Ability of pressure treatment with wood preservatives to kill or limit emergence of invasive insects using *Arhopalus productus* as a model species

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Abstract

A number of high-profile invasive species introductions have been associated with solid wood packaging materials (SWPM). The United Nations Food and Agriculture Organization currently recommends fumigation or heat treatment for preventing species introductions associated with SWPM, yet neither of these methods provides long-term protection against reinfestation. Chemical pressure impregnation may provide this protection, but little is known about the ability of these processes to kill established insect pests. In order to assess this technology, naturally infested samples were pressure-treated with three conventional wood preservative systems, and the ability of larvae and adults to emerge from these materials in field conditions was determined over a 2-year period. Larvae survived the initial treatment processes, but no adults emerged from the treated material. These results were surprising because the larvae survived both the high pressures during treatment and the complete penetration of the galleries.

The increasing pace of global trade has created huge opportunities to move materials rapidly to markets that heretofore might be beyond reach because products would spoil before reaching their final destination. More rapid movement, however, comes with a cost in terms of simultaneously increasing the risk that pests will inadvertently be transported on these goods. One particularly important avenue for importing pests is solid wood packing material (SWPM). SWPM is used to efficiently move a diverse array of material. SWPM is often a single use item and is cut from low value timbers that may contain existing fungal and insect infestations. A number of high profile beetle introductions have been documented to have occurred through SWPM (Haack 2003).

The risk of introducing invasive species through SWPM infested with wood inhabiting beetles is a major concern to the United Nations Food and Agriculture Organization (FAO). The FAO currently recommends heat treatment or fumigation to mitigate this risk; however, neither of these treatment methods provides protection against later reinfestation (FAO 2007). In addition, neither of these mitigation methods is independently verifiable by the importing countries. There is a continued need for mitigation treatments that are broadly effective at eliminating established pests and preventing pest reintroductions and whose presence can be verified during the entire life cycle of the material. Pressure treatment with preservatives may represent an alternative approach to SWPM mitigation that meets these requirements. This process would produce an external barrier to repel pests and residual chemical loadings could be easily verified.

The effectiveness of barriers for excluding termites and other traditional wood-boring insects from lumber used in structures is well-documented (Quarles 1992, Mankowski and Morrell 1993, Myles 1994, Preston et al. 1996, Yamaguchi 2001, Potter and Hillery 2002, Kard 2003). However, SWPM is often already infested with insects that could complete their life cycles in the importing country. Thus, the ability of these treatments to inhibit emergence of existing infestations from the wood is equally important.

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Table 1. — Treating parameters used to impregnate beetle infested ponderosa pine boards with selected wood preservatives.

		Vacuum cycle		Pressure	
Treatment	Treating solution temperature	Vacuum achieved	Duration	Pressure achieved	Duration
	(°C)	(kpa)	(min)	(kpa)	(min)
ACQ	29	−81	120	1000	900
Borate	27	−85	10	1103	20
Experimental formulation	22	−86	10	1241	30

Pressure treatments can penetrate a reasonable degree into lumber of most wood species; however, most treatments are not complete. Intuitively, pressure treatment would be expected to easily penetrate along pathways produced by the larval galleries; however, many wood boring beetles tightly pack their galleries with frass that can inhibit fluid flow (Furniss and Carolin 1977). In these cases, the preservative treated shell becomes the primary barrier against insect movement into and out of the wood.

Developing data on the ability of various systems to penetrate into beetle galleries and the surrounding wood as well as the ability of these treatments to inhibit later beetle emergence will be critical for allowing pressure treatments to be used for mitigation. The objective of this research was to determine if established wood-boring insect populations found in lumber cut from fire-killed ponderosa pine logs (*Pinus ponderosa*) from central Oregon could complete their life cycle after the material had been pressure treated with one of three different wood preservatives.

Materials and methods

Beetle infested boards were obtained from a mill located in Gilchrist, Oregon. The lumber was cut from fire-killed Ponderosa pine (*Pinus ponderosa L.*) trees harvested from a stand located near Davis Lake, Oregon. The lumber was heavily infested with larvae of the new house borer (*Arhopalus productus LeConte*).

