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Monitoring Ash (*Fraxinus* spp.) Decline and Emerald Ash Borer (*Agrilus planipennis*) Symptoms in Infested Areas

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Abstract

Emerald ash borer (*A. planipennis*) (EAB) has had a devastating effect on ash (*Fraxinus*) species since its introduction to North America and has resulted in altered ecological processes across the area of infestation. Monitoring is an important tool for understanding and managing the impact of this threat, and the use of common methods by the many groups engaged in monitoring increases the value of monitoring data. We provide detailed methods for monitoring populations of ash trees, emerald ash borers, and lingering ash trees. These comprehensive methods can assist ecologists and managers in understanding the dynamics and effects of EAB infestations. Choice among these methods depends on the scientific and policy questions of interest and the stage of infestation being monitored.

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Cover Photo

Researcher Rachel Kappler measures an ash tree. Photo by Rachel Hefflinger, The Ohio State University

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INTRODUCTION

Before the invasion of emerald ash borer (EAB, *Agrilus planipennis* Fairmaire), ash trees (*Fraxinus* spp.) were widely distributed across temperate forests in the eastern United States, reaching their highest densities in the Great Lakes region (Flower et al. 2013a). In Ohio alone, there are estimates of ~3.8 billion ash trees representing a significant component of the forest composition (Herms et al. 2004). Within the past 10 years, the invasive beetle has devastated eastern deciduous forests, killing billions of ash trees, subsequently changing the species composition, structure, and associated functions of these ecosystems (Flower et al. 2013a). The insect's devastation of regional forests and urban plantings is costing up to an estimated $18 billion due to reductions in land value, removal of dead ash trees, and tree replacement (Kovacs et al. 2010, Sydnor et al. 2007). With such drastic and immediate impacts, monitoring ash decline and assessing the effects of EAB is vital when prescribing a course of action that will mitigate the ecological and economic effects. Monitoring data can give land managers baseline information that may assist them in timing management activities such as hazard tree removal, invasive plant removal, and re-planting of desirable tree species.

EAB is likely to have both short-term and long-term effects on ecosystem dynamics. To quantify and better understand the full impacts of EAB, data describing levels of EAB infestation and its effects on ash populations may be coupled with current data on forest ecosystems. A cascade of ecological effects may result from the successional and structural changes triggered by ash mortality (Gandhi and Herms 2010). Previous studies show that gaps potentially lead to a release of shade tolerant species and influx of invasive species, both of which may alter the successional trajectory of the forest (Gandhi and Herms 2010). U.S. Forest Service researchers have developed and deployed the methods presented here to answer questions directly related to EAB population dynamics, ash tree mortality, tree fall, and forest responses. Information collected from the monitoring approach presented here can confirm EAB presence and density, which can help inform landowners regarding the appropriate management approach. For instance, by measuring EAB densities and patterns of tree mortality, Knight et al. (2008) revealed that individual ash trees can decline from healthy to dead in as little as 2 years in forests with high EAB densities, threatening public safety because of the increased potential of tree falls. Furthermore, such a monitoring approach can reveal the magnitude of the potential ecological consequences, which remain largely uninvestigated.

Recent studies have shown the immediate impacts of EAB on ash mortality and have investigated how ash population dynamics are altered by this invasive pest (Flower et al. 2013a, Gandhi and Herms 2010, Klooster et al. 2013, Knight et al. 2013). A recent study in southeastern Michigan observed EAB-induced mortality of greater than 99 percent for ash trees and saplings over 2.5 cm d.b.h. (diameter at breast height, 1.37 m) (Herms et al. 2010). Despite this extreme mortality rate, the established seedlings persisted because EAB cannot infest seedlings and small saplings. The seed bank, however, declined because few parent trees survived, resulting in little ash regeneration in these areas (Klooster et al. 2013). Herms et al. (2010) found that EAB continued to remain at low levels in these areas, suggesting that the borer may infest the ash trees as soon as they reach a sufficient size.

To better understand the resistance of ash populations to EAB, lingering ash trees have been monitored, propagated, and tested (Knight et al. 2012, Koch et al. 2012). The term lingering ash describes a healthy ash tree of >10 cm d.b.h. existing in a site that is known to have been infested for several years and where >95 percent of trees have already died. Surveys conducted in 2010 and 2011 at Indian Springs Metro Park in southeastern Michigan and Oak Openings Preserve Metro Park in northwestern Ohio indicated similar patterns of decline and survival (Knight et al. 2012). Of the lingering ash trees that were healthy in 2010, 74 and 78 percent remained healthy in 2011 at Oak Openings and Indian Springs, respectively (Knight et al. 2012). Individuals that were in decline in 2010 continued to follow this degenerating trend in 2011. It is necessary to continually monitor the lingering ash while EAB populations remain at low levels surrounding these sites in order to determine trees that may exhibit rare resistance or tolerance to this pest (Knight et al. 2012). Understanding these dynamic interactions and trends will help managers observe the trajectory of EAB spread.

We recommend using the ecological monitoring methods presented here to assess EAB-induced ash tree decline and plant community responses, determine EAB population dynamics, and track lingering ash populations after EAB has killed >95 percent of the large ash trees. We report here methods developed and tested over a decade of long-term monitoring and research efforts that provide a framework that can be used throughout the entire region of EAB infestation. We seek to provide researchers and managers with a standardized methodology that can help them collect information they need to manage the numerous issues associated with introduced forest pests. Many users will want to choose a subset of our methods, selecting those measures most closely linked to the goals of their monitoring program and to the experience and skills of their monitoring teams. This report describes three procedures for assessing EAB infestation and effects on ash populations: ash monitoring plots, EAB traps, and lingering ash surveys.

