The Spatial Distribution of Riparian Ash: Implications for the Dispersal of the Emerald Ash Borer

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Abstract.—A pilot study to assess riparian ash connectivity and its implications for emerald ash borer dispersal was conducted in three subbasins in Michigan's Southern Lower Peninsula. Forest Inventory and Analysis data were used to estimate ash biomass. The nineteen percent of plots in riparian physiographic classes contained 40 percent of ash biomass. Connectivity of riparian and upland ash was assessed using the spatial pattern analysis program FRAGSTATS. Higher mean proximity and patch cohesion was found among riparian patches. Greater connectivity and high ash biomass in riparian patches may facilitate spread of this insect.

Introduction

The emerald ash borer (EAB) (*Agrilus planipennis* Fairmaire, Coleoptera: Buprestidae), a native of Asia, was initially discovered in the United States in May 2002. Although the method of introduction is unknown, it is believed that EAB arrived in solid wood packing material (i.e., crates and wood pallets) transported to Detroit, Michigan (Haack *et al.* 2002). The extent of its damage and its life history traits indicate that EAB has been established in the United States since the early 1990s (Herms *et al.* 2004). Although the majority of devastation has affected ash trees in southeastern Michigan, EAB has dispersed throughout Michigan's Lower Peninsula and into Indiana, Ohio, and Windsor, Ontario. In addition, isolated EAB-positive locations have been identified in Michigan's Upper Peninsula (Michigan Department of Agriculture 2005), Maryland, and Virginia (Herms *et al.* 2004).

In the United States, EAB is known only as a pest to ash (*Fraxinus* spp.). Although EAB is a threat to all ecosystems where ash is found, EAB poses a substantial risk to riparian forests. Riparian forests tend to have high biodiversity (Goforth *et al.* 2002) and serve ecologically important roles in forest ecosystems, which enhance their value and vulnerability. Throughout Michigan, ash, particularly black and green ash, is a dominant overstory component of riparian forests (Tepley *et al.* 2004). White ash, largely an upland species, is typically found on dry to dry-mesic sites; however, in the Southern Lower Peninsula (SLP), white ash is often found growing along the margins of wet-mesic deciduous swamps (Barnes and Wagner 2004). Because ash species occupy different sites, it is important to understand how the spatial arrangement of ash may influence EAB dispersal patterns.

Not only are riparian ash at risk for EAB infestation, they may serve as EAB dispersal conduits. Preliminary research from a case study at an infestation site in Tipton, MI, offers evidence that riparian forests may facilitate EAB dispersal by channeling the direction of movement (McCullough *et al*. 2004). This study found that larval gallery density decreased with increasing distance from the source of infestation and that EAB seemed to display directional dispersal, as the majority of infested trees followed the path of a drainage ditch (McCullough *et al*. 2004). Therefore, presence of ash in riparian forests creates potential corridors of available habitat that may direct the course of dispersal into uninfested areas.

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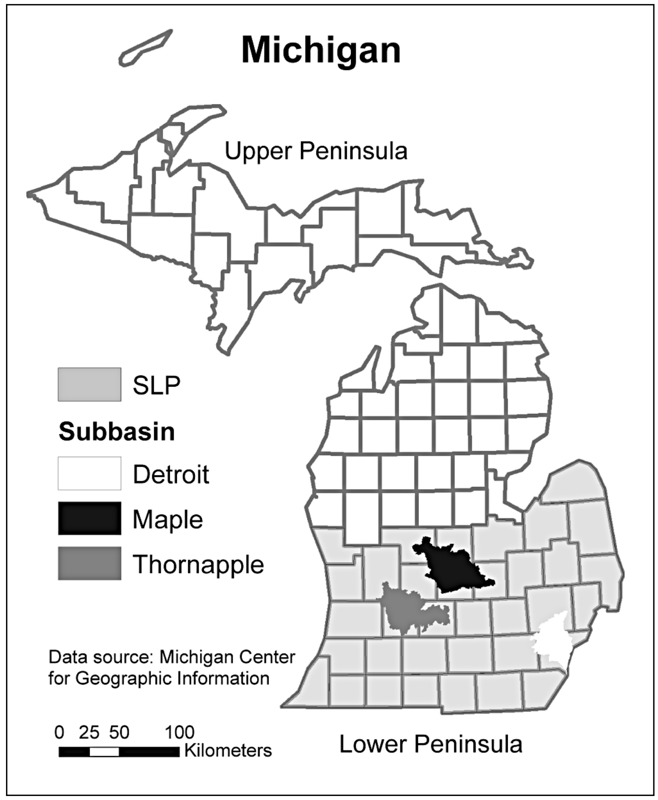
It is widely believed that corridors connecting similar patches of habitat facilitate the movement of organisms (Tewksbury *et al*. 2002). Haddad and Baum (1999) found that a contrast between corridor and surrounding habitat enhanced the effectiveness of corridors in increasing butterfly density within suitable corridor-linked patches. These studies suggest that ash patches with high connectivity may facilitate dispersal along connected corridors and have higher EAB densities. In addition, if corridors of ash habitat are bordered by contrasting or unsuitable habitats, especially in the fragmented SLP, these areas may be more susceptible and have higher rates of spread. Therefore, assessments of the spatial distribution of riparian ash may help predict directionality of dispersal.

