[The Great Lakes Entomologist](https://scholar.valpo.edu/tgle)

Volume 33
Number 2 - Summer 2000 *Number 2 - Summer 2000*

Article 1

June 2000

Dispersal and Re-Capture of Marked, Overwintering *Tomicus Piniperda* (Coleoptera: Scolytidae) From Scotch Pine Bolts

A. V. Barak
USDA

D. McGrevy
USDA

G. Tokaya
New York State Agricultural Experiment Station

DISPERSAL AND RE-CAPTURE OF MARKED, OVERWINTERING *TOMICUS PINIPERDA* (COLEOPTERA: SCOLYTIDAE) FROM SCOTCH PINE BOLTS

A. V. Barak[1], D. McGrevy[1], G. Tokaya[2]

ABSTRACT

The pine shoot beetle (PSB), *Tomicus piniperda* is a recently established exotic pest of live pine in the southern Great Lakes region of the U.S. and Canada. Scotch pine, *Pinus sylvestris* L. is the most susceptible pine species, but the adult also attacks several other North American species of *Pinus*. This research investigated the dispersal behavior of beetles emerging from overwintering sites to aid in the development of effective monitoring and management practices. Scotch pine logs with overwintering PSB were sprayed with fluorescent pigments to mark dispersing beetles. These logs were placed in piles in the centers of three circular trap arrays of 8-unit Lindgren traps, baited with α-pinene, and placed at distances of 50, 100, 200, 300 and 400 meters from the center along equally spaced radii. An estimated average of 393 PSB, or 23.4% of the overwintering PSB, dispersed from each of three log piles during the initial spring dispersal flight, and 21.9% of these were captured in traps. Traps within 100 meters caught 56.0 to 67.8% of the marked PSB recovered. Most (95.3%) marked PSB were trapped within 400 meters, but 12 beetles (4.7%) were trapped 780–2,000 meters away in adjacent trap arrays. The dispersal pattern of the population, as indicated by trap catch, was to the northeast, in the direction of prevailing westerly/southerly winds up to 4.77 m/s daily average during beetle flight. Regression analysis suggests that the PSB within the experimental area had a predicted dispersal distance of 900 meters in an area that contained numerous traps. Dispersal distances may be greater under of conditions of strong and steady winds or if traps or abundant host material removed fewer PSB from the dispersing population. The use of traps to monitor specific sites should consider the direction of prevailing winds. Trap catches of wild PSB suggest that optimal inter-trap spacing for efficient detection could be about 78 m.

The pine shoot beetle (PSB), *Tomicus piniperda* L.(Coleoptera: Scolytidae) is a recently introduced exotic pest of *Pinus* spp. in the Great Lakes region, with Scotch pine, *Pinus sylvestris* (L.), the most susceptible species (Bakke 1968, Långström 1980, Haack and Kucera 1993, Haack and Lawrence 1994). The beetle was able to feed on the shoots of *P. ponderosa*

[1]USDA, APHIS, PPQ, Otis Plant Protection Center, Building 1328, Otis ANGB, MA 02542-5008.

[2]New York State Agricultural Experiment Station, IPM Building, Geneva, NY 14456.

Dougl., *P. banksiana* Lamb. and *P. resinosa* Ait. nearly as well as on *P. sylvestris*, generally preferring hard pine to soft pine species such as eastern white pine, *P. strobus* L. (Lawrence and Haack 1994). The PSB is Eurasian in origin and probably entered the United States on ships in at least two locations in the southern Great Lakes region in pine dunnage (large shoring timbers) or other pine wood with bark attached. (Carter et al. 1996).

PSB adults damage pine trees during summer and fall by mining the healthy shoots of the current year and sometimes the previous years growth (Kauffman et al. 1998). After the first hard frosts the beetles leave the shoots and overwinter by boring into the bark at the base of the same pine trees on which they have previously fed on the shoots. In late winter and early spring, following a few days of temperatures above approximately 10–14°C (50–57°F) the beetles disperse and seek weakened or dying pine trees or recently cut pine logs in which to reproduce (Bakke 1968). Långström and Hellqvist (1993) suggested that reduced "momentary vigour" of an otherwise healthy tree distressed by several factors, including the exposure of interior stand trees to a new edge after cutting, could induce attack. Females construct galleries under the bark, where they mate and lay eggs which hatch into grubs which feed on the cambium tissue. A secondary dispersal flight may take place as some parental adult beetles leave the established galleries to produce second, sister broods in suitable pine material. Following pupation and eclosion, the new F_1 beetles emerge after about 600 degree days (50°F base)(Knodel and Barak 1996), and infest new shoots where they undergo maturation feeding prior to overwintering (Bakke 1968, Långström 1983).

