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SEASONAL SHOOT-FEEDING BY *TOMICUS PINIPERDA* (COLEOPTERA: SCOLYTIDAE) IN MICHIGAN

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ABSTRACT

Seasonal shoot-feeding by *Tomicus piniperda* (L.) was monitored at 2-week intervals on 15 Scotch pine, *Pinus sylvestris* L., trees from 8 April through 16 November 1994 in southern Michigan. All shoots that showed evidence of *T. piniperda* attack were removed every two weeks. In 1994, initial spring flight of *T. piniperda* began on 22 March. At least two live *T. piniperda* adults were found on the 15 trees on each sampling date from 8 April through 1 November 1994. In addition, at least one freshly attacked, beetle-free shoot was found on each sampling date except for 1 November. The greatest numbers of newly attacked shoots, with or without adults present, were found from mid-June through mid-August. All adults found in April and May were likely parent adults, while those from June onward were primarily brood adults. Therefore, at all times of the year, live *T. piniperda* adults can be found on live pine trees, either feeding in the shoots or overwintering at the base of the trunk. Implications of these findings are provided in light of the US federal quarantine on *T. piniperda*.

Established populations of the pine shoot beetle, *Tomicus piniperda* (L.) (Coleoptera: Scolytidae), were first discovered in Ohio in 1992 and as of January 2000 it had spread to 271 counties in 11 US states and 32 counties in 2 Canadian provinces [Haack and Kucera 1993, Haack 1997, Haack et al. 1997, NAPIS 2000; Canadian Food Inspection Agency (pers. comm.)]. Given that *T. piniperda* is a major pest of pines throughout its native Eurasian range (Bakke 1968, Långström 1983, Salonen 1973, Ye 1991), the United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS) implemented a federal quarantine in 1992 on the movement of pine from *T. piniperda*-infested counties to uninfested counties within the US (USDA APHIS 1992). The quarantine regulates the movement of pine logs, pine Christmas trees, and pine nursery stock.

Tomicus piniperda is univoltine. Adults overwinter within the outer bark at the base of the trunk of live pine trees. In early spring, when daily high temperatures begin to exceed 12°C, *T. piniperda* adults initiate flight and seek suitable breeding material such as recently cut or fallen pine logs and stumps. After completing one egg gallery, some parent adults re-emerge and initiate additional egg galleries. In the Great Lakes region, adults of the new

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generation typically begin to emerge in June. These new adults fly to the crowns of pine trees and feed inside one or more shoots during summer and early fall. Then, in apparent response to the first few hard freezes in fall, adults exit the shoots and move to their overwintering sites (Bakke 1968, Haack and Lawrence 1995, 1997b; Långström 1983, McCullough and Smitley 1995, Salonen 1973).

Given the above life-history information, it was thought that there might be a "*T. piniperda*-free" window in spring during which time pine nursery stock could be shipped to areas outside the quarantine zone without inspection or treatment. In theory, this window of opportunity would begin after all adults had left their overwintering sites in early spring and end before the next generation of adults would start shoot feeding in early summer. This scenario is based on the assumption that during spring, parent adults reproduce but do not shoot-feed. However, from studies in northern Europe (Långström 1983, Salonen 1973), it was known that some *T. piniperda* parent adults shoot-feed immediately after overwintering and then look for breeding sites, while others first breed and then shoot-feed before starting their next egg gallery. Since the original source or sources of the North American *T. piniperda* populations are not known (Carter et al. 1996), the type of early-season shoot-feeding behavior reported in Scandinavia might also be observed in the US. Therefore, given the great interest that the US nursery industry had in this question, we decided to explore the seasonal shoot-feeding behavior of a *T. piniperda* population in Michigan.

MATERIALS AND METHODS

In April 1994, we selected 15 open-grown Scotch pine, *Pinus sylvestris* L., trees that were growing in a Christmas tree plantation near Eaton Rapids, Eaton County, MI, that was heavily infested with *T. piniperda*. The 15 trees that we selected were 3–4 m tall and were growing in an area of the 10-ha plantation that was no longer under active management, i.e., these pine trees had not been sheared in several years and were generally 1–2 m taller than the pine Christmas trees under active management.

