Failure to Phytosanitize Ash Firewood Infested With Emerald Ash Borer in a Small Dry Kiln Using ISPM-15 Standards

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J. Econ. Entomol. 103(3): 597–602 (2010); DOI: 10.1603/EC09264

ABSTRACT Although current USDA–APHIS standards suggest that a core temperature of 71.1°C (160°F) for 75 min is needed to adequately sanitize emerald ash borer, *Agrilus planipennis* Fairmaire-infested firewood, it is unclear whether more moderate (and economical) treatment regimes will adequately eradicate emerald ash borer larvae and prepupae from ash firewood. We constructed a small dry kiln in an effort to emulate the type of technology a small- to medium-sized firewood producer might use to examine whether treatments with lower temperature and time regimes successfully eliminate emerald ash borer from both spilt and roundwood firewood. Using white ash (*Fraxinus americana* L.) firewood collected from a stand with a heavy infestation of emerald ash borer in Delaware, OH, we treated the firewood using the following temperature and time regime: 46°C (114.8°F) for 30 min, 46°C (114.8°F) for 60 min, 56°C (132.8°F) for 30 min, and 56°C (132.8°F) for 60 min. Temperatures were recorded for the outer 2.54-cm (1-in.) of firewood. After treatment, all firewood was placed under mesh netting and emerald ash borer were allowed to develop and emerge under natural conditions. No treatments seemed to be successful at eliminating emerald ash borer larvae and perpupae as all treatments (including two nontreated controls) experienced some emerald ash borer emergence. However, the 56°C (132.8°F) treatments did result in considerably less emerald ash borer emergence than the 46°C (114.8°F) treatments. Further investigation is needed to determine whether longer exposure to the higher temperature (56°C) will successfully sanitize emerald ash borer-infested firewood.

KEY WORDS emerald ash borer, phytosanitation, pest quarantines, regulatory compliance, firewood

The emerald ash borer, *Agrilus planipennis* Fairmaire, is an exotic, invasive species that has infested and killed millions of ash trees since its accidental importation from Asia in the early 1990s (Poland and McCullough 2006, Pureswaran and Poland 2009). All major eastern North American ash species (green ash, *Fraxinus pennsylvanica* Marsh.; white ash, *Fraxinus americana* L.; black ash, *Fraxinus nigra* Marsh; and blue ash, *Fraxinus quadrangulata* Michx.) are susceptible to emerald ash borer (Cappaert et al. 2005, Anulewicz et al. 2007), and the economic impacts of the emerald ash borer are alarming. In Michigan alone, Poland and McCullough (2006) estimate that the loss of ash resource based upon stumpage value would likely exceed US$1.7 billion. They also estimate that the undiscounted potential loss of all urban ash trees in the United States to be US$20–60 billion, not including the cost of disposal of this infested wood. An economic analysis of Sydnor et al. (2007) concluded that the cost of removing and replacing ash trees in Ohio municipalities could exceed US$4 billion.

Currently, the infestation is established across >25,890 km^2 (10,000 square miles) in southeastern Michigan, northwestern Ohio, northeastern Indiana, and western Ontario (Smitley et al. 2008). As of October 2009, localized infestations also have been detected in Kentucky, Illinois, Iowa, Maryland, Minnesota, Missouri, New York, Pennsylvania, Virginia, West Virginia, Wisconsin, and Quebec, Canada. Most of these outlier infestations are likely linked to the artificial spread of the emerald ash borer through the movement of infested nursery stock, logs, or firewood before implementation of state and federal quarantines (Stone et al. 2005). Although infested nursery stock, logs, or firewood can move freely within quarantine zones, these regulated items cannot cross quarantine boundaries without a compliance agreement

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issued by a regulatory agency. Currently, the Ohio Department of Agriculture regulations specify four treatments that meet compliance standards for movement of regulated ash material. These include 1) debarking of logs plus removal of 1.3 cm (0.5 in.) of sapwood, 2) chipping to less than 1 in. (2.54 cm), 3) fumigating, or 4) kiln drying. Of these four treatments, kiln drying may be the most cost effective method for sanitizing ash firewood. However, in most cases, firewood producers in Ohio are not using heat sanitization. Rather, because of the emerald ash borer quarantine, many firewood producers in Ohio are selling their wood locally and many customers from outside the state have stopped buying firewood from Ohio producers. Thus, there is interest in the feasibility of using inexpensive technology to sanitize emerald ash borer-infested ash firewood.