PSB is currently (as of June 20, 2000) established in 296 counties in the southern Great Lakes region, including northern Illinois, Michigan, Indiana, Ohio, northwest Pennsylvania, New York, southern Ontario, and several counties in northern West Virginia, northern Maryland, and southern Wisconsin. Recently, pine shoot beetle has been detected in northern New Hampshire and Vermont, and several Quebec, Canada counties bordering these states (NAPIS Database 2000).

A federal quarantine (USDA 1992) has been enacted to regulate the movement of pine Christmas trees, wreaths and boughs, pine nursery stock, pine logs and bark chips from infested (regulated) counties in the affected states. Movement of pine materials with or without roots, outside of this area, is based on an inspection certification, or on a Christmas tree grower IPM compliance agreement. Regulations have been proposed by which logs from infested areas, which may harbor overwintering beetles, can be shipped to mill yards in un-infested areas where they can be stored and processed or de-barked before the emergence of potential spring brood. This is based on a theory that when overwintering beetles within these logs emerge and disperse during spring flight, they would find sufficient brood material in the logs within the mill yard and would not disperse to find brood material outside of the mill yard. This research investigates the distance and direction of short range dispersal of self-marked overwintering PSB for the purpose of providing supporting data for monitoring programs and formulation of regulatory procedures for PSB.

Flourescent pigments have been shown to be useful to mark dispersing scolytid beetles. Linton et al. (1987) and McMullen et al. (1988) reported no significant influence on adult mortality or flight of marked *Dendroctonus ponderosae* Hopkins. Cook and Hain (1992) used fluorescent powders to demonstrate the success of self-marking techniques with laboratory reared *D. frontalis* Zimmermann and *Ips grandicollis* (Eichoff). They found nearly 100 percent marking if powders remained dry, but some decrease in life span was associated with the marking. They further found no significant effect on flight initiation (both species) or semiochemical perception (*I. grandicollis*), and opined that if beetles are trapped shortly after emergence, marking should not hinder dispersal studies. Turchin and Thoeny (1993) used self marking techniques successfully with field collected *D. frontalis* brood in mark-recapture studies. Zolubas and Byers (1995) also successfully used fluorescent powders to mark host-seeking *Ips typographus* L. for release in a *Picea abies* L. forest and subsequent recapture in pheromone-baited traps.

MATERIAL AND METHODS

Overwintering beetles. Scotch pine logs with overwintering PSB were obtained from an abandoned Christmas tree plantation located in Galena, LaPorte County, Indiana during late February, 1998. Trees with the greatest evidence of shoot feeding were identified. A section of the bole from about 10 cm below the original ground base of the tree to a height of about 60 cm above the ground was removed and saved. The logs were transported to the New York State Agricultural Experiment Station (NYSAES) at Geneva, New York, and stored in a walk-in cooler at about 4.4°C (40°F). Prior to conducting the experiment, the logs were divided into three piles based on diameter (smallest, medium sized and largest) with each pile then randomly divided among four groups (one control group and one group for each of three trap arrays) to obtain expected similar numbers of PSB in each pile.

Experimental design. Three trap and log arrays were assembled on the grounds of the NYSAES at the North and South Research Farms, and the Crittenden Farm, Geneva, NY. Each array consisted of 8-unit multiple funnel traps (Lindgren, 1983) each baited with a two-vial, 100%, α-pinene lure (90–95% (-) enantiomer, 150 mg / day release rate per vial)(PheroTech, Inc., Delta B.C., Canada). Traps were arranged in concentric circles at radial distances of 50 (4 traps), 100 (8 traps), 200 (16 traps), and 300 or 400 m (16 traps)(Figure 1). Traps were placed along radii, equally spaced at increments of 22.5, 45 or 90°E, depending on the number of traps set at the distance. Each array was oriented along a north to south axis except at the Crittenden Farm where the array was rotated ca. 12°E west of north to accommodate the dimensions of the site. Bearings were determined with a surveyors transit. Distances from the center were determined with Bushnell Yardage Pro (Overland Park, Kansas) laser rangefinders to ± 1.0 meter. Traps were hung from 2 m, 0.95 cm (3/8 inch) diam. iron rebar hangers with a 90°E bend at the top. The rod was driven into the ground so that the bottom of the trap cup was approximately 0.3 m above the ground.

All but seven traps were placed precisely at the full distance of 400 m at the North and South Farms, with some exceptions due to property boundaries. At the smaller Crittenden Farms, a complete array of 400 m traps could not be placed, so the outer circle of 16 traps was placed 300 m from the center. After completion of this array, 10 additional traps were placed at 400 meters depending on the terrain and after permission from the private landowners. Stands of old Scotch pine with visible shoot damage were found 900 m south of the Crittenden Farm array and 350 m southwest of the center of the Crittenden Farm trap array.

