SPECIAL TECHNOLOGY DEVELOPMENT PROJECT PROPOSAL-- FY 1999

PROJECT STATUS: New, not previously funded.

PROJECT NUMBER: NA-99-04

PROJECT TITLE: Development of an Improved Lure for Detection, Survey, and Management of the Pine Shoot Beetle

SUBJECT: Bark beetles, exotic insect, monitoring, management, Tomicus piniperda

PROJECT OBJECTIVE: This project will evaluate responses by the pine shoot beetle, Tomicus piniperda (L.), to attractive semiochemicals (pheromones and host compounds) and determine the optimal mixture for an improved lure to be used in detection, survey, mass-trapping, and reducing the spread of T. piniperda. Ultimately, this will lead to implementation of a cost-effective pheromone-trapping technique as a means for detecting new infestations, preventing further spread, and reducing currently established populations of T. piniperda.

BRIEF DESCRIPTION OF PROJECT: Tomicus piniperda is among the most damaging insect pests of pine trees in Europe and Asia (Långström and Hellqvist 1991; Ye 1994). In July 1992, T. piniperda was found near Cleveland, Ohio, and as of October 1998, it was established in 243 counties in nine US states (Illinois, Indiana, Maryland, Michigan, New York, Ohio, Pennsylvania, West Virginia, and Wisconsin) and 21 counties in Ontario, Canada (NAPIS 1998). Because this insect poses a potentially significant threat to major pine-producing areas of the US, a federal quarantine was implemented in November 1992 that regulates movement of pine logs with attached bark, pine Christmas trees, and pine nursery stock from infested to uninfested counties in the US. The enactment of the quarantine has had a significant economic impact on Christmas tree growers, lumber companies, and nursery producers in the infested counties, as well as on regulatory agencies in both infested and uninfested states.

Accurate delimitation of the area infested with T. piniperda is necessary to ensure that regulations and management tactics are implemented to reduce the risk of accidentally introducing T. piniperda to uninfested areas of the US. Currently, trap logs are used by many state inspection and regulatory agencies to detect new infestations of T. piniperda. However, trap logs may have limited efficacy due to (1) lack of suitability of host logs if the bark is damaged or phloem has desiccated, (2) poor placement of trap logs in the field, (3) damage of trap logs by small animals (e.g., bark feeding by mice and voles), (4)

the necessity for timely removal and assessment of trap logs prior to brood emergence and deterioration of galleries by competitors and predators, and (5) difficulty in confirmation of beetle identification due to parental re-emergence and colonization by other bark beetles which are nearly identical to the pine shoot beetle in appearance. In addition, trap logs require felling of numerous healthy trees; logs are heavy, bulky, and require debarking; and, hence, are relatively costly, labor intensive, and potentially hazardous to use.

The current alternative to trap logs is the use of funnel traps baited with the host volatile alpha-pinene (Haack and Lawrence 1997). Although alpha-pinene is attractive to T. piniperda, it does not compete well against freshly cut pine logs and stumps. Therefore, especially at low population levels, trap logs are usually superior to alpha-pinene-baited funnel traps. However, pheromones, either alone or in combination with alpha-pinene, may be equal or superior to trap logs for detecting T. piniperda. An improved T. piniperda trapping system, using pheromones, would improve many regulatory and management activities. For instance, an effective pheromone lure would reduce the time and effort involved in T. piniperda detection, survey, and inspection programs, compared with trap logs. Attractive pheromones could also be used more effectively for mass-trapping, population suppression, and reducing the spread of T. piniperda. The use of pheromones has not been used in the past because the T. piniperda pheromone system was not well understood. Although there was early evidence to support pheromone production by T. piniperda (Schonherr 1972), later studies reported that T. piniperda lacked a pheromone (Bouhot et al. 1989, Lanne et al. 1987, Loyttyniemi et al. 1988).

Despite the serious economic damage by T. piniperda in Europe and Asia and considerable research over the past 30 years, progress toward identifying effective pheromones has been slow. In addition to alpha-pinene, a number of host volatiles including (+)-3-carene, -terpinolene (Byers et al. 1985, Schroeder and Eidmann 1987), and ethanol (Schroeder and Lindelow 1988, Vité et al. 1986) have been reported to mediate attraction of T. piniperda to host materials. In addtion, some insect-produced compounds have shown potential as attractants including myrtenol and trans-verbenol (Francke and Heeman 1976, Kangas et al. 1970, Zhou et al. 1997). Furthermore, in recent studies by Czokajlo (1998), using coupled gas-chromatographic electro-antennal detection (GC-EAD), myrtenol and trans-verbenol were confirmed as attractive pheromones and alpha-pinene-oxide and nonanal were identified as new candidate pheromones for T. piniperda. These four compounds have shown considerable promise for development of an effective attractive lure, increasing attraction to alpha-pinene by up to 400 % (Czokajlo 1998). After three decades of research, development of an effective pheromone for T.

piniperda is finally nearing fruition.

This project will determine the most attractive blend of host volatiles and pheromone components for T. piniperda. Through field trapping experiments to be conducted in infested Scotch pine Christmas tree plantations in Michigan and Indiana, we will test various combinations of known attractive host volatiles and pheromone candidates. We will use multiple funnