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Forester and Logger Response to Emerald Ash Borer in Massachusetts and Vermont: A Secondary Disturbance

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Abstract

Forester and logger responses to the invasive emerald ash borer (EAB) could substantially affect regions across the United States. We analyzed forester and logger responses to EAB in Massachusetts and Vermont, exploring characteristics associated with purposeful targeting of substantial ash properties; managing forests differently because of EAB; and regeneration goals. One-third of respondents increased timber sales on ash properties, motivated by ecological, not economic, impacts of EAB. Nearly 60% said EAB changed their management activity in stands with ash; changes influenced by the ecological impact of EAB and not economic factors. Those influenced by EAB's ecological impact to choose properties with substantial ash were more likely to have increased harvest area size, sawtimber removal, and harvest intensity. Loggers were more likely than foresters to remove small-diameter ash and low-grade trees. Both rated regenerating economically valuable species well adapted to the site as their highest essential priority.

Study Implications: There is a finite window to address emerald ash borer (EAB) to sustain ash and its cultural, ecological, and economic benefits. Given the time constraint and limited resources available to address EAB, finding strategic approaches to mitigate EAB impact is critical. This survey sought to understand forester and logger response to EAB; given their impact on the landscape, informing their management strategies is one critical approach to the conservation of ash. Understanding the ecological impact of current management approaches could help optimize silvicultural strategies. Silvicultural strategies mitigating EAB ecological impacts would likely be of greatest interest to foresters and loggers.

Keywords: insects, invasives, silviculture, forest management, family forest owner

The invasive emerald ash borer (EAB; *Agrilus planipennis*) is an introduced phloem-feeding insect from China that attacks and kills all species of North American ash (*Fraxinus* sp.). Since its discovery in Michigan in 2002 (Herms and McCullough 2014), EAB is the costliest invasive insect in the United States. (Aukema et al. 2011). Spreading across thirty-six US states and the District of Columbia (USDA Animal and Plant Health Inspection Service 2023) and five Canadian provinces (Natural Resources Canada 2023), EAB is generating extensive mortality and widespread harvesting of ash (Holt et al. 2022). Emerald ash borers typically kill North American ash species within 4 to 9 years of initial infestation (Knight, Brown, and Long 2013; McCullough and Mercader 2012) and therefore have the potential to cause regional or range-wide elimination of these culturally, ecologically, economically, and aesthetically important hardwood species (Herms and McCullough 2014).

Emerald ash borers' selective elimination of these species alters forest structure and composition (Abella et al. 2019; Lovett et al. 2016; Siegert, Engelken, and McCullough 2021); disrupts carbon, water, and nutrient cycles (Kolka et al. 2018; Van Grinsven et al. 2017; 2018); and likely undermines ecosystem services provisioning, including timber production, carbon storage, recreation, and habitat (Boyd et al. 2013; Peltzer et al. 2010). The *Fraxinus nigra* species specifically holds cultural significance to the indigenous people of North America, particularly as a source of basket-weaving materials (Costanza et al. 2017).

Emerald ash borer impacts go beyond the primary impacts of the insect itself; the human response to invasive forest insects is an important secondary disturbance that can influence the timing, intensity, and species removed in a timber harvest, as well as future conditions for regeneration, adding to the total disturbance caused by an invasive insect (See, for

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example Irland [1996]; Kizlinski et al. [2002]);Waring and O'Hara [2005]; Leverkus et al. [2018]; Markowski-Lindsay et al. [2020]; Holt et al. [2022]). There is scant scientific literature about the specific silvicultural response to invasive insects and, importantly, regeneration goals of these activities to better understand whether these practices will ensure the provision of crucial forest benefits. As such, anticipating the secondary impacts of invasive insects, such as EAB, requires an understanding of the potential response of landowners and the professionals they often contract to steward their lands.

Family forest owners (FFOs) are the predominant forest landowners in regions threatened by EAB in the United States. An estimated 23% of the FFO land is owned by people who have a formal forest management plan to guide decisions about timber harvesting (Butler et al. 2021), meaning many timber harvests on FFO lands are opportunistic. Even if a forest management plan is in place, timber harvesting is often triggered by other ecological, social, and financial factors (Kittredge 2004), including forest health issues.

When a landowner decides to harvest, two primary actors determine the specifications of timber harvests (e.g., intensity, timing, and spatial pattern, species, and quality of trees to be removed): foresters and loggers (Maker, Germain, and Anderson 2014). Foresters are professionals with a college-level education and experience in a broad range of forest-related topics (Catanzaro, Lukacic, and Kittredge 2021). Loggers are expert in safely felling trees and transporting logs to a roadside location (Catanzaro, Lukacic, and Kittredge 2021). Combined, the decisions foresters and loggers make about forest management influence thousands of acres a year in regions such as New England in the United States. These timber harvests represent the largest disturbance to forests affected by EAB (Thompson et al. 2017). Thus, to understand the total impact of EAB on forested landscapes, we must not only understand the primary ecological disturbance of EAB but also the secondary human disturbance resulting from the harvesting decisions of foresters and loggers to this invasive insect. To date, there have been no efforts in any country to quantify how foresters or loggers react to the presence of an invasive forest insect in the landscape, including EAB.

Our study focuses on two New England states, Massachusetts and Vermont, dominated by FFOs and containing northern hardwood forests with a large component of white ash species (*F. americana*). The EAB reached this region in 2012 and by 2018 had spread to 265 towns in New England. By 2022, just 10 years after its introduction, it spread to 656 towns (figure 1). There is an estimated 1.8 billion cubic feet of ash volume in New England (Oswalt et al. 2019), composed largely of white ash (*F. americana*) and green ash (*F. pennsylvanica*) (Butler et al. 2015). The region is among the most forested and populated parts of the United States. The spread and impact of EAB is projected to continue increasing, and there is much uncertainty about what the best management approaches are for forests affected by this pest. New England and the entire Northeast also host more invasive forest insects than any other region in the United States. (Liebhold et al. 2013). Thus, there is an urgent need to improve our understanding of the primary and secondary impacts of EAB and other disturbance vectors and develop appropriate management responses to help sustain the ability of US forests to provide timber and other ecosystem services.

Social science literature on foresters and loggers is scant, and studies related to operational responses to EAB nonexistent. Supplement 1 summarizes the literature we found on these professionals, but none of it is directly applicable to this important topic. There is a major gap in our understanding of how foresters and loggers working on behalf of landowners respond to forest insects, EAB in particular. The relative abundance and cultural and economic values associated with tree species threatened by invasive insects varies considerably; thus, there is a need for understanding forester and logger behaviors in response to these threats across diverse taxa and invasion contexts.

This study investigates the operational response of foresters and loggers in Massachusetts and Vermont to the presence of EAB. Our goal is to better anticipate the impacts of insect-related harvesting on current forest landscapes and to help shape response strategies to ensure future forests are capable of supporting the many benefits on which we rely. Specifically, this article describes whether foresters and loggers in the study area are (1) purposefully targeting properties with substantial ash for timber harvesting more than they would before the onset of EAB; (2) managing their forests differently because of EAB, and, if so, in which way(s); and (3) establishing regeneration goals as essential priorities in stands with ash.