Release and marking of adult beetles. A hand pump tank sprayer was used to individually spray logs to runoff with an aqueous solution of a Day-Glo (Cleveland, Ohio) fluorescent pigment (magenta, arc yellow or Saturn yellow). Approximately 375 g of pigment, with 10 ml Triton X-100 wetting agent (to aid suspension) was mixed with 3.75 l water and agitated con-

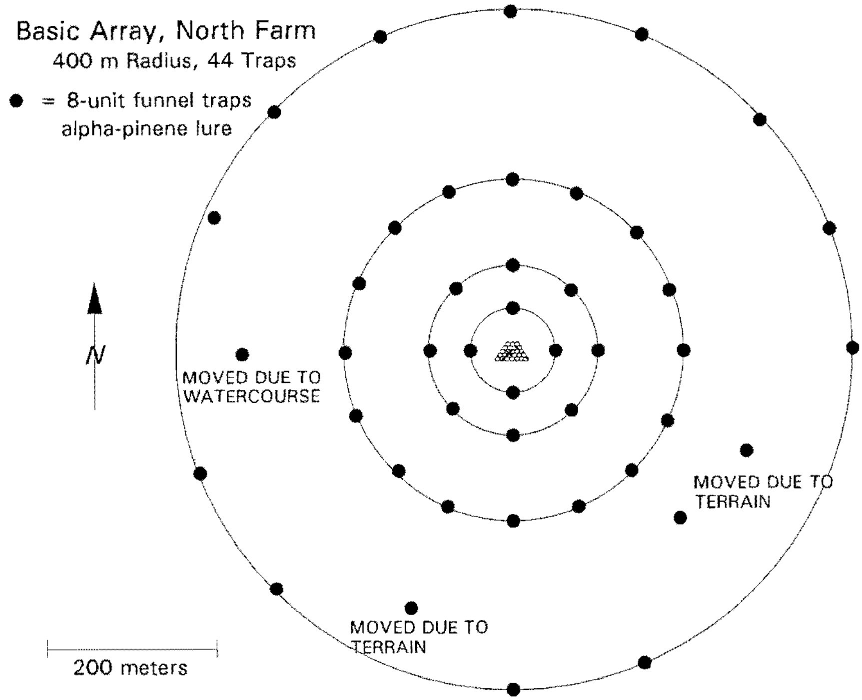

Figure 1. Basic trap array used in dispersal and re-capture study of self-marked, overwintering *Tomicus piniperda* (L.). Logs with overwintering beetles were placed at the center of a 400 m radius trap arrays with traps 50, 100, 200 and 400m from the center. The experiment was conducted at the experimental farms of the NYSAES, Geneva, New York. The North Farm array is represented here.

tinuously during spraying. After spraying, logs were allowed to air dry. At the center point of each trap array a pile of 24–25 marked, infested logs of the same color was arranged in a stack four logs high. The stack was arranged on a wood frame about 0.3 m above the ground to keep logs from sinking into thawing soil. The piles were then covered with a plastic sheet and a silvered mylar sheet to reflect sun to keep the logs cool. This was done to prevent premature emergence and flight. The log piles were uncovered on March 21, when flight-inducing temperatures were forecasted and dry weather was expected. Swarming PSB were allowed to self-mark with dry pigment when they emerged from or climbed over the logs before taking flight. Logs and traps were removed on April 21 due to farm work considerations, by which time the primary spring flight was over.

Control logs. One group of 23 logs was used as a controls to estimate beetle flight from the trap array log piles. These logs were held in a shaded, screened porch at the IPM building, NYSAES, Geneva, New York, during the dates the marked logs were in the trap arrays. Logs were placed individually in 25.4 cm (10 in) diameter, 0.9 m (3 ft) long cardboard tubes. The tubes were closed at one end, and the other end was fitted with a plastic funnel which terminated in a ca. 70 ml bottle to collect emerging beetles. Emerged PSB found in the collection bottles were counted and recorded every few days between March 27 and May 20. On May 19–20, after beetle collections from control logs had terminated, and before possible F_1 brood emergence, control logs were examined for remaining adults by removing the bark. Control log emergence was used to estimate dispersing PSB flight from the logs in the trap arrays, after adjusting for log numbers.

Trap monitoring. Array traps were checked every few days from March 26 through April 21. Trap catches were placed in separate covered plastic condiment cups until examined. Trapped beetles were illuminated by a UV mineral light and examined under a dissecting microscope for pigment marking. PSB were considered marked if pigment contamination was imbedded between the setae, intersegmental membranes or joints. Completely clean, unmarked PSB were also trapped and were considered to be from the wild population. Beetles with only slight, superficial pigment were thought to have picked up pigment contamination through direct contact with a heavily marked PSB, if one was present in the trap cup. The clearly visible marking of most beetles was interpreted as evidence that marking was practically 100%.

