Tomicus piniperda (Coleoptera: Scolytidae) Emergence in Relation to Burial Depth of Brood Logs

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ABSTRACT The pine shoot beetle, *Tomicus piniperda* (L.), is an exotic pest of pines, *Pinus* spp., that was first found in the United States in 1992. A federal quarantine currently regulates movement of pine Christmas trees and pine nursery stock from infested to uninfested counties. The current national Pine Shoot Beetle Compliance Management Program requires *T. piniperda*-infested brood material to be disposed of by burning, chipping, or burial. The burial option requires that the infested pine material be buried at a depth of at least 30 cm. We tested this requirement by burying logs with similar levels of infestation at 0, 15, 30, 45, 61 and 76 cm and then monitoring for *T. piniperda* emergence. Logs were buried at two times during larval development (early and late) and in two soil types (sandy loam and loam). Emergence patterns from the two soil types were similar. Overall, 1,747 *T. piniperda* adults were collected from the 24 exposed control logs, but only 34 adults from the 120 buried logs, including 24 adults from logs buried at 15 cm, eight adults from 30 cm, one adult from 45 cm, and one adult from 61 cm. In comparing mean emergence density from buried logs with that of exposed logs, 98.6% mortality occurred at 15 cm, 99.5% at 30 cm, and >99.9% at ≥45 cm. Mean date of *T. piniperda* emergence to the soil surface was affected by burial depth and burial date, but not soil type.

KEY WORDS *Tomicus piniperda*, cultural control, exotic pest

THE PINE SHOOT beetle, *Tomicus piniperda* (L.), is a major pest of pines, *Pinus* spp., throughout its native range of Europe, Asia, and North Africa (Bakke 1968; Långström 1983; Ye 1991). In North America, *T. piniperda* was first discovered in Ohio in 1992 (Haack and Kucera 1993; Haack 1997; Haack et al. 1997), and as of November 1999, it was known to occur in 271 counties in 11 U.S. states, and in 25 counties in Ontario and eight counties in Quebec, Canada.

The general biology of *T. piniperda* is well documented (Bakke 1968; Salonen 1973; Långström 1983; Ye 1991; Haack and Lawrence 1995a, b; 1997a; Lawrence and Haack 1995, McCullough and Smitley 1995; Haack et al. 1997, 1998; Kauffman et al. 1998). *T. piniperda* is univoltine and overwinters as an adult in the outer bark on the lower trunk of live pine trees. In the Great Lakes area, adults generally initiate flight in March and seek brood material for reproduction. Recently cut or fallen pine trunks, branches, and stumps commonly serve as breeding sites. Typically, the new generation of adults emerges in early June. Instead of initiating a second generation, the new adults fly to the crowns of pine trees and feed inside shoots throughout the summer. In fall, in response to freezing temperatures, the adults exit the shoots and move to their overwintering sites on the lower trunks of pine trees near groundline.

Since 1992, a federal quarantine has been imposed by the United States Department of Agriculture, Animal and Plant Health Inspection Service, on the movement of pine from *T. piniperda*-infested counties to uninfested counties within the United States (USDA–APHIS 1992). The quarantine regulates the movement of pine logs, pine Christmas trees, and pine nursery stock. The most significant change in the federal quarantine was the implementation in 1997 of the Pine Shoot Beetle Compliance Management Program for the Christmas tree and nursery industries (McCullough and Sadof 1996, 1998; USDA–APHIS 1996). This voluntary compliance program allows growers in infested areas to ship their trees to uninfested areas, provided that the growers strictly follow a series of management guidelines. The rationale for the compliance program is that if all necessary pest management steps are followed, the resulting *T. piniperda* population will be too low to pose a significant risk of spreading the beetle to new areas.