Little information is available on phytosanitation methods for firewood (e.g., Simpson et al. 1987) provide information on kiln drying times to lower the moisture content of oak firewood but do not address sterilization). As such, it is unclear what temperature and time regimes may successfully sanitize emerald ash borer-infested firewood. There are, however, well developed heat sanitation standards for wood packaging material (WPM) such as pallets. Many countries base their WPM regulations on the International Standards for Phytosanitary Measures Guidelines for Regulating Wood Packaging Material in International Trade (ISPM-15). ISPM-15 standards are one of several international phytosanitation standards adopted by the International Plant Protection Convention, an international treaty that is designed to help prevent the spread and introduction of pests of plants and plant products, and promote appropriate control measures. For phytosanitation of WPM, ISPM-15 standards require WPM to reach a core temperature of 56°C (132.8°F) for a minimum of 30 min. Although no known research has examined how the ISPM-15 standards relate to firewood, several studies have examined the effectiveness of different heat sanitation treatments for pallets (Bond 2002, 2005).

Recently, the draft of the New Pest Response Guidelines, Emerald Ash Borer, *Agrilus planipennis* (Fairmaire), version 1.1, was published by USDA–APHIS (2008), and outlines the regulations needed to be in compliance with current USDA quarantine regulations related to moving emerald ash borer-infested firewood. Based on these guidelines, all firewood, including emerald ash borer-infested ash firewood, must be treated so that the center of the wood is heated to at least 71.1°C (160°F) for at least 75 min to be moved outside the quarantine area (Treatment Schedule T314-a, USDA–APHIS 2008). These requirements are consistent with McCullough et al. (2007), who found in a laboratory study that no emerald ash borer prepupae survived in emerald ash borer-infested wood and bark chips exposed to an experimental heat treatment of 71.1°C (160°F) for 120 min, although a small number survived at 55°C (131°F) for 120 min, a temperature close to the current ISPM-15 standards for heat sanitation.

Although McCullough et al. (2007) found that some emerald ash borer prepupae may survive in ash chips exposed to temperatures similar to current ISPM-15 standards, they and others (e.g., Sela and Ormsby 2007) suggest that more research is needed on the thermotolerance of emerald ash borer, especially research outside of the laboratory that emulates field conditions. Consequently, the objective of this research was to determine directly whether current ISPM-15 standards, or some lesser temperature and time regime, are effective at sanitizing emerald ash borer-infested ash firewood. In addition, we wished to conduct these sanitation efforts in a "real-world" setting, using the type of facility available to small- to medium-scale firewood producers in Ohio to examine the costs that might be associated with implementing ISPM-15 phytosanitation methods. These data will provide a baseline with which to develop more comprehensive phytosanitation procedures for emerald ash borer-infested ash firewood.

