A REGIONAL ASSESSMENT OF EMERALD ASH BORER IMPACTS IN THE EASTERN UNITED STATES: ASH MORTALITY AND ABUNDANCE TRENDS IN TIME AND SPACE

Randall S. Morin, Scott A. Pugh, Andrew M. Liebhold, and Susan J. Crocker[1]

Abstract—The nonnative insect, emerald ash borer (*Agrilus plannipennis* Fairmaire), has caused extensive mortality of ash tree species (*Fraxinus* spp.) in the eastern United States. As of 2012, the pest had been detected in about 15 percent of the counties in the 37 states that comprise the natural range of ash in forests of the eastern United States. Here we use regional forest inventory data from the USDA Forest Service Forest Inventory and Analysis program to quantify ash mortality, volume, and standing dead tree abundance relative to the year of initial emerald ash borer detection. Results from remeasured plots indicate that the annual ash mortality rate increases dramatically over the background level several years after initial invasion of the pest into a county. The corresponding decrease in ash volume and increase in standing dead trees continues for several more years until the live ash resource is reduced to very low levels in local areas.

INTRODUCTION

The nonnative insect, emerald ash borer (EAB; *Agrilus plannipennis* Fairmaire), was initially detected in Michigan and Ontario in 2002 although it had probably established in the early 1990s (Siegert et al. 2014). As of 2012, EAB had been discovered in about 15 percent of the counties in the 37 states that comprise the natural range of ash species (*Fraxinus* spp.) in forests of the eastern United States (Figs. 1,2). As it continues to spread, EAB has the potential to functionally extirpate ash with extensive economic and ecological impacts. An essential part of the management for any invasive pest is measuring the extent of its impacts over time and space (Parker et al. 1999). Here, we use remeasured regional forest conditions using inventory data from the USDA Forest Service Forest Inventory and Analysis (FIA) program to quantify changes in live ash volume, ash mortality, and ratio of standing dead to live tree abundance, relative to the historical spread of EAB.

[1] Research Forester (RSM), Northern Research Station, USDA Forest Service, 11 Campus Blvd., Ste. 200, Newtown Square, PA 19073; Forester (SAP), Northern Research Station, U.S. Forest Service; Research Entomologist (AML), Northern Research Station, U.S. Forest Service; and Research Forester (SJC), Northern Research Station, U.S. Forest Service. RSM is corresponding author: to contact, call (610) 557-4054 or e-mail at rsmorin@fs.fed.us.

METHODS

The study area includes counties in the 14 states where EAB had been detected as of 2012. This area includes: Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Wisconsin (Fig. 1). Forest conditions of grouped counties were estimated from the 2005 to 2012 inventory years by the year of first EAB detection.

Two metrics were employed to assess the impact of EAB on regional dynamics of all ash species in the study area: annual mortality rate and annual volume change. Annual mortality rate was computed as the proportion of annual mortality to initial live volume. Annual volume change was calculated as the difference between annual volume estimates as a percentage of the first estimate.

RESULTS

The background annual mortality, computed as annual mortality as a fraction of initial volume, for ash species across all counties (invaded and non-invaded) in the 14-state study area as computed for 2005 was 0.5 percent. Results from remeasured plots indicate that