ASH MONITORING PLOT METHODS

Ash monitoring plots can be used either in the short term, to get a snapshot of ash tree health, EAB symptoms, and species composition, or in the long term, to further understand the temporal effects of EAB on forests. The effects of EAB have previously been quantified using field or monitoring plots, by estimating ash canopy dieback, and counting D-shaped exit holes and woodpecker attacks on areas of infestation (Smith 2006). Flower et al. (2013a) successfully used these methods to quantify the impacts of EAB on non-ash tree growth and forest carbon uptake. Although recording EAB symptoms of *Fraxinus* spp. is the primary focus of the monitoring plots, this approach may be adapted to quantify the presence of invasive plants, plant cover, seedling density, overstory tree growth, and the resulting changes in canopy openness.

We recommend establishing a minimum of three plots in each forest stand (area of the forest with relatively homogeneous composition) and using large main plots to measure larger trees and nested smaller subplots and

Figure 1.

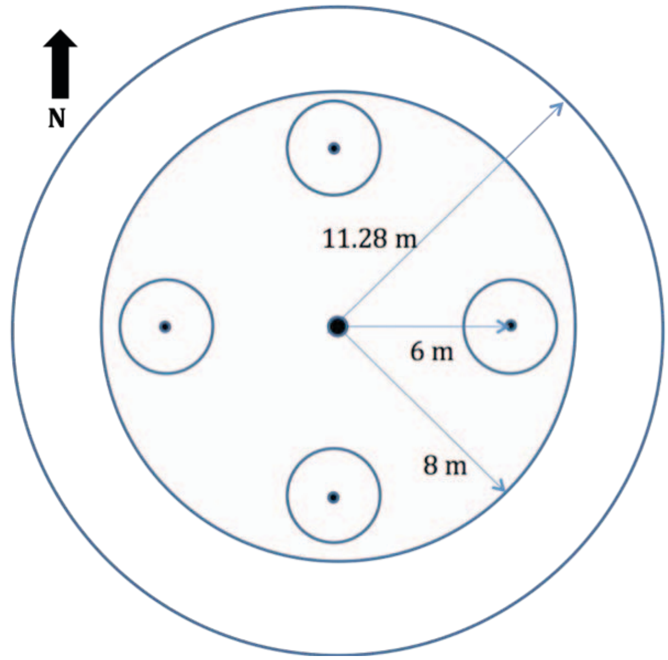

Figure 1.—A diagram of the EAB monitoring plot with a large main plot, nested subplot, and four microplots.

microplots to measure saplings and seedlings, respectively (Fig. 1). In our study design, each circular large main plot has an area of 400 m^2 (11.28-m radius) for monitoring ash trees ≥10 cm d.b.h. Observations of other tree species of the same size class may also be conducted within the main plot. Ash saplings taller than 1.37 m and <10 cm d.b.h. are measured within a nested subplot centered in the plot (8-m radius; 200 m^2); saplings and shrubs of other taxa may also be counted within the subplot. Surveying trees in a systematic order facilitates identification of individual trees between years without needing to tag each tree. For example, we begin in the north and move clockwise around the plot (as viewed from the center). Because the subplot is similar in size to the Forest Inventory and Analysis (FIA) subplot (U.S. Forest Service 2011a), FIA methods such as canopy cover by layer (U.S. Forest Service 2011b) may also be used in the subplot if desired. Depending on the goals of the study, data collected for each ash tree and sapling may include d.b.h., ash canopy condition rating, common symptoms, crown class, crown ratio, dead tree breakup, and dead tree fall. These measurements are described in detail below and an example data sheet is included in Appendix 1.

For the surveillance of ash seedlings less than 1.37 m tall, four microplots (each 1.13-m radius; 4 m^2) are placed 6 m from plot center in each cardinal direction. Studies that require the inclusion of herbaceous plants, shrubs, and seedlings of other taxa may follow the same microplot procedure for these counts.

Ash Canopy Condition Rating

Ash trees tend to thin and die back as they are attacked by EAB (Flower et al. 2013b, Smith 2006). Ash trees experience water and nutrient stress as EAB larvae feed and create galleries. These galleries correlate with visible loss of canopy, as assessed by a user-friendly ash canopy condition rating system (Flower et al. 2013b). The canopy condition rating scale (Table 1, Fig. 2, Smith 2006), is used to record the health of each ash tree and sapling as infestation progresses. Dieback is defined as dead twigs (without leaves). Only consideration of the sun-exposed branches is necessary, because shedding may naturally occur on shaded or suppressed branches. If possible, it is best for two people to view each tree from different angles and reach consensus on a canopy rating. These ash canopy condition rating classes correlate with more general measures of tree canopy health used by FIA (Royo et al. 2012); however, they are more specific to the decline progression of EAB-infested ash trees (Smith

1

2

Figure 2.—The ash canopy condition rating scale is used to categorize ash canopies in different stages of decline. The numbers on the right side of the page correspond to ratings listed in Table 1. (Figure 2 continued on page 3.)