The presence of beetles in any given board is difficult to predict without destroying the sample. In order to ensure that a minimum number of boards in a given treatment group were infested, a preliminary trial was performed (Schauwecker 2006). The results indicated that a minimum of 60 samples that were at least 200-mm wide and 1-m long were required in order to ensure that at least 30 boards would each contain a minimum of two larvae.

Material for the full study was collected as 2.5-m-long sections. Two 1-m-long samples were cut from either end and the remaining 0.5 m long middle section was retained to assess beetle activity. The 320 sections were randomly allocated to one of 4 treatment groups, each with 80 boards. The cross sections were end-coated with a two-part marine grade epoxy to retard longitudinal penetration; then the samples were pressure treated with one of 3 chemicals: ammoniacal copper quaternary compound (ACQ), disodium octaborate tetrahydrate (DOT), or a mixture of 30 ppm imidacloprid, 300 ppm 2-n-octyl-4-isothiazolone-3-one, and 100 ppm green dye (Sensient Colors Inc., Milwaukee, Wisconsin). The dye was added as an indicator of chemical penetration. The ACQ and DOT treatments were performed in single charges at commercial treatment facilities, while the treatments with the third chemical were performed in an experimental retort that required five separate charges using the same treatment parameters. All treatments were performed at ambient temperatures (20 to 29 °C) (**Table 1**).

Twenty-five mm was cut from the ends of each treated board to remove the epoxy end coat and the freshly exposed surfaces were coated with a paraffin mixture containing 15 ppm imidacloprid to retard beetle movement through the wood. This was done because of concerns that the larvae might be able to bore through the epoxy and thereby avoid the pressure treated barrier.

All existing galleries on the surfaces of the samples were marked using spray paint so that new beetle activity could be distinguished. During this process, 10 samples were randomly selected from each of the three chemical treatments for chemical analysis. The remaining material was numbered and stickered (6-mm spacing) to allow air movement and placed inside screened enclosure boxes. The samples were then exposed outdoors in western Oregon. All samples, including the controls, were inspected after 1 month for evidence of new gallery formation on the exterior surfaces (these new galleries were recorded and marked using a different color of spray paint). An additional 10 samples were randomly removed from the three treatment groups for chemical analysis to determine if additional preservative migration had occurred. The remaining 60 samples from each treatment group were then inspected at 4-week intervals for evidence of beetle activity during the remainder of the study. In addition, any other observations concerning the appearance of the samples such as mold growth or the development of seasoning checks were noted. The samples were then returned to the enclosure after each inspection in the same order that they were removed. This process was repeated monthly for 12 months with an additional inspection after 2 years. The presence of live beetles in the boards was assessed 12 months after treatment by destructively sampling 20 of the original 60 boards per treatment. The samples were split lengthwise into small slivers, exposing any beetles present.

Climate data were collected for each 4-week period from a weather station located near Corvallis, Oregon (44°38′03″ N./ 123°11′ 24″ W.) and operated by the Oregon State University College of Oceanic and Atmospheric Sciences. The maximum and minimum daily temperatures were collected along with the amount of precipitation. Temperature data were averaged for each 4-week period, while the total amount of precipitation was also noted. This information was used, along with the other observations collected during the inspections to better understand larval and insect behavior. Degree days, which are normally used to describe insect development, were not used because of a lack of basic knowledge concerning the developmental rates of *A. productus* (Furniss and Carolin 1977).

Chemical analysis: Preservative penetration was assessed by cutting nine 10-mm-thick cross sections from along the length of 10 boards per treatment for a total of 180 sections per treatment. The depth of preservative penetration along the

Table 2. — HPLC conditions used to analyze imidacloprid in wood extracts.