Materials and Methods

Sample Selection

We investigated forester and logger responses to EAB in Massachusetts and Vermont where most of the region's diverse temperate forests include a component of ash (figure 1). This region also has a high percentage of privately owned forestland (Massachusetts: 63% of all forested acres; Vermont: 78% of all forested acres) (Butler et al. 2021), and partial forest harvesting is the dominant ecological disturbance (Thompson et al. 2017). As of 2022, much of Massachusetts' forests had been infested with EAB (216 of 351 towns), and Vermont had EAB detections in 35 of 256 towns (nearly every county) (figure 1). We sought to obtain a complete listing of all foresters and all loggers in both states. Our sample consisted of 965 recipients comprising 311 foresters and 654 loggers.

Survey Design and Administration

Differences between the forester and logger professions necessitated design of two survey instruments using a multi-step approach. We conducted one-on-one cognitive interviews with foresters and loggers from both states to identify key issues to be included in each survey. Once drafted, we convened an advisory committee to obtain stakeholder input on the surveys; members included state foresters and forest resource scientists from the states and the USDA Forest Service. We pretested the instruments with loggers and foresters in our survey region. Survey materials were approved by the University of Massachusetts-Amherst Institutional Review Board.

To understand whether foresters and loggers have an operational response to the presence of EAB in the area, we asked a series of questions to characterize and quantify their behavior (Table 1).

- Targeting ash: how their choice of properties with a substantial ash component for timber harvesting (i.e., ash comprising greater than 5% of the total volume of the stand) compares to what they did before EAB arrived in

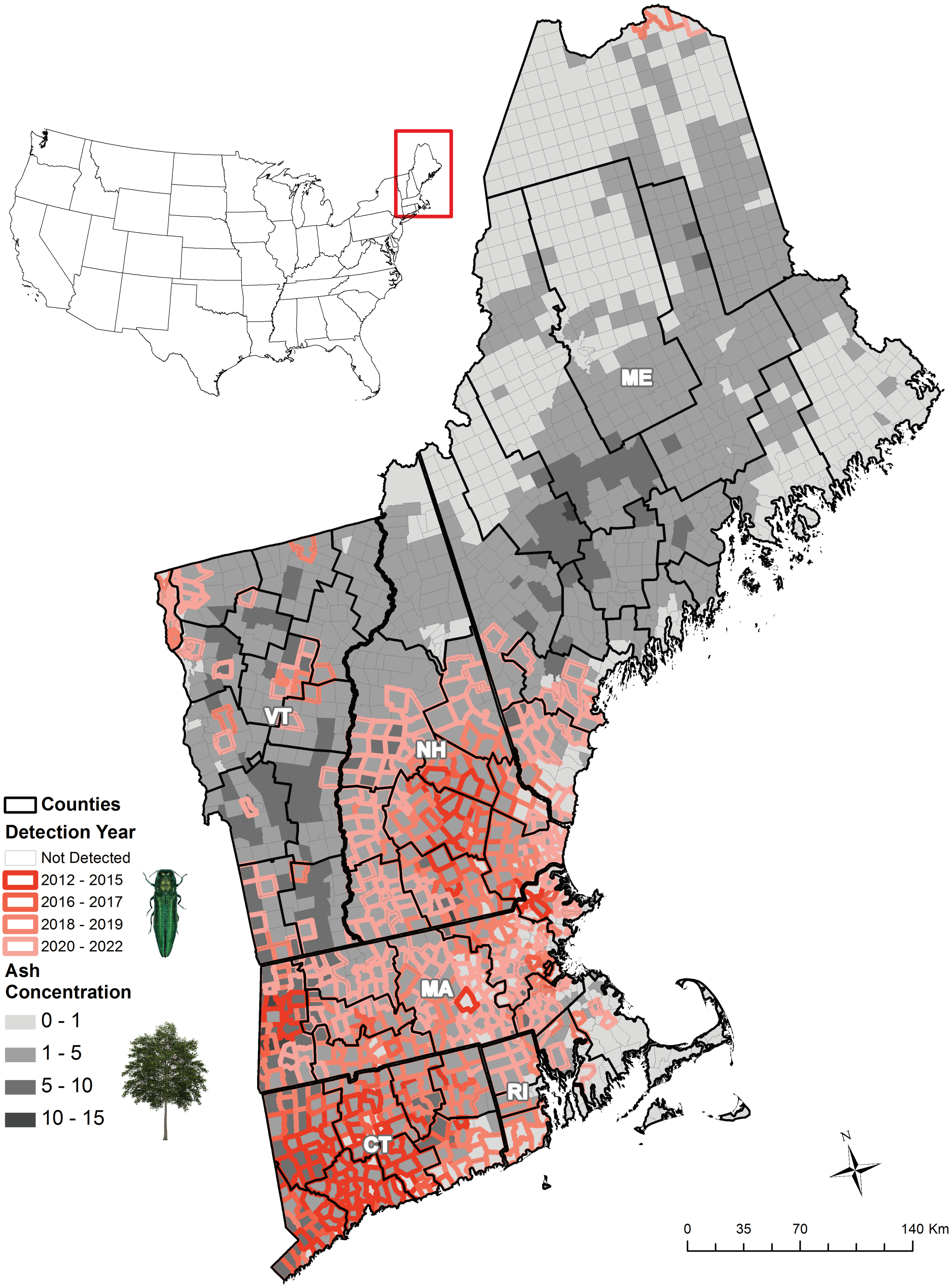

Figure 1 Map of New England ash abundance and emerald ash borer (EAB) detection year. Ash abundance is indicated as a percent of the total forest biomass, estimated from a regional imputation of Forest Inventory and Analysis plots (Duveneck, Thompson, and Wilson 2015). EAB arrived in New England in 2012 and, as of the creation of this map in March 2022, had been detected in 656 towns. Detection polygons denote the year of EAB detection in each town from data gathered from multiple agency sources.

Table 1. Dependent variable coding for models of EAB-related operations.

Model	Survey question	Survey response	Coding
Targeting ash	How does respondent's number of timber sales set up on properties with a substantial ash component compare with what they did before EAB arrived in their area?	More activity since EAB arrival	1
		Activity stayed about the same	0
		Fewer/Not applicable/Don't know	Excluded
Overall management impacts	How much has EAB's ecological impact on the forest changed their management activity in stands that include ash?	Great deal/quite a lot	1
		Some/very little/not at all	0
		Doesn't make decisions	Excluded
Specific management impacts	How has EAB caused them to change each of several specific management practices?	Greatly increased/ increased	1
		About the same	0
		Greatly decreased/ decreased/ Not applicable	Excluded
Essential regeneration goals	How are they prioritizing regeneration goals for properties with EAB or properties within towns with EAB?	Essential priority	1
		Not essential	0

their area. For foresters, their activity refers to the number of timber sales set up; for loggers, it refers to the number of timber harvests conducted.

- Overall management impacts: how much EAB's ecological impact on the forest changed their activity in stands that include ash. For foresters, their activity refers to the way they manage stands that include ash; for loggers, it refers to which trees were harvested in stands that include ash.
- Specific management impacts: how EAB changed specific management practices, including those related to ash diameter size harvested, low-grade trees (i.e., trees of poor quality not considered acceptable growing stock), size of area to be harvested, harvest intensity, gap size in regeneration harvests, time between set-up and harvest.
- Essential regeneration goals: whether regenerating economically valuable species well-adapted to the site and regenerating species diversity are essential regeneration priorities.

In addition to these factors, the survey collected information on respondent concern with and knowledge and awareness of EAB, experience working in areas with EAB, and other profession-related characteristics.

We implemented the survey online in 2021 using a modified tailored-design approach (Dillman, Smyth, and Christian 2014). Of the 311 foresters and 654 loggers in our sample (includes those who participated in the cognitive interviews and pretests), we obtained an overall 28% cooperation rate ($n = 273$) comprised of a 50% cooperation rate for foresters ($n = 157$) and 18% for loggers ($n = 116$).

We conducted nonresponse analysis of early versus late responders to assess response bias. Early responding foresters were more frequently in counties with higher ash concentrations than late-responding foresters (5% vs. 4% average concentration); there was no significant difference between early and late-responding loggers in the nonresponse analysis.

Supplement 2 provides additional detail on design methodology; Supplement 3 presents the final survey instruments.

Operational Response Models

We used binary logit models (Greene 2011) to explore the characteristics associated with each operational response: (1) purposeful targeting of substantial ash properties for timber harvesting versus before the onset of EAB; (2) managing their forests differently because of EAB (in general and for specific management options); and (3) regeneration goals. We estimated a binary logit model for each, deriving the dependent variable for each from Likert scale responses as described below and defined in Table 1. For each, we pooled the foresters and loggers together, indicating profession as one of the explanatory variables. To better understand who is having an impact on stands potentially affected by EAB in the project area, we focused our analysis on foresters and loggers who work with properties having substantial (>5%) ash volume (roughly 55% of all respondents, or $n = 149$). We estimated eleven models in total.

To better understand the characteristics of those purposefully targeting ash properties, we asked foresters and loggers how their current harvest activities compared with those before EAB arrived in the area. Respondents were given a Likert response of More, Same, Fewer, Not applicable and Don't know. Out of the 134 respondents for whom the question was applicable, only three reported doing Fewer sales and two responded Don't know. As a result, we constructed a binary logit model comparing those whose activity involved More sales on properties with substantial ash with those who are doing the Same as before; the other five Likert responses were excluded from the analysis.

Several models explored overall management behavior as well as specific management activities. The survey asked how much EAB's ecological impact changed their activity in stands that include ash. Respondents were given a Likert response of Great deal, Quite a lot, Some, Very little, and Not at all; loggers were also given an opt-out option: I don't make decisions about which trees to harvest. Respondents were grouped into two categories: those who had substantially changed their management activity (i.e., Great deal, Quite a lot) and those who had not substantially changed management (i.e., Some, Very little, Not at all); loggers who chose the opt-out response were excluded from the analysis (four respondents). Differences between the two groups were characterized using a binary logit.

Respondents indicated how EAB has caused them to change each of several specific management practices with a Likert scale: Greatly increased, Increased, About the same, Decreased, Greatly decreased, Not applicable. Respondents were grouped into two categories, analyzed using a binary logit: those that have increased (i.e., Greatly increased or Increased) the management practice and those that kept it at the same level (i.e., About the same). Few responded that they decreased practices (i.e., 1–16 respondents, depending on the practice). We analyzed seven different management practices: removal of ash at least 12 in. in diameter (i.e., sawtimber), removal of ash less than 12 in. in diameter, removal of low-grade trees, size of area to be harvested, intensity of harvests, gap size in regeneration harvests, time between set-up and actual harvest.

The survey presented regeneration goals, and we were interested in describing who has determined these regeneration priorities to be "essential." The survey provided a 5-point Likert scale response: Essential, High priority, Medium priority, Low priority, Not a priority. Focusing on understanding the "essential" priority category, respondents were grouped into two categories: those that consider the regeneration goal essential (i.e., Essential) and those that do not (i.e., all other response choices). Loggers who do not make decisions about which trees to harvest (four respondents) were excluded from the analysis. Differences between the two groups were characterized using a binary logit. Two regeneration goals are included in the models: regenerating economically valuable species well-adapted to the site and regenerating species diversity. With only one hundred respondents answering the regeneration questions and low percentages associated with the Essential category, goals associated with regenerating ash or species well-adapted to climate change are excluded from this parametric analysis.

Each model specification associates the operational response with numerous EAB-related items and professional characteristics, including respondent awareness of EAB, respondent opinion on how quickly ash dies after EAB detection, concern about EAB's ecological impact on the forest, experience working in areas with EAB, how often EAB's ecological impact influenced them to choose properties with substantial ash, how often the recent increased value of ash (based on cognitive interview results with foresters and loggers) influenced them to choose properties with substantial ash, profession tenure, acreage of total timber sales in a typical year, and ash concentration in county of respondent (Table 2).

We tested for multicollinearity among explanatory variables using variance inflation factor diagnostics (VIF). High multicollinearity is associated with VIF scores above 2.5 (Allison 1999), and the highest VIF score across all eleven models was 1.3. We used Stata17 for all data processing and analyses.

Results

Sample Statistics

Of the 273 respondents to the survey (157 foresters, 116 loggers), 149 stated that, in a typical year, they work on properties with a substantial volume of ash (>5% total volume), represented by 83 foresters and 66 loggers (figure 2). Of those foresters working with substantial ash volumes, 77% identified themselves as consulting foresters, 6% as public lands foresters, 4% as industrial foresters, 1% as a forester for a conservation organization, and 12% "other" (e.g., recently retired, utility forester). The operational response models and all the following results reflect these 149 respondents working with substantial ash volumes. Of these, 128 (74 foresters, 54 loggers) cumulatively reported that they set up (foresters) or conducted harvests (loggers) on 931 properties in a typical year. A total of 121 (70 foresters, 51 loggers) provided information to indicate that they cumulatively harvest 52,258 ac in a typical year. Similarly, 116 respondents (65 foresters, 51 loggers) provided information to indicate that, cumulatively, they harvest roughly 82.7 million board feet in a typical year.

For targeting properties with substantial ash, 38% of respondents had increased activity in stands with substantial ash over that before EAB arrived, whereas 62% of respondents did not change their activity level. Over half (57%) of respondents said that EAB's ecological impact on the forest changed their management activity in stands with ash. For specific management activities, the increase in activity was dependent on the management practice. The majority (85%) of respondents increased their removal of ash at least 12 in. in diameter and nearly 50% increased their intensity of harvests (See figure 3). Nearly 40% of respondents said that regenerating economically valuable species well adapted to the site was an essential priority and around 30% said that regenerating species diversity was an essential priority (figure 4). Table 3 and Supplement 4 presents detail by profession.