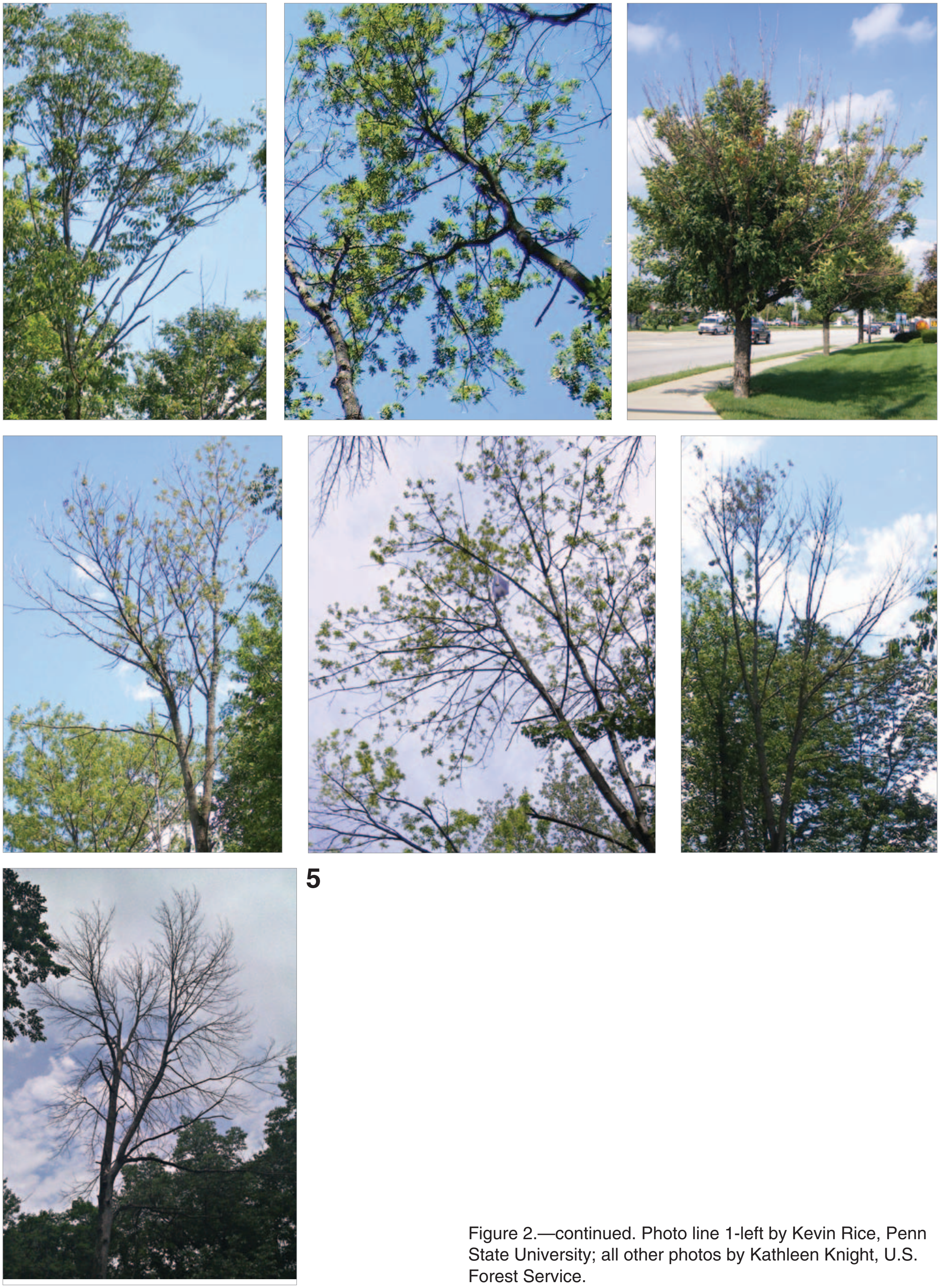

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Figure 2.—continued. Photo line 1-left by Kevin Rice, Penn State University; all other photos by Kathleen Knight, U.S. Forest Service.

Table 1.—Ash canopy condition rating scale used to quantify degree of decline and dieback of ash trees (*Fraxinus* spp.)

Rating	Description
1	Canopy is full and healthy
2	Canopy has started to lose leaves (thinning), but no dieback (dead top canopy twigs without leaves) is present
3	Canopy has less than 50% dieback
4	Canopy has more than 50% dieback
5	Canopy has no leaves, epicormic sprouts may be present on the trunk

2006). While not a symptom of EAB, the presence of seeds is often noted to facilitate future collection of seeds. For more information on ash seed collection, see Knight et al. (2010 a, b).

Common Symptoms

Common EAB symptoms are recorded for each ash tree and sapling to indicate the degree of stress and severity of infestation within an individual tree. EAB exit holes are D-shaped and show where adults have emerged (Fig. 3); these are the only external symptoms that are specific to EAB. However, they are often seen only late in the infestation process (Cappaert et al. 2005). If the bark is peeling off the tree, serpentine galleries beneath the bark are also specific to EAB (Fig. 4). Other symptoms assessed may be associated with EAB but are also found on stressed ash trees that are not necessarily infested. Other problems that can cause these symptoms include ash yellows, native beetle infestation, and ash decline syndrome (Michigan State University 2005, Sinclair and Lyon 2005). EAB is a food source for woodpeckers; prolific woodpecker feeding is often evident in EAB-infested trees (Smith 2006) (Fig. 5). Epicormic and basal shoots typically develop as a result of dieback in the bole (Figs. 6, 7). As larvae feed on the phloem, the tree produces lignified calluses (Knight, personal observation). This increased surface area causes splitting in the bark, which sometimes allows viewing of the EAB gallery inside the tree (Fig. 5).

