D-shaped emergence holes (Wisconsin DNR 2008; Wilson & Rebuk 2005; Pennsylvania DCNR 2009). Symptoms of emerald ash borer are common to those of any stressed tree. Often, rapid crown dieback in the top third of the canopy will be the first symptom of an attack (Wilson & Rebuk 2005) and persist until significant dieback throughout the rest of the crown has been fatal. As with most stressed trees, epicormic branching is common with EAB infections (USDA Animal

and Plant Health Inspection Service 2008). Other symptoms such as bark splitting and increased woodpecker activity have also been noted (McCullough & Katovich 2004; Wisconsin DNR 2008).

Using GIS Data in Risk Modeling

Invasive species frequently receive great attention due to the potential for rapid spread and widespread damage. Invasive species pose challenges to indigenous life forms because they use valuable resources, have no natural predators, and thrive in environments suitable for their survival. Using GIS to model invasive species will aid in the process of understanding their dispersal, distributions, and habitats. Defining where a species may survive is dependent on being able to determine its existing or potential habitat (Holcombe et al 2007). In addition, GIS has been used for other research such as the development of a hazard rating system for pine beetles (Cook et al 2007), predicting the spread of forest pathogens (Hunter et al 2007) and monitoring landscape classification (Mora & Iverson 2002). In conjunction with remote sensing and photogrammetry, GIS can be used to identify these types of hazards and/or risks. These areas of interest are studied by researchers using GIS to analyze satellite images, aerial photos and field survey data. One example of risk modeling is a study approach to early detection over a large area that involves remote sensing technology. Narrow-band hyperspectral instruments have the capability to identify early signs of stress in vegetation and trees and, in some cases, even when symptoms are not visible to the human eye (Pontius et al 2007).

Kernel Density

Kernel density calculations involve features that are present within proximity of each other. This type of density can be applied for point or line features. Kernel density uses a function that fits a smooth curved surface over each point that is used in the analysis (ESRI 2008). Surface value diminishes with increasing distance from the point, which means the point is dark and becomes lighter with distance. If the surface values overlap then the density calculation sums them up to receive a magnitude value. Increasing search radius does not greatly affect density calculations because the area of the circle is incorporated into the equation (ESRI 2008). Possible uses for this function include population density, housing density, and wildlife reports.

Methodology

Each respective layer (campgrounds, nurseries, etc) was added to GIS. Complied datasets included coordinate points were for states only. Merging all the attributes from their respective layer together yields points for the entire study area. Each layer was then analyzed using the Kernel Density function in the Spatial Analyst menu. Figure 1 represents the exact values placed in each field for the density calculations. Each layer was calculated using the same values. The population field indicates a numeric value if actual population density was a point of emphasis. In this case, there was not a

population field so each attribute is only counted once. Smaller the cell sizes provide greater detail for the image. Since this project encompasses several large states, a broad cell size of 1000 X 1000 was selected. Search radius indicates the distance around each individual cell for which the density calculation will include. In Figure 1, the distance is 16000 meters or 10 miles so the function will calculate all attributes within 10 miles of a respective cell. Once all three layers received a density calculation, they were summed up by using the raster calculator in the Spatial Analysis Toolbar.