Weather data. Data on air temperature, and wind speed and direction were obtained from the Vegetable Research Farm, NYSAES, Geneva, NY, station number 3031840.

Analysis. Statistix for Windows V. 2.0 (Analytical Software, Tallahassee, Florida) was used for statistical analysis. Log diameter and length for each group was subjected to analysis of variance and multiple means comparison (Scheffe's test). Multinomial chi-square testing was applied to distributions of marked vs. wild beetles, and to spatial distributions of both marked and wild beetles after areas were divided into NE and SW halves separated by a trap border. Linear regression was used to determine wether the mean number of PSB emerged from controls varied with log diameter (measured midlength, with bark on) and to analyze the effect of trap distance on marked PSB trapped. The number of beetles trapped by each trap and the distance from the log pile from which the beetles emerged were used to compute directional vectors proportional to beetle numbers times trap distance.

RESULTS

Overwintering beetles. Although there were differences in group log diameters (ANOVA, $F = 4.42$:df = 3,92; $P<0.006$), the number of PSB collected from control logs was independent of log diameter (P=0.275, $r^2 = 0.057$; df = 1,21)(Table 1). Length was not considered important, since PSB overwinters in the basal area, and log lengths exceeded the region in which beetles overwinter.

Estimated number of dispersing beetles. A mean of 16.17 ± 3.88 SEM beetles per log were collected from the control logs during the primary flight period (Table 2.) A collection peak occurred between March 27 and April 2. Between April 3–14, new beetle counts increased by only a total of 33, and the primary dispersal was then considered over. Additional collections through May 20 show that a total of 1,590 beetles were collected from the control logs, an average of 69.13 ± 10.08 per log. No pupae or pharate adults were found when the bark was peeled from the logs, and the galleries only contained F_1 grubs. Therefore, the sums of beetles collected in the emergence vials were considered to be the total number of beetles overwintering

Table 1. Diameter and length (mean ± SE) of Scotch pine logs obtained from an abandoned Christmas tree plantation and which were known to harbor overwintering Tomicus piniperda (L.) based on the observation of shoot feeding and basal boring dust. Diameter measurement was with the bark on at center log.

Experimental Site	Logs / Pile	Diameter (cm)[1] Mean ± SE	Length (cm)[1] Mean ± SE
Control	23	11.1 ± 0.39[a]	51.7 ± 1.81[a*]
North Farm	24	12.6 ± 0.45[a]	68.9 ± 0.84[b]
South Farm	24	11.1 ± 0.36[ab]	64.6 ± 0.68[b]
Crittenden Farm	25	10.7 ± 0.34[b]	65.4 ± 1.02[b]

[1]Means within columns followed by same letter not differing from other means within group at 0.05 level, Scheffe's test, $P < 0.05$.
*Short logs used as control logs to fit collection tubes.

Table 2. Estimation of *Tomicus piniperda* (L.) dispersing from log piles, based on control log beetle collections.

		Cumulative count to date				
Study Site	# of logs	Mar. 31	Apr. 14	Apr. 20 a	Apr. 23	May 20
Control (collected)	23	296	372	508a	626	1,590
Mean ± SEM / log		12.87 ± 3.27	16.17 ± 3.88	22.09 ± 4.76	27.22 ± 27.22±5.58	69.13± 10.08
Estimated dispersing beetles (control mean * # of logs)						
North Farm	24	309	388	530		
95% CI		146–471	195–581	293–767		
South Farm	24	309	388	530		
95% CI		146–471	195–581	293–767		
Crittenden Farm	25	322	404	552		
		152–491	202–605	305–799		

[a]This date was considered to be included in the secondary flight of the brood forming PSB.

in the logs. Beetles that were collected before April 20 represented 23.4% of the overwintering population. A majority of beetles remained with the logs to construct brood galleries, and all logs were heavily galleried. After forming brood, these parental adult beetles were then collected, and were considered to represent the secondary dispersal flight.

Trapped beetle numbers. We estimated that between 19.1 and 22.5% of marked, primary flight beetles were recovered in array traps by April 14 (Table 3). On April 20–21, the day the traps were removed from the array, only eight additional beetles were caught. We considered this the end of the first flight in the field. Trapped wild (unmarked) beetles (n = 166) also had a corresponding primary flight, with only seven beetles trapped between April 14 and April 21. We calculated that 23.4% of the overwintering PSB left the log piles during the primary flight, based on emergence from control logs. Traps at all distances caught an estimated 21.9% of this 23.4% during the primary flight period, or 5.1% of the total beetles calculated to be in the logs.