Most respondents (62%) said they knew a substantial amount about EAB. Just over half (59%) think that the impact of EAB on ash happens in less than 5 years. The vast majority (87%) are substantially concerned about EAB's ecological impact on the forest. Over 70% have experience working in a town or on a property with EAB in the last 5 years. Slightly over 40% of respondents indicated that EAB's ecological impact has frequently influenced them to choose

Table 2. Model explanatory variables, definitions and coding.

Variable	Definition
Knows EAB	Knows a great deal/quite a lot about EAB (1) vs. some/very little (0)
Immediate impact	After EAB detection, thinks ash dies in less than 5 years (1) vs more than 5 years/doesn't know (0)
Concerned	Extremely/moderately concerned about EAB's ecological impact on the forest (1) vs. some/slight/no concern (0)
Experience	Worked in a town or on a property with EAB in last 5 years (1), Otherwise (0)
Ecological impact influence	EAB's ecological impact always/often influenced them to choose properties with substantial ash (1) vs sometimes/rarely/never (0)
Economic impact influence	Increased value of ash always/often influenced them to choose properties with substantial ash (1) vs sometimes/rarely/never (0)
Profession	Forester (1) vs logger (0)
Tenure	Number of years in profession (continuous)
Ln total acreage	Acreage (ln) of total timber sales in a typical year (continuous)
Ash concentration	Ash concentration of respondent's county

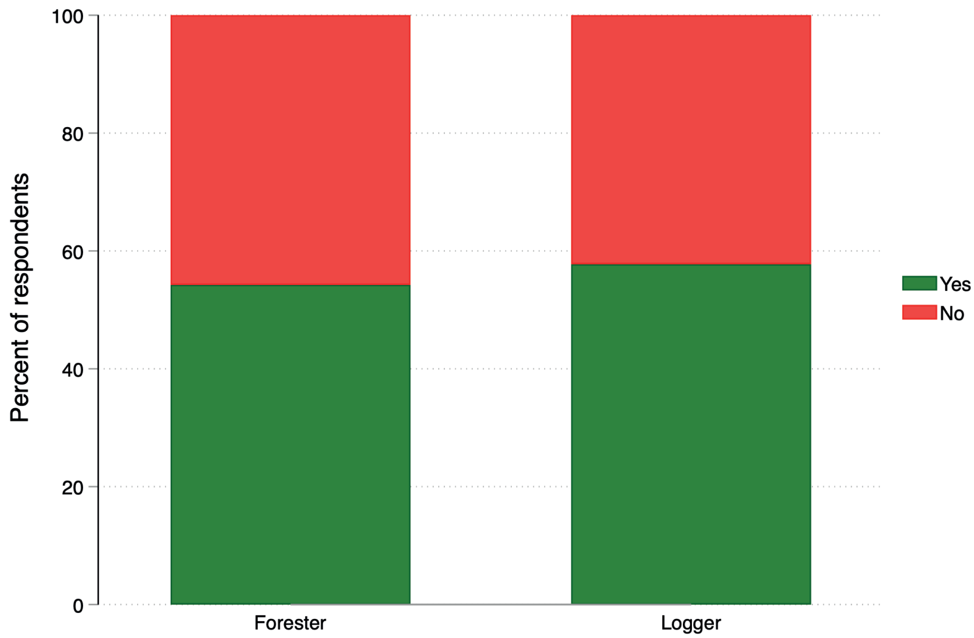

Figure 2 Percent of respondents engaged in harvesting activity on properties that include a substantial ash component (>5% of the volume) in a typical year, by profession (n = 153 foresters; 116 loggers)

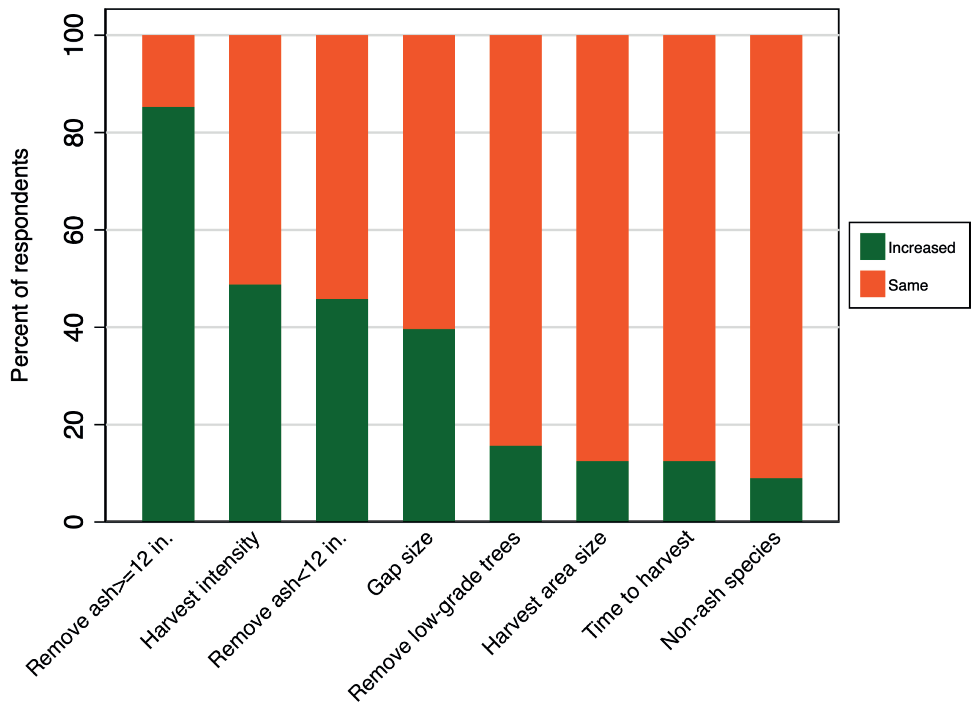

Figure 3 How emerald ash borer changed specific management practices for respondents who changed the way they manage stands because of the emerald ash borer

properties with substantial ash. Only 14% indicated that the recent increased value of ash influenced them to choose properties with a substantial ash component. The respondents were split roughly evenly between foresters (56%) and loggers (44%) who on average had been in their profession for 28 years, had an average of 432 acres of total timber sales in a typical year (Table 4 presents the average of the log of acres), and were in a county with approximately 5% ash concentration. (Table 4)

Operational Response Models

Below, we present results for each of the eleven models shown in Table 5; Supplement 5 presents additional detail.