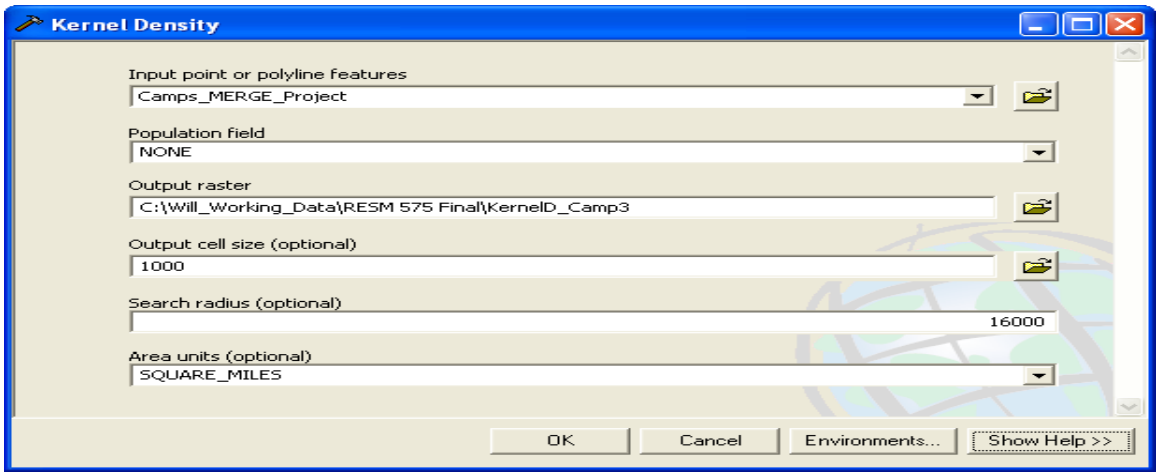

Figure 1. Kernel Density Parameters

The additive model represented a total number of features for a given cell instead of using a multiplicative model that only accounts for presence or absence. If a multiplicative model was used, a cell containing a camp and nursery but no sawmill would yield a value of 0, which means nothing would be counted for the final density raster grid. Once the additive model was completed, density in square miles was reported. Figure 2 shows the model procedure used for the calculations.

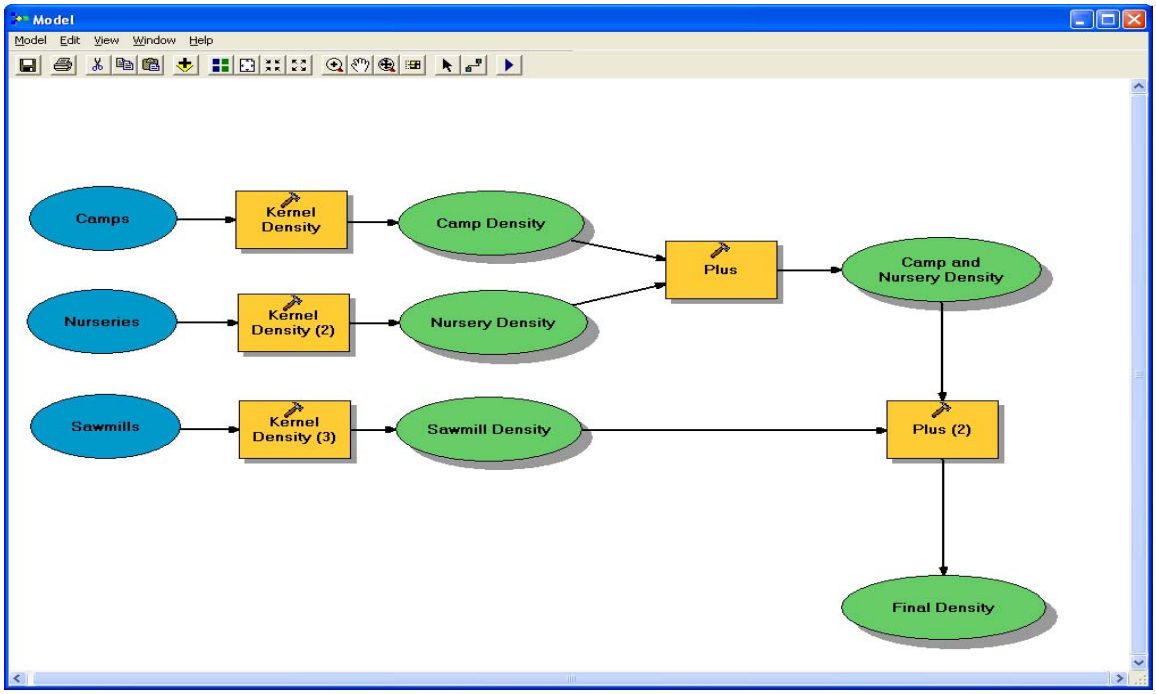

Figure 2. Model Framework for Kernel Density Calculations

Results

Campgrounds

Kernel Density calculations show that campgrounds exhibit a dispersed distribution (Figure 3). When reclassified, only 24,224 acres of land recorded between 16-18 campgrounds per 10 square miles, which were the highest reported densities. The vast majority of campground density (≤ 6 per 10 sq mi) encompasses approximately 121 million acres of the study area or 97%. Many of the high density spots were located in eastern Pennsylvania and spreading into New Jersey. Campground distribution also had high densities along Lake Erie in Ohio and western Pennsylvania. West Virginia has a low density of campgrounds in most areas of the state. However, Fayette County reported a density of 8-10 camps per 10 sq miles which coincides with emerald ash borer already being found in the county. It is also the only county in West Virginia to have EAB reported and was believed to be brought in by infested firewood.

