Impact of Debarking and Bark Grinding on Survival of *Ips calligraphus* (Coleoptera: Curculionidae: Scolytinae)

Robert A. Haack[1], Toby R. Petrice[1], John L. Foltz[2], and Hui Ye[3]

[1] USDA Forest Service, Northern Research Station, 2601 Coolidge Rd, Ste. 203, East Lansing, MI 48823.
(email: robert.haack@usda.gov; emeritus) (email: toby.petrice@usda.gov).

[2] Department of Entomology and Nematology. University of Florida, Gainesville, FL 32611.
(email: foltz@ufl.edu; emeritus).

[3] School of Ecology and Environmental Science, Yunnan University, Kunming, 650504, Yunnan, China. (email: yehui@ynu.edu.cn).

Abstract

Chipping and debarking of infested woody material such as branches and logs are common sanitation methods used to kill bark- and wood-infesting insects. The sixspined ips, *Ips calligraphus* (Germar), is a native North American bark beetle (Coleoptera: Curculionidae: Scolytinae) that infests several pine (*Pinus*) species. We evaluated *I. calligraphus* mortality after debarking and grinding, using 12 recently cut longleaf pine (*Pinus palustris* Mill.) logs that had undergone natural colonization for three weeks in Florida. Initial bark beetle densities were estimated from samples collected the day before debarking. Similar amounts of bark were collected at three steps in the debarking and grinding processes: first immediately after debarking, and then after grinding and screening as either "fines" that fell through the screen, or as larger bark nuggets and flakes that stayed on top of the screen. Half the bark was inspected by hand on the day of debarking while the other half was placed in rearing cans and monitored for live beetles for the next 10 weeks. Percent mortality was estimated by comparing the number of emerged beetles collected from the rearing cans to the estimated initial adult beetle populations just prior to debarking. Overall, mortality was estimated at 99.4% after debarking and 100% after grinding for *I. calligraphus*, and 98.9% after debarking and 99.8% after grinding for the two smaller *Ips* species combined: *Ips avulsus* (Eichhoff) and *Ips grandicollis* (Eichhoff). These findings are discussed in relation to the Eurasian scolytine *Tomicus piniperda* (L.), a bark beetle similar in size to *I. calligraphus*, which was established throughout the Great Lakes region at the time of this study.

Keywords: Scolytinae, survival, sanitation, chipping, cultural control

---

Chipping and debarking of woody plants are common sanitation methods used to kill bark- and wood-infesting insects. High levels of control are especially important when trees are infested with exotic insect species because movement of wood cut from these trees is often restricted by local, state, or federal quarantines. Insect survival after chipping has been evaluated for various exotic beetles (Coleoptera), including species of Buprestidae (McCullough et al. 2007), Cerambycidae (Wang et al. 2000, Haack et al. 2010) and Scolytinae (Curculionidae) (Spence et al. 2013, Jones and Paine 2015, Chen et al 2020). Debarking of logs to control bark beetles (Curculionidae: Scolytinae) has been evaluated less often. However, in one study in Germany, Dubbel (1993) reported that debarking Norway spruce [*Picea abies* (L.) H. Karst.] logs lowered the population of *Ips typographus* (L.) bark beetles in the bark by 93%. A log, once debarked, is generally not suitable for bark beetle colonization because most bark beetles construct their galleries at the interface of the bark and wood (Thorn et al. 2016, Hagge et al. 2019).

The sixspined ips, *Ips calligraphus* (Germar), is found throughout much of North America, from southern Canada to Florida, and also in parts of the Caribbean (Ciesla 1973, Atkinson 2024). *Ips calligraphus* is typically a secondary invader of pines (*Pinus*), infesting recently cut logging slash and trees weakened by drought, lightning, wind, fire, and defoliation (Anderson and Anderson 1968, Ciesla 1973, Wilkinson et al. 1978, Haack 1985, Garraway 1986, Haack et al. 1987b, 1989). The objective of the current study was to evaluate adult bark beetle survival after mechanical debarking and subsequent bark grinding using infested pine logs at a commercial sawmill in Florida with an emphasis on *I. calligraphus*.

The impetus for this study was the US federal quarantine on the Eurasian pine shoot beetle, *Tomicus piniperda* (L.) (Scolytinae), which was first discovered in the US state of Ohio in July 1992 and had spread to 12 US states by 2000 (Haack and Kucera 1993, Haack and Poland 2001). The types of host material under quarantine varied over time but usually included pine (*Pinus*) logs and lumber with bark, Christmas trees, nursery stock, stumps, and bark (Haack and Poland 2001). When this study was conducted (2002) the only approved sanitation treatment for pine bark in any form was fumigation with methyl bromide (Haack and Poland 2001). Given that situation, several US states petitioned USDA APHIS (United States Department of Agriculture, Animal and Plant Health Inspection Service) to consider other options for pine bark, such as composting bark to a specified temperature or grinding bark to below a specified size. To estimate how debarking might affect survival of *T. piniperda,* whose adults measure 3.5–5 mm long (Postner 1974, Haack and Kucera 1993), consideration was given to various native bark beetles of similar size, including *Dendroctonus rufipennis* (Kirby) (4.4–7.0 mm long), which infests spruce (*Picea*), *Dendroctonus simplex* LeConte (3.4–5.0 mm long), which infests larch (*Larix*), and *I. calligraphus* (3.8–5.9 mm long; Wood 1982). For the current study, survival of *I. calligraphus* and associated species were evaluated, with the study conducted in Florida where *I. calligraphus* is active throughout the year (Haack 1985).