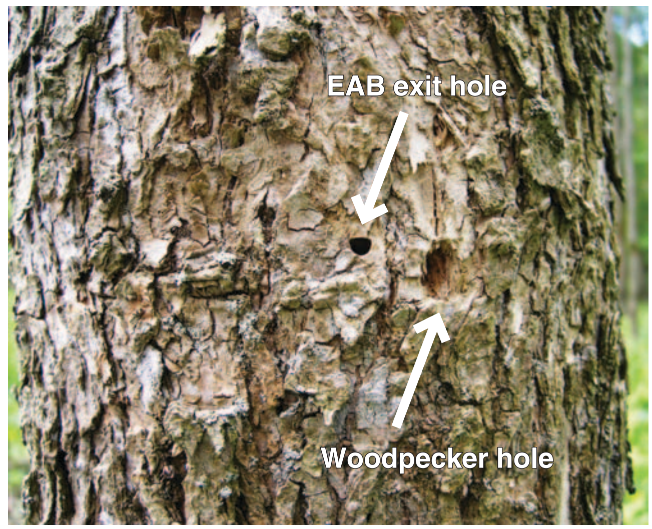

Figure 3.—EAB adult exit hole and woodpecker hole on an ash tree. Photo by Kathleen Knight, U.S. Forest Service.

Figure 4.—EAB larval feeding galleries with characteristic "S" shape. Photo by Kathleen Knight, U.S. Forest Service.

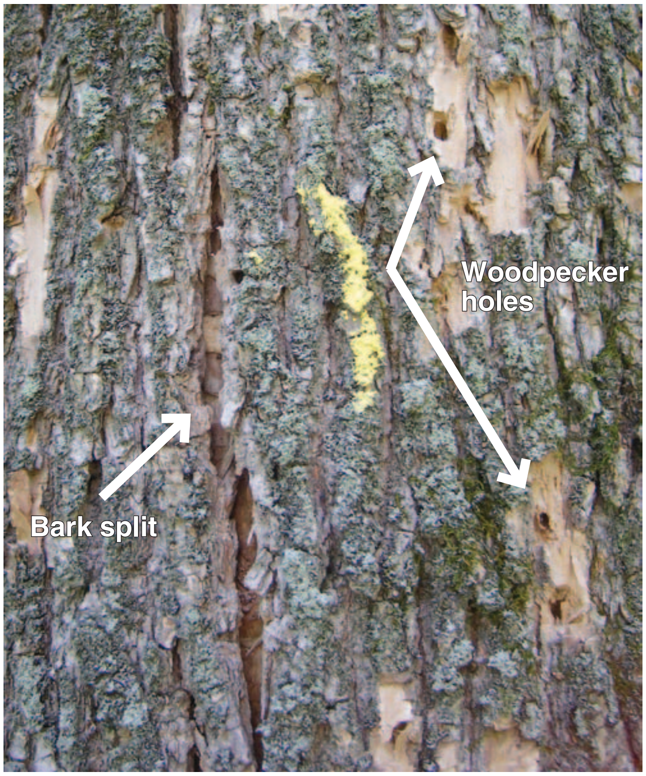

Figure 5.—Bark splitting with visible larval galleries, numerous woodpecker holes, and EAB exit hole on an ash tree trunk. Photo by Kathleen Knight, U.S. Forest Service.

Figure 7.—Basal sprouts on an EAB-infested ash tree. Photo by Kathleen Knight, U.S. Forest Service.

Figure 6.—Epicormic sprouts on an EAB-infested ash tree. Photo by Rachel Kappler, Bowling Green State University.

Crown Class

The qualitative classification system, known as "crown class," describes the relative illumination of a tree's canopy. Crown class is recorded as dominant, codominant, intermediate, or suppressed (Oliver and Larson 1996) (Table 2). Understanding the position of the ash trees in the canopy of a forest will assist in understanding the role of ash in the structure of the forest. Crown class affects ash mortality from EAB, with shaded trees (intermediate and suppressed) exhibiting more rapid mortality than trees with better light exposure (dominant and co-dominant) (Knight et al. 2013).

Crown Ratio

Crown ratio is the proportion of the height of the tree that has live foliage. In healthy trees, this correlates with the growth form of the tree, which may vary depending on the tree species, on whether the tree is open grown or surrounded by other trees, and on genetically determined traits. In stressed trees, it also relates to the amount of defoliation and dieback taking place due to stresses

Table 2.—Crown class categories (Oliver and Larson 1996)

Category	Description
Dominant	Above general canopy of stand; receives direct sunlight on top and all sides
Codominant	Average position in stand; receives direct sunlight on top and at least one side
Intermediate	Below general canopy; receives direct sunlight on top
Suppressed	Completely overtopped; receives no direct sunlight

Table 3.—Breakup categories used for dead ash trees

Rating	Description
A	All branches have fine twigs
B	>50% of branches have fine twigs
C	≤50% of branches have fine twigs
D	No fine twigs, tertiary branches present
E	Main stem and possibly primary or secondary branches present

Table 4.—Fallen tree categories used in ash monitoring plots

Code	Description
L	Ash leaning
U	Ash uprooted
SH	Ash snapped high, above d.b.h.
SL	Ash snapped low, below d.b.h.
F	Non-ash tree has fallen on it
AF	Ash tree has fallen on it

that may be related to EAB. It is a comparison of the length from the top of the live crown (not including top dieback) to the "obvious live base," with respect to the tree's total height (U.S. Forest Service 2011b), and recorded in categories of 10 percent.