Materials and Methods

Dry Kiln Construction. Using a prefabricated 3.7- by 4.3-m (12- by 14-feet) high-wall storage barn with 220 volt electrical service, we purchased and installed a L200 Small Dry Kiln System from Nyle Corporation (Brewer, ME). Although it required 40-amp, 220-V electrical service, we used this small dry kiln model as it allowed us to reach higher temperatures than other smaller dry kiln systems available. We insulated the dry kiln with 8.9 cm (3.5 in.) of DOW extruded polystyrene insulation, a foam insulation board with plastic film on both sides which is moisture resistant and offers a *R-value* of R-3. We then added a layer of foil-backed foam insulation 1.3 cm (0.5 in.) to increase our *R-value* and help reflect any heat back into the kiln. Finally, we covered all surfaces inside the dry kiln with 1.3 cm (0.5 in.) plywood to protect the insulation as firewood was loaded into the dry kiln for treatment. Our estimated total *R-value* of 23 was near the recommended levels provided by Nyle Corporation (*R-value* of 26–28). Once insulated, the dry kiln compressor and circulation fans were installed in the building, and a control unit was mounted on the outside of the dry kiln and housed within a weather-proof structure. The total cost of the dry kiln unit, building, and construction materials (e.g., insulation, plywood, dimensional lumber, screws, and adhesive) was $9,368.01, not including labor costs for construction, electrical service, or sales tax. Although not inexpensive, these costs were significantly less than those associated with other premanufactured and delivered dry kilns. In addition, it may be possible to construct a less expensive dry kiln by using fiberglass insulation covered by plastic to help protect the fiberglass insulation from moisture (Bowe et al. 2007). However, the *R-value* of such an insulated system may result in longer heat times and increased energy use to reach treatment temperatures.

Collection and Sanitation Treatments of Emerald Ash Borer-Infested Ash Firewood. Firewood was collected from six large white ash trees harvested located within a heavy emerald ash borer infestation in the city of Delaware, OH. Only white ash firewood was collected as this was the only ash species in the infested woodlot and we anticipated that the response to phytosanitation would not differ between white and green ash based upon similarities in physical properties (Forest Products Laboratory 1987). Trees were harvested over two different days in December 2007 and January 2008. As the firewood was collected during the dormant season, most emerald ash borer were either late-stage larvae or prepupae, which are thought to be the most resilient life stages of emerald ash borer (McCullough et al. 2007). All firewood was cut following standard practices, resulting in pieces 45–60 cm (18–24 in.) in length. Pieces <13 cm (5 in.) in diameter (large end) were not split, whereas larger pieces were split into triangular pieces. Firewood was stacked adjacent to the dry kiln and left uncovered to replicate what we consider to be normal storage conditions.

For each treatment, we used three H14–002 HOBO External Input Temperature/RH Data Loggers to measure wood temperature, each with a LCD External Temp Probe that has a temperature range from 40° to 100°C (−40° to 212°F) and an accuracy of ±0.7°C at 20°C (±1.3°F at 68°F). These data loggers are within the specified tolerances suggested by the Heat Treatment Schedule T314-a (USDA–APHIS 2008). The data loggers were located outside the dry kiln allowing us to monitor the firewood temperature without disturbing the sanitation treatment. A hole roughly equivalent to the diameter of the temperature probe was drilled to a depth of ≈1 in into three pieces of firewood (a split, triangular piece, a large roundwood piece, and small roundwood piece). The temperature probes were then inserted into each hole allowing us to accurately monitor the temperature of the outer 2.54 cm (1 in.) of each type of firewood. Finally, as the interior of each stack would take longer to heat than those pieces on the outside of the stack (as discussed in greater detail below, treatments were stacked on pallets in the kiln), we placed the monitored pieces (small roundwood, large roundwood, and split) in the middle of each stack. In this way, our estimates of the effectiveness reflect the time it takes for different firewood types in the interior of the stack to reach the treatment temperatures; those pieces on the outside of the stack likely reached higher temperatures for longer periods.

We first conducted a pilot test to better understand the heating dynamics of the dry kiln using 100 pieces of white ash firewood; that is, to determine the lag time from kiln start-up to the outer 2.54 cm (1-in.) of the firewood reaching the ISPM-15 treatment temperature of 56°C (132.8°F). We placed the emerald ash borer-infested firewood into the dry kiln with a set point of 65.5°C (150°F), near the maximum temperature setting for the kiln. The rapid initial increase in temperature caused us to reduce the kiln temperature overnight on the first day (to ensure that the target temperature was not reached and treatment time exceeded while no one was present). The pilot test demonstrated, however, that the rate of temperature increase slowed considerably over time. In addition, without using the circulation fans, the dry kiln reached a temperature of near 54°C (129°F) and held steady for several hours. Once the circulation fans were used, the temperature of the firewood reached 56°C (132.8°F) relatively quickly. This pilot test remained at the treatment temperature of 56°C (132.8°F) for 82 min rather than the 60 min associated with the longest planned treatment, due in part to the speed of temperature increase once the fans were turned on and the time required for the firewood to cool down below the treatment temperature. Collectively, these factors caused the outer 2.54-cm (1-in.) of the emerald ash borer-infested firewood to remain at a temperature near the ISPM-15 standard for over 16 h, with total time in the kiln equaling nearly 74 h (Fig. 1a).