PSB dispersal distance. Capture of marked PSB was negatively cor-

Table 3. Number of marked and unmarked *Tomicus piniperda* (L.) trapped after dispersion from marked log piles at three sites, and estimated percentage of dispersing beetles trapped based on control log collections.

	Cumulative trap count to date (% of estimated PSB)[a]			
Logs Source	# of Traps	Mar. 31	Apr. 14	Apr. 20/21[b]
North Farm	44	70 (22.7)	84 (21.6)	87 (16.4)
South Farm	44	69 (22.3)	74 (19.1)	74 (14.0)
Crittenden Farm	54	76 (23.6)	91 (22.5)	96 (17.4)
Unmarked (Wild) (all sites)	142	146	159	166

[a]Estimated percentage (from Table 2) of dispersing PSB trapped.
[b]The last day traps were active in array.

related with distance ($y = 83.37–28.41*\text{Log } x$ (meters), $r^2 = 0.943$, $F = 182.5$, df = 1,11, $P < 0.001$) over the 400 m array (Figure 2). Although most beetles were recovered within 400 meters, 12 beetles dispersing from the North and South Farms were recovered in adjacent arrays 780–2,035 meters from the release point. Since adjacent arrays (North and Crittenden) represented a

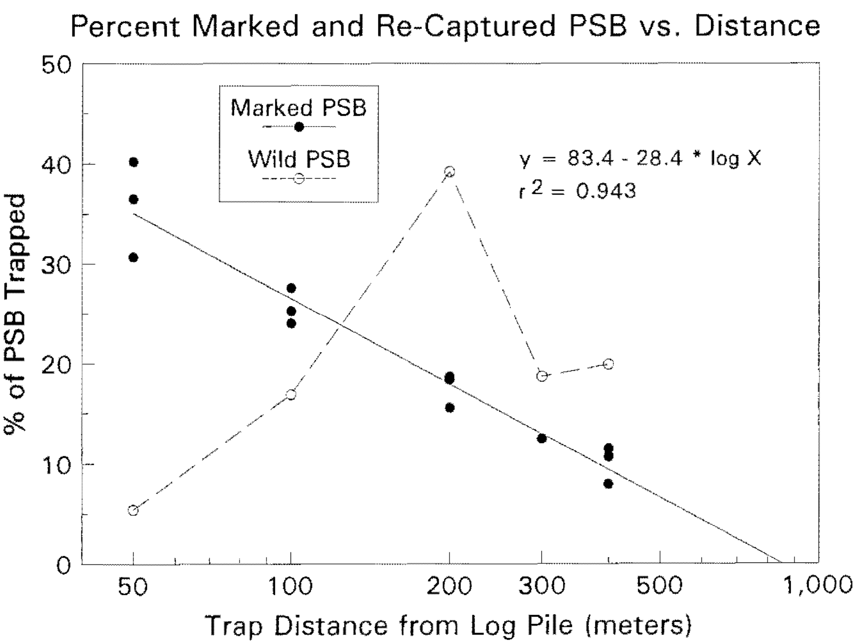

Figure 2. Percent of marked and native (unmarked) *Tomicus piniperda* (L.) trapped versus trapping distance. Percent at any distance is % of marked or wild beetles trapped, not of the estimated total dispersing population.