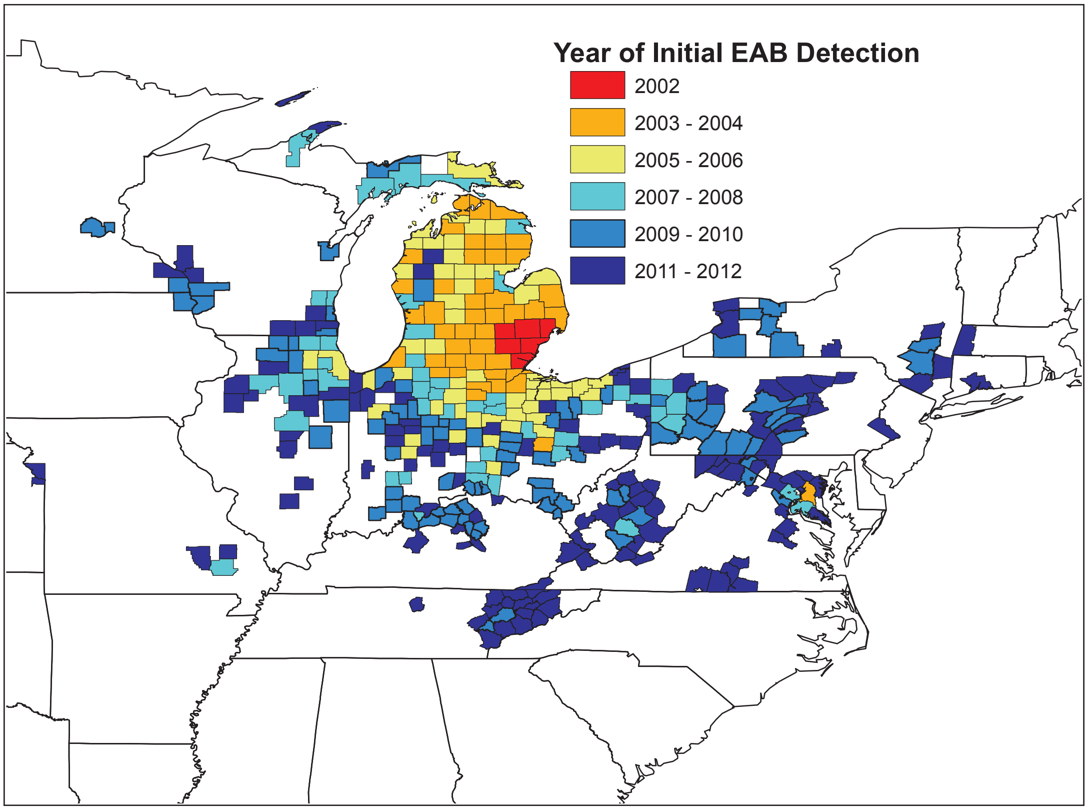

Figure 1—Year of initial EAB detection by county, 2013.

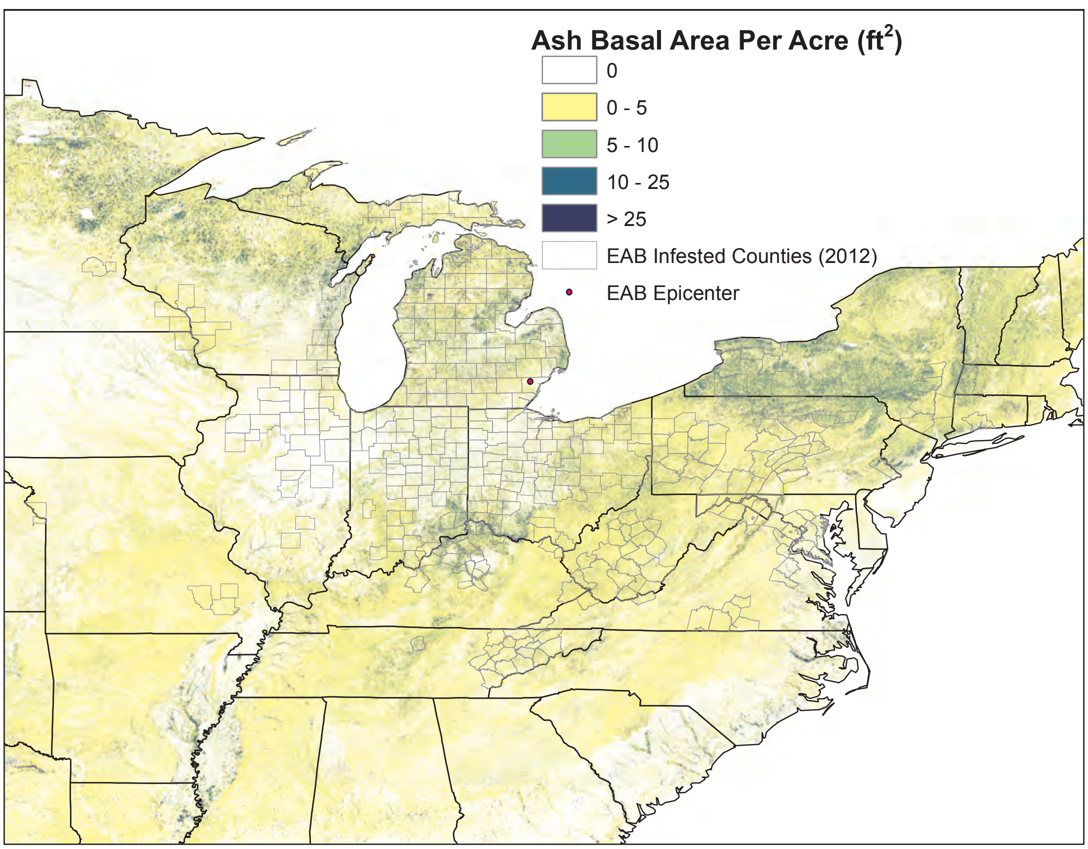

Figure 2—Spatial distribution of ash basal area per acre in the eastern United States, 2009.

annual ash mortality rates increase dramatically over the background level in the fourth to seventh inventory year after initial invasion of the pest into a county (Table 1). The exception is the 2002 invasion category where EAB has likely been present since the early to mid-1990s (Siegert et al. 2014).

This lag between initial invasion and mortality is also reflected in the change in ash volume over time. Volume generally continues to increase after EAB invasion for 3 to 4 inventory years before beginning to decrease (Table 1). Large decreases in volume of 5 percent or more appear to have a longer lag period of nearly a decade.

Some of the areas with the highest ash density have yet to be invaded by EAB. For example, northern Minnesota, northern Wisconsin, northern Pennsylvania, and southern New York (Fig. 2).

DISCUSSION

The impact of EAB on ash mortality has been demonstrated in localized (Ghandi et al. 2008) as well as regional studies (Pugh et al. 2011). As EAB continues to spread across the range of ash in the United States, FIA data can be used to quantify subsequent mortality across time and space. The annual mortality rate has been used in pest impact assessments with FIA data (Morin and Liebhold 2015) because it can be compared to background mortality levels to quantify the level of increase due to a particular disturbance agent. This metric is most useful for understanding the ecological impacts of pest invasion because it quantifies mortality as a function of the resource that was present prior to establishment. Our analyses indicate that the annual mortality rate doubles after approximately 4 to 7 years and then continues to rise. The rate is as high as 20 percent in the areas that have been invaded the longest (Fig. 1; Table 1).

Similarly, annual volume change is valuable for assessing resource loss over time. Although volume generally continues to increase for 3 to 4 inventory years after invasion by EAB, once volumes begin to decrease the losses can be dramatic because the amount of live volume available is further reduced over time. For example, the areas invaded by EAB since 2003-2004 were gaining ash volume at 3 to 4 percent annually before and immediately after invasion, but 5 to 6 years after invasion, volume began to decrease. By 2012, ash volume was decreasing

Table 1—Regional trends in annual mortality rate and annual volume change by inventory year and EAB invasion year for the county groups shown in Figure 1A.

	Inventory year							
EAB invasion year	2005	2006	2007	2008	2009	2010	2011	2012
	Annual mortality rate (%)							
2002	19.7	11.5	8.3	8.2	9.6	9.9	14.8	19.7
2003-2004	1.2	1.0	1.0	1.3	1.3	2.3	3.1	4.7
2005-2006	0.6	0.6	1.3	1.5	1.3	1.7	2.1	3.4
2007-2008	1.4	1.5	1.0	1.4	1.6	1.6	1.6	2.2
2009-2010	1.7	0.9	1.0	1.3	1.0	1.0	1.3	1.6
2011-2012	1.0	1.4	1.4	1.3	1.2	1.1	1.1	1.2
	Annual volume change (%)							
2002	-	-2.4	-13.2	-13.1	-22.7	-2.1	-41.9	-77.7
2003-2004	-	3.0	3.0	3.8	-2.6	0.0	-2.2	-7.5
2005-2006	-	4.9	1.6	1.9	-0.5	1.8	1.7	-4.3
2007-2008	-	4.8	1.5	3.0	-2.3	2.9	-0.4	2.7
2009-2010	-	3.7	1.3	2.1	0.7	1.6	2.7	-0.9
2011-2012	-	1.2	6.7	2.2	2.6	1.1	2.6	2.2

at nearly 8 percent per year. The lag period between initial invasion and the onset of ash volume decrease can be attributed in part to the nature of the scale of historical invasion data; a county is considered invaded once EAB is found reproducing in any location but it may take several years for the insect to invade the entire county.

Two factors that complicate the interpretation of the results of these analyses are the 5-year remeasurement period for plots and the annual comparison of full-cycle estimates. For example, the lag for all the metrics in this analysis is likely to be highly correlated with the 5-year cycle of remeasurements. Additionally, each estimate shares approximately 80 percent of observations with previous and subsequent estimates so a full set of new observations is only available after 5 years.

CONCLUSIONS

FIA remeasurement data can provide powerful information to quantify the impacts of an invasive pest by estimating mortality rates and volume trends across time and space. However, due to confounding factors addressed above, an analysis of estimates by measurement year may provide more information about the timing of impacts after invasion providing enough samples are available annually.

The increase in ash mortality and the corresponding decrease in ash volume typically begin 3 to 7 years after a county is designated as EAB invaded and continues for several more years until the live ash resource is reduced to very low levels in local areas. As EAB continues to spread, it has the potential to functionally extirpate a large fraction of the ash component with potentially devastating economic and ecological impacts. Further monitoring and analysis will be needed to quantify the timing and magnitude of EAB impacts as its range expands across the eastern United States.

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