Once the pilot test was complete, we began the planned sanitation treatments. Each treatment consisted of ≈100 pieces, including 70% split firewood and 30% round (or unsplit) firewood, including both small- (approximately <10 cm [<4 in.] in diameter) and medium-sized (approximately >10 cm [>4 in.] in diameter) pieces stacked approximately seven rows high on pallets (similar to the pilot test). We conducted four treatments, varying either temperature or time. We randomly selected wood from each collection period to serve as controls to ensure that the firewood was infested with emerald ash borer. This firewood (100 pieces from the first collection and 64 pieces from the second collection) was set aside and stacked inside the large storage building adjacent to the dry kiln. Each treatment was sanitized using the appropriate temperature and time treatment combination, including 46°C (114.8°F) for 30 min, 46°C (114.8°F) for 60 min, 56°C (132.8°F) for 30 min, and 56°C (132.8°F) for 60 min. Figure 1b shows the temperature and time relationship for the last treatment (56°C [132.8°F] for 60 min). Each treatment had an initial temperature of ≈2°C (36°F). After each treatment, firewood was stacked in the large storage building in the same area as the control treatments. All sanitation treatments were completed by mid-March 2008.

Once all the treatments were complete, we placed the firewood for each individual treatment under a mesh net fitted on a PVC frame in late April 2008 before emerald ash borer emergence, allowing any emerald ash borer that survived to emerge under natural conditions. In addition, we marked existing "D-shaped" exit holes originating from previous emerald ash borer emergence. In this way, we were able to determine from which piece of firewood emerald ash borer emerged for each treatment and count newly formed emergence holes from any adults surviving the heat treatments.