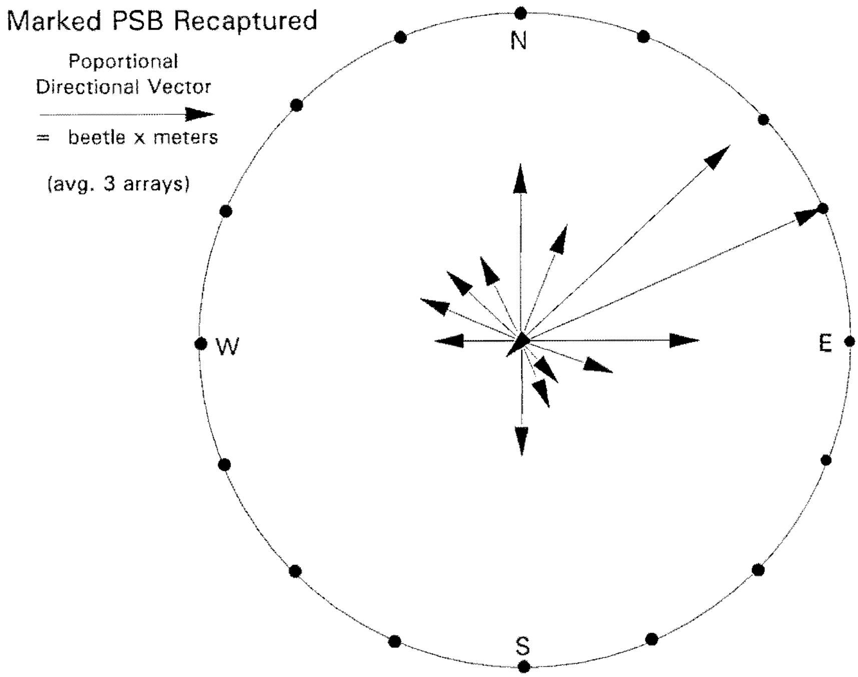

Figure 3. Proportional vectors of trap count * trap distance (beetle-meters) of marked and trapped *Tomicus piniperda* (L.) dispersing from a source at the center of three 400 m radius trap arrays. Data from the arrays were pooled.

local concentration of traps but subtended only a small arc of potential dispersal, these beetles were not considered in the analysis. While marked beetles were trapped largely within 100 meters of the log pile, the catch of native beetles was highest at the 200 meter distance and had no linear correlation with trap distance.

Directional dispersal. Directional vectors clearly show a northeast dispersal pattern, based on trap catch and distance traveled (Figure 3). Further, higher numbers of marked PSB were trapped in the northeast "half" of the trap arrays compared with the southwest "half " (Table 4). Wild (unmarked) PSB had spatial distributions of trap catch different from marked beetles, and the distributions within the arrays were not uniform or in a consistent direction.

Weather data. Winds from the south to west were prevalent (Table 5). Wind velocities were 5–15 m/s on five of nine days, but periods of calm (0–5 m/s) did occur on four days.

DISCUSSION

For the purpose of PSB IPM, it has been hypothesized that if logs with overwintering beetles are transported to a mill yard, and if the beetles

Table 4. Directional dispersal of marked and recaptured overwintering *Tomicus piniperda* (L.) dispersing from log piles at the center of a circular trap array. Unmarked beetles are considered to be from the wild population.

Beetles Direction	North Farm	South Farm	Crittenden Farm
Marked PSB[a]	Number trapped (% of total trapped within site)		
Northeast half[b]	43 (52.4)	49 (72.1)	64 (66.6)
Boundary Traps[d]	6 (7.3)	8 (11.8)	4 (4.2)
Southwest half	33 (40.2)	11 (12.2)	28 (29.2)
Sub-total	82	68	96
Unmarked (wild) PSB			
Northeast half[c]	12 (66.7)	15 (50.0)	24 (20.3)
Boundary Traps	1 (5.6)	3 (10.0)	7 (5.9)
Southwest half	5 (27.8)	12 (40.0)	87 (73.7)
Sub-total	18	30	118

[a]The distribution of marked and unmarked (wild) differed ($\chi2 = 300.3$; df = 8; $P = <0.0001$).
[b]The distribution of marked PSB by sectors differed ($\chi2 = 48.85$; df = 8; $P = <0.001$).
[c]The distribution of wild PSB by sectors differed ($\chi2 = 45.83$; df = 8; $P < 0.0001$).
[d]Boundary traps are those traps in the array along radii separating the NE traps from the SW traps.

Table 5. Daily wind speed and wind direction during the peak of the dispersal flight of *Tomicus piniperda* (L.) at Geneva, New York, 1998.

Date, 1998	Wind Speed m / s	Wind Speed m.p.h.	Wind Direction
Mar. 25	0–2.24	0–5	SE
Mar. 26	0–2.24	0–5	SE
Mar. 27	4.47–6.7	10–15	W
Mar. 28	0–2.24	0–5	SW
Mar. 29	4.47–6.7	10–15	W
Mar. 30	0–2.24	0–5	S
Mar. 31	2.24–4.47	5–10	S
Apr. 01	2.24–4.47	5–10	SE
Apr. 02	2.24–4.47	5–10	SW

emerge from overwintering, they will not disperse from the mill yard in sufficient numbers to colonize brood material which may be nearby. Instead, the beetles would colonize logs within the mill yard. In this study a large proportion of overwintering beetles dispersed hundreds of meters from artificial log piles, even though brood material (the overwinter logs) or simulated brood material odors (the traps) were available within that distance. The abundant, large logs present in a millyard would probably be much more attractive than numerous traps. Therefore, if more strongly attractive brood material (logs) would have been available within the arrays, perhaps there would have been fewer PSB dispersing over longer distances. However, if beetles were to be present in potentially high numbers, even a small percentage of dispersing or windblown beetles escaping an infested millyard could represent a risk to nearby pines. Logs with overwintering beetles may be stockpiled on the periphery of a millyard, and thus even short dispersal flights could place them outside of a yard property under management. With Scotch pine strands close to timber storage sites (abundant brood material), Långström and Hellqvist (1991) reported that losses in growth volume of trees, due to heavy shoot feeding, declined with distance from the storage site out to 500 m compared with no losses to trees 1500 m distant. Brood material elimination plays an important part in PSB IPM programs for Christmas tree plantations (McCullough, D. G. and C. S. Sadof 1998). The principle of sanitation, through timely processing of logs, would also apply to millyards or log storage areas (or the immediate surrounds), where pine logs from infested (regulated) areas may colonize other logs or suitable pine material.