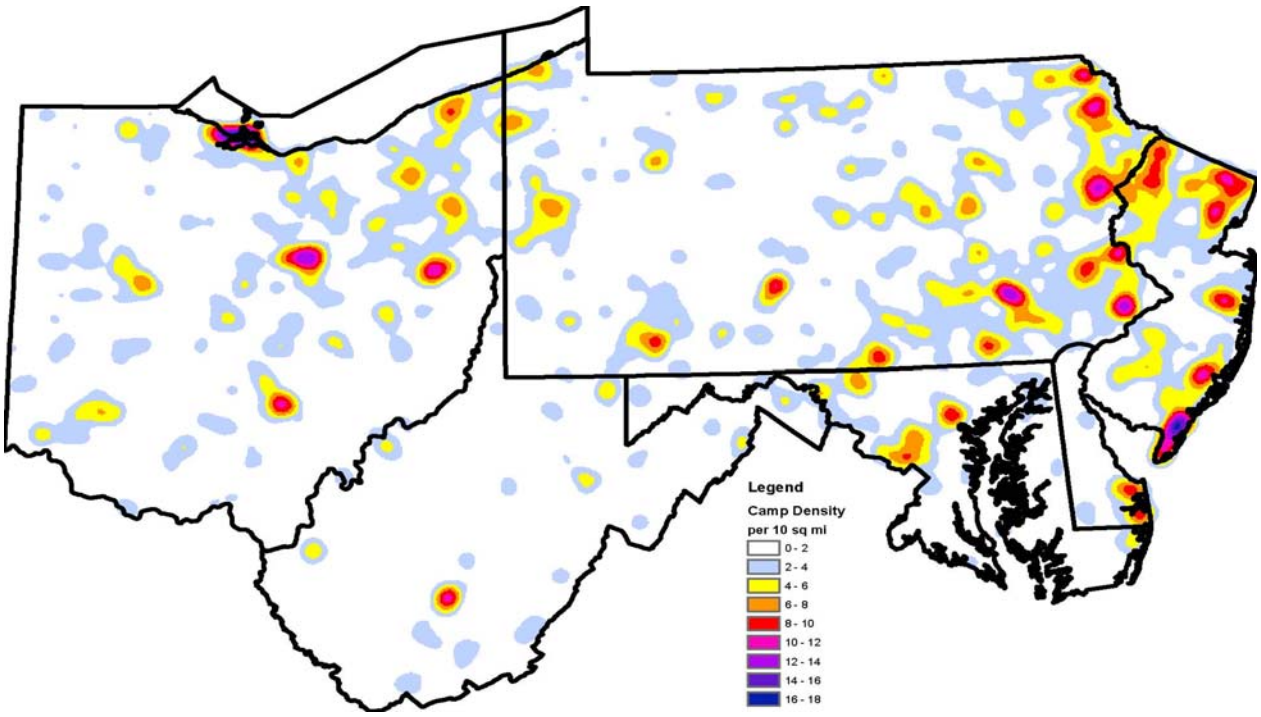

Figure 3. Campground Density

Nurseries

Nursery data indicates a much more different density output than the campgrounds (Figure 4). High density nursery areas seem to interact with major cities with high population. Overall, very high density areas (28-41) encompass roughly 390,000 acres of land within the study region. These areas are confined mostly in eastern Pennsylvania and throughout the state of New Jersey. Other high density centers include all major cities in Ohio (Cleveland, Columbus, Cincinnati, and Toledo) and Pittsburgh. West Virginia has no recording of density over 3-6 nurseries per 10 sq mi. High population areas in and around the Baltimore and Washington D.C. area also highly dense. Prince George County, in Maryland, was one of the first reported cases of EAB infestation of nursery stock back in 2004. The density map classifies that location in the 13-17 range which is somewhat high compared to most areas.