Materials and Methods

On 28 February 2002, 12 longleaf pine (*Pinus palustris* Mill.) logs were selected for the study at the Georgia-Pacific plywood plant in Hawthorne, Alachua County, Florida (N 29.589° Lat, W 82.038° Long). The logs were from trees that had been cut the previous day in a commercial stand in neighboring Levy County, FL. We selected logs that were nearly fully barked, and laid them horizontally, about 30 cm apart, and supported them 15−25 cm off the ground using dry, debarked pine logs (Fig. 1a). We numbered the logs from 1 to 12 and measured their length and diameter at their base and top (Table 1). To increase the likelihood of rapid colonization by *I. calligraphus* adults, two racemic ipsdienol bubblecap lures (40-mg, 50:50 mix of the two enantiomers; Phero Tech Inc., Delta, British Columbia, Canada) were attached to the upper surface of each log at distances of about ¼ and ¾ of their length (Fig. 1b). Ipsdienol is one of the main components of the *I. calligraphus* aggregation pheromone (Renwick and Vite 1972, Miller et al. 2005).

The bark surface of the test logs was inspected for frass 3−5 times weekly for the next two weeks. Frass is a mixture of boring fragments and feces that *Ips* adults expel from the trees they colonize as they construct their galleries in the cambial area of the tree (Schmitz 1972, Gouger et al. 1975). Frass was observed on most logs on 8 March 2002, and by 12 March all logs had several piles of frass visible. Debarking of the test logs was scheduled for the following week, considering that the parent adult beetles were the main focus of the study and therefore we needed to debark the logs before parent adults began to reemerge and depart the logs. Reemergence of parent adults is common soon after a female has fully constructed her egg gallery and stopped oviposition (Garraway 1986, Haack et al. 1987a).

The first step was to estimate the number of adult bark beetles present in the logs. This was done by randomly selecting four of the 12 logs on 19 March 2002 and then randomly selecting three locations along the trunk to remove a 50-cm-long ring of bark and counting all adult *Ips* bark beetles present in the bark and outer sapwood (Fig. 1c). There are three species of *Ips* bark beetles in the southeastern United States, and all three construct galleries at the sapwood-bark interface and can be found in the same trees (Connor and Wilkinson 1983): *I. calligraphus* being the largest, with *I. avulsus* (Eichhoff) (2.1–2.8 mm long) and *I. grandicollis* (Eichhoff) (2.9–4.6 mm) being smaller (Wood 1982). We recorded the number of *I. calligraphus* adults separately but combined the number of adults of the two smaller *Ips* bark beetles. When sampling these four trees, we counted adults that were still tunneling through the bark as well as those that had already initiated nuptial chambers and egg galleries. These values along with the surface area of bark inspected were used to estimate the average density of *Ips* adults present on the test logs (Table 1). These average density values were then used to estimate the entire population of adult *Ips* bark beetles in all 12 logs.

On 20 March 2002, we spray-painted the bark near the ends of each log so that we could determine using bark color when each log had passed through the debarker (Fig. 1d). The entire bark collection system was cleaned prior to debarking the test logs. Each log was debarked one after the other with bark collected at three processing steps. First, about 5 gallons (19 L) of bark was collected in a bucket from each log after debarking with a Nicholson A1 35-inch ring debarker (Nicholson Forest Products Equipment, Sidney, BC, Canada) that removed the bark in both large and small pieces (Fig. 1e). Next, the remaining bark passed

Figure 1. (A) View of some of the 12 longleaf pine test logs and how they were supported off the ground. (B) One of the two ipsdienol lures that was attached to each of the 12 test logs. (C) View of some test logs with one showing where three 50-cm-long rings of bark had been removed to estimate the initial density of *Ips* parent adults present one day prior to debarking. (D) Some of the test logs awaiting debarking that show how the ends of each log were painted blue so that the bark from each log could be kept separate during debarking process. (E) Bark moving from the debarker down a chute towards the grinder. (F) Hui Ye inspecting bark for insects. Half of the bark recovered on the day of debarking was hand-inspected for live and dead insects, with the other half placed in rearing cans.

through a Montgomery 57-CS-KC grinder (Montgomery Industries International, Inc., Jacksonville, Florida), which had two stages of grinding. The initial grind occurred when a set of rotating hammers punched the bark through a series of rectangular pockets formed by stationary anvils. The second grind happened when the bark was directed against a curved sizing screen with 1-inch-wide openings (2.5 cm). After passing through the Montgomery grinder, the bark was in the form of nuggets, flakes and small-

Table 1. Length, diameter and bark surface area of the 12 test logs that were debarked in the present study, and the average adult density of the two smaller *Ips* species combined (*I. avulsus* and *I. grandicollis*) and separately for *I. calligraphus* based on sampling three 50-cm-long rings of bark that were removed from four of the test logs the day prior to debarking.