The management guidelines for the compliance program are based primarily on published and unpublished research findings from several studies conducted during 1992–1996 (Sadof et al. 1994; Haack and Lawrence 1995a, 1995b; 1997a, 1997b; Lawrence and Haack 1995; McCullough and Smitley 1995; Haack 1997; Haack et al. 1997, 1998; Kauffman et al. 1998; McCullough et al. 1998; McCullough and Sadof 1998). However, for some guidelines, information specific to *T. piniperda* was lacking; for example, no specific data were available for the proper burial depth of infested pine logs. The original regulation, as written in the compliance program (USDA–APHIS 1996), required that pine brood material (if not chipped or burned) be buried at a minimal depth of 30 cm (12 in) by 20 May. In 1999, USDA-APHIS revised certain aspects of the compliance program. With respect to log burial, the minimal depth of 30 cm was not changed, however, the deadline date of 20 May could be changed by each infested state based on their own local climatic conditions (Haack et al. 1998). Although no data were available for *T. piniperda*, the emergence of two other bark beetles, *Dendroctonus brevicomis* LeConte and *Dendroctonus rufipennis* (Kirby), was effectively stopped when logs were buried below 35–40 cm (Miller and Keen 1960; Safranyik and Linton 1982). Therefore, the USDA-APHIS Science Panel for *T. piniperda* considered 30 cm to be a relatively safe guideline. Our main objective, therefore, was to determine how variation in the burial depth of infested pine logs affected subsequent emergence of *T. piniperda* progeny adults. A secondary objective was to investigate how soil type and burial date influenced *T. piniperda* emergence from buried logs.

Materials and Methods

In early February 1997, 150 log bolts were cut from the trunks of Scotch pine, *Pinus sylvestris* L., trees at the Michigan State University Kellogg Experimental Forest near Augusta, Kalamazoo Co., MI. Logs were ≈13 cm in diameter and 40 cm in length. On 12 February 1997, logs were placed throughout a Christmas tree plantation near Mason, Ingham Co., MI, known to harbor a high population of *T. piniperda*. To allow *T. piniperda* adults to colonize the logs fully, each log was elevated a few cemtimeters above the ground on two heavy-gauge wire supports. *T. piniperda* spring flight was first recorded at the Christmas tree plantation on 21 March 1997.

Two burial sites, one with a sandy soil and one with a loamy soil, were selected on 16 April 1997 at Kellogg Forest. The sandy site was classified as a Bronson sandy loam (mesic Aquic Hapludalfs), which consists of moderately well-drained, moderately rapidly permeable soils on outwash plains with a 0–3% slope (Austin 1979). The typical Bronson sandy loam is described as a sandy loam from 0 to 23 cm, a loamy sand from 23 to 43 cm, and a sandy loam from 43 to 84 cm. The loamy site was classified as a Sleeth loam (mesic Aeric Ochraqualfs), which consists of somewhat poorly drained, moderately permeable soils on outwash plains with a 0–2% slope (Austin 1979). The typical Sleeth loam is described as a loam from 0 to 25 cm, a clay loam from 25 to 33 cm, a sandy clay loam from 33 to 74 cm, and a clay loam from 74 to 94 cm. Both burial sites were open fields. These two soil types represented the typical range of soils that are commonly planted to pine Christmas trees in Michigan.

Three trenches were dug at each site with a backhoe on 18 April 1997. Each trench was ≈5 m long, 60 cm wide, and 1 m deep. On 25 April 1997, the first set of experimental logs was buried at Kellogg Forest. For each trench, two exposed logs served as controls and 10 logs were buried. Two logs were placed side-by-side at depths of 15, 30, 45, 61, and 76 cm. The logs in each pair were touching each other. Measurements of log burial depth were made from the upper surface of each log. Adjacent pairs of logs within each trench were separated by at least 60 cm. A section of straight wire was inserted vertically in the soil between each pair of logs before the soil was returned to the trench. Each wire, which extended above the soil line, was labeled and used to mark the center of each pair of logs. Each trench was filled by shovel with the original soil and then walked over to pack the soil down. On 9 June 1997, the same procedure was used to bury the second set of logs. Based on an examination of a few of the extra logs, most *T. piniperda* brood were eggs or first instars at the time of the first burial, whereas most were last instars and pupae with a few teneral adults at the time of the second burial.