In a regression analysis similar to Schlyter (1992) we suggest that the principal dispersal distance under our experimental conditions may be nearly 900 meters (Figure 2). To reduce risk of establishment, brood material within approximately a kilometer of a beetle source must be destroyed prior to any brood emergence, since it is within range of colonizing PSB. Though traps caught a few PSB at a distances of 780 meters or more, no trap had more than one marked PSB per trap at these distances. Therefore, the number of PSB dispersing from our infested logs may not have been high enough to assure that beetles at such distances would pair successfully and produce a new infestation, as females mate after dispersal and initial brood gallery construction.

Since most beetles were trapped relatively close to the log piles, how far and in what numbers these beetles would have flown if they were not removed from the dispersing population by trapping is unknown. Maximum dispersal may not be as great when the beetles do not need to fly far to find abundant brood material (logs), such as in a millyard. A larger trap array (at least 2 km radius) with less emphasis on close range trapping and greater inter-trap distance may give a more accurate view of dispersal patterns and colonization potential in an area where brood material would be widely dispersed.

Wind speed and direction appeared to be an important factor in the dispersal pattern of the beetles. The locus of the dispersing population had drifted to the northeast, and the data of Table 5 could explain this pattern. At no time was the wind from a northerly direction, and only three days had mild, SE winds. The days of highest wind speed occurred during the peak of the primary dispersal flight, and were from the westerly. It is understood that a beetle would locate an attractant source by flying upwind in the odor plume, yet the dispersal pattern was primarily downwind. Byers et al. (1989) found that with *I. typographus*, daily changes in wind velocity affected trap catch. When daily wind speed changed from 2.23 to 4.0 m/s and 2.7 m/s to 3.76 m/s, trap catches were reduced, and when the daily wind speeds decreased from 4.0 to 2.7 m/s and 3.76 to 1.56 m/s on the corresponding, following days, trap catches rebounded. It is not known precisely how wind velocity affects PSB, but it must also be considered likely to have an effect upon dispersal distance and direction. Our data indicate that for five of nine days wind speed exceeded the aforementioned higher velocities, with the highest winds in the direction of the dispersal pattern. If the PSB were not able to effectively fly upwind in a plume on windy days and were instead blown downwind, this would explain the trapping pattern. During calm periods between gusts or low winds the beetles could locate traps, even those opposite the prevailing winds, but close to their origin as shown in Figure 3. In fact, the highest single trap catch (15 PSB) was 50 meters due west at the North Farm, contrary to the prevalent winds. The placement of traps in the spring should take prevailing wind directions into consideration for maximum likelihood of detection, especially if traps were to be placed about trees or millyard logs suspected of harboring PSB. Even with abundant attractant brood material, as in a millyard, gusty winds could carry PSB outside of the immediate trapping area. Further, logs with PSB located on the lee side of a millyard would pose a greater risk of escape. Timely processing of logs would reduce the risk.

While marked PSB were trapped relatively close to the source, the largest number of native PSB were trapped at 200 meters from the marked log stacks. The inter-trap distances at the 400, 300 and 200 meter circles were 156, 117 and 78 meters, respectively. Wild PSB coming from outside the arrays were most numerously trapped by the more closely spaced 200 m traps. This could be an indicator of more optimal trap spacing. More than twice as many wild PSB were trapped at 200 meters with 1.5 to 2 times the trap density, but this occurred after 40% of the trapped wild PSB were already intercepted by the more distant and widely spaced traps. Trap catch declined greatly inside the 200 meter radius, even though the inner trap circles provided a concentrated source of α-pinene from the lures and log piles. If traps or logs are used as an exclusion, monitoring or detection tool around a particular site, perhaps recommended spacing should be about 75–100 m, or until new information becomes available.

ACKNOWLEDGMENTS

We wish to thank Therese Poland and Toby Petrice, USDA Forest Service, East Lansing, MI, for their assistance in obtaining a source of field collected PSB. We appreciated the assistance of personnel from the USDA, APHIS Biocontrol Laboratory, Niles MI, for help in cutting logs, and Nancy Consolie, NYSAES, Geneva, New York, for logistical support. We further acknowledge Therese Poland, USDA, FS, East Lansing, MI, Clif Sadof, Purdue University, West Lafayette, IN, William Kaufman, USDA, APHIS, Niles MI and David Lance of this Laboratory, for helpful comments on this manuscript. We also thank the two anonymous reviewers for helpful comments.