Log number	Log length (m)	Log diameter (cm)		Surface area (m^2)*	Average adult density (m^2) **	
		Base	Top		Smaller *Ips*	*Ips calligraphus*
1	8.6	35	26	8.24	90.4	20.0
2	12.3	34	21	10.62		
3	12.6	32	18	9.89		
4	10.7	42	28	11.76		
5	10.7	38	20	9.74		
6	7.9	36	26	7.69		
7	13.9	47	25	15.71	115.1	19.9
8	13.2	39	27	13.68		
9	10.7	38	24	10.42		
10	13.3	41	24	13.27		
11	13.3	35	25	12.53	106.9	10.4
12	10.6	37	22	9.82	126.0	16.0

* Surface area was calculated considering the log a cylinder, using the average of the base and top diameters as the log diameter.
** The three rings of bark sampled on four of the test logs represented a surface area of about 1.35 m^2 on log 1, 1.66 m^2 on log 7, 1.44 m^2 on log 11, and 1.23 m^2 on log 12, for a total area of about 5.7 m^2.

er particles. All this material then passed over a shaker screen [exact screen opening size was not recorded, however 3/8 inch (9.5 mm) is common] that allowed the smaller bark fragments (fines) to pass through. We collected all bark from both the "fines" pile and also at the end of the shaker screen where the bark fell on large plastic tarps. Approximately 50 gallons (189 L) of bark was collected at each of the three process steps, filling two large plastic bags each. Therefore, about one third of all bark from the 12 test logs was collected after passing through the Nicholson debarker with similar amounts of bark collected from each log. The remaining two thirds of the bark was collected after it passed through the Montgomery grinder and over the shaker screen as either fines or nuggets and flakes.

One bag of bark from each of the three bark-collection locations was inspected by hand on 20 March, focusing primarily on live and dead bark beetles and associated Coleoptera that were mostly whole and found among or on the outer surfaces of the bark fragments (Fig. 1f). We did not count small insect parts, such as legs or elytra, or break apart all pieces of bark to look for insects that may have been inside. The remaining three bags of bark were transported to a walk-in insect rearing room on the University of Florida campus in Gainesville, FL, that is maintained by the Department of Entomology and Nematology. There the bark was placed into 21 ventilated 5-gallon (19 L) rearing cans, seven cans per bark-collection location. Each can had two 4-inch-diameter (10 cm) ventilation holes cut on opposite sides near the midpoint of the can wall that were covered with fine-mesh screening and also had a collection jar mounted in the center of each screen (Fig. 2a). We filled each rearing can with bark to a height near the collection jars so that insects emerging through the bark could easily access the jars (Fig. 2b). All 21 cans were kept in the same room that was maintained at about 27 °C with continuous lighting. Over the next six weeks of March and April, all collection jars were inspected 2–3 times per week for insects, and then about once per week to the end of May when emergence appeared to cease. All bark beetles and other associated Coleoptera were collected and identified to family, genus, or species.

We summarized the numbers and types of beetles reared from each of the three bark-collection locations. We estimated the original *Ips* population in all 12 logs by multiplying the average density of adult *Ips* found in the four logs sampled on 19 March by the total surface area of all 12 logs after subtracting the bark area that we had removed during initial sampling. When making the survival calculations it was assumed that all insects remained with the logs and bark during debarking and grinding and that none of the surviving insects escaped or were lost as the bark moved along the conveyor belts or was being collected. Moreover, it was

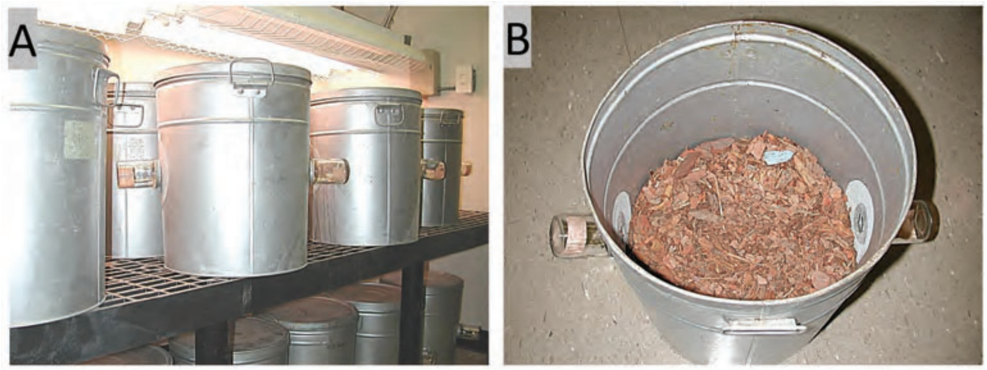

Figure 2. (A) Walk-in environmental room where bark was placed in 21 rearing cans with continuous light, and (B) view inside one of the rearing cans showing that bark was added to a level near the entrance of the collection jars.

assumed that half of all bark, and therefore half of all *Ips* adults, could have been present in the bark that was inspected by hand and the other half could have been present with the bark placed in the rearing cans. Similarly, for the bark in the rearing cans, it was assumed that one third of the bark, and thus one third of the *Ips* population, was in the rearing cans containing bark collected directly from the Nicholson debarker, with the other two thirds of the bark (and *Ips*) being collected after passing through the Montgomery grinder as either fines or nuggets and flakes.