Brood adults emerging from the soil were captured with traps constructed from large plastic, opaque containers with the open end measuring 36 by 51 cm. This trapping area probably captured most beetles as they emerged from the soil because a pair of logs averaged 26 by 40 cm. Two holes (2 cm diameter) were cut on opposite sides of each container in the center of the 36-cm-wide sides. Over each hole a plastic lid (6 cm diameter) with a 2-cm-diameter hole in the center was glued. A plastic cup was screwed on each lid. In addition, ≈50 holes (1 mm diameter) were drilled through the top of each trap to allow water and air to enter. To guard against adults chewing through these small holes, a layer of fine-mesh nylon screening was glued over the holes. Using the wire as a guide, each trap was centered over a pair of buried logs. Similar traps were placed over each pair of exposed control logs. To reduce the likelihood that beetles would escape from beneath the edge of each container, sand was piled around the perimeter of each trap.

When beetles emerged from the soil and entered each trap, they walked or flew to the two lighted areas on the container walls and became trapped in the plastic cups. Beetles were collected by unscrewing the plastic cups and transferring the contents into labeled bags. The traps were installed on 11 June 1997, before any *T. piniperda* brood adults emerged. Traps were monitored for emerging insects from 13 June (Julian day 164) until 27 September 1997 (Julian day 270). Collections were made at intervals of 2–3 d during June and July, and then weekly through September. The mean date of adult emergence was calculated from the Julian days on which adults were collected. Upon removal of the traps in October, we found that some adult beetles had become trapped under the screen. These beetles were not used in calculating average emergence date, but they were used in calculating the number of beetles emerging per unit of log surface area (see below).

On 2 October 1997, all 144 test logs were recovered, and in the next few days they were washed, inspected, debarked, and reinspected. The following information was recorded: (1) log diameter inside the bark, (2) log length, (3) number of bark beetle exit holes per log (0, <50, and ≥50), (4) presence or absence of *T. pin-*

Table 1. Adult *T. piniperda* emergence density (mean ± SEM) and emergence Julian day (mean ± SEM), and adult *I. pini* emergence density (mean ± SEM) for beetles collected from Scotch pine logs buried on two dates and at six depths; data were combined for the two soil types

Burial depth, cm	*T. piniperda*					*I. pini*	
	n^a	Mean no./m²	Mean emergence date			n^a	Mean no./m²
			1st burial	2nd burial	Combined		
0	1,747	216.3 ± 35a	179 ± 0.2b	181 ± 0.1bc	180 ± 0.1b	114	11.0 ± 5.2a
15	24	3.0 ± 1.7b	191 ± 2.1a	180 ± 1.2bc	182 ± 1.4b	6	1.2 ± 0.6b
30	8	1.1 ± 0.6b	195 ± 0a	177 ± 3.2c	184 ± 3.8b	2	0.5 ± 0.5b
45	1	0.1 ± 0.1b	—	190b	190b	5	1.2 ± 0.9b
61	1	0.1 ± 0.1b	—	220a	220a	0	0b
76	0	0b	—	—	—	0	0b
n^b		72	603	1088	1691		36
F		133.0	48.2	18.8	21.1		7.3
df		5, 66	2, 600	4, 1083	4, 1686		5, 30
P<		0.0001	0.0001	0.0001	0.0001		0.0001

Means followed by the same letter (within columns) are not significantly different at the $P = 0.05$ level (Ryan-Einot-Gabriel-Welsch mean separation test).

[a] Total number of adults collected in traps.

[b] Sample size for density data is the number of traps and for emergence data it is the number of beetles.

iperda egg galleries, and (5) percentage of the log surface area covered by *T. piniperda* larval feeding galleries (0, 1–25, 26–50, 51–75, and 76–100%). Emergence density per unit of log surface area was calculated for each trap by dividing the total number of *T. piniperda* adults collected from a given trap by the combined surface area of the pair of logs that were beneath that same trap. All beetles caught in a given trap were assumed to have come from the pair of logs that were directly beneath the trap.