LITERATURE CITED

Bakke, A. 1968. Ecological studies on bark beetles (Coleoptera: Scolytidae) associated with Scots pine (*Pinus sylvestris* L.) in Norway with particular reference to the influence of temperature. Medd. Nor. Skogforsoksves. 21:443–602.

Byers, J. A., O. Anderbrandt and J. Löfqvist. 1989. Effective trapping radius: a method for comparing species attractants and determining densities of flying insects. J. Chem. Ecol. 15(2): 749–765.

Carter, M. C. A., J. L. Robertson, R. A. Haack, R. K. Lawrence and J. L. Hayes. 1996. Genetic relatedness of North American populations of *Tomicus piniperda* (Coleoptera: Scolytidae) J. Econ. Entomol. 89: 1345–1353.

Cook, S. P. and F. P. Hain. 1992. The influence of self-marking with fluorescent powders on adult bark beetles (Coleoptera: Scolytidae). J. Entomol. Sci. 27(3): 269–279.

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 R. K. Lawrence. 1994. Geographic distribution of *Tomicus piniperda* in North America: 1992–1994. Newsl. Mich. Entomol. Soc. 39:14–15.

Haack, R. A. and R. K. Lawrence. 1997. Tomicus piniperda (Coleoptera: Scolytidae) Reproduction and behavior on Scotch pine Christmas trees taken indoors. Great Lakes Entomol. 30: 19–31.

Kauffman, W. C., R. D. Waltz, and R. B. Cummings. 1998. Shoot feeding and overwintering behavior of *Tomicus piniperda* (Coleoptera: Scolytidae): Implications for management and regulation. J. Econ. Entomol. 91(1): 182–190.

Knodel, J. J. and A. V. Barak. 1996. Development of a pest management program for minimizing the economic impact of pine shoot beetle in pine nurseries and plantations of New York. New York Agricultural Experiment Station, Geneva, New York. Pub. No. 20-03.

Långström, B. 1980. Distribution of pine shoot beetle attacks within the crown of Scots pine. Studia Forestalia Suecica No. 154, 25 pp.

Långström, B. 1983. Life cycles and shoot-feeding of the pine shoot beetles. Studia Forestalia Suecica No. 163, 29 pp.

Långström, B. and C. Hellqvist. 1991. Shoot damage and growth losses following three years of Tomicus-attacks in Scots pine stands close to a timber storage site. Silva Fennica. 25: 133–145.

Långström, B. and C. Hellqvist. 1993. Induced and spontaneous attacks by pine shoot beetles on young Scots pine trees: tree mortality and beetle performance. J. Appl. Ent. 115: 25–36.

Lindgren, B. S. 1983. A multiple funnel trap for scolytid beetles (Coleoptera). Can. Entomol. 115: 299–302.

Linton, D. A., L. Safranyik, L. H. McMullen and R. Betts. 1987. Field techniques for rearing and marking mountain pine beetle for use in dispersal studies. J. Entomol. Soc. Brit. Colum. 84:53–57.

McCullough, D. G. and C. S. Sadof. 1998. Evaluation of an integrated management and compliance program for Tomicus piniperda (Coleoptera: Scolytidae) in pine Christmas tree fields. J. Econ. Entomol. 91: 785–795.

McMullen, L. H., L. Safranyik, D. A. Linton and R. Betts. 1988. Survival of self-marked mountain pine beetles emerged from logs dusted with fluorescent powder. J. Entomol. Soc. Brit. Colum. 85: 25–28.

NAPIS. 2000. National Agricultural Pest Information System Database. http://www.ceris.purdue.edu/napis/pests/psb.

Schlyter, F. 1992. Sampling range, attraction range, and effective attraction radius: estimates of trap efficiency and communication distance in coleopteran pheromone and host attractant systems. J. Appl. Entomol. 114:439–454.

Turchin, P. and W. T. Thoeny. 1993. Quantifying dispersal of southern pine beetles with mark-recapture experiments and a diffusion model. Ecol. Appl. 3: 187–198.

United States Department of Agriculture, APHIS, PPQ. 1992. Part 301, domestic quarantine notices. 301.50, pine shoot beetle. Federal Register, 57 (224) Thursday, November 19, 1992. Rules and Regulations, pp 54492-54499. Washington, D.C.

Zolubas, P. and J. A. Byers. 1995. Recapture of dispersing bark beetles Ips typographus L. (Col., Scolytidae) in pheromone-baited traps: regression models. J. App. Entomol. 119: 285–289.