Results

In addition to *I. calligraphus,* several species of bark beetles and associated Coleoptera were recovered during the initial bark dissections as well as during the subsequent rearing period (Tables 2 and 3). For the bark that was inspected soon after debarking and grinding, 142 beetles were recovered in a state that could be identified (Table 2). The 142 beetles represented eight families of Coleoptera, with about 75% of the total being bark beetles (Scolytinae), and the next largest group being Trogositidae (ca. 15%; Table 2). Of the 142 beetles, 125 were dead and 17 were alive. Of the 17 live beetles re-

Table 2. Summary data for the number of individual beetles by taxonomic group found either dead or alive in longleaf pine bark inspected by hand soon after mechanical debarking was complete in March 2002. Similar amounts of bark were collected at three steps during the debarking and grinding process: (1) after debarking but before grinding (debarker), and then after grinding and screening as either (2) bark nuggets or flakes that did not pass through the screen (grinder: nuggets) or (3) bark fines that passed through the screen (grinder: fines).

	Number of adults collected dead or alive by location							
	Debarker		Grinder: nuggets		Grinder: fines		All combined	
Insect	Dead	Alive	Dead	Alive	Dead	Alive	Dead	Alive
Bostrichidae	0	1	0	0	0	0	0	1
Cerambycidae	1	0	0	0	1	0	2	0
Colydiinae	3	4	0	0	0	0	3	4
Elateridae	0	0	0	0	1	0	1	0
Histeridae	2	0	0	0	0	0	2	0
Scolytinae (total)	81	5	11	0	9	0	101	5
Dendroctonus terebrans	0	0	0	0	1	0	1	0
Smaller *Ips*	77	3	11	0	7	0	95	3
Ips calligraphus	4	2	0	0	1	0	5	2
Tenebrionidae	1	0	0	0	1	0	2	0
Trogositidae	8	6	0	0	6	1	14	7
Grand Total	96	16	11	0	18	1	125	17

Table 3. Summary data for the number of live beetles collected from rearing cans that contained longleaf pine bark collected soon after mechanical debarking was complete in March 2002. Similar amounts of bark were collected at three steps during the debarking and grinding process: (1) after debarking but before grinding (debarker), and then after grinding and screening as either (2) bark nuggets or flakes that did not pass through the screen (grinder: nuggets) or (3) bark fines that passed through the screen (grinder: fines). Data are presented by various taxonomic groups and by month of collection.

	Number collected by location				Month collected		
Family	Total	Debarker	Grinder: nuggets	Grinder: fines	March	April	May
Bostrichidae	1	1	0	0	1	0	0
Cerambycidae	1	1	0	0	1	0	0
Colydiinae	21	18	1	2	9	10	2
Corylophidae	1	1	0	0	0	1	0
Histeridae	1	1	0	0	1	0	0
Scolytinae (total)	59	46	7	6	41	14	4
Gnathotrichus sp.	1	1	0	0	1	0	0
Ips avulsus	30	22	4	4	24	6	0
Ips grandicollis	6	4	0	2	2	4	0
Ips calligraphus	2	2	0	0	1	1	0
Pityophthorus sp.	20	17	3	0	13	3	4
Silvanidae	1	0	0	1	1	0	0
Staphylinidae	1	1	0	0	1	0	0
Tenebrionidae	14	11	0	3	7	6	1
Grand Total	100	80	8	12	62	31	7

covered, 16 were found in bark collected from the Nicholson debarker with the remaining one found in the bark fines after passing through the Montgomery grinder (Table 2). The 17 live beetles included one bostrichid, 4 colydiines (Zopheridae), 5 scolytines, and 7 trogositids (Table 2). Of all 142 beetles recovered, about 79% were found in the bark collected from the debarker and 21% in the bark collected from the grinder (8% in the bark nuggets and 13% in the bark fines).

From the bark placed in the rearing cans, 100 live beetles were collected, representing nine beetle families (Table 3). The three largest groups of beetles reared were the Scolytinae (59 individuals), Colydiinae (21), and Tenebrionidae (14), with just one individual each for the other six families (Table 3). Eighty of the 100 live beetles were reared from bark collected from the debarker with 20 reared from the bark after passing through the grinder (8 from the bark nuggets and 12 from the bark fines). Of the 100 live beetles, 62 were collected during the last 11 days of March after processing (March 21–31), 31 beetles in April, and 7 in May 2002 (Table 3).