Average emergence density and emergence date were first analyzed with analysis of variance (ANOVA) (SAS Institute 1988; PROC GLM) for a factorial design (2 soil types x two burial dates x six burial depths). Emergence density values were analyzed after log (n + 1) transformation; emergence date values were not transformed. The factors in each analysis that were not significant were then used to pool the data in subsequent analyses. A significance level of $P = 0.05$ was used for all analyses. When the ANOVA was significant, mean separation among treatments was conducted with the Ryan-Einot-Gabriel-Welsch multiple comparison test (SAS Institute 1988, Day and Quinn 1989). Differences in the following variables were analyzed with respect to soil type at each burial depth (Fisher exact test) and burial depth within each soil type (χ-square test): (1) proportion of logs that had *T. piniperda* egg galleries, (2) exit holes, (3) larval galleries that covered 50% or more of the log surface area, and (4) ≥50 exit holes per log.

Results and Discussion

Overall, 1,747 *T. piniperda* adults were collected from the 12 traps that covered the 24 exposed control logs, whereas only 34 adults were collected from the 60 traps that covered the 120 buried logs (Table 1). Of these 34 beetles, 24 (71%) emerged from logs buried at 15 cm, eight (23%) from 30 cm, one (3%) from 45 cm, and one (3%) from 61 cm. No *T. piniperda* were collected from logs buried at 76 cm. Moreover, of the 34 *T. piniperda* adults that emerged from the buried logs, nine (26%) were from the first set of buried logs and 25 (74%) were from the second set of buried logs. Similarly, 28 (82%) of the 34 adults collected from buried logs emerged through the Sleeth loam soil, whereas six adults (18%) emerged through the Bronson sandy loam soil.

The overall factorial-model ANOVAs for the emergence density data were significant ($F = 29.5$; df = 23, 48; $P < 0.001$; $n = 72$ traps), with significant contributions made by burial depth ($F = 132.1$, df = 5, $P < 0.001$), but not soil type ($F = 3.2$, df = 1, $P > 0.082$) or burial date ($F = 1.79$, df = 1, $P > 0.187$). Therefore, after pooling by soil type and burial date, mean emergence density was greater for exposed logs than for logs buried at any depth (Table 1). Among the buried logs, mean emergence density did not differ by burial depth when the exposed logs were included in the analysis (Table 1). However, when the exposed logs were removed from the analysis, mean emergence density decreased with increasing burial depth ($F = 3.3$; df = 4, 55; $P < 0.002$; $n = 60$ traps; Table 1).

When average *T. piniperda* emergence densities were compared at each depth with average emergence density for the control logs (data from Table 1), then mortality was 98.5% in logs buried at 15 cm, 99.5% mortality at 30 cm, and >99.9% mortality at depths of ≥45 cm. These comparisons assume that initial *T. piniperda* attack densities were similar among logs. Although the actual number of egg galleries was not recorded, *T. piniperda* egg galleries were observed on 142 of the 144 experimental logs after they were debarked in October (Table 2). It is likely that *T. piniperda* attack density did not vary significantly among treatments because trap logs were of similar size, had similar bark characteristics, were placed in the same field during *T. piniperda* colonization, and were assigned randomly to the various treatments.

Nearly all logs (99%) contained exit holes, indicating that *T. piniperda* brood in buried logs usually were able to complete development and emerge as adults

Table 2. Percentage of Scotch pine logs that contained *T. piniperda* egg galleries, *T. piniperda* larval galleries that covered ≥50% of the log surface area, and at least one exit hole or ≥50 *T. piniperda* exit holes, by burial depth and soil type

Burial depth, cm	% logs with egg galleries		% logs with ≥50% of surface area with larval galleries		% logs with ≥1 exit hole		% logs with ≥50 exit holes	
	Loam[a]	Sand[b]	Loam	Sand	Loam	Sand	Loam	Sand
0	100a	100a	100a	100a	100a	100a	100a	100a
15	100a	100a	92a	83a	100a	100a	75a	67a
30	92a	100a	75a	100a	92a	100a	50a	75a
45	92a	100a	67a	100a	92a	100a	33b	92a
61	100a	100a	50b	100a	83a	100a	8b	75a
76	100a	100a	58b	100a	92a	100a	25b	92a