Ash Breakup Rating and Fallen Category

After it dies, a tree continues to decay, impacting the forest's structure and potentially creating a safety hazard, depending on the tree's location. To understand how quickly the dead ash trees break apart and fall down, we developed a categorical rating system for canopy breakup (severity of breakup is rated A-E) (Table 3, Fig. 8). The fallen tree categories (Table 4) describe how the tree fell and how it interacts with surrounding tree species.

Tree and Sapling Data Checklist

- Tree species
- d.b.h.
- Ash canopy condition rating

For live ash trees, record:

- Crown class
- Crown ratio
- Note seed production

For dead ash trees, record:

- Breakup rating
- Tree fall

Between 1.25 and 1.75 m height on the trunk of each living or recently dead ash tree, record the number of:

- EAB holes
- Woodpecker holes

For each ash tree, record the presence/absence of:

- Woodpecker feeding holes anywhere on the tree
- Epicormic and basal shoots
- Bark splitting

Seedling Data Checklist

- Seedling species
- Percent cover
- Number of new seedlings with colyledons
- Number of established seedlings <1.37 m tall

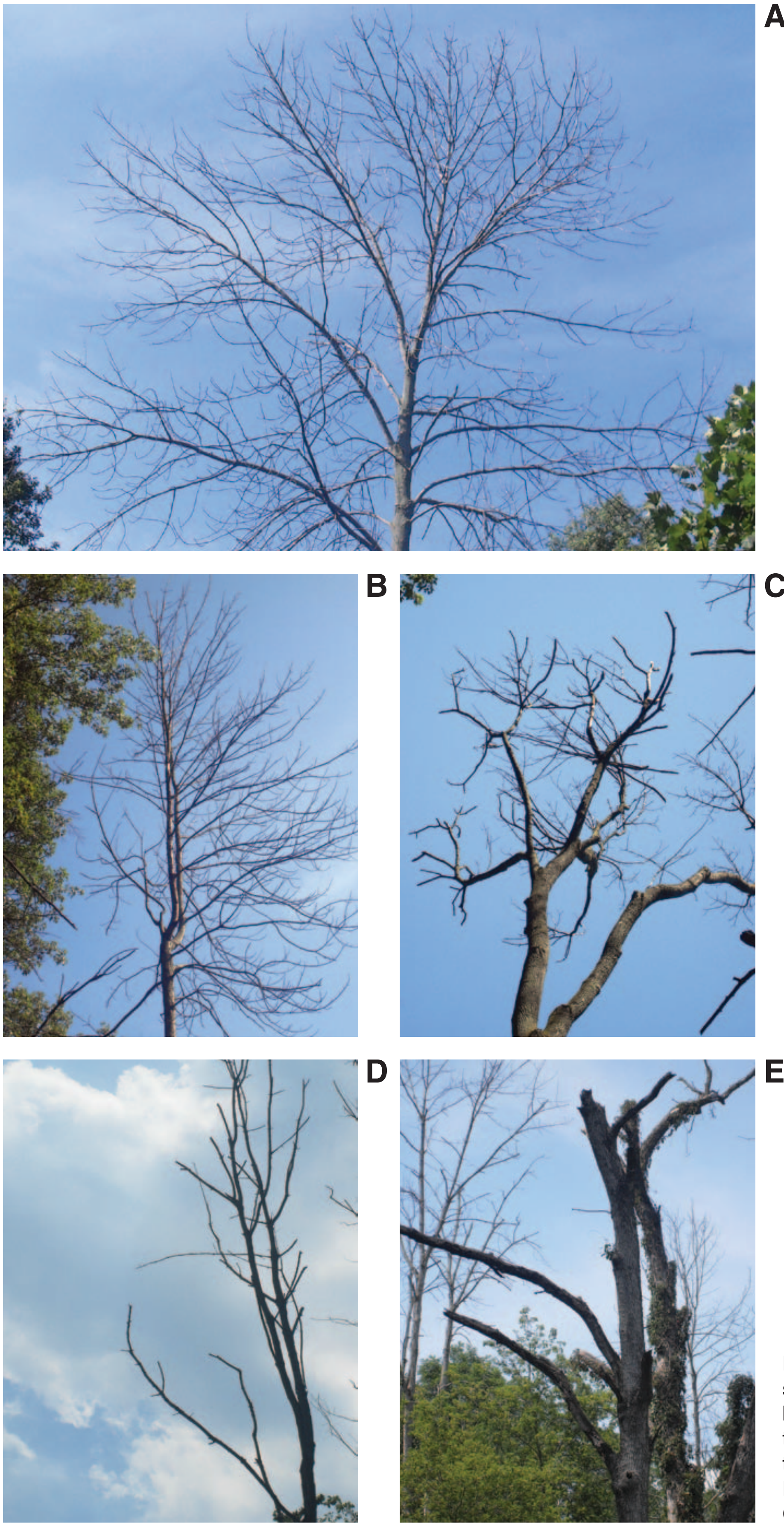

Figure 8.—The ash tree breakup rating scale is used to categorize the stages of branch loss of dead ash trees. The letters to the right of the photos correspond to the breakup categories in Table 3. Photos by Rachel Kappler, Bowling Green State University.