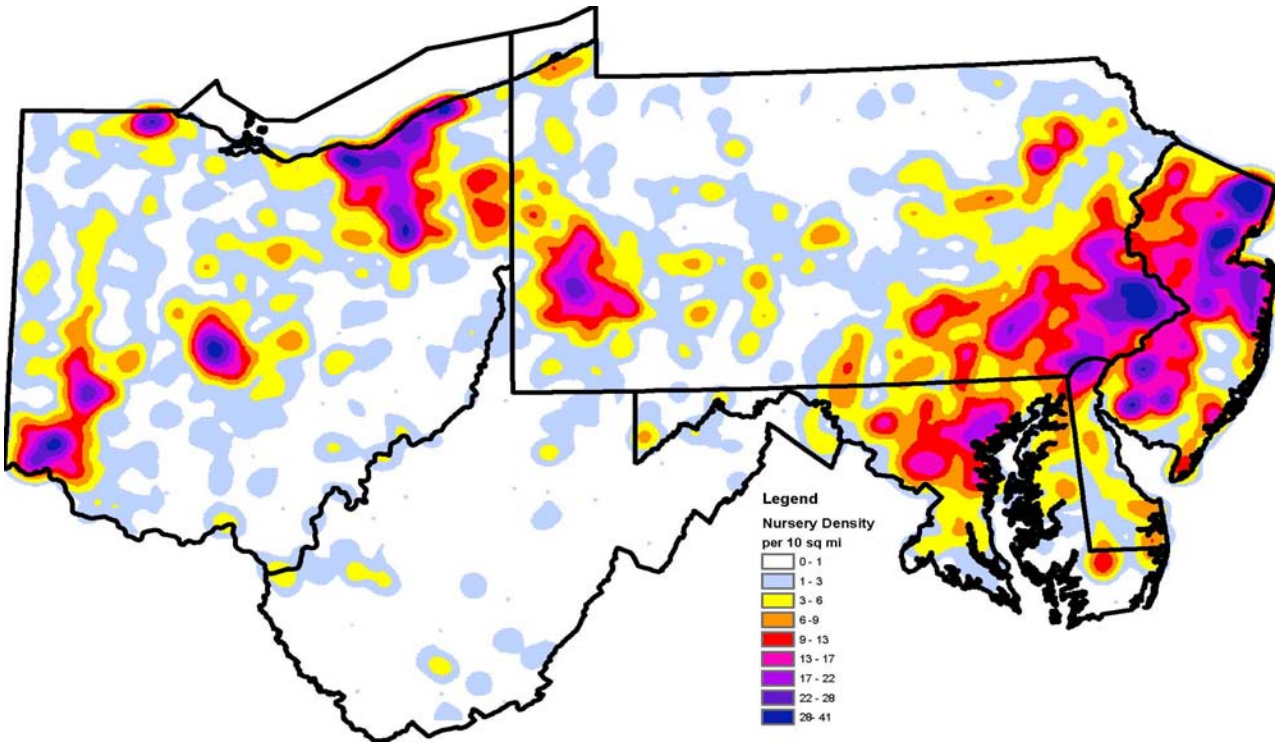

Figure 4. Nursery Density

Sawmills

In contrast to camps and nurseries, sawmill density is more prevalent in rural areas rather than the industrial cities. Density values peak around Philadelphia which is probably attributed to firewood dealers more so than actual sawmills (Figure 5). However, only about 33,000 acres are within the 45-58 range. Roughly 85% of the study area is classified with five or less points per 10 sq mi. With the exception of Philadelphia, most other dense areas of wood producers fall within West Virginia and western Maryland. Unlike other layers, New Jersey had a lower density of wood products due to the fact the

most of the state is densely population and compact with non-forest conditions.