Column	Inertsil ODS-3 C-18, 150 by 4.6 mm, 3 μm
Mobile phase A	30 percent acetonitrile/70 percent water applied to column from minute 0 to 8 and 11 to 25
Mobile phase B	90 percent acetonitrile/10 percent water applied to column from minute 8 to 11
Detector	UV light, 270 nm
Flow rate	1 mL/min
Injection volume	10 μL
Data collection time	8 minutes
Imidacloprid retention time	5 minutes

wide and narrow faces was estimated to the nearest mm, and these values were averaged for each board. The presence of boron was determined by ovendrying the 180 cross sections, sanding the cut surfaces to remove any boron carried by the saw blade, and spraying with boron indicator in accordance with AWPA Standard A3–00 Method 1. A color change from yellow to red indicated the presence of boron (AWPA 2004b). Copper and dye penetration in the ACQ and imidacloprid samples, respectively, were easily seen without indicators. In addition to the depth of treatment, the percentage of beetle galleries that were completely penetrated was also measured for each treatment.

Two 15-mm-thick assay zones were removed from three of the cross sections per board, one assay zone from the narrow and the other from the wide face of the original board. The samples were then ovendried (103 °C for ACQ and DOT and at 80 °C for imidacloprid samples) and ground to pass a 30 mesh screen. The ACQ treated material was analyzed for copper oxide content using a Spectro Titan x-ray Fluorescence Analyzer, according to AWPA Standard A11–93 (AWPA 2004c). The borate treated samples were analyzed using AWPA standard A2–98 Method 16 (AWPA 2004a).

Samples were analyzed for imidacloprid content by weighing 0.62 to 0.74 g samples of wood flour and extracting this material in 25 mL of methanol in screw cap bottles while sonicating for 3 hours. An aliquot (10μl) of the extract was then removed from the screw cap bottle through a 0.2-μm syringe-filter. The filtered extract was then analyzed by high performance liquid chromatography (HPLC, **Table 2**, Jin and Walcheski 2006). Isothiazolone was not analyzed in this experiment because the test was primarily insect driven, while isothiazolone was primarily added to provide fungal protection.

Data analysis: The monthly emergence data from the 60 samples per treatment were analyzed using an Analysis of Variance (ANOVA), where the untreated control group was used as a reference level ($\alpha = 0.05$).

Chemical analyses for ACQ and borate were examined to determine if they met the current AWPA standards for ground contact or Formosan termite (*Coptotermes formosanus* Shiraki) exposure applications respectively. In addition, the percentage of completely penetrated galleries bisected in each section was calculated and compared to the controls using an ANOVA.

Table 3. — Preservative retentions in beetle infested ponderosa pine lumber treated with ACQ, borates, or imidacloprid.

Treatment	Sample orientation	Number of samples analyzed	Mean retention (SE)	95 percent confidence interval
			(kg/m^3)	
Borate	Narrow side	60	9.1 (1.1)	6.4 to 11.9
	Wide side	60	5.7 (0.1)	3.0 to 8.4
ACQ	All samples	60	8.1 (0.5)	7.2 to 9.0
Imidacloprid	All samples	60	0.015 (0.001)	0.12 to 0.018

Results and Discussion

Chemical penetration and retention

All three treatments completely penetrated the ponderosa pine sapwood; however, only a thin treated shell, approximately 3-mm thick, was produced around the heartwood portion of the samples. In addition, all galleries were completely treated, regardless of whether they were found in the heartwood or sapwood. The thickness of the treated shell in the borate samples did not visibly increase 1 month after treatment, nor was there evidence of significant borate diffusion away from the treated insect galleries.

Copper oxide retentions in the assay zone from the ACQ treated boards averaged 8.1 kg/m^3 (**Table 3**), easily exceeding the targeted 6.4 kg/m^3 retention specified for ground contact exposure (AWPA 2004d). The ANOVA analysis of the borate retentions indicated that a 1 month diffusion period did not significantly affect retention (*p*-value of 0.38 with an F statistic of 0.77). Borate retention was significantly lower on the wide face, most likely due to the larger heartwood content (**Table 3**). Imidacloprid retentions for all materials tested averaged 0.015 kg/m^3, with little variation among samples (95% confidence interval from 0.12 to 0.018 kg/m^3). The relatively small retention variation may be a result of treating the materials in a laboratory environment under more controlled conditions. There currently are no standard retentions for imidacloprid; however, a level about one third of that achieved in these tests is effective against Formosan termites (Preston, personal communication).