On 8 April 1994, and continuing at 2-week intervals through 16 November 1994, we thoroughly inspected each of the 15 trees, cutting and removing all current-year and 1-year-old shoots that showed evidence of *T. piniperda* shoot feeding, i.e., a circular, ca. 2-mm wide, entrance hole through the bark. On the first sampling date, we removed shoots attacked in 1994 as well as those attacked in earlier years. Current-year attacks usually had resin near the entrance hole that was yellow and relatively pliable, and the surrounding needles were still green in color. Attacks from earlier years tended to have resin that was whitish in color and would easily crumble when touched, and the surrounding needles were usually yellow to brown in color. The attacked shoots were placed in labeled plastic bags and then refrigerated until inspected, which was usually within 24 h of collection. During the inspection process, we recorded the number of individual attacks (i.e., feeding tunnels) on each shoot, the location of each attack (i.e., on current-year or 1-year-old growth), the presence or absence of *T. piniperda* adults in each tunnel, and whether each adult was alive or dead. In addition, other notes were taken on the condition and length of the tunnels, the color and condition of the foliage, the presence and condition of pitch tubes that surrounded the entrance to some tunnels, and the color of the adult beetles.

A one-way ANOVA (PROC GLM, SAS Institute 1989) was used to test for differences among collection periods in the average number of attacked

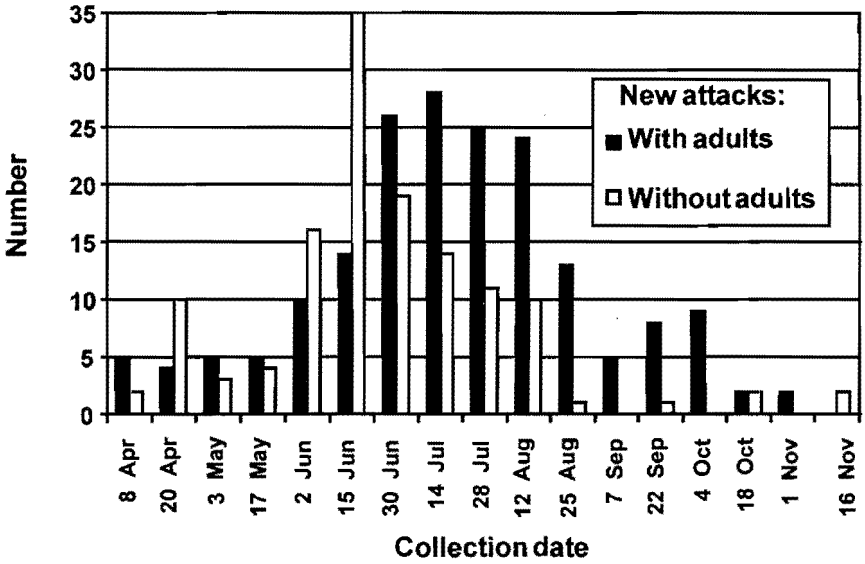

Figure 1. Total number of newly attacked shoots collected from 15 Scotch pine trees in Michigan at 2-week intervals from 8 April through 16 November 1994 and either did or did not contain live *Tomicus piniperda* adults inside the shoot.

shoots per tree, after square root transformation, and the percentage of recently attacked shoots that contained *T. piniperda* adults, after arcsine square-root transformation. When the ANOVA was significant at the $p = 0.05$ level, mean separation among collection periods was conducted with the Ryan-Einot-Gabriel-Welsch multiple comparison test (Day and Quinn 1989, SAS Institute 1989).

RESULTS AND DISCUSSION

Overall, we found two or more live *T. piniperda* adults during every inspection from 8 April through 1 November 1994 (Fig. 1). No live adults were found in the shoots on the last inspection date of 16 November. In other 1994 studies that occurred at the same or a nearby field site, initial spring flight began on 22 March and fall shoot departure occurred primarily between mid-October and mid-November (Haack and Lawrence 1997). The first *T. piniperda* feeding tunnels found in current-year growth occurred on 2 June 1994.

During the April 1994 inspections of the 15 test trees, we collected 368 *T. piniperda*-attacked shoots that appeared to have been attacked in 1993 (Table 1). The first light-brown *T. piniperda* adults, indicating the new generation of beetles, were found in shoots collected on 15 June 1994. Newly emerged adults gradually turn from light brown to dark brown or black as

Table 1. Summary data for the number of prior-year (1993) or current-year (1994) shoots that had been attacked by *Tomicus piniperda* on each of 15 Scotch pine trees from which all attacked shoots were removed every 2 weeks from 8 April through 16 November 1994 in Michigan. Data are presented on the number of live adults collected per tree and the number of shoots per tree that had been recently attacked but lacked *T. piniperda* adults.