Three species of *Ips* were reared from the bark samples as well as individuals representing two other bark beetle genera (*Gnathotrichus* and *Pityophthorus*) (Table 3). Two *I. calligraphus* were reared, both from the bark collected from the debarker, but none emerged from the bark collected after grinding (Table 3). For the 2 smaller *Ips* species, 30 *I. avulsus* were collected and 6 *I. grandicollis*. For these smaller *Ips*, 26 of the 36 individuals were from bark collected from the debarker with 10 reared from bark after passing through the grinder (4 from the bark nuggets and 6 from the bark fines; Table 3). Of the 20 *Pityophthorus* individuals reared in the present study (Table 4), 17 were recovered after debarking and 3 from the bark nuggets after grinding.

Both debarking and grinding resulted in near complete mortality of the *Ips* bark beetles (Table 4). The values used to make these calculations are shown in Table 4 for the two smaller *Ips* species combined (*I. avulsus* and *I. grandicollis*) and separately for *I. calligraphus*. The estimated average (± SE) *Ips* densities in the 12 test logs were 109.6 ± 7.5 smaller *Ips* adults / m^2 of bark surface area (range 90.4–126.0) and 16.6 ± 2.3 *I. calligraphus* adults / m^2 (range 10.4–20.0) (Tables 1 and 4). These values indicated an estimated initial population in the 12 logs of 14,080 smaller *Ips* adults and 2,176 *I. calligraphus* adults (Table 4). Of these *Ips* adults, half were assumed to have been present in the bark placed in the rearing cans, i.e., about 7,040 smaller *Ips* adults and 1,088 *I. calligraphus* adults (Table 4). After rearing was complete, 36 smaller *Ips* (26 from bark collected after debarking and 10 from bark

Table 4. Summary data for the values and calculations used to determine bark beetle mortality following debarking and grinding of bark from naturally infested longleaf pine logs in Florida. Data are presented for the two smaller *Ips* species combined (*I. avulsus* and *I. grandicollis*) and separately for *I. calligraphus*.

Value or calculation	Smaller *Ips*	*Ips calligraphus*
A: Estimated (Est.) adult density	110 / m^2	17 / m^2
B: Original total log surface area	133.7 m^2	133.7 m^2
C. Area removed during sampling (see Table 1)	5.7 m^2	5.7 m^2
D. Bark surface area when debarked (B–C)	128 m^2	128 m^2
E: Est. total No. adults (A × D)	14,080	2,176
F: Est. No. adults in reared bark (E / 2)	7,040	1,088
G: Est. No. adults that could have been in reared bark collected from the debarker (F × 1/3)	2,347	363
H: Est. No. adults that could have been in reared bark collected from the grinder (F × 2/3)	4,693	725
I: No. adults reared from bark collected from the debarker	26	2
J: No. adults reared from bark collected from the grinder	10	0
K: % Adult survival after the debarker (I / G × 100)	1.11 %	0.55 %
L: % Adult mortality after the debarker (100 – K)	98.89 %	99.44 %
M: % Adult survival after the grinder (J/H × 100)	0.21 %	0.0 %
N: % Adult mortality after the grinder (100 – M)	99.79 %	100 %

collected after grinding) and 2 *I. calligraphus* (both from the bark collected after debarking) had been collected alive (Tables 3 and 4). These values yielded mortality estimates for smaller *Ips* of 98.9% after debarking and 99.8% after grinding, and similarly, 99.4% after debarking and 100% after grinding for *I. calligraphus* (Table 4).

Discussion

In the case of *I. calligraphus*, debarking alone resulted in over 99% mortality, and when followed by bark grinding, 100% mortality was achieved. Therefore, if *I. calligraphus* is a good surrogate for *T. piniperda*, then debarking followed by bark grinding should result in near complete mortality of *T. piniperda* and other bark beetles of similar size in pine bark products such as nuggets and mulch. As stated above, Dubbel (1993) reported that debarking Norway spruce logs resulted in 93% mortality for *I. typographus*, but they also reported only 30% mortality for the smaller bark beetle *Pityogenes chalcographus* (L.) in the same logs. Adult *I. typographus* measure 4.2–5.5 mm long (Cavey et al. 1994), being similar in size to *I. calligraphus,* and *P. chalcographus* measure 1.6–2.9 mm long (Cavey et al. 1994), similar to *I. avulsus*. Likewise, in our study, it was the smallest *Ips* species reared (*I. avulsus*) that was collected in the highest numbers, with the next most numerous taxon being the *Pityophthorus* bark beetles, which are also rather small, i.e., about 1.6 mm long (Goyer et al. 1980).

High levels of scolytine mortality have also been reported when trunks and branches of infested trees were mechanically chipped. For example, Lanz and Baeskow (1986) reported 95–99% mortality of the bark beetle *P. chalcographus* after chipping. Similarly, for the ambrosia beetles *Euwallacea* sp. and *Xyleborus glabratus* Eichhoff, chipping resulted in 97–99% mortality (Spence et al. 2013, Jones and Paine 2015, Chen et al. 2020). Given the small size of most scolytines, chipping or debarking followed by grinding will seldom provide 100% control but can dramatically lower the scolytine population that is present at the time of processing.