The purpose of this study is to evaluate the spatial arrangement of ash habitat patches and assess the connectivity of riparian ash. To accomplish this goal, we will (1) map ash biomass and riparian ash distribution for the entire Lower Peninsula, (2) compare ash abundance in the SLP by physiographic class, and (3) calculate connectivity indexes for riparian and upland ash forest patches for three subbasins in the SLP. Our motivation is to identify the importance of riparian ash as it relates to the direction and rate of EAB dispersal, and provide information that may help mitigate the rapid spread of this insect.

Figure 1.—*Study area. The Southern Lower Peninsula and the Detroit, Maple, and Thornapple subbasins.*



SLP = Southern Lower Peninsula.

Methods

Study Area

Ash biomass was mapped for the entire Lower Peninsula (fig. 1); however, specific analysis of FIA plots was conducted only in the SLP. The SLP includes Allegan, Barry, Berrien, Branch, Calhoun, Cass, Clinton, Eaton, Genesee, Gratiot, Hillsdale, Huron, Ingham, Ionia, Jackson, Kalamazoo, Kent, Lapeer, Lenawee, Livingston, Macomb, Monroe, Montcalm, Muskegon, Oakland, Ottawa, Saginaw, St. Clair, St. Joseph, Sanilac, Shiawassee, Tuscola, Van Buren, Washtenaw, and Wayne Counties (fig. 1).

The study area for the connectivity analysis included three subbasins (classified by the Natural Resources Conservation Service and U.S. Geological Survey) located in the SLP: Detroit, Maple, and Thornapple (fig. 1). Subbasins are defined by the Watershed Boundary Dataset as eight-digit hydrologic unit codes (HUCs), formerly the lowest watershed accounting unit. Each eight-digit HUC represents approximately 448,000 acres (Laitta *et al.* 2004).

Mapping Ash Distribution

Forest inventory data were obtained from all FIA plots measured in the Lower Peninsula between 2000 and 2005. Forested plots were brought into Arc Map 9.0 and were used to create an interpolated surface of ash biomass using the ordinary cokriging method (ESRI 2004); log transformed biomass of all ash species and log transformed biomass of all tree species were used as covariates. Once the predicted surface of ash biomass was created, nonforest areas were masked using a land cover dataset for the Lower Peninsula, developed by the Integrated Forest Monitoring Assessment and Prescription (IFMAP) project, to reveal predicted ash biomass on forested land area only. Riparian ash forest types were mapped for the Lower Peninsula. These forest types were selected from (1) wetland vector polygons mapped from aerial photographs by the U.S. Fish & Wildlife Service during an inventory of national wetlands (National Wetlands Inventory [NWI]) data), and (2) pixels from the IFMAP land cover dataset that were classified as lowland deciduous (IFMAP land cover classification is derived from Landsat Thematic Mapper satellite imagery). Riparian ash forest types from NWI data are defined as Palustrine system, forested or scrub-shrub class, with the subclass or secondary subclass equal to the broadleaf deciduous category (in which ashes, among others, are canopy dominants).

Estimates of Ash Abundance

Total ash biomass was calculated for all FIA plots in the SLP measured between 2000 and 2005 by multiplying oven-dry tree biomass and the current number of trees per acre, then decoding by all species of ash. Ash biomass was summarized by physiographic class code, and estimates were compared by riparian and upland site. Physiographic classes—narrow floodplains/bottomlands, broad floodplains/bottomlands—and all hydric classes were defined as riparian; all other physiographic classes were considered upland.

Fragmentation Analysis

An IFMAP raster image file was extracted using a mask for each of the three subbasins. Three separate raster grids containing only those land cover/land use pixels within the boundary of each subbasin were created. The grids were then input into the spatial pattern analysis program for categorical maps, FRAGSTATS, in which landscape connectivity metrics were calculated for riparian and upland ash patches (McGarigal *et al*. 2002). Under IFMAP forest type classification, lowland deciduous and northern hardwood cover types represented riparian and upland ash patches, respectively. For estimates of fragmentation, the mean proximity index (McGarigal *et al*. 2002) was used and is defined as

$$\text{PROX\_MN} = \frac{\sum_{j=1}^{n} \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^2}}{n_i} \qquad (1)$$

where:

a_{ijs} is the area of patch i of patch type j within specified distance s of patch ij (the focal patch); h_{ijs} is the distance between patch ijs and the focal patch (based on patch edge-to-edge distance, computed from cell center to cell center); and n_i is the total number of patches in class i. The patch cohesion index was calculated as an estimate of connectivity and is defined as

$$\text{COHESION} = \left[1 - \frac{\sum_{j=1}^{n} p_{ij}}{\sum_{j=1}^{n} p_{ij}\sqrt{a_{ij}}}\right]\left[1 - \frac{1}{\sqrt{A}}\right]^{-1} \bullet (100) \qquad (2)$$