	Shoot collections from 8 April to 2 June 1994			Shoot collections from 15 June to 16 November 1994[b]													
				Number of adults found							Number of shoots with no adults						
Tree	1993 attacks	1994 attacks with no adults	1994 attacks with 1 adult	Jun	Jul	Aug	Sep	Oct	Nov	Sum	Jun	Jul	Aug	Sep	Oct	Nov	Sum
1	37	0	1	0	1	3	0	0	0	4	1	1	0	0	0	0	2
2	18	3	1	0	1	3	0	1	0	5	0	2	0	0	0	0	2
3	15	0	2	3	3	1	0	0	0	7	2	0	1	0	0	0	3
4	18	1	3	5	1	2	0	1	0	9	2	0	0	0	0	0	2
5	23	2	8(2)	2	6	6	3	1	1	19	2	1	1	0	0	0	4
6	32	3	0	2	1	1	2	0	0	6	1	2	1	0	1	0	3
7	18	1	1	2	4(1)	0	1	0	0	7(1)	1	0	1	0	0	0	2
8	7	1	0	0	2	0	0	0	0	2	5	0	0	0	0	0	5
9	22	1	3(1)	1	2	1	0	0	0	4	1	0	0	0	0	0	1
10	38(1)[a]	3	1	4	3	5(1)	0	0	0	12(1)	6	1	1	0	0	1	9
11	35(1)	3	5	4	5	5	0	1	1	16	5	2	0	0	1	0	8
12	33	6	4(2)	5	3	3	3	0	0	14	6	2	5	0	0	0	13
13	14	9	3	10(2)	4	2	3	2	0	21(2)	8	4	0	0	0	0	12
14	14	1	0	2	6	1	0	2	0	11	12	4	1	0	0	0	17
15	44(2)	1	2	2	12	4	1	3	0	22	2	6	0	1	1	1	11
Total	368(4)	35	34(5)	42(2)	54(1)	37(1)	13	11	2	159(4)	54	25	11	1	3	2	96

[a]Numbers within parentheses represent the number of adults that were dead at the time of shoot inspection.
[b]Data were summed over two consecutive collection periods, starting with the 15 June collection period: June collections were made on 15 and 30 June, and similarly on 14 and 28 July, 12 and 25 August, 7 and 22 September, 4 and 18 October, and 1 and 16 November.

they conduct their maturation feeding inside the shoots (Långström 1983). Therefore, all live adults collected between 8 April and 2 June were likely parent adults, whereas the vast majority of adults collected on 15 June and onward were progeny adults. Data in Table 1 are divided between these two periods when primarily parent adults were shoot-feeding (8 April–2 June) or progeny adults were shoot-feeding (15 June–16 November). In Sweden, Långström (1983) noted that a few *T. piniperda* parent adults, especially females, could be found shoot-feeding throughout the entire summer and even into the fall. Moreover, Schroeder and Risberg (1989) reported that some *T. piniperda* adults can overwinter twice and even produce brood in the second season.

On each of the five collection dates from 8 April to 2 June, we found 4 to 10 live adults among the 15 study trees (Fig. 1). In addition, for each of the five collections from 8 April to 2 June, we found from 2 to 16 newly attacked shoots among the 15 trees that lacked adults (Fig. 1), indicating that some adults had entered the shoots, tunneled, and already left within the 2-week period between collections.

Overall, from 8 April to 1 November 1994, we collected 197 *T. piniperda* adults; 184 were alive and 13 were dead (Table 1). Of the 184 live adults, 29 were collected between 8 April and 2 June and thus were likely parent adults, while 155 were collected between 15 June and 1 November and were most likely progeny adults. Similarly, of the 13 dead *T. piniperda* adults collected in 1994, 4 were found in shoots that had apparently been attacked in 1993, 5 were in newly attacked shoots collected between 8 April and 17 May, and 4 were found in newly attacked shoots collected between 30 June to 12 August 1994 (Table 1). In addition, we found 131 newly attacked shoots on the 15 sample trees that lacked adults; 35 of these empty shoots were collected between 8 April and 2 June, and 96 were collected between 15 June and 16 November (Table 1).

Overall, for the 197 *T. piniperda* adults collected in this study, we recovered 1 adult per shoot on 183 occasions and 2 adults per shoot on 7 occasions. For the 7 shoots that contained 2 adults, there was 1 shoot that contained 2 dead adults (collected 8 April), 1 shoot that contained 1 dead and 1 live adult (collected 14 July), and 5 shoots that contained 2 live adults (1 shoot collected 15 June, 2 on 14 July, 2 on 29 July, and 1 on 7 September). When 2 adults were found on the same shoot, they were always in separate tunnels.