Of all 59 bark beetles reared in the present study, the 4 individuals that emerged in May were all *Pityophthorus* species. Given that May represented a time period about 6–10 weeks after the initial debarking, the beetles emerging in May could have been brood adults that developed in the bark. Generation times during summer are usually completed in a month or less for *Pityophthorus* species (which have 2 larval instars) as well as *I. calligraphus* (which has three larval instars) (Hedlin and Ruth 1970, Haack 1985, Haack et al. 1987a, Wagner et al. 1987, Furniss and Kegley 2018). Each of the four *Pityophthorus* beetles that emerged in May was recovered from a different rearing can, with two reared from bark collected after debarking and two from the bark nuggets after grinding. Unfortunately, the bark was not examined for larval galleries and exit holes after rearing was complete, so we cannot state for certain if these late-emerging adults were in fact brood adults.

Besides bark beetles, a wide variety of other Coleoptera were reared from the bark samples (Table 3). Most of these beetles were only identified to family, but a few were identified to genus or species. The one bostrichid collected was likely one of the four pine-infesting *Stephanopachys* species present in Florida (Beiriger 2002). The one reared cerambycid was identified as *Acanthocinus obsoletus* (Olivier). This adult was collected from bark that had only been processed with the debarker. Adults of *A. obsoletus* measure 7–13 mm long (Yanega 1996) and are early colonizers of bark-beetle infested pine trees (Ulyshen and Hanula 2010). This cerambycid was the largest beetle species collected from the rearing cans. Given that this cerambycid was collected on the first day of inspection of the rearing cans (22 March 2002), this unsexed adult was likely searching for a mate or ovipositing on the bark surface when the log entered the debarker.

The reared specimens of Colydiinae, Corylophidae, Silvanidae, and Staphylinidae were not identified to genus or species. Species of Corylophidae and Silvanidae are fungus-feeders (Thomas 1993, Bowestead and Leschen 2002), Staphylinidae are predaceous (Wegensteiner at al. 2015), while many Colydiinae can be both predaceous and fungivorous (Ivie 2002). The reared Tenebrionidae were members of the genus *Corticeus*, which are facultative bark beetle predators (Triplehorn 1990, Hain et al. 2011). Given the small size of most of the above beetles, and their close association with bark beetles (Goyer et al. 1980), it is understandable that many individuals would be present on the test logs, and some would survive the debarking and grinding processes.

In summary, our results indicate that debarking and subsequent bark grinding results in near complete mortality of larger bark beetles such as *I. calligraphus*, but is slightly less effective against smaller species such as *I. avulsus*, *I. grandicollis*, and *Pityophthorus* spp. Given similarities in adult size between *I. calligraphus* and *T. piniperda*, debarking and subsequent bark grinding of logs infested with *T. piniperda* should also result in very high mortality of *T. piniperda.* In recent treatment protocols approved by USDA APHIS for movement of bark nuggets and mulch from areas quarantined for Asian longhorned beetle [*Anoplophora glabripennis* (Motschulsky); Coleoptera: Cerambycidae) (USDA APHIS 2014), or the emerald ash borer (*Agrilus planipennis* Fairmaire; Coleoptera: Buprestidae) (USDA APHIS 2020a), bark chips and mulch were required to be less than one inch (2.5 cm) in at least two dimensions prior to movement to areas outside the quarantine zones. Given the results of the present study, a similar regulation for movement of pine bark from areas infested with *T. piniperda* would likely also provide an acceptable level of risk. Although USDA APHIS removed the domestic federal quarantines for both *T. piniperda* and *A. planipennis* in 2020 (Haack 2020, USDA APHIS 2020b, 2020c), a similar treatment protocol for bark would likely prove effective for future bark- and wood-infesting insects similar in size or larger than *I. calligraphus*.

Acknowledgments

We thank James R. Meeker (currently Entomologist, USDA Forest Service, Forest Health Protection, but at the time of this study was with the Florida Forest Service) for helping arrange the study at the Georgia-Pacific plant; staff of the Georgia-Pacific plywood plant for supplying the pine logs used in this study and allowing us to use their debarking and grinding equipment; and Yigen Chen (senior statistician, E. & J. Gallo Winery), James R. Meeker (USDA Forest Service) and two anonymous reviewers for their valuable comments on an earlier version of this paper . This research was supported in part by the USDA Forest Service.

Literature Cited

Anderson, N. H. and D. B. Anderson. 1968. *Ips* bark beetle attacks and brood development on a lightning-struck pine in relation to its physiological decline. Florida Entomologist 51: 23–30.

Atkinson, T. H. 2024. Bark and ambrosia beetles of the Americas. Available from: https://www.barkbeetles.info/

Beiriger, R. L. 2002. Three bostrichid beetles new to Florida (Coleoptera: Bostrichidae). Insecta Mundi 16(4): 214.

Bowestead, S. and R. A. B. Leschen. 2002. 94. Corylophidae LeConte 1852. Pages 390-394 in: R. H. Arnett Jr, M. C. Thomas, P. E. Skelley, and J. H. Frank (eds.), American beetles, Volume 2: Polyphaga: Scarabaeoidea through Curculionoidea. CRC Press. Boca Raton, FL.