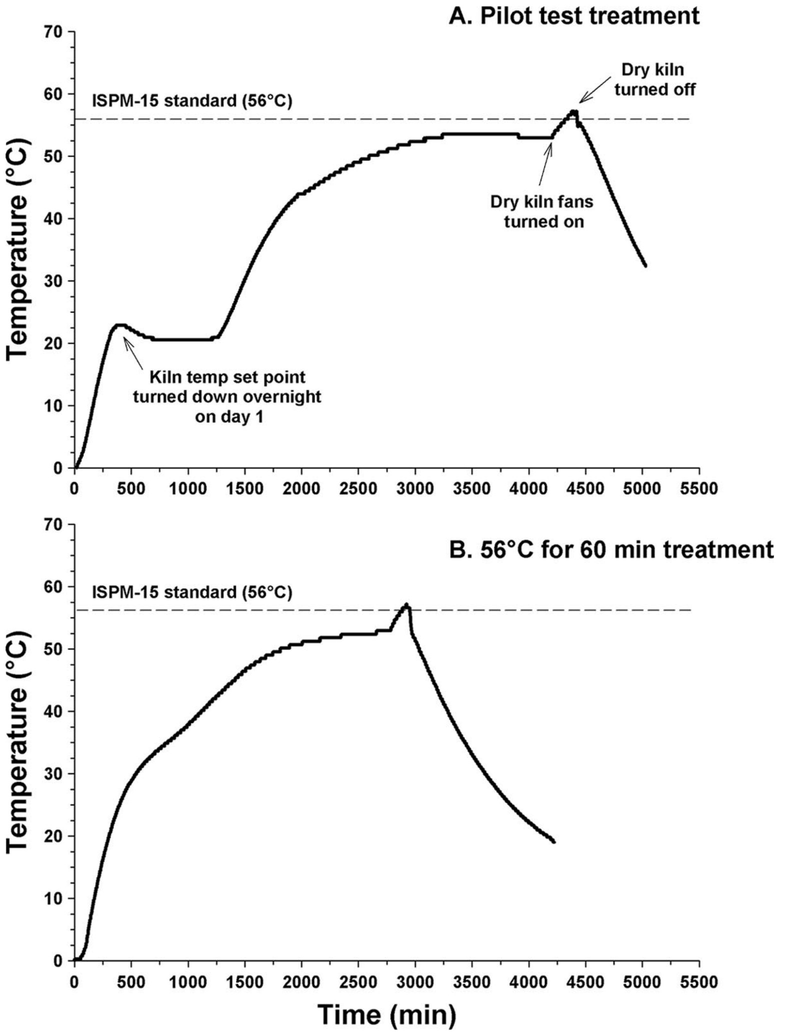

Fig. 1. Relationship of temperature and time for the pilot test treatment (A) and the 56°C for 60-min treatment (B). The graphs represent the firewood piece in each treatment that was slowest to reach 56°C, which was the large round piece and split piece, respectively.

Results and Discussion

Effectiveness of Phytosanitation Treatments. Overall, total heating time in the dry kiln (from when firewood was loaded and dry kiln was turned on to when treatment time was achieved at the target temperature) ranged from 22.0 to 25.6 h for the 46°C (114.8°F) treatments and 42.9–49.2 h for the 56°C (132.8°F) treatments (Table 1). Some emerald ash borer adults emerged from firewood subjected to all treatment regimes, although considerably fewer emerald ash borer emerged from both the 56°C (132.8°F) treatments (Table 1). We also observed several dead emerald ash borer prepupae after the treatments. However, the fact that some adult emerald ash borer did successfully emerge suggests that they were not 100% effective as sanitation treatments, which is consistent with findings of McCullough et al. (2007) relative to survival of emerald ash borer prepupae in bark and wood chips subjected to heat treatments in the laboratory.

After the period of emerald ash borer emergence had passed (late-September) we examined each piece of firewood for new emergence holes. In total, we observed a total of 978 "D-shaped" exit holes, and 938 adult emerald ash borer. Both controls and 46°C (114.8°F) treatments had very high emergence rates, with very few pieces showing no signs of emerald ash borer emergence (Table 1). The 56°C (132.8°F) treatments seemed more effective, with fewer emerald ash borer adults, although all treatments showed some sign of emerald ash borer emergence holes by this measure. The discrepancy between number of observed emerald ash borer adults and number of emergence holes suggests that some "D-shaped" exit holes may have been missed during the initial inspection period. Others probably were missed after posttreat-

Table 1. Description of treatments, emerald ash borer larvae and prepupae survival, and energy used to sanitize emerald ash borer-infested firewood using a small dry kiln

Treatment temp (°C)	Treatment time (min)	Actual time ≥ treatment temp (min)	Total time in kiln (h)	No. pieces	No. exit holes	No. adult EAB observed	kWh used
None (control 1)				100	322	354	0
None (control 2)				64	181	156	0
46	30	36	22.0	96	283	301	103
46	60	70	25.6	101	119	121	120
56	30	38	42.9	101	17	3	194
56	60	66	49.2	100	42	3	213
56[a]		82	73.6	99	14	0	290

[a] This pilot test treatment was not part of the research design thus no treatment time is indicated. Temperatures remained steady for over 16 h near 54°C before reaching 56°C after kiln fans were turned on. EAB, emerald ash borer.

ment adult emergence. Many of the firewood pieces had deeply furrowed bark, characteristic of large ash trees, which made some exit holes difficult to detect. Regardless, no treatment seemed unconditionally successful at completely sanitizing emerald ash borer-infested firewood; however, we suggest these results provide a starting point with which to refine sanitation efforts. One such treatment that may hold promise is extended heating at or near temperatures similar to the ISPM-15 standards. Based upon our pilot study designed to better understand the heating and drying characteristics of the dry kiln, we did not observe any adult emerald ash borer from firewood subjected to 56°C (132.8°F) for 82 min and at a total heating time of 74 h (Table 1). Within this 74-h period, the wood was exposed to near 56°C temperatures for over 16 h (Fig. 1a). However, more research is needed to determine whether this extended exposure to ISPM-15 or near ISPM-15 standards is successful at eliminating emerald ash borer from ash firewood.