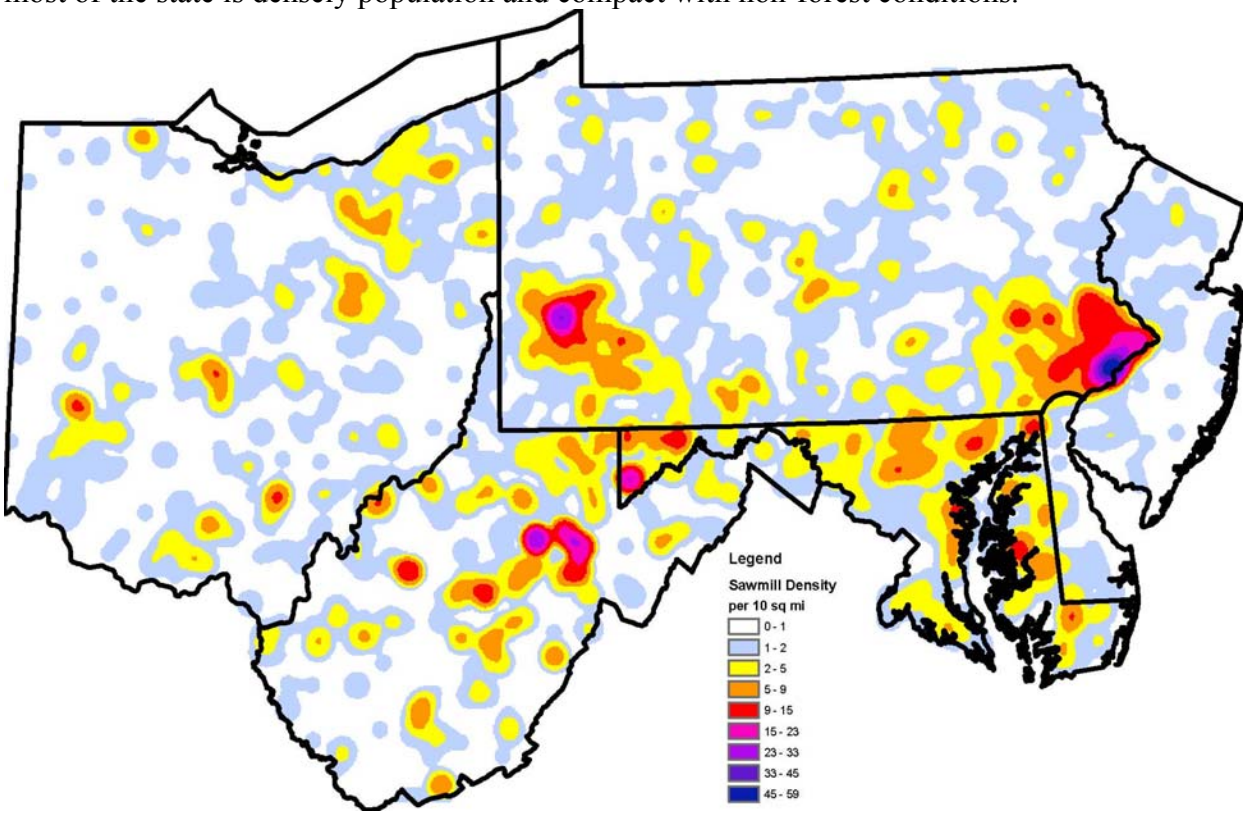

Figure 5. Sawmill Density

The Final Output

The final output map for density was produced after combining all three layers through an additive model (Figure 6). Most of the study region received some type of density value. Plain white regions of the map had a density less than one which means that very few point features were located within the ten-mile search radius. When re-classed to equal interval density values, a lot of subtle information was lost which drastically reduced the detail of the final map; therefore, the nine ranges were left as is. As expected, the density calculations were biased toward larger cities within the study area.