Targeting Properties with Substantial Ash

The model describing characteristics of those who are purposefully targeting properties with substantial ash indicates two significant characteristics. Those who frequently (i.e., always or often) choose properties with substantial ash

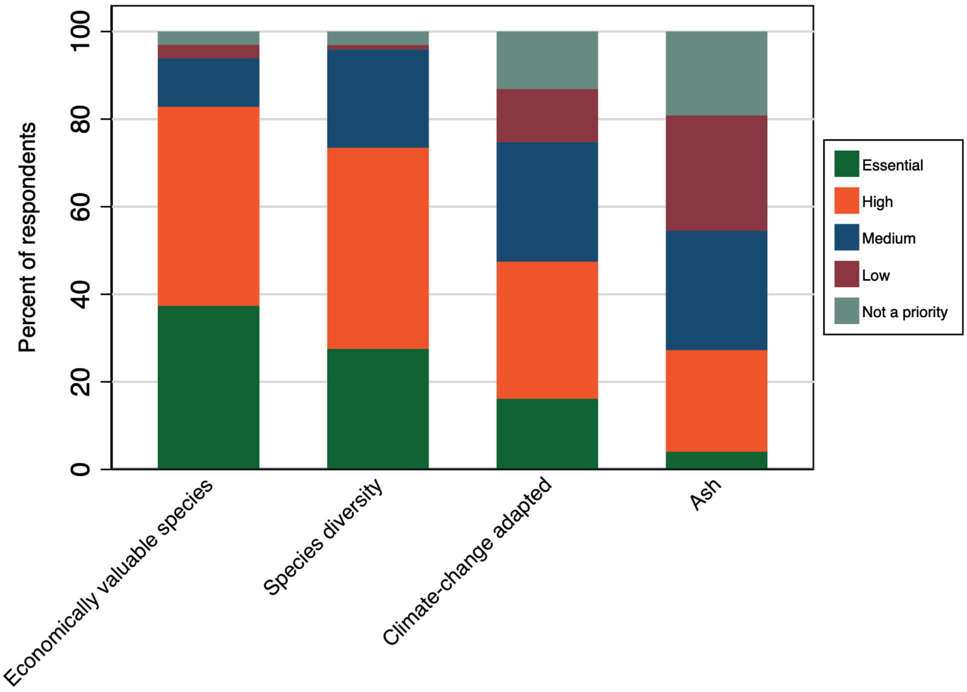

Figure 4 How respondents who work on a property or in a town with emerald ash borer prioritize specific regeneration goals

Table 3. Descriptive statistics of dependent variables for respondents who work in areas containing substantial ash concentrations.

Dependent variables	Combined	Foresters	Loggers
	Mean (standard deviation) *Sample size*		
Targeting more substantial ash properties (vs Same)	0.38 (0.49) *n = 129*	0.35 (0.48) *n = 75*	0.43 (0.50) *n = 54*
Great impact on overall management (vs Some-None)	0.57 (0.50) *n = 135*	0.54 (0.50) *n = 79*	0.61 (0.49) *n = 56*
Increase in removing ash ≥12 in. (vs Same)	0.85 (0.36) *n = 129*	0.83 (0.38) *n = 77*	0.88 (0.32) *n = 52*
Increase in removing ash < 12 in. (vs Same)	0.46 (0.50) *n = 107*	0.33 (0.48) *n = 60*	0.62 (0.49) *n = 47*
Increase in removal of low-grade trees (vs Same)	0.16 (0.37) *n = 121*	0.07 (0.26) *n = 72*	0.29 (0.46) *n = 49*
Increase in size of area to be harvested (vs Same)	0.13 (0.33) *n = 112*	0.13 (0.33) *n = 72*	0.13 (0.33) *n = 40*
Increase in harvest intensity (vs Same)	0.49 (0.50) *n = 125*	0.53 (0.50) *n = 78*	0.43 (0.50) *n = 47*
Increase in gap size (vs Same)	0.40 (0.49) *n = 116*	0.44 (0.50) *n = 75*	0.32 (0.47) *n = 41*
Increase in time between set-up and harvest (vs Same)	0.13 (0.33) *n = 112*	0.14 (0.35) *n = 71*	0.10 (0.30) *n = 41*
Essential to regenerate economically valuable species (vs Not)	0.37 (0.49) *n = 99*	0.31 (0.47) *n = 55*	0.45 (0.50) *n = 44*
Essential to regenerate species diversity (vs Not)	0.28 (0.45) *n = 98*	0.24 (0.43) *n = 54*	0.32 (0.47) *n = 44*

because of EAB's ecological impact on the forest are nine times more likely to have increased harvesting activity on substantial ash properties than those who maintain their status quo ($p < 0.0001$). Those with greater acreages of annual total timber sales are less likely to increase harvesting activity on substantial ash properties ($p < 0.10$); meaning greater acreage is associated with maintaining the status quo.

Changing Management

Overall management.

The model describing the likelihood that EAB's ecological impact has substantially (Great deal/Quite a lot) changed the way foresters and loggers manage stands that include ash includes two significant characteristics. Those who are Extremely (or Moderately) concerned about EAB's ecological

Table 4. Descriptive statistics of independent variables for respondents who work in areas containing substantial ash concentrations.

Independent variable	Units	Combined	Foresters[a]	Loggers[a]
			Mean (standard deviation) *Sample size*	
Knows EAB	1/0	0.62 (0.48) *n = 149*	0.67 (0.47) *n = 83*	0.55 (0.50) *n = 66*
Immediate impact	1/0	0.59 (0.49) *n = 148*	0.58 (0.50) *n = 83*	0.62 (0.49) *n = 65*
Concerned	1/0	0.87 (0.34) *n = 149*	0.89 (0.31) *n = 83*	0.83 (0.38) *n = 66*
Experience	1/0	0.72 (0.45) *n = 149*	0.71 (0.46) *n = 83*	0.73 (0.45) *n = 66*
Ecological impact influence	1/0	0.42 (0.50) *n = 138*	0.39 (0.49) *n = 80*	0.47 (0.51) *n = 58*
Economic impact influence	1/0	0.14 (0.35) *n = 138*	0.14 (0.35) *n = 79*	0.15 (0.36) *n = 59*
Profession	1/0	0.56 (0.50) *n = 149*	1 (0) *n = 83*	0 (0) *n = 66*
Tenure	Years	28.3 (13.1) *n = 126*	30.5 (13.8)* *n = 77*	25.0 (11.2)* *n = 49*
Total annual timber sale acreage	Ln(acres)	5.4 (1.3) *n = 121*	5.7 (1.2)** *n = 70*	4.9 (1.4)** *n = 51*
Ash concentration	Percent	0.05 (0.02) *n = 145*	0.6 (0.2) *n = 82*	0.5 (0.2) *n = 63*

[a] Tests of significant differences between foresters and loggers: * $p \le 0.05$, ** $p \le 0.01$. Pearson's χ^2 test was used for Knows EAB, Immediate Impact, Concerned, Experience, Ecological Impact Influence, and Economic Impact Influence, and a two-sample t-test was used for Total annual timber sale acreage, and Ash concentration.

impact on the forest are nine times more likely to have substantially changed the way they manage stands that include ash than those who are less concerned ($p < 0.01$). Those who frequently (i.e., Always or Often) choose properties with substantial ash because of EAB's impact on the forest are five times more likely to have substantially changed the way they manage stands that include ash than those who maintain their status quo ($p < 0.001$).

Specific management activities.