Cavey, J., S. Passoa, and D. Kucera. 1994. Screening aids for exotic bark beetles in the Northeastern United States. U.S. Department of Agriculture, Forest Service, Northeastern Area, NA-TP-11-94.

Chen, Y., T. W. Coleman, A. L. Poloni, L. Nelson, and S. J. Seybold, 2020. Reproduction and control of the invasive polyphagous shot hole borer, *Euwallacea* nr. *fornicatus* (Coleoptera: Curculionidae: Scolytinae), in three species of hardwoods: Effective sanitation through felling and chipping. Environmental Entomology, 49: 1155−1163.

Ciesla, W. M. 1973. Six-spined engraver beetle. USDA Forest Service, Forest Pest Leaflet 141.

Connor, M. D. and R. C. Wilkinson. 1983. *Ips* bark beetles in the South. USDA Forest Service, Forest Insect and Disease Leaflet 129.

Dubbel, V. 1993. Survival of spruce bark beetles during machine debarking. AFZ, Allgemeine Forst Zeitschrift 48(7): 359–360. (in German)

Furniss, M. M. and S. J. Kegley. 2018. Biology of *Pityophthorus pulchellus tuberculatus* (Coleoptera: Curculionidae: Scolytinae) in lodgepole pine in northern Idaho. Environmental Entomology 47: 775–780.

Garraway, E. 1986. The biology of *Ips calligraphus* and *Ips grandicollis* (Coleoptera: Scolytidae) in Jamaica. The Canadian Entomologist 118: 113–121.

Gouger, R. J., W. C. Yearian, and R. C. Wilkinson. 1975. Feeding and reproductive behavior of *Ips avulsus*. The Florida Entomologist 58: 221–229.

Goyer, R. A., G. J. Lenhard, T. E. Nebeker, and L. D. Jarrard. 1980. How to identify common insect associates of the southern pine beetle. US Department of Agriculture, Agriculture Handbook No. 563. 33 pp.

Haack, R. A. 1985. Seasonal development and emergence-flight patterns of *Ips calligraphus* in Florida. The Florida Entomologist 68: 658–667.

Haack, R. A. 2020. Where have all the pine shoot beetles gone, long time passing. The 1992 PSB federal quarantine is coming to an end. Newsletter of the Michigan Entomological Society. 64(2): 1–3.

Haack R. A. and D. Kucera. 1993. New introduction—common pine shoot beetle, *Tomicus piniperda* (L.). USDA Forest Service, Northeastern Area, Pest Alert NA-TP-05-93. 2 pp

Haack, R. A. and T. M. Poland. 2001. Evolving management strategies for a recently discovered exotic forest pest: the pine shoot beetle, *Tomicus piniperda* (Coleoptera). Biological Invasions 3: 307–322.

Haack, R. A., R. C. Wilkinson, and J. L. Foltz. 1987a. Plasticity in life-history traits of the bark beetle *Ips calligraphus* as influenced by phloem thickness. Oecologia 72: 32–38.

Haack R. A., R. C. Wilkinson, J. L. Foltz., and J. A. Corneil. 1987b. Spatial attack pattern, reproduction, and brood development of *Ips calligraphus* (Coleoptera: Scolytidae) in relation to slash pine phloem thickness: A field study. Environmental. Entomology 16: 428–436.

Haack, R. A., R. F. Billings, and A. M. Richter. 1989. Life history parameters of bark beetles (Coleoptera: Scolytidae) attacking West Indian pine in the Dominican Republic. Florida Entomologist 72: 591–603.

Haack, R. A., F. Hérard, J. Sun, and J. J. Turgeon. 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: a worldwide perspective. Annual Review of Entomology, 55: 521–546.

Hagge, J., F. Leibl, J. Müller, M. Plechinger, J. G. Soutinho, and S. Thorn. 2019. Reconciling pest control, nature conservation, and recreation in coniferous forests. Conservation Letters 12:e12615.

Hain, F. P., A. J. Duehl, M. J. Gardner, and T. L Payne. 2011. Natural history of the southern pine beetle. Pages 13-24 in: R. N. Coulson and K. D. Klepzig (eds.), Southern pine beetle II. USDA Forest Service, Southern Research Station. General Technical Report SRS-140. Asheville, NC.

Hedlin, A. F. and D. S. Ruth. 1970. A Douglas-fir twig mining beetle, *Pityophthorus orarius* (Coleoptera: Scolytidae). The Canadian Entomologist, 102: 105–108.

Ivie, M. A. 2002. Colydiidae Erichson 1845. Pages 445–453 in: R. H. Arnett Jr, M. C. Thomas, P. E. Skelley, and J. H. Frank (eds.), American Beetles, Volume 2: Polyphaga: Scarabaeoidea through Curculionoidea. CRC Press. Boca Raton, FL.

Jones, M. E. and T. D. Paine. 2015. Effect of chipping and solarization on emergence and boring activity of a recently introduced ambrosia beetle (*Euwallacea* sp., Coleoptera: Curculionidae: Scolytinae) in southern California. Journal of Economic Entomology 108: 1852–1859.