Insect emergence data

Insect emergence data were considered by season for the purposes of this study. Fall months were defined as August 16th to November 15th, winter ran from November 16th to February 15th, spring was defined as February 16th to May 15th, and summer May 16th to August 15th.

There was a considerable amount of beetle activity in control samples in the fall immediately after treatment, but this activity was entirely larval in nature and no adult emergence holes were noted on the treated samples (**Fig. 1**). The number of new galleries found on the surface declined as temperatures declined. One active subterranean termite (Isoptera Rhinotermitidae *Reticulotermes hesperus*) colony was present in the untreated samples and an adult new house borer was also collected from this material, but no other adult beetles were captured. Ten new galleries were found on the surface of the borate treated material in the fall; however, none of these new galleries were adult exit holes. Adult exit holes are distinctly oval in nature, and lacked frass packing (Eaton and Lyon 1954). Similarly, 4 new larval galleries were found on the surface of the ACQ treated material. A distinct ammonia odor

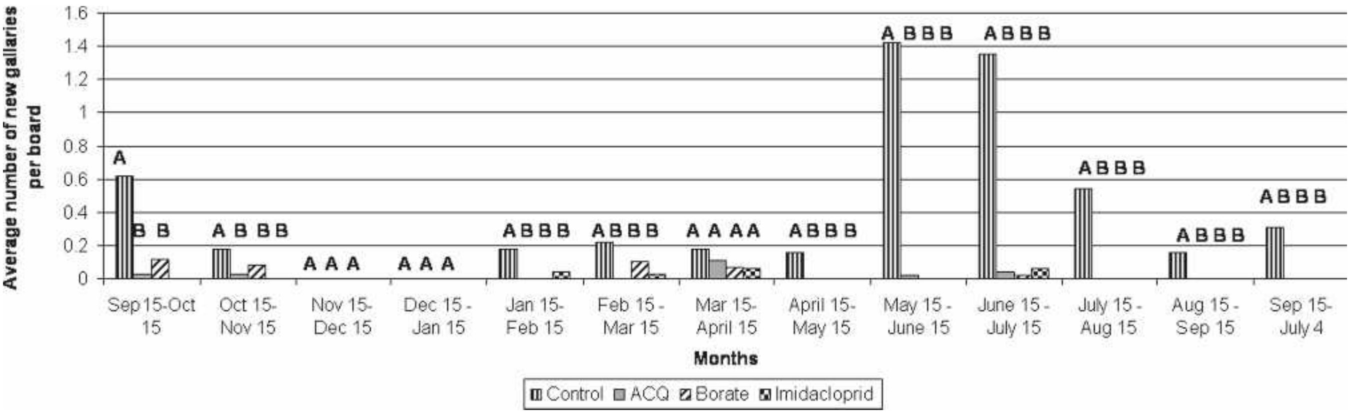

Figure 1. — Average number of new larvae or adult holes detected per month on the surfaces of beetle infested pine samples treated with ACQ, borates, or imidacloprid or left untreated (control). Imidacloprid treated materials were not included during the first three time periods.

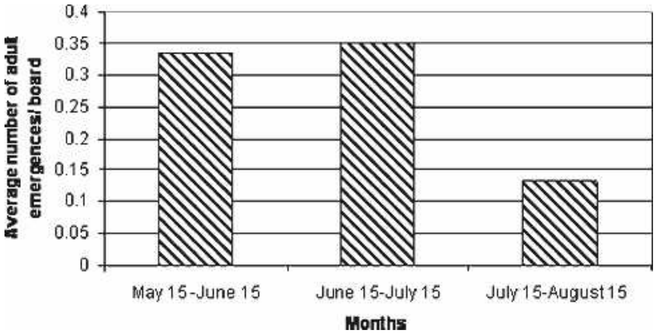

Figure 2. — Average number of new adult insect emergence holes found in 60 untreated ponderosa pine control samples over a 3-month period.

was also noted in the ACQ treated material, and it was unclear what effect, if any, this odor had on beetle activity. By November 15th, average daytime temperatures declined below 10 °C and insect activity ceased. The material treated with imidacloprid was not in test during this time period due to delays in the treating process, but were installed on November 15th. However, the same control samples as those used for the other treatments were used for comparison.

The presence of viable larvae in the treated materials was surprising given the complete preservative penetration. Larval movement toward the surface and the degree of gallery treatment would suggest that larvae were capable of ingesting the treated wood. However, separate laboratory studies indicated that larvae mined new tunnels but did not ingest the wood (Schauwecker 2006). This avoidance behavior may be a function of larvae avoiding potentially toxic heartwood as they tunnel in normal trees. Although this behavior allows larvae to survive for long periods on stored fats, the inability to locate untreated wood should eventually result in death by starvation.

Insect activity in the winter was only observed when average high temperatures exceeded 10 °C. All insect activity observed during this time period resulted from larvae emerging on the surface and then reentering the material. The large amount of rain received during this period was conducive to fungal growth and chemical leaching. Fruiting bodies of *Schizophyllum commune*, a common early colonizer of sapwood, were found on one of the control samples, while substantial mold growth was noted in the top five layers of the borate treated samples. These layers received a majority of the moisture from the rainfall. Larval activity on the surface of the untreated material far exceeded that seen in the treated material once temperatures exceeded 10 °C in mid-January and February. Destructive examination of the 500-mm-long untreated scraps retained from the sample preparation showed that two or more larvae were present in 50 percent of the samples. The larvae moved slowly when exposed but became more active at temperatures in excess of 25 °C.

The spring months were associated with increased insect activity in the samples; however, activity was largely confined to the untreated control samples. All larval activity observed on March 15th and April 15th was associated with larvae emerging on the surface and reentering the material. Average daytime highs during this time period were 12 and 17 °C, respectively. Larval activity significantly increased in the untreated control samples during the period ending on May 15th. Eighty-five new observations of beetle activity were made over this time period, and 21 of these were adult exit holes. However, only two new galleries were detected on the surfaces of the ACQ and imidacloprid treated material, and neither of these holes was caused by an exiting adult. No new larval galleries or adult exit holes were found on the surfaces of the borate treated material. Increased insect activity in the controls likely reflected the significantly higher average daytime high temperatures seen during this time period. Mold growth that was present throughout the winter on the borate treated materials receded as the wood dried. The heaviest amounts of mold growth were centered on old frass-packed larval galleries, suggesting that fungal spores were transported by the larvae or that the fungi were using partially modified wood components found in the frass.

Insect activity peaked during the summer as evidenced by both elevated larval activity and a large number of adult exit holes in the control boards (**Fig. 2**). Eighty-one new insect galleries were detected on the control samples during the period ending on June 15th, and 20 of these were adult exit holes. No adult exit holes were found in the treated samples, and the number of new insect galleries found on the surface of these materials also greatly diminished. The lack of adult insect emergence from the treated material could be attributed to the insecticide nature of the wood preservatives investigated. No new insect activity associated with the treated materials was found between June 16th and September 15th, while the number of new adult emergence holes in the control samples peaked during July. Two adult insects from these boards were positively identified as new house borers. Seasoning checks were abundant in all samples at the August 15th and September 15th inspections, suggesting that the boards were drying to the point where beetle development might be affected. While new adult emergence holes were found in the control samples during the August 15th inspection, the number greatly decreased as did new gallery frequency. Twenty boards from each treatment were randomly selected following the September 15th inspection and dissected. None of the treated material contained live larvae, while nine live larvae were recovered from the untreated controls. Dead insects spanning every life stage were recovered from all of the treated materials. Some larvae had surfaced on the control samples during the second year of observation, but no larval galleries or exit holes were found on the surface of the treated materials.

Conclusions and implications

Ponderosa pine lumber with active wood-boring insect populations was easily treated with conventional wood preservative to retention levels that will prevent the emergence of adults. However, none of the wood preservatives investigated prevented immature insects from continuing to survive within the wood. The periodic surfacing of larvae would be a significant concern since these larvae could move to adjacent wood in contact with the infested materials to continue their life cycles. As a result, further assessment of the potential for this occurrence is strongly recommended before pressure treatment is contemplated as a method for pest mitigation from SWPM.

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