Seven models describe the likelihood that the respondent has increased specific management activities (vs. maintaining status quo activity levels) and show variability in characteristics across the seven activities:

1. Ash removal greater or equal to 12 in. diameter: Those who frequently (i.e., Always or Often) choose properties with substantial ash because of EAB's ecological impact on the forest are ten times more likely to have increased large ash removal than those who maintain their status quo ($p < 0.05$). Those who are Extremely (or Moderately) concerned about EAB's ecological impact on the forest are eight times more likely to have increased large ash removal than those who are less concerned ($p < 0.05$). Those who have worked in a town or on a property with EAB in the last 5 years were nearly four times more likely to have increased large ash removal than those who have not worked in a town or on a property with EAB ($p < 0.10$).
2. Ash removal less than 12 in. diameter: Loggers were nearly 5 times more likely (1/0.21) to have increased small ash removal than foresters ($p < 0.01$). Those who have worked in a town or on a property with EAB in the last 5 years were nearly four times more likely to have increased small ash removal than those who have not worked in a town or on a property with EAB ($p < 0.01$).
3. Removal of low-grade trees: Loggers were nearly four times more likely (1/0.26) to have increased low-grade tree removal than foresters ($p < 0.05$).
4. Size of area to be harvested: Those who frequently (i.e., Always or Often) choose properties with substantial ash because of EAB's ecological impact on the forest are sixteen times more likely to have increased the size of the area to be harvested than those who maintain their status quo ($p < 0.01$). The longer the tenure in their profession, the more likely to have increased the size of the area to be harvested due to EAB ($p < 0.10$); figure 5 shows the probability of harvest size increase over the range of professional tenure.
5. Intensity of harvests: Those who frequently (i.e., Always or Often) choose properties with substantial ash because of EAB's ecological impact on the forest are three times more likely to have increased the intensity of their harvests due to EAB than those who maintain their status quo ($p < 0.01$).
6. Gap size in regeneration harvests: Those who thought that ash mortality is more likely to happen in the short term (<5 years) after EAB detection were two times more likely to increase the gap size in regeneration harvests than those who thought mortality would happen in the longer (5 + years or didn't know) term ($p < 0.10$).
7. Time between harvest set-up and actual harvest: Those who thought that ash mortality is more likely to happen in the short term (<5 years) after EAB detection were

Table 5. Odds ratios for binary logit models of EAB-related operations.

Independent variable	(Obj.1) Targeting ash properties	(Obj.2a) Overall management	(Obj.2b) Specific management activities							(Obj.3) Essential regeneration priorities	
			≥12*in*. dia.	<12*in*. dia.	Low grade trees	Area size	Harvest intensity	Gap size	Time between	Economic value	Species diversity
Knows_EAB	1.22	1.48	0.40	1.49	0.99	0.53	0.94	0.53	4.77	2.79^	1.20
Immediate Impact	1.66	1.31	1.66	1.18	3.76	3.32	1.11	2.32^	8.13^	2.24	4.26*
Concerned	0.66	8.89**	8.25*	1.11	2.51	0.95	1.64	1.29	0.50	2.85	0.85
Experience	0.95	1.19	3.90^	3.90**	1.74	1.08	1.63	1.21	0.52	omitted[a]	omitted[a]
Ecological impact	8.58***	4.90***	9.97*	0.94	1.63	16.0**	2.91*	0.94	4.04	1.40	2.06
Economic impact	1.59	1.92	1.64	1.88	0.84	3.03	1.70	1.28	1.22	0.65	0.23
Profession	0.82	0.50	0.67	0.21**	0.26*	1.56	1.83	1.75	4.26	0.40^	0.88
Tenure	0.97	1.02	0.99	1.02	0.97	1.07^	0.97	0.97	1.03	1.00	1.01
Ln total acreage	0.70^	0.96	1.11	0.90	0.77	0.75	0.97	1.01	0.41*	1.23	0.91
Ash concentration	5.7e7	2.2e5	1.42	521.36	5.68	2.7e5	1092.4	0.22	0.15	1.7e5	0.16
Constant	1.26	0.05*	0.44	0.31	0.23	0.002*	0.33	0.72	0.19	0.02*	0.14
n	103	109	104	86	99	92	105	94	92	83	82
Percent n = 1 (yes)	40%	61%	88%	50%	14%	14%	52%	15%	12%	39%	27%

^ $p \leq 0.10$,
* $p \leq 0.05$,
** $p \leq 0.01$,
*** $p \leq 0.001$
[a] Variable omitted due to lack of variability across estimation sample.

eight times more likely to have increased the time between harvest set-up and actual harvest than those who thought mortality would happen in the longer (5 + years or didn't know) term ($p < 0.10$). The larger the acreage of total timber sales in a typical year, the less likely to have increased the time between harvest set-up and actual harvest ($p < 0.05$); figure 6 shows how the probability of increased time between harvest set-up and actual harvest changes over the acreage of total annual timber sales.

Essential Regeneration Priorities

The two models describing the likelihood of a regeneration activity being an essential priority showed variability in significant characteristics.

1. Regenerating economically valuable species well-adapted to the site: If the respondent stated that they have substantial knowledge (i.e., Great deal/Quite a lot) about EAB, they are nearly three times more likely to prioritize regenerating economically valuable species as

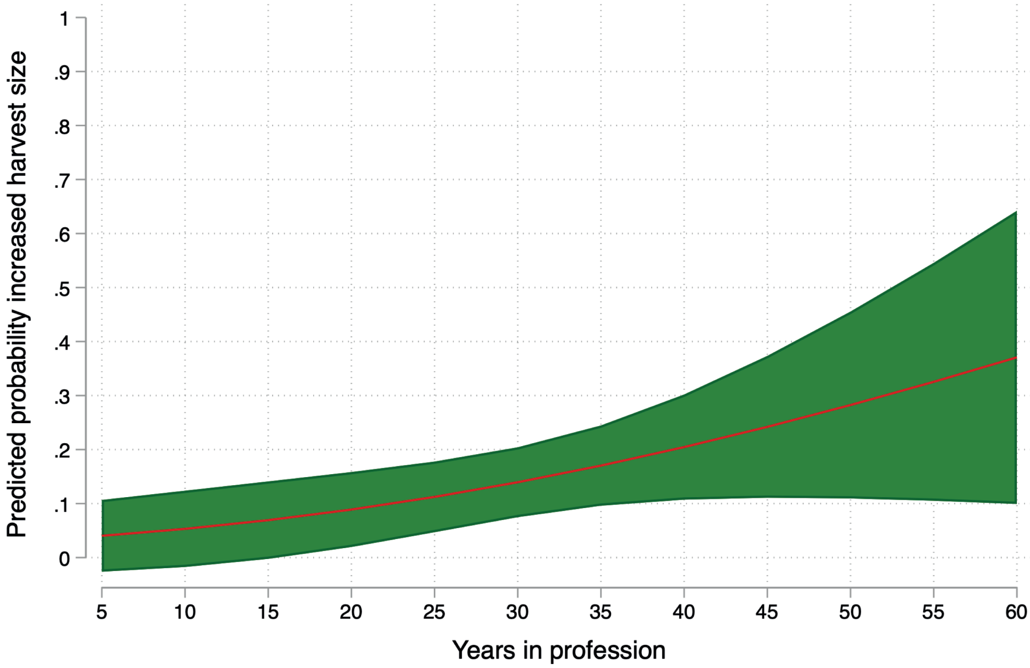

Figure 5 Probability of having increased harvest size due to emerald ash borer, by years in profession, with 95% confidence intervals