Economic Costs. Before each treatment, we noted the electricity meter reading and assessed the total energy used to treat the firewood included in each treatment (Table 1). Energy costs for our treatments ranged from a low of $6.18 for our 46°C (114.8°F) for 30 min treatment to $12.78 for our 56°C (132.8°F) for 60 min treatment (assuming an average cost of $0.06 per kWh of electricity). These energy costs are lower than would typically be incurred as we only treated 100 pieces of wood. However, assuming that a full cord of firewood (3.6 m^3 [128 $feet^3$]) includes 300 pieces of firewood (based on the mixture of split and roundwood firewood cut between 45 and 61 cm [18 and 24 in.]) and that the drying time for a full cord of ash firewood is linear in a similar fashion as oak firewood at lower moisture content levels (Simpson et al. 1987), we estimate that the energy costs per cord using these treatments will range from US$18.54 to $38.34 depending on a variety of factors, such as length of treatment time, time of year, moisture content of the firewood, and dry kiln design, and insulation. However, total kiln time and energy use may be decreased by using the fans sooner to raise the temperature of the firewood. Additional costs would be associated with labor needs to load and unload the dry kiln.

Unfortunately, these costs were associated with treatments that were not effective at sanitizing emerald ash borer-infested firewood. However, the pilot treatment (dry kiln operation of 74 h) showed some promise for phytosanitation and the electricity costs associated with this treatment were US$17.40, suggesting that the estimated energy costs to treat one cord of firewood would be near US$52.20, depending again on a variety of factors such as time of year, moisture content of the firewood, dry kiln design and insulation, and fan use.

In conclusion, our results demonstrate that time and temperature standards associated with ISPM-15 (56°C for 30 min) for heat sanitation of WPM are not effective at sanitizing emerald ash borer-infested white ash firewood. Despite the failure of ISPM-15 standards (applied to the outer 2.54 cm [1 in.] of the firewood) to totally eradicate emerald ash borer, the treatment did result in considerable mortality of emerald ash borer. Our study also suggests that a small dry kiln may be suitable technology to heat sanitize emerald ash borer under the right temperature and time regimes. For example, our pilot experimental run (outer 2.54 cm [1 in.] of firewood heated to 56°C [132.8°F] for 82 min and a total heating time of 74 h) seemed to successfully kill all emerald ash borer larvae and prepupae, as evidenced by a lack of adult emergence. During this 74-h period, the wood was exposed to near 56°C temperatures for several hours. It may be that the additional time associated with this treatment was adequate to sanitize emerald ash borer-infested firewood; however, additional research and replication is needed to confirm the results from this pilot study, and whether a combination of lower temperature but longer exposure time relative to the current Treatment Schedule T314-a (USDA–APHIS 2008) may be effective. Finally, if exposure to a regime of lower temperature for longer time is found to effectively sanitize emerald ash borer-infested ash firewood, a detailed economic analysis should be conducted to help firewood producers determine whether there is a financial benefit to heat sanitizing emerald ash borer-infested firewood.

Acknowledgments

We thank the USDA Forest Service Northern Research Station for logistical support and Stephen Rist, Marie Semko-Duncan, Matthew Solensky, Bryant Chambers, and Chuck

Vrotney for technical support. Financial support for this project was provided by a grant from the Division of Forestry, Ohio Department of Natural Resources and the USDA Forest Service, Northeastern Area State and Private Forestry, Wood Education and Research Center (grant 97C244), and by state and federal funds appropriated to the Ohio Agricultural Research and Development Center, and The Ohio State University.

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Received 7 August 2009; accepted 28 December 2009.