EVALUATING THE USE OF PLASTIC BAGS TO PREVENT ESCAPE OF THE EMERALD ASH BORER, *AGRILUS PLANIPENNIS* (COLEOPTERA: BUPRESTIDAE) FROM FIREWOOD

Therese M. Poland[1], Tina M. Ciaramitaro[2], Deepa S. Pureswaran[3] and Andrea Diss-Torrance[4]

ABSTRACT

The emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is a highly destructive exotic pest of ash (*Fraxinus*) in North America. Human movement of infested logs, primarily pieces of firewood, is a major pathway for long distance spread of the beetle. Firewood may be confiscated at campgrounds, rest-areas, and key transportation gateways. Treatment guidelines for handling and storage of confiscated firewood are urgently needed to prevent new establishments of *A. planipennis*. In three laboratory experiments, we evaluated the efficacy of using 4-mil-thick plastic bags to contain and prevent escape of beetles from infested firewood-sized logs. For all experiments, control logs were unbagged and kept in horizontal rearing tubes in the laboratory. Treatment logs were loosely double-bagged or tightly single-bagged, and held on open laboratory benches or in rearing tubes or cans. Beetles emerged from both control and treatment logs during the course of the experiments. With a single exception, all beetles emerging from treatment logs died within the bags with no escapees. The one exception was a beetle from a tightly single-bagged log that chewed through the plastic. In contrast, all beetles emerging from control logs were collected live in the rearing containers. Double bagging firewood to contain *A. planipennis* during transport or storage could be an inexpensive and effective way of preventing escape of beetles from ash firewood.

Since the discovery of the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) in Detroit, Michigan in 2002, it has caused extensive mortality of ash, *Fraxinus* spp., while spreading across southeast Michigan, Ohio, and Ontario (Haack et al. 2002, Poland and McCullough 2006, Poland 2007). In addition to this core infested area, numerous outlier populations have been found throughout Michigan's Lower Peninsula, Ohio, Indiana, and Ontario, as well as isolated infestations in Maryland, Illinois, Pennsylvania, West Virginia, Wisconsin, Missouri, Michigan's Upper Peninsula, and Quebec (EAB Info 2008). It is estimated that the beetle has killed more than 40 million ash trees in Michigan and tens of millions in surrounding states (EAB Info 2008). Spread of *A. planipennis* is a result of natural dispersal and human-assisted movement of infested materials including ash nursery stock, logs and firewood (BenDor et al. 2006).

Agrilus planipennis develops in the cambial region of ash trees. Adult beetles

[1]USDA Forest Service, NRS, 1407 S. Harrison Rd., Rm. 220, East Lansing, MI 48823. (e-mail: tpoland@fs.fed.us).

[2]Department of Entomology, 243 Natural Sciences, Michigan State University, East Lansing, MI 48824. (e-mail: ciarami2@msu.edu).

[3]Canadian Food Inspection Agency, OPL, Natural Resources Canada, Canadian Forest Service, PO Box 4000, 1350 Regent Street, Fredericton, NB E3B 5P7. (e-mail: pureswar@msu.edu).

[4]Division of Forestry, Wisconsin Department of Natural Resources, 101 S. Webster St., Madison, WI. (e-mail: Andrea.DissTorrance@wisconsin.gov).

chew their way out of the tree in early summer leaving D-shaped emergence holes. Each female can lay 50 to 90 eggs in bark crevices during her lifetime (Bauer et al. 2004, Lyons et al. 2004). Eggs hatch within two weeks and the larvae feed in the cambial region from mid-June until mid-October . The larvae create serpentine-shaped galleries or feeding tunnels that are packed with frass. Larvae overwinter as pre-pupae in cells they construct about 1.3 cm deep in the sapwood or outer bark. Pupation begins in spring, followed by adult emergence roughly 3 weeks later (Bauer et al. 2004, Lyons et al. 2004). Some *A. planipennis*, however, overwinter as young larvae rather than as prepupae, and then require a second year of development before emerging as adults (Cappaert et al. 2005).

Federal, state and provincial regulatory and natural resource agencies implemented long term programs to contain and reduce populations of *A. planipennis*. These programs have resulted in the removal of hundreds of thousands of ash trees infested with *A. planipennis*. Some merchantable logs are being processed into products such as lumber and tool handles. Currently, the accepted method for disposal of ash logs to ensure mortality of *A. planipennis* life stages, is to grind wood into 2.54-cm or smaller pieces (USDA APHIS 2003). However, because of the overwhelming volumes of infested ash, not all wood can be processed or disposed of in an approved manner. A common use for much of the infested wood is for firewood.