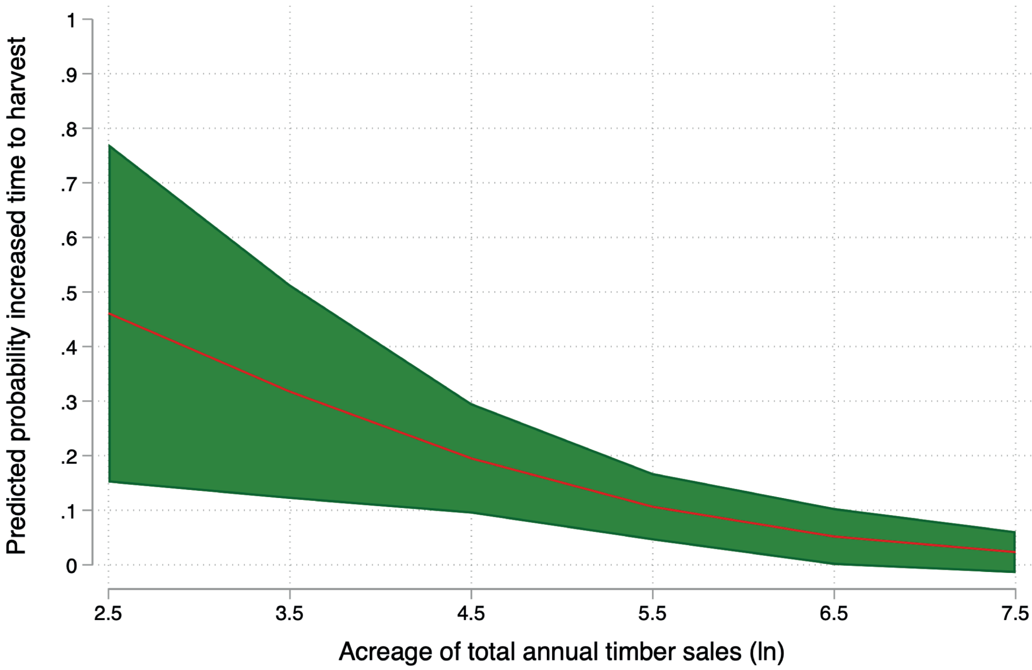

Figure 6 Probability of having increased time between set-up and actual harvest due to emerald ash borer, by acreage (ln) of total annual timber sales, with 95% confidence intervals.

essential than those who said they knew less about EAB ($p < 0.10$). Loggers were over two times (1/0.40) more likely to have regenerating economically valuable species as an essential priority than foresters ($p < 0.10$).

2. Regenerating species diversity: Those who thought that ash mortality is more likely to happen in the short term (<5 years) after EAB detection were four times more likely to prioritize species diversity as essential than those who thought mortality would happen in the longer (5 + years or didn't know) term ($p < 0.05$).

Discussion

Although forest landowners make the decision to have a timber harvest and, if so, the goals for the harvest, it is typically a forester or logger who makes decisions about tree selection, intensity, pattern, and the timing of the harvest. Relative to the number of forest landowners, foresters and loggers are a small number of actors, but they have a substantial impact on forests. Respondents to our survey report planning (foresters) or implementing (loggers) timber harvests on at least 52,200 ac per year in our project area (even more if adding in the nearly 20% of the sample who did not respond to that question). Although there could be some acres double counted (e.g., a forester and logger reporting on the same timber harvest), the amount of land affected by these actors is unquestionably large. As such, they should be a prime target audience for information about appropriate strategies to conserve ash and mitigate the impacts from its loss in a forest. Understanding the reaction of foresters and loggers to EAB is essential to understanding EAB's total impact on our forests.

Targeting Properties with Ash

Ash mortality following EAB infestation has been extensive in most cases, and the secondary disturbance of foresters and loggers increasing ash harvests as a preemptive intervention has the potential to greatly accelerate the loss of ash from the landscape and compound the ecological impacts of EAB. However, almost two-thirds of respondents (62%) report that they have not increased the number of timber sales they set up on properties with substantial ash compared with what they did before EAB arrived. This is a positive finding from this work and should help quell fears that there is a whole-sale effort to liquidate ash through timber harvesting across the landscape (MacLean et al. 2020).

Nonetheless, over one-third of respondents (38%) did report conducting more timber sales on properties with substantial ash than before EAB arrived. Those for whom the increased value of ash frequently influenced them to choose properties with substantial ash were no more likely to have increased timber sales on properties with substantial ash than those who were not influenced by the increased value of ash. Instead, increased timber sales on substantial ash properties were more likely with those respondents for whom EAB's ecological impact influenced them to choose properties with substantial ash. This significant finding about the ecological impacts of EAB suggests that foresters and loggers would be open to recommendations of silvicultural strategies to ensure the ecological well-being of the forest for future harvests. In fact, respondents rated information about silvicultural strategies to deal with EAB as the top priority for further information (70% of foresters and 43% of loggers) (Supplement 4 shows detail). As such, developing strategies to conserve ash where possible and to ensure timely and sufficient regeneration of well-adapted species if ash survival is not possible would benefit these influential actors.

Our survey found that the greater the total acreage of timber sales in a typical year, the more likely foresters and loggers in the study region are associated with maintaining the same number of harvests on properties with a substantial ash component as compared with before EAB arrived in the area. This finding may also imply that the secondary impact of humans may be less than it could be in this region because those foresters and loggers harvesting the largest amount of acreage do not appear to be increasing their harvesting of ash.

Previous research investigating forest landowner response to invasive forest insects (Markowski-Lindsay et al. 2020) suggests roughly two-thirds of responding FFOs in the area encompassing our study region would be motivated to have a timber harvest in response to a hypothetical invasive forest insect. Our study found landowners were sole initiators of EAB-influenced timber harvests only 7% of the time, whereas foresters or loggers were sole initiators 43% of the time and worked with landowners 36% of the time to initiate a harvest (Supplement 4 shows detail). Our results indicate that these foresters and loggers are involved with 217 properties that include a substantial ash component (or 23% of the total number of properties reported harvested in a typical year). The discrepancy between the landowner study and our results may indicate that FFO intent does not always translate to action (Holt et al. 2022) or that there are limits to the harvesting capacity of foresters and loggers in the region. Regardless, we found that foresters and loggers are targeting fewer properties for timber harvesting than FFOs report they would treat. The total secondary disturbance of EAB is likely a combination of FFO interest and forester and logger implementation of FFO goals, within their capacity.