Figure 9.—New green ash seedlings, germinated in the current year, can be identified by their cotyledons. Photo by Kathleen Knight, U.S. Forest Service.

Seedling Data Collection

For collection of seedling data, a circular microplot with a radius of 1.13 m is placed 6 m from the plot center in each cardinal direction (Fig. 1). It is helpful to construct a frame to place in the microplot to visualize its radius and bounds. The number of new and established ash seedlings less than 1.37 m tall is recorded along with their percent cover. An example data sheet is included in Appendix 2. New seedlings are identified by their cotyledons (Fig. 9). We use the following percent cover classes: <1, 1, 2-5, 6-10, 11-20, 21-30, 31-40, etc. If relevant, microplots are used to record other plant species or as locations to measure canopy openness or other features of interest.

EAB TRAP METHODS

Visual signs of EAB presence can be difficult to detect in early stages of infestation. Currently, the best way to detect EAB before visual signs are apparent is to trap EAB adults using sticky purple prism traps containing a lure (Francese et al. 2008) (see Table 5 for vendors). These traps are made of corrugated plastic that is folded to make a triangular prism; each side is 36 by 60 cm. The sides are coated with TangleTrap®, a clear insect trapping glue that remains sticky throughout the summer. A spreader is used to hold the trap together and to attach a rope or hanger. The lure, usually a sponge sealed in a plastic pouch, is attached to the spreader. The lures contain concentrations of volatile compounds also found on ash bark and shown to be attractive to EAB (Crook et al. 2008). More recently, national survey programs have switched from traps painted the old shade of purple termed “standard purple” or “Coroplast purple” to a new shade of purple termed “TSU purple” or “Sabic purple,” which has been shown to increase attractiveness to EAB (Francese et al. 2010). Survey programs have also begun to use a (Z)-3-hexenol lure (Crook et al. 2012, Grant et al. 2011) in addition to the manuka oil lures to enhance attractiveness to EAB (USDA APHIS PPQ 2013).

Table 5.—Trap supply resources

Items	Supplier
Lures, traps, and hangers	Synergy Semiochemicals Corp., Box 50008 South Slope RPO, Burnaby, British Columbia, Canada. http://www.semiochemical.com/html/eab_trapping.html#top
Pre-glued purple prism traps	Great Lakes IPM, Inc., 10220 E Church Rd., Vestaburg, MI, USA; 800-235-0285; http://www.greatlakesipm.com
Metal spreaders and hangers	Midwest Wire Products Ltd., 649 S. Lansing Ave., Sturgeon Bay, WI, USA; 800-445-0225 , ext 124; http://www.wireforming.com
Sling shot, throw line, and throw bags	Sherrill Tree, 200 Seneca Rd., Greensboro, NC, USA; 800-525-8873; http://www.sherrilltree.com

Safety, cost, and efficacy should all be considered when determining which traps and lures to use in a research or monitoring study. For example, when the goal is to detect new infestations, it may be beneficial to use the most attractive traps and lures. When the goal is to monitor relative EAB density over time in areas known to be infested by EAB, cheaper and safer options that are less attractive may be acceptable. Manuka oil lures with "standard purple" traps have performed well for this purpose.

At least four traps should be hung at each forest location per year. The traps are hung in living ash trees ≥10 cm d.b.h., preferably along the forest edge or in an open area close to an ash woodlot (Francese et al. 2008). If no other trees are available, smaller ash trees or lingering ash may be used. The GPS coordinates, ash species, d.b.h., and canopy condition rating are recorded. There are many methods to hang traps, which are described along with trap assembly details in USDA APHIS PPQ (2008). To hang traps high in the canopy of ash trees, the preferable method is the rope method, using a forester's sling shot, a throw line, 3/16 inch braided nylon rope, and a 14-ounce throw bag. For more information about the use of these tools and associated safety protocols, see Knight et al. (2010 a, b). The weight is attached to the throw line and the sling shot is used to shoot the weight over an ash tree branch. The branch chosen should be at least halfway up the tree or ~13 m off the ground and tested to be sturdy (Francese et al. 2008). The nylon rope is attached to the throw line and pulled over the branch; each end of the nylon rope is then attached to the trap spreader. The trap is pulled up into the tree and the excess rope is tied around the tree trunk at chest height.

We recommend putting the traps up in May or June just before reaching 450 growing degree days (base 50° F) (USDA APHIS PPQ 2013). Studies have shown first emergence of EAB at 450-670 GDD (base 50° F) in April-June (Cappaert et al. 2005, Discua 2013). Adults feed on ash foliage, on average, for 5 to 7 days before mating; females feed an additional 5 to 7 days before oviposition. Multiple matings can occur; however, beetles survive for only 3 to 6 weeks after emergence (Bauer et al. 2004, Cappaert et al. 2005, Lyons et al. 2004). Manuka oil lures are effective for 60 days and then must be replaced. We recommend counting EAB on the traps during re-luring, because insects can fall off if the trap is later damaged. The traps are taken down in August to count the number of adult EAB. Example data sheets for traps are included in Appendix 3.