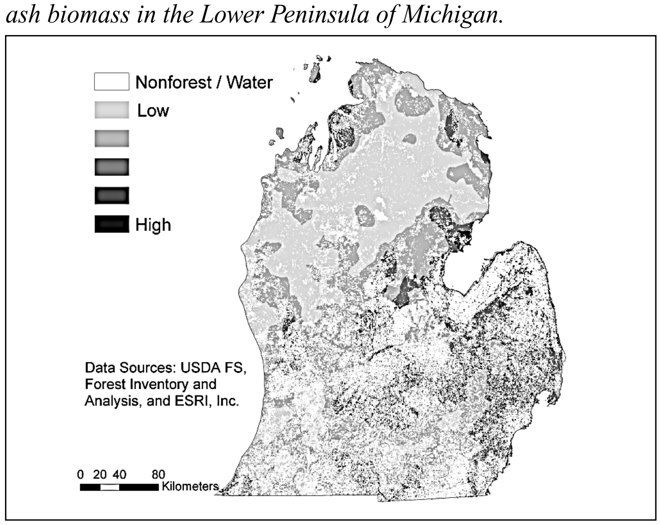
where:

p_{ij} is the perimeter of patch i of patch type j in terms of number of cell surfaces, a_{ij} is the area of patch ij in terms of number of cells and A is the total number of cells in the landscape (McGarigal *et al.* 2002).

Results

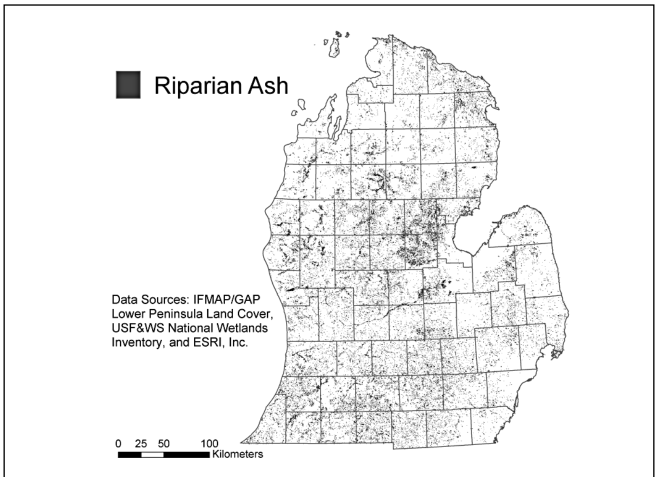
A map of log transformed ash biomass for all ash species in the Lower Peninsula was created (fig. 2). Ash biomass is relatively low throughout much of the Northern Lower Peninsula. In contrast, high proportions of ash biomass are found in the SLP. Although forests in the SLP tend to have higher ash biomass,

Figure 2.—*Ordinary cokriged interpolation of log transformed ash biomass in the Lower Peninsula of Michigan.*



the forests are made up of smaller parcels, as the degree of forest fragmentation decreases from south to north. Riparian ash forest types are distributed throughout the Lower Peninsula (fig. 3). Though concentrated in the central portion of the Lower Peninsula, riparian ash forest types make up much of the ash biomass in the SLP. Throughout the Lower Peninsula, riparian ash forest types form narrow, sinuous bands and tend to be clustered around watercourses.

Figure 3.—*Distribution of riparian ash forest types in the Lower Peninsula of Michigan.*



The majority of forest area in the SLP is classified as uplands (table 1). A total of 1,714 plots were sampled and 19 percent were in riparian physiographic classes. Although making up less than a quarter percent of total area, plots in riparian physiographic classes held 40 percent of ash biomass. Mean ash biomass was higher in riparian plots at 17,546 pounds per acre; upland plots had a mean ash biomass of 6,290 pounds per acre (table 1). Twenty-four percent of plots in riparian physiographic classes (or riparian plots) had no ash biomass; 55 percent of plots in upland physiographic classes (or upland plots) had no ash biomass.

The mean proximity index for riparian forest type patches was greater than upland patches in two of the three subbasins (table 2). Lowland deciduous forest type patches in the

Table 1.—*Analysis of FIA plots by physiographic class code, Southern Lower Peninsula of Michigan, 2000–05.*

	Floodplain physiographic class	Upland physiographic class
Total number of plots	327	1,387
Total ash biomass (lbs/acre)	5,737,567	8,724,879
Mean ash biomass/plot (lbs/acre)	17,546	6,290
Standard deviation	24,463	13,461
Number of plots with no ash	80	760

FIA = Forest Inventory and Analysis.

Table 2.—*Landscape metrics for lowland deciduous and northern hardwood forest types in three subbasins in the Southern Lower Peninsula of Michigan.*

Forest type			Subbasin: Detroit	Subbasin: Maple	Subbasin: Thornapple
Forest type	Lowland deciduous	Total area (acres)	7,112.92	27,726.92	23,052.28
		Percentage of landscape (%)	1.90	4.58	4.25
		Number of patches	5,323.00	14,422.00	17,022.00
		Mean patch area (acres)	1.34	1.92	1.35
		Mean proximity index (MPI)	4.98	19.43	6.98
		Standard deviation of MPI	19.28	86.43	28.20
		Connectance index	0.39	0.22	0.23
		Patch cohesion index	82.46	89.39	82.19
	Northern hardwood	Total area (acres)	20,449.21	12,579.94	29,452.22
		Percentage of landscape (%)	5.45	2.08	5.42
		Number of patches	21,299.00	10,625.00	16,471.00
		Mean patch area (acres)	0.96	1.18	1.79
		MPI	2.75	1.73	9.27
		Standard deviation of MPI	4.30	4.15	57.28
		Connectance index	0.25	0.18	0.18
		Patch cohesion index	67.81	70.62	85.59

Detroit, Maple, and Thornapple subbasins had mean proximity index values of 4.98, 19.42, and 6.98, respectively. Northern hardwood forest type patches had mean proximity indices of 2.75, 1.73, and 9.27 in the Detroit, Maple, and Thornapple subbasins, respectively. Patch cohesion had greater variability for northern hardwood forest patches than for lowland deciduous patches. In northern hardwood forest patches, the patch cohesion index was 67.81 in the Detroit subbasin, 70.62 in the Maple subbasin, and 85.59 in the Thornapple subbasin (table 2). On average, the patch cohesion index was higher in lowland deciduous patches and was more stable, ranging from 82.46 to 89.39 to 82.19 in the Detroit, Maple, and Thornapple subbasins, respectively. Average landscape area is 3.58 percent in riparian plots and 4.32 percent in upland plots. Northern hardwood patches occupied an average of 20,827 acres per subbasin, while lowland deciduous patches contained an average of 19,297 acres per subbasin.

Discussion

Riparian forests are associated with many types of surface waters (Palik *et al.* 2004), including rivers and streams. As a result of this association, riparian forest types often have a linear, sinuous pattern that is influenced by stream flow. This pattern of distribution is suitable for guiding EAB dispersal and maximizing the distance an insect will travel. Therefore, the spatial distribution of riparian ash may be important in facilitating long-distance dispersal of EAB in the SLP by funneling EAB movement along corridors of suitable ash habitat, particularly in areas bordered by unsuitable or non-ash environments. Although riparian ash forests do not account for a total area greater than upland ash forests, average ash biomass is higher in riparian forest types. The damage potential and potential capacity for supporting EAB density is therefore higher in riparian ash forest types. EAB represents a substantial risk to riparian forests in the highly fragmented SLP because riparian ash forest types create corridors of potential EAB habitat and contain a high proportion of ash. These factors increase the vulnerability of riparian forests to EAB and enhance the ability to direct dispersal.

The ability to direct dispersal is related to spatial arrangement. The mean proximity index measures the relative fragmentation and isolation of similar patch types (McGarigal *et al*. 2002). Higher mean proximity values for riparian forest patches indicate that riparian patches were surrounded by a higher number of similar patch types than were upland patches. Similar to the mean proximity index, the patch cohesion index is a measure of the physical connectedness of corresponding patch types (McGarigal *et al*. 2002). Patch cohesion was higher in lowland deciduous patches, which is an indication that riparian forest patches offer greater connectivity between patches relative to upland, northern hardwood forest types. Higher connectivity between riparian ash patches increases the likelihood of stronger EAB travel along riparian corridors.

Although this study is preliminary, initial results suggest that (1) the forests in the SLP, where the distribution of riparian ash is great, are highly fragmented; (2) riparian ash forest types make up a small percentage of total area but contain a large amount of ash biomass; and (3) riparian ash forest types are more highly connected to patches of similar forest type than are upland ash forest types. Thus, the spatial distribution and pattern of riparian ash abundance in the SLP may influence the direction and rate of EAB spread by allowing EAB to quickly increase radial dispersal along narrow, connected corridors.

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