Lanz, W. and J. Baeskow. 1986. Control of *Pityogenes chalcographus* by chipping small-diameter Norway spruce wood. Forst und Holzwirt. 41: 178–182. (In German)

McCullough, D. G., T. M. Poland, D. Cappaert, E. L. Clark, I. Fraser, V., Mastro, S. Smith, and C. Pell. 2007. Effects of chipping, grinding, and heat on survival of emerald ash borer, *Agrilus planipennis* (Coleoptera: Buprestidae), in chips. Journal of Economic Entomology 100: 1304–1315.

Miller, D. R., C. Asaro, and C. W. Berisford. 2005. Attraction of southern pine engravers and associated bark beetles (Coleoptera: Scolytidae) to ipsenol, ipsdienol, and lanierone in southeastern United States. Journal of Economic Entomology 98: 2058–2066.

Postner, M. 1974. Scolytidae (= Ipidae), Borkenkäfer. Pages 334–482 in: W. Schwenke (ed), Die Forstschädlinge Europas, II Käfer, vol 2. Verlag Paul Parey. Hamburg and Berlin, Germany. (in German)

Renwick, J. A. A. and J. P. Vite. 1972. Pheromones and host volatiles that govern aggregation of the six-spined engraver beetle, *Ips calligraphus*. Journal of Insect Physiology 18: 1215-1219.

Schmitz. R. F. 1972. Behavior of *Ips pini* during mating, oviposition, and larval development (Coleoptera: Scolytidae). The Canadian Entomologist 104: 1723–1728.

Spence, D. J., J. A. Smith, R. Ploetz, J. Hulcr, and L. L. Stelinski. 2013. Effect of chipping on emergence of the redbay ambrosia beetle (Coleoptera: Curculionidae: Scolytinae) and recovery of the laurel wilt pathogen from infested wood chips. Journal of Economic Entomology 106: 2093–2100.

Thomas, M. C. 1993. The flat bark beetles of Florida (Coleoptera: Silvanidae, Passandridae, Laemophloeidae). Arthropods of Florida and Neighboring Land Areas 15: 1–93.

Thorn, S., C. Bässler, H. Bußler, D. B. Lindenmayer, S. Schmidt, S. Seibold, B. Wende, and J. Müller. 2016. Bark-scratching of storm-felled trees preserves biodiversity at lower economic costs compared to debarking. Forest Ecology and Management 364: 10–16.

Triplehorn, C. A. 1990. Review of the genus *Corticeus* (Coleoptera: Tenebrionidae) of America north of Mexico. Annals of the Entomological Society of America 83: 287–306.

Ulyshen, M. D. and J. L. Hanula. 2010. Patterns of saproxylic beetle succession in loblolly pine. Agricultural and Forest Entomology 12: 187–194.

USDA APHIS (United States Department of Agriculture, Animal and Plant Health Inspection Service). 2014. Pest response guidelines: Asian longhorned beetle (*Anoplophora glabripennis*). Available from: https://www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/downloads/response-guidelines.pdf

USDA APHIS 2020a. Emerald ash borer program manual *Agrilus planipennis* (Fairmaire). Available from: https://www.aphis.usda.gov/import_export/plants/manuals/domestic/downloads/eab.pdf

USDA APHIS. 2020b. 7 CFR Parts 301 and 319—Deregulation of pine shoot beetle. Federal Register, 1 October 2020. 85(191): 61,806–61,809.

USDA APHIS. 2020c. 7 CFR Part 301—Removal of emerald ash borer domestic quarantine regulations. Federal Register, 15 December 2020. 85(241): 81,085–81,095.

Wagner, T. L., W. S. Fargo, R. O. Flamm, R. N. Coulson, and P. E. Pulley, 1987. Development and mortality of *Ips calligraphus* (Coleoptera: Scolytidae) at constant temperatures. Environmental Entomology, 16: 484–496.

Wang, B., V. C. Mastro, and W. H. McLane. 2000. Impacts of chipping on surrogates for the longhorned beetle *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in logs. Journal of Economic Entomology 93: 1832–1836.

Wegensteiner, R., B. Wermelinger, and M. Herrmann. 2015. Natural enemies of bark beetles: predators, parasitoids, pathogens, and nematodes. Pages 247–304 in: F. E. Vega and R. W. Hofstetter (eds), Bark Beetles. Biology and Ecology of Native and Invasive Species. Elsevier/Academic Press, London, UK.

Wilkinson, R. C., R. W. Britt, E. A. Spence, and S. M. Seiber. 1978. Hurricane-tornado damage, mortality, and insect infestations of slash pine. Southern Journal of Applied Forestry 2:132–134.

Wood, S. L. 1982. The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae), a taxonomic monograph. Great Basin Naturalist Memoir 6: 1–1356.

Yanega, D. 1996. Field guide to northeastern longhorned beetles (Coleoptera: Cerambycidae). Illinois Natural History Survey, Manual 6. Champaign, IL.