Overall Forest Management Impacts

The decisions foresters and loggers make about the species, intensity, pattern, and timing of a timber harvest all influence the residual stand structure and composition of the post-harvest forest. Changes to forest management will therefore change forest structure and composition, potentially leading to different forest benefits (e.g., timber production, carbon storage rates, habitat). As with targeting ash (See Targeting Properties with Ash section), changed management practices in stands with ash were more likely for those respondents for whom EAB's ecological impact influenced them to choose properties with substantial ash. Over half (57%) of respondents said that EAB's ecological impact on the forest changed their management activity in stands with substantial ash. Although concern over the ecological impact is the main driver in the model, we would be naïve to assume that economic value is unimportant to all foresters and loggers. Although our regression model results indicate that changed overall management practices in stands including ash did not vary with whether a respondent was influenced by the increase economic value of ash or not, that does not indicate that economic value does not matter to respondents. Indeed, our sample statistics indicate that over half of the respondents report being influenced at some level to choose substantial ash properties because of the increased value of ash (3% Always, 12% Often, 37% Sometimes influenced by the increased value); this influence did not appear to have a relationship to overall management practices in our regression. We feel that this area needs further study. Addressing EAB does require a change in approaches within stands with a substantial ash component to ensure that the future goals are met (D'Amato et al. 2020). The change in management activity could have a positive or negative impact on ecological well-being, depending on the specific forest management practices being changed.

Changes to Specific Management Practices

When asked about specific management practices, we found that foresters and loggers who chose substantial ash properties because of EAB's ecological impact were sixteen times more likely to have increased the size of the area to be harvested, ten times more likely to have increased harvesting of trees ≥ 12 in. diameter at breast height (i.e., sawtimber ash) and three times more likely to have increased harvest intensity (*sensu* Holt et al. 2022) than those who were not influenced by EAB's ecological impact. These respondents may be harvesting larger areas to address all the ash on a property, with the assumption that the trees will not be alive at the next entry. Increasing harvesting intensity may derive from the desire to mitigate the ecological impact of EAB by regenerating desirable species less tolerant of shade, or it could simply be due to the increased removal of sawtimber ash. Increased removal of sawtimber ash may come from SLAM (SLow Ash Movement) recommendations designed to limit the spread of EAB in areas with active infestations (McCullough, Mercader, and Siegert 2015). These recommendations were interpreted by some to indicate sawtimber removal should be occurring in all areas with ash, regardless of EAB status. The fact that foresters and loggers in the study area are increasing their removal of sawtimber-sized trees (85% of respondents increased their removal of sawtimber ash) may provide a challenge for the preservation of ash, because these trees are sexually mature and able to produce seed source to regenerate future ash cohorts. To preserve ash as a component in our forests, strategies that maintain mature male and especially female individuals across the landscape are essential. Guidance reflecting the desire to conserve ash would include strategies to maintain at least some of these sawtimber individuals. Respondents who thought ash mortality was imminent (i.e., less than 5 years) were more likely to have a longer wait time between set up and harvest. Although only significant at the p-level < 0.10, this counterintuitive result requires further study.

One significant difference in EAB's influence on specific management practices between foresters and loggers is that loggers in the region report removing more low-grade trees. Removal of low-grade trees is a practice that increases the intensity of the harvests, increasing the likelihood of regenerating shade intolerant and midtolerant species. It also helps to improve the ratio of acceptable to unacceptable growing stock, increasing overall stand vigor and value, which maintains silvicultural options in the future.

Now that we know that some foresters and loggers are changing their specific management practices in stands with substantial ash in the study region, the question then becomes whether the practices they are applying (i.e., harvesting more area, with greater intensity, and larger diameter trees) are the appropriate strategies to conserve ash and regenerate forests that will meet both landowner and societal goals. Removing more sawtimber ash, increasing harvesting intensity, and (in the case of loggers) removing more low-grade trees suggests the opportunity to increase light conditions, which should favor shade midtolerant and intolerant species, including white ash (if seed source is present), if applied correctly. To support these on-the-ground efforts, it would be helpful to model the outcomes of various silvicultural strategies on stands of substantial ash to determine recommended practices tailored to the study region. Such an effort could help provide guidance to foresters and loggers in the area on the most effective strategies to preserve the ecological well-being of the forest.

Essential Regeneration Goals

It is imperative that our forests regenerate species well adapted to the site to ensure the continued provision of personal and public benefits, and foresters and loggers play an essential role in forest regeneration. When asked about their efforts to regenerate ash, a minority of respondents rated it as an essential (4%) or high priority (23%), suggesting that minimal effort is being directed to regenerating ash. Foresters and loggers rated regenerating economically valuable species well adapted to the site as their highest essential priority (37% of respondents), followed by regenerating species diversity (28%) and species well adapted to climate change (16%). Essential and high priority ratings described most goals for the respondents: 83% for economically valuable species (i.e., 95% of foresters, 68% of loggers), 73% for species diversity (i.e., 81% of foresters, 63% of loggers), and 47% for species well adapted to climate change (i.e., 55% of foresters, 39% of loggers). This finding reinforces the desire for addressing the ecological impact of EAB by moving the forest towards greater species diversity and resilience. Loggers more frequently rated regenerating economically valuable species well adapted to the site as essential versus foresters who more frequently rated it as a high priority. Developing silvicultural strategies to address these regeneration goals would help foresters and loggers achieve their goals and increase the likelihood of their adoption.

Conclusion

There is a finite window to address EAB to sustain ash and its cultural, ecological, and economic benefits. Given the time constraint and limited energy and resources available to address EAB, finding strategic approaches is critical. Helping inform the management strategies of foresters and loggers is one strategic and critical approach to the preservation of ash. Increased outreach regarding the appropriate application of known strategies to deal with EAB would benefit this community of practitioners, including opportunities for them to share their knowledge and experience with one another. In addition, the development of models to better understand the ecological impacts of their current management approach and the refinement of these practices to optimize these strategies would increase their ability to address this challenge. Silvicultural strategies that mitigate the ecological impact of EAB will likely be of greatest interest to foresters and loggers.

Although this survey sought to better understand forester and logger response to EAB, it is only one of several invasive pests and pathogens in the region. Forester and logger response to EAB may not relate to other current or future invasive insects. Further, we do not know whether the results of our study are applicable to foresters and loggers in other areas of the United States. Nonetheless, to conserve threatened tree species for their cultural and ecological benefits as well as for ensuring forest resiliency into the future, it is essential to include foresters and loggers in secondary impact analyses. It is likely that forester and logger response to other invasive insects or pathogens will be influenced by ecological and economic impacts specific to the targeted tree species. Future research should investigate forester and logger response to other invasive insects or pathogens, paying particular attention to methods to increase the response rate of loggers who are often in the field and focusing their limited time on business practices.

Supplementary Materials

Supplementary data are available at *Journal of Forestry* online.

Supplementary Material

Supplement 1. Additional literature review detail
Supplement 2. Additional methodological detail
Supplement 3. Forester and logger surveys
Supplement 4. Sample data distributions
Supplement 5. Coefficient and standard error results for binary logit models of EAB-related operations

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper in the Journal of Forestry.

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