Each of the 15 test trees had evidence of *T. piniperda* attack in 1993 and 1994. In fact, each of the 15 trees had at least one live adult or one newly attacked shoot that lacked an adult between 8 April and 2 June 1994 (Table 1). Then, from the 15 June collection and onward, we collected between 2 and 22 live adults from each of the 15 test trees and an additional 1 to 17 newly attacked shoots per tree that lacked *T. piniperda* adults (Table 1).

Considering the period 15 June through 16 November when progeny adults were actively shoot-feeding, the average number of newly attacked shoots per tree, both with or without *T. piniperda* adults, was highest during June (6.4 attacks/tree), July (5.2), and August (3.2) (Table 2). Similarly, the average number of newly attacked shoots per tree that lacked live *T. piniperda* adults was highest during June (3.6 empty shoots/tree) and then decreased steadily through November (Table 2). Of the newly attacked shoots, the percent that contained *T. piniperda* adults was lowest for shoots collected during June (44%), and highest for shoots collected in September (92%) (Table 2). These results indicate that *T. piniperda* adults are especially active in June, often residing within a shoot for less than 2 weeks. In contrast, by late summer (e.g., September), fewer beetles and even fewer newly attacked but empty shoots are found, indicating that *T. piniperda* adults are

Table 2. Mean (±SE) number of live *Tomicus piniperda* adults per tree, mean number of shoots per tree that had been attacked by *T. piniperda* in 1994 but lacked an adult inside the shoot, and mean percent of the newly attacked shoots that contained one or more *T. piniperda* adults based on 15 Scotch pine trees from which all attacked shoots were removed every 2 weeks from April through November 1994 in Michigan. Data were summed over two consecutive collection periods, starting with the 15 June collection period because that is when adults of the new generation were first observed in the shoots.

Month [a]	No. of live adults	No. of empty shoots	No. of adults plus empty shoots	Percent of newly attacked shoots with *T. piniperda*
June	2.8 ± 0.7 a[b]	3.6 ± 0.9 a	6.4 ± 1.3 a	43.9 ± 6.2 b
July	3.5 ± 0.7 a	1.7 ± 0.5 b	5.2 ± 1.1 a	72.4 ± 6.3 ab
August	2.5 ± 0.5 a	0.5 ± 0.3 bc	3.2 ± 0.6 a	75.5 ± 8.6 ab
September	0.9 ± 0.3 b	0.1 ± 0.1 c	0.9 ± 0.3 b	91.7 ± 8.3 a
October	0.7 ± 0.2 b	0.2 ± 0.1 c	0.9 ± 0.3 b	78.1 ± 12.9 ab
November	0.1 ± 0.1 b	0.1 ± 0.1 c	0.3 ± 0.1 b	50.0 ± 28.9 ab
F	12.3	15.6	17.8	3.3
df	5,84	5,84	5,84	5,55
$P<$	0.0001	0.0001	0.0001	0.0112

[a]June collections were made on 15 and 30 June, and similarly on 14 and 28 July, 12 and 25 August, 7 and 22 September, 4 and 18 October, and 1 and 16 November.
[b]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).

less likely to move to new trees in late summer. The dramatically lower rate of new attacks starting in mid-October was expected given that this period of time coincides with the movement of adults to their overwintering sites in the Great Lakes region (Haack et al. 1998).

The above results also have important implications for the use of foliar insecticides to control *T. piniperda*. Currently, it is recommended that a cover spray be applied to pine Christmas trees and nursery stock during mid-June (McCullough and Sadof 1996, 1998, McCullough and Smitley 1995), which coincides with the initiation of shoot-feeding by brood adults in the Great Lakes region. However, given that *T. piniperda* adults move freely between trees during June through August, consideration should be given to (a) the treatment area, including both fields that will and will not be harvested during the year of spraying but which are in close proximity, and (b) the residual activity of the insecticide being applied and the possible need for multiple applications.

Given that live *T. piniperda* adults were found in shoots during every collection period from 8 April through 2 June, it is clear that no safe period exists during spring when pine nursery stock can be shipped without inspection and not risk spreading *T. piniperda*. That is, in areas infested with *T. piniperda*, it is possible that any given live pine tree could harbor *T. piniperda* adults throughout the entire year. For example, *T. piniperda* adults could be found in shoots during summer, in their overwintering sites at the base of pine trees in winter, and in either location during spring and fall. Therefore, the behavior of the *T. piniperda* population that we monitored in Michigan is very similar to the behavior documented in Finland (Salonen

1973) and Sweden (Långström 1983) in that some parent adults shoot-fed in spring prior to emergence of the new F_1 generation.

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