EAB Traps Data Checklist

- Trap tag number
- GPS coordinates
- Date trap was set
- Date lure was replaced
- Date trap was removed
- Ash species
- Ash tree d.b.h.
- Ash canopy condition rating
- Number of EAB at re-lure date
- Number of EAB at removal date

LINGERING ASH SURVEY

To investigate ash trees that may be resistant or tolerant to EAB infestation, any naturally occurring ash tree still alive after the initial die off should be surveyed. Example data sheets are included in Appendix 4. To avoid investigating trees that are simply the last to die, we suggest observing a threshold of 2 years after >95 percent mortality occurs. Lingering ash must be a sufficient size to ensure they were large enough for EAB to infest during the peak of the infestation. EAB infests ash trees as small as 2.5 cm d.b.h. However, ash species have the capacity for rapid growth and may rapidly attain a much larger size after the infestation passes through. For this reason, we recommend surveying trees ≥10 cm d.b.h. Tagging each tree as well as using a global positioning device will assist with future surveillance. The data collected for the lingering ash are very similar to that collected for ash in monitoring plots.

SAFETY

In addition to the typical hazards associated with outdoor research, studying EAB in forest ecosystems may involve researchers collecting data in forest stands with standing dead trees. Dead trees are a hazard, because they can fall or drop limbs without warning. It is important for researchers to wear hard hats, avoid going out on windy days, and be aware of their surroundings at all times.

Lingering Ash Tree Data Checklist

- GPS coordinates
- Tree species
- Tag number
- d.b.h.
- Ash canopy condition rating

For live ash trees, record:

- Crown class
- Crown ratio
- Note seed production

For dead ash trees, record:

- Breakup rating
- Tree fall

Between 1.25 and 1.75 m height on the trunk of each living or recently dead ash tree, record the number of:

- EAB holes
- Woodpecker holes

For each ash tree, record the presence/absence of:

- Woodpecker feeding holes anywhere on the tree
- Epicormic and basal shoots
- Bark splitting

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Appendix 1.—Example tree data (≥10 cm d.b.h. trees in 11.3 m radius plot, <10 cm d.b.h. ash trees in 8-m radius subplot)

Site	Plot	Tree number	Species	d.b.h. 2011 (cm)	Dead 2011	Ash condition 2011	d.b.h. 2012 (cm)	Ash condition 2012	EAB exit holes 2012	Woodpecker holes 2012 (present - number)	Epicormic sprouts 2012	Basal sprouts 2012	Bark splits 2012	Ash seeds 2012	Canopy class 2012	Crown ratio 2012(%)	Dead 2012	Dead tree breakup 2012	Fallen category 2012
OO2	3	1	*Ulmus americana*	13.8	N		13.8										Y		
OO2	3	2	*Acer saccharinum*	48.7	N		49.5								C		N		
OO2	3	3	*F. pennsylvanica*	20.4	N	4	20.4	5	8	Y - 0	N	N	Y				Y	B	
OO2	3	4	*F. pennsylvanica*	3.6	N	1	3.8	1	0	N - 0	N	N	N	N	S	50	N		
OO2	3	5	*F. pennsylvanica*	28.9	Y	5	28.9	5			N	N	N				Y		U
OO2	3	6	*Ulmus americana*	15.3	Y		15.3										Y		
OO2	3	7	*F. pennsylvanica*	20.2	N	3	20.9	3	6	Y - 12	Y	Y	Y	Y	C	40	N		
OO2	1	8	*Acer saccharinum*	32.3	N		33.4								C		N		
OO2	3	8	*F. pennsylvanica*	15.9	N	1	16.8	2	0	Y - 0	Y	N	N	N	I	40	N		
OO2	3	9	*F. pennsylvanica*	21.1	N	4	21.1	5	12	Y - 10	N	Y	Y				Y	A	
OO2	3	10	*F. pennsylvanica*	20.0	N	1	20.3	3	7	Y - 5	Y	Y	Y	N	C	20	N		
OO2	3	11	*Populus deltoides*	96.2	N		96.4								D		N		
OO2	3	12	*F. pennsylvanica*	16.0	N	2	16.7	2	8	Y - 10	Y	Y	Y	Y	S	60	N		
OO2	3	13	*Ulmus americana*	16.5	N		16.9								I		N		
OO2	3	14	*Ulmus americana*	13.0	N		13.6								S		N		
OO2	3	15	*Ulmus americana*	25.0	N		26								C		N		
OO2	3	16	*F. pennsylvanica*	31.9	N	2	31.9	4	15	Y - 50	Y	N	Y	N	C	10	N		
OO2	3	17	*F. pennsylvanica*	24.7	N	1	24.9	3	30	Y - 5	Y	N	Y	Y	C	20	N		
OO2	3	18	*F. pennsylvanica*	4.2	N	1	5	1	2	Y - 0	N	N	Y	N	S	40	N		

Appendix 2.—Example ash seedling data (seedlings <1.4 m tall in 4 m^2 microplots)