Data were pooled by burial date within each soil type, and $N = 12$ logs at each burial depth within each soil type.
Percentage values (within a given parameter and row) followed by the same letter are not significantly different at the $P = 0.05$ level (Fisher exact test).
[a] Sleeth loam.
[b] Bronson sandy loam.

into the soil (Table 2). However, more larval feeding and more adult exit holes were found on the logs buried in the sandy loam soil at depths of 45–76 cm (Table 2), suggesting that brood survival was more successful in logs buried in sandy loam compared with loam. The higher water holding capacity of the heavier Sleeth loam soil may have elevated the moisture content of the logs to levels that hindered brood development and survival. Total monthly precipitation during 1997 at the Kellogg Forest was 3.9 cm in April (below normal), 11.7 cm in May (above normal), and 11.3 cm in June (above normal). Reduced brood survival has been reported for various bark beetles when phloem (inner bark) moisture levels increase much above what is commonly found in live trees (Beanlands 1967, Webb and Franklin 1978). In fact, the relationship between elevated water content and reduced bark beetle attack and survival is the basis for the practice of sprinkling water on the cut logs to reduce bark beetle attack (McMullen and Betts 1982, Syme and Saucier 1995).

The overall factorial-model ANOVAs for the average date of emergence data were significant ($F = 22.8$; df = 11, 1,679; $P < 0.001$; $n = 1,691$ *T. piniperda* adults), with significant contributions made by burial date ($F = 12.5$, df = 1, $P < 0.001$) and burial depth ($F = 23.9$, df = 4, $P < 0.001$) but not soil type ($F = 1.2$, df = 1, $P > 0.268$). Therefore, after pooling for soil type, the average date of *T. piniperda* emergence was significantly delayed with increasing burial depth, especially for logs buried early in larval development (Table 1). The delay in emergence with respect to burial date was especially noticeable for the beetles that emerged from the first set of buried logs at depths of 15 cm ($F = 20.2$; df = 1, 22; $P < 0.001$; $n = 24$ adults), and 30 cm ($F = 17.4$; df = 1, 6; $P < 0.006$; $n = 8$ adults; Table 1).

In addition to *T. piniperda* adults, several *Ips pini* (Say) (Coleoptera: Scolytidae) adults were collected from logs buried on the second burial date in early June (Table 1). The first set of logs was likely buried before *I. pini* initiated its spring flight in 1997, and thus none were available to colonize the first set of logs. The emergence pattern of *I. pini* was similar to that of *T. piniperda* in that log burial significantly reduced emergence, although a few *I. pini* adults emerged from depths of 45 cm (Table 1). Moreover, *I. pini* adults were collected from logs buried in the loam soil to a depth of 45 cm, but only to 15 cm in the sandy loam soil.

The two burial dates used in the current study, 25 April and 9 June, coincided with early and late *T. piniperda* brood development. The original deadline in the compliance program for log burial was 20 May (USDA–APHIS 1996). For the nine U.S. states that were infested with *T. piniperda* in 1996, 20 May was considered a date when most *T. piniperda* brood would be in late larval development. The fact that only a few *T. piniperda* adults emerged through the soil when logs were buried late in brood development (9 June) indicates that the deadline for log burial could be extended closer to the time of probable adult emergence. However, because climatic conditions vary from place to place and from year to year (Haack et al. 1998), a cushion of safety should be factored in when selecting deadline dates for the various management guidelines of the *T. piniperda* compliance program.

Overall, burial depths of 15 and 30 cm were highly effective in killing almost all *T. piniperda* brood. Therefore, the current USDA–APHIS Pine Shoot Beetle Compliance Management Program regulation to bury *T. piniperda*-infested brood material to depths of at least 30 cm in spring appears to be very safe. Nevertheless, to stop all *T. piniperda* emergence, burial depths of 75 cm or deeper would need to be practiced.

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