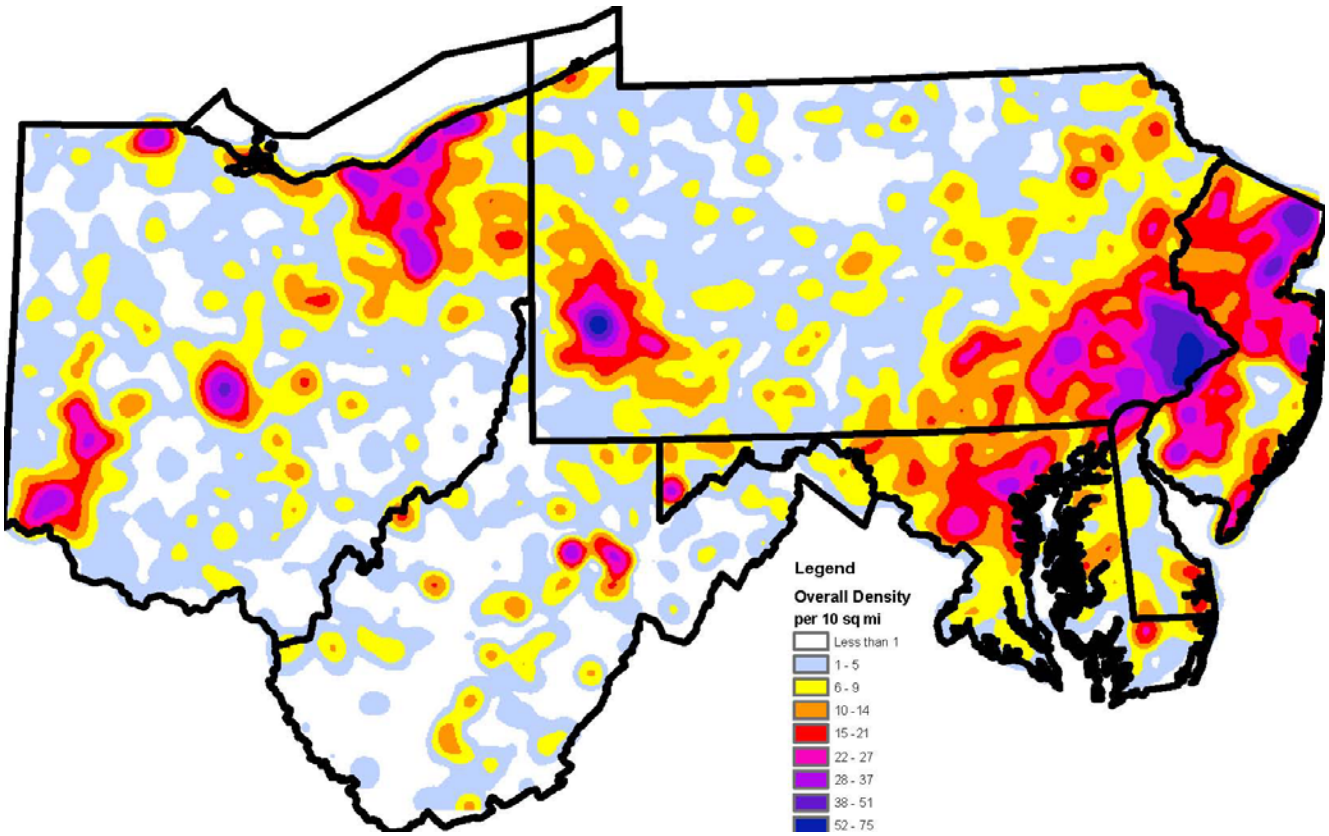

Figure 6. Final Density Calculation

Conclusions

The final map provides a smooth and dynamic output that easily identifies places that EAB could be spread (holding other factors constant) using sawmill, camp, and nursery vectors. Kernel density is a useful tool to evaluate points because it gives a magnitude on how they are affecting or not affecting the problem at hand. The density outputs are well within reason and provide a solid base for future modeling experiments with other invasive species but only if the new invasive has similar dispersal methods. In retrospect, nurseries are most likely skewing some of the density data toward the cities relating back to Figure 4. In the future, investigating the idea of weighting each of these layers by importance would yield a more accurate approach. Campgrounds seem to have the greatest affect because they have the most interaction with the public followed by sawmills and nurseries, respectively. With proper regulation and policy enforcement, nurseries could have little effect on the EAB because stock would be vigorously monitored before being transported.

From a management standpoint, these maps will have a positive input of containing EAB spread. Agencies, such as the US Forest Service, can pinpoint locations of high density and monitor them more frequently than those with low density numbers. This will save time and money which are two crucial components with any resource problem. With the addition of other factors, treatment strategies can be conceived within reason.

One major limitation for this study is data acquisition. Finding every campground, nursery, wood dealer is impossible. Although, even though every feature cannot be found, a large sample size will still yield an accurate description of real world representation.

Data Acquisition and Projections

Campground data was primarily collected through an on-line business index called RefUSA. This index had business names, addresses, phone numbers, XY coordinates, and some e-mail addresses. Phone books for each state were also consulted to find additional campgrounds for the study area. RefUSA was the only source for nursery data because it included such a large dataset and included many other businesses that did not pertain to the project. Sawmill and firewood dealers were taken from an extensive list from natural resource agencies from each state in order to receive accurate information. RefUSA also gave listing for wood producers and was combined with the state and government data assuming there was no overlap.

The shapefiles and raster grids used for the study are listed in Table 1. Each dataset has the projected coordinate system listed as well as format, type of data, and the creator.

Table 1. Datasets used for density analysis

Data Layer	Coordinate System	Projection	Format	Type
Study_Area	NAD_1983_UTM_Zone_17N	Transverse_Mercator	Shapefile	Vector-Polygon
Camps_MERGE	NAD_1983_UTM_Zone_17N	Transverse_Mercator	Shapefile	Vector- Point
Nursery_MERGE	NAD_1983_UTM_Zone_17N	Transverse_Mercator	Shapefile	Vector- Point
Sawmill_MERGE	NAD_1983_UTM_Zone_17N	Transverse_Mercator	Shapefile	Vector- Point
Camp_Density	NAD_1983_UTM_Zone_17N	Transverse_Mercator	GRID	Raster
Nursery_Density	NAD_1983_UTM_Zone_17N	Transverse_Mercator	GRID	Raster
Sawmill_Density	NAD_1983_UTM_Zone_17N	Transverse_Mercator	GRID	Raster
Final_Density	NAD_1983_UTM_Zone_17N	Transverse_Mercator	GRID	Raster

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