Site	Plot	Microplot	Species	% Cover	Number of new	Number of established
OO2	1	N	*F. pennsylvanica*	2-5	3	2
OO2	1	E	*F. pennsylvanica*	<1	2	0
OO2	1	E	*F. nigra*	1-2	0	2
OO2	1	S	*F. pennsylvanica*	<1	1	0
OO2	1	W	*F. pennsylvanica*	<1	1	0
OO2	2	N	*F. pennsylvanica*	11-20	2	4
OO2	2	E	*F. pennsylvanica*	11-20	2	3
OO2	2	S	*F. pennsylvanica*	6-10	0	3
OO2	2	S	*F. nigra*	2-5	2	2
OO2	2	W	*F. pennsylvanica*	6-10	2	2
OO2	3	N	*F. pennsylvanica*	11-20	3	2
OO2	3	E	*F. pennsylvanica*	11-20	0	4
OO2	3	S	*F. pennsylvanica*	6-10	0	4
OO2	3	W	*F. pennsylvanica*	6-10	0	3

Appendix 3.—Example EAB trap data

Site	Trap number	Latitude	Longitude	Date Set	Date Re-lured	Date Removed	Ash species	d.b.h. (cm)	Ash condition	Number EAB at re-lure	Number EAB end of summer
FT1	1	41.5541 N	83.6961W	5/3/2012	7/1/2012	8/28/2012	F. pennsylvanica	20.5	3	2	2
FT1	2	41.554	83.695	5/3/2012	7/1/2012	8/28/2012	F. pennsylvanica	16.8	4	4	5
FT1	3	41.555	83.694	5/3/2012	7/1/2012	8/28/2012	F. pennsylvanica	15.2	3	3	3
FT1	4	41.555	83.693	5/3/2012	7/1/2012	8/28/2012	F. pennsylvanica	21.3	3	5	7
OO	1	41.682	83.666	5/3/2012	7/2/2012	8/27/2012	F. americana	17	4	80	85
OO	2	41.682	83.667	5/3/2012	7/2/2012	8/27/2012	F. americana	13.1	4	106	110
OO	3	41.687	83.671	5/3/2012	7/2/2012	8/27/2012	F. americana	10.8	3	67	67
OO	4	41.689	83.672	5/3/2012	7/2/2012	8/27/2012	F. pennsylvanica	34.3	3	93	95

Appendix 4.—Example lingering ash data

Site	Latitude	Longitude	Species	Tag number	d.b.h. 2011	Dead 2011	Ash condition 2011	Ash condition 2012	EAB exit holes 2012	Woodpecker holes 2012 (present - number)	Epicormic sprouts 2012	Basal sprouts 2012	Bark splits 2012	Ash seeds 2012	Canopy class 2012	Crown Ratio 2012(%)	Dead 2012
OOFL	41.5708 N	83.8698 W	*F. pennsylvanica*	1	15.3	N	1	1	0	N - 0	N	N	N	N	I	50	N
OOFL	41.5908 N	83.8700 W	*F. pennsylvanica*	2	17.2	N	2	2	1	Y - 6	N	N	N	Y	I	60	N
OOFL	41.6108 N	83.8702 W	*F. pennsylvanica*	3	23.2	N	1	2	4	N - 0	Y	N	Y	N	C	40	N
OOFL	41.6308 N	83.8704 W	*F. pennsylvanica*	4	15.5	N	1	3	15	Y - 11	Y	Y	Y	N	I	30	N
OOFL	41.6508 N	83.8703 W	*F. pennsylvanica*	5	17.8	N	4	5	7	Y - 15	Y	Y	Y	N		0	N
OOFL	41.6708 N	83.8705 W	*F. pennsylvanica*	6	20.7	N	4	5	8	Y - 12	Y	Y	Y	N		0	N
OOFL	41.6908 N	83.8710 W	*F. pennsylvanica*	7	22.0	N	3	5	7	Y - 11	N	Y	Y	N		0	Y
OOFL	41.7108 N	83.8710 W	*F. pennsylvanica*	8	14.5	N	3	4	8	Y - 8	Y	Y	Y	N	S	10	N
OOFL	41.7308 N	83.8702 W	*F. pennsylvanica*	9	25.0	N	2	1	0	N - 0	Y	N	N	Y	C	70	N
OOFL	41.7508 N	83.8700 W	*F. pennsylvanica*	10	17.0	N	1	1	0	N - 0	N	N	N	Y	I	40	N
OOFL	41.7708 N	83.8698 W	*F. pennsylvanica*	11	16.6	N	3	4	7	Y - 9	Y	Y	Y	N	I	30	N
OOFL	41.7908 N	83.8701 W	*F. pennsylvanica*	12	19.2	N	2	2	5	Y - 1	N	N	N	N	C	70	N
OOFL	41.8108 N	83.8700 W	*F. pennsylvanica*	13	12.4	N	1	1	0	N - 0	N	N	Y	N	S	50	N
OOFL	41.8308 N	83.8706 W	*F. pennsylvanica*	14	11.6	N	2	2	0	N - 0	Y	N	Y	N	S	40	N

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Emerald ash borer (*A. planipennis*) (EAB) has had a devastating effect on ash (*Fraxinus*) species since its introduction to North America and has resulted in altered ecological processes across the area of infestation. Monitoring is an important tool for understanding and managing the impact of this threat, and the use of common methods by the many groups engaged in monitoring increases the value of monitoring data. We provide detailed methods for monitoring populations of ash trees, emerald ash borers, and lingering ash trees. These comprehensive methods can assist ecologists and managers in understanding the dynamics and effects of EAB infestations. Choice among these methods depends on the scientific and policy questions of interest and the stage of infestation being monitored.

KEY WORDS: ash mortality, invasive species, lingering ash, ash canopy rating, dead tree breakup, prism trap, genetic resistance

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