Agrilus planipennis can survive and emerge from logs cut from infested trees (Petrice and Haack 2006); therefore, movement of ash logs from infested to uninfested counties is regulated by a federal quarantine (USDA APHIS 2003). In the case of firewood, all hardwood species are regulated because inspectors cannot easily identify the species of tree that was cut. Nevertheless, *A. planipennis* has continued to spread and new outlier infestations, many of which resulted from human-assisted movement of infested ash material prior to enactment of the quarantine, have been detected each year. Furthermore, movement of firewood is extremely difficult to regulate and enforce. Unlike nursery trees and wood products that are produced and moved by licensed businesses, firewood is often moved by the general public. Despite extensive outreach efforts many individuals are unaware of regulations prohibiting movement of firewood from infested areas.

Petrice and Haack (2006) evaluated the effects of tree cutting date, storage conditions, and splitting on survival of *A. planipennis* in firewood logs. Adults successfully completed development and emerged from logs representing each cutting date (July through December), logs stored in both full sun and shade, both split and whole logs, and logs that were untarped or held under a tarp. Emergence, survival, and size of *A. planipennis* adults was significantly reduced for logs that were cut early during larval development (July or August), and for logs that were split and stored untarped in full sun or shade. However, no firewood handling conditions completely eliminated *A. planipennis* emergence.

In order to prevent the spread of *A. planipennis* through movement of firewood, state regulatory and natural resource agencies are enforcing quarantine regulations by conducting inspections for firewood at campgrounds, rest areas and key transportation gateways. Treatment guidelines for storage and handling of confiscated firewood are urgently needed to prevent new establishments of *A. planipennis*. Personnel responsible for confiscated firewood may not have access to expensive treatment facilities or equipment. Plastic bags are inexpensive and readily available; however, they have not been evaluated for their ability to confine *A. planipennis* adults emerging from firewood. Our objective was to evaluate the use of plastic bags to contain logs and prevent escape of *A. planipennis*. Specifically, we conducted three experiments that compared emergence of *A. planipennis* from control logs placed in rearing tubes and 1) logs that were sealed inside two plastic bags and placed inside vertical or horizontal rearing containers, 2) logs that were sealed inside two plastic bags and held in the open on a laboratory bench, and 3) pairs of logs that were sealed inside a single plastic bag that was pressed tightly against the logs and held in vertical rearing containers.

MATERIALS AND METHODS

Ash trees that were infested with *A. planipennis* were cut between 15 December 2006 and 11 January 2007 at field sites near Brighton, MI (Livingston County) and Lansing, MI (Ingham County). Trees were felled and bucked into logs approximately 60 cm log and 11-12 cm in diameter then held in a cold room for 4 to 10 months at 5 ± 2 °C until used for experiments.

Experiment 1 examined the effect of double bagging on logs held in rearing containers. It was conducted from 1 March 2007 to 10 April 2007. Thirty infested logs were removed from cold storage and randomly assigned to three treatments with 10 logs per treatment: 1) unbagged control logs placed in horizontal rearing tubes; 2) logs that were sealed inside two plastic bags and then placed in horizontal rearing tubes; and 3) logs that were sealed inside two plastic bags and then placed in vertical rearing cans. Rearing tubes consisted of cardboard tubes with plastic end caps (30 cm outside diameter, 1.26 cm thick wall, 75 cm long; Saginaw Paper Tube, Saginaw, MI). One plastic end cap was modified by cutting a 20 cm diameter hole that was sealed with mesh screen. A 6 cm diameter hole was similarly cut in the center of the mesh screen into which a plastic specimen cup was inserted as a collection jar. Infested logs were placed inside the rearing tubes and as beetles emerged from the logs they tended to move into the collection jars in response to light. Rearing tubes were laid horizontally in rows on wooden shelving. Rearing cans consisted of 114 liter (30 gallon) plastic garbage pails. Each garbage pail was modified by cutting a 15 cm diameter hole in the side that was sealed with mesh screen. A plastic specimen cup was inserted into the center of the screen as described above. Plastic bags were "contractor grade" clear, 60 × 120 cm, 4 mil thick (= 4/1000 inch or 0.1 mm) poly bags (BrownCor, Milwaukee, WI). Logs were inserted individually into a bag and the end of the bag was twisted shut and secured with a cable tie. The bagged log was then inserted into a second bag and secured in a similar manner. The double bagged logs were then placed inside the assigned rearing containers. Logs were held in rearing containers to capture any adults that might escape through the bags. The rearing containers were held in the laboratory at 25 ± 3 °C with overhead fluorescent lighting that was left on constantly.

Experiment 2 evaluated whether the effectiveness of bagging was reduced if bagged logs were fully exposed to ambient light. It was conducted from 11 April 2007 to 26 May 2007. Sixteen infested logs were removed from cold storage and randomly assigned to one of two treatments: 1) unbagged control logs in horizontal rearing tubes; and 2) logs that were sealed inside two plastic bags and held in the open on a bench top in the laboratory. The rearing tubes were in the same laboratory as Experiment 1. The double-bagged logs were in an adjacent laboratory on a bench top beside a window with natural light. The temperature in the adjacent laboratory was similar to that in the rearing container room; however, there was natural light and overhead fluorescent lights were on only during the work day (approximately 08:00 to 17:00) and were not left on overnight or on weekends.

Experiment 3 was conducted during 12–27 November 2007 to determine whether beetles can chew their way out of plastic bags if the bags were tightly wrapped around the logs. Twenty logs were randomly assigned to one of two treatments with 5 pairs of logs per treatment: 1) unbagged pairs of control logs in horizontal rearing tubes; and 2) pairs of logs introduced in a plastic bag that was tightly secured around them and kept in vertical rearing cans.

For all experiments, log dimensions (diameter and length) were measured and recorded at the beginning of the experiment. In addition, any exit holes from previously emerged *A. planipennis* adults were tallied and marked. After placing the logs inside the bags and rearing containers, they were checked every other day for emerging adults. Each time the collection jars were checked, the lids or end caps of the containers were also removed to retrieve any beetles that remained inside the rearing container. In addition, the bagged logs were examined by carefully inspecting the bag for holes and looking through the transparent bag to note any beetles inside. Once beetles stopped emerging (i.e., no new beetles were collected for 6 days) the experiments were ended. Logs were removed from their rearing containers or bags. All dead *A. planipennis* adults found inside the rearing containers and bags were tallied. The number of new emergence holes on each log was also tallied. For experiment 1, a subsample of four logs from each treatment was dissected to determine the average number of dead adults and larvae that remained inside the logs. For experiment 2, two logs from each treatment were dissected to determine the average number of dead adults and larvae inside. For experiment 3, five logs from each treatment (one log per pair) were similarly dissected and assessed.

For experiment 1, the data were analyzed by one-way ANOVA by treatment (PROC GLM, SAS Institute 2002). The Ryan-Einot-Gabriel-Welsch multiple comparison test was used to compare differences among treatments when ANOVA was significant. Log measurement data were not transformed. The number of existing and new exit holes, number of live and dead adults collected in bags or rearing containers, and number of dead adults and dead larvae inside the logs were standardized by surface area (2000 cm^2) similar to the area of a log. Density data per 2000 cm^2 were transformed by log (x + 1) to satisfy assumptions of normality and homoscedasticity prior to analysis. For Experiments 2 and 3, log measurement data and transformed (log (x + 1)) density data were compared between the two treatments by a *T*-test (PROC TTEST, SAS Institute 2002). The α-level was set at 0.05 for all statistical tests.

RESULTS AND DISCUSSION

For all experiments, several new emergence holes were found on all logs with many live *A. planipennis* adults emerging from the control logs; however, none of the adults that emerged from the double-bagged logs in Experiments 1 and 2 (Tables 1 and 2) chewed through the bags whereas one beetle chewed through the bag of the single-bagged logs in Experiment 3 (Table 3). In Experiment 1, logs assigned to the different treatments were similar in overall dimensions and *A. planipennis* attack density. There were no significant differences among treatments in log length (56.8 ± 0.9 cm, mean ± SE; $F = 0.27$; df = 2, 27; $P = 0.7$), log diameter (11.8 ± 0.8; $F = 3.32$; df = 2, 27; $P = 0.06$), density of exit holes at the start of the study, density of new exit holes at the end of the study, and density of dead adults and larvae found inside the logs at the end of the experiment (Table 1). All 184 *A. planipennis* adults that emerged from the unbagged control logs were collected live in the rearing tubes or collection jars; whereas, all 186 of the *A. planipennis* that emerged from the double-bagged logs held in rearing tubes or in rearing cans were found dead in the bags at the end of the experiment (Table 1).

After finding that no *A. planipennis* escaped from the bags in Experiment 1, we conducted another experiment in which we held the bagged logs under more natural lighting conditions similar to what might be experienced in an outdoor regulatory setting where firewood might be confiscated and held. Since *A. planipennis* respond positively toward light, we believed that beetles might move more readily towards the edges of the bag and try to escape if all sides of the bags were exposed to light rather than when the bagged logs were held in dark rearing containers with only a small opening at the collection jar which provided a point source of light. However, in Experiment 2, we again found

Table 1. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm^2 log surface area) from logs that were double-bagged in 4-mil-thick plastic bags and held in containers (rearing tubes or rearing cans) and for unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 10 logs per treatment. A subsample of 4 logs per treatment were dissected to determine the density of dead *A. planipennis* inside the logs.

		Treatment			
Variable	**N**	**Unbagged logs in rearing tubes**	**Bagged logs in rearing tubes**	**Bagged logs in rearing cans**	***F*; df; *P***
Exit holes at start	10	0.1 ± 0.1 a	0.2 ± 0.2 a	0.4 ± 0.1 a	0.85; 2, 27; 0.4
Live adults in container	10	13. ± 4.7 a	0 ± 0 b	0 ± 0 b	37.4; 2, 27; 0.0001
Dead adults in bag or container	10	0 ± 0 b	6.9 ± 1.9 a	11.6 ± 3.5 a	11.8; 2, 27; 0.0002
New exit holes	10	14.0 ± 4.7 a	6.9 ± 1.9 a	11.2 ± 3.5 a	0.58; 2, 27; 0.56
Dead adults in log	4	1.3 ± 1.2 a	1.1 ± 0.8 a	3.1 ± 1.4 a	1.0; 2, 27; 0.38
Dead larvae in log	4	1.2 ± 0.8 a	0.7 ± 0.4 a	3.4 ± 1.4 a	1.34; 2, 27; 0.37

Means within a row followed by different letters are significantly different from each other, Ryan-Einot-Gabriel-Welsch multiple comparison test, $P < 0.05$. Data were transformed log (x + 1).

Table 2. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm^2 log surface area) from logs that were double-bagged in 4-mil-thick plastic bags and held on an open laboratory bench and from unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 8 logs per treatment. A subsample of 2 logs per treatment were dissected to determine density of dead *A. planipennis* inside the logs.

		Treatment		***T*-Test**	
Variable	**N**	**Unbagged logs in rearing tubes**	**Bagged logs on lab bench**	***T***	***P***
Exit holes at start	8	0.7 ± 0.5 a	0.3 ± 0.2 a	0.39	0.70
Live adults in container	8	22.7 ± 5.2 a	0 ± 0 b	11.3	0.0001
Dead adults in bag or container	8	0 ± 0 b	7.8 ± 2.0 a	-4.36	0.0007
New exit holes	8	22.7 ± 5.2 a	7.8 ± 2.0 b	2.43	0.02

Means followed by different letters are significantly different, *T*-test, $P < 0.05$. Data were transformed by log (x + 1).

Table 3. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm^2 log surface area) from pairs of logs that were tightly single-bagged and held in containers (rearing cans), and from pairs of unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 5 pairs of logs per treatment. One log from each pair was dissected to determine the density of dead *A. planipennis* inside the logs (N = 5 logs).

		Treatment		***T*-Test**	
Variable	**N**	**Unbagged logs in rearing tubes**	**Bagged logs in cans**	***T***	***P***
Exit holes at start	5	0.7 ± 0.6 a	1.1 ± 0.6 a	0.75	0.47
Live adults in container	5	12.9 ± 1.9 a	0.1 ± 0.1 b	14.4	0.0001
Dead adults in bag or container	5	0 ± 0 b	11.2 ± 3.8 a	5.49	0.0006
New exit holes	5	13.0 ± 1.9 a	11.3 ± 3.7 a	0.78	0.45
Dead adults in log	5	0.3 ± 0.1 b	2.2 ± 0.5 a	3.76	0.005
Dead larvae in log	5	3.1 ± 1.4 a	6.7 ± 1.8 a	1.25	0.24

Means followed by different letters are significantly different, *T*-test, $P < 0.05$. Data were transformed by log (x + 1).

that no beetles escaped from the bagged logs (Table 2). Logs assigned to the two treatments were similar in overall dimensions. There was no significant difference between treatments in log length (58.5 ± 0.9 cm; $T = 0.5$; $P = 0.6$) or log diameter (11.8 ± 0.8; $T = 1.59$; $P = 0.3$), or density of exit holes at the start of the experiment (Table 2). However, there was a significantly higher density of new exit holes on the unbagged control logs compared to the logs that were double-bagged and held on the laboratory bench. This suggests that the control logs may have had a higher attack density than the bagged logs. It is possible that mortality may have been higher within the bagged logs. Only 2 logs were dissected per treatment to determine mortality of adults and larvae within the logs thus replication was too low to determine significant differences. Nevertheless, several adult *A. planipennis* emerged from logs that were double-bagged and held on the laboratory bench and all 59 of the adults died inside the bags by the end of the experiment. Conversely all 217 of the adults that emerged from the control logs were found live in the rearing tubes or collection jars (Table 2).

In the first two experiments, individual logs were placed in bags that were sealed loosely around the logs. When firewood is confiscated, several pieces of wood may be placed in a bag until it is full and the plastic is pressed snugly against the logs. We believed that beetles would be more likely to chew through the plastic bag when it is pressed tightly against the bark that they are chewing through. Therefore, in Experiment 3, pairs of treatment logs were tightly single-bagged, so that the bag was pressed snuggly against the bark surface of the logs. Results were similar to those obtained in Experiments 1 and 2. All 132 beetles emerging from unbagged control logs emerged alive into the rearing tubes and collection jars (Table 3). On the other hand, all of the 122 beetles that emerged from the tightly single-bagged logs were found dead pressed against the logs inside the bags, except for one beetle that managed to chew a hole in the plastic bag and was found in the rearing can (Table 3). As with the previous two experiments there was no difference between treatments in log length (57.3 ± 0.5 cm; $T = 0.93$; $P = 0.37$) or log diameter (11.4 ± 0.4 cm; $T = 1.34$; $P = 0.19$). There were also no differences in density of new exit holes or dead larvae between the treatment and control logs. However, there was a significantly higher density of dead adults in the bagged-logs compared to the control logs suggesting that the bags were effective in causing some beetle mortality prior to emergence. These results indicate that there is minimal risk of beetles escaping from firewood held in single bags closed tightly around the logs.

This study demonstrates that double-bagging using plastic bags is an inexpensive, accessible, and effective way to prevent escape of *A. planipennis* from ash firewood. A survey by the Michigan Department of Agriculture indicates that about 78% of sites whose origins of infestation could be determined or estimated resulted from firewood movement (M. Philips, pers. comm.). Mandatory double-bagging of firewood that is transported or confiscated would decrease potential escape from infested material.

Bagging firewood is already being implemented by Minnesota and Wisconsin state parks (WiDNR 2008, MnDNR 2008) as well as the Ohio (ODA 2008) and South Dakota Departments of Agriculture (SDDA 2008). Adults that emerge will be contained by the plastic and eventually die. Plastic coverings have been used in other applications to contain, kill, or prevent infestation by other wood-boring insects and bark beetles. Covering logs with polyethylene sheeting, known as "tarping", has been commonly used to store elm wood infected with Dutch elm disease (Krawczyk et al. 1982, Svihra 1987) to prevent escape and colonization of *Scolytus multistriatus* (Marsham) (Coleoptera: Curculionidae: Scolytinae). Tarping and sealing firewood piles to prevent infestation is used effectively in integrated pest management and control of bark beetles (Buffam and Light 1968, Sanborn 1996, Donaldson and Seybold 1998).

While tightly single-bagging logs presents minimal risk of *A. planipennis* escaping from infested ash firewood, our results suggest that double-bagging logs loosely in contractor grade 4 mil plastic bags would be a simple, cost-effective means to prevent escape of *A. planipennis* and establishment of new infestations. Plastic bags may be practical for small quantities of firewood; larger containers might be designed to accomplish the same effect where wood quantities are large. For instance, at the Mackinac Bridge in Michigan, large metal containers are used to hold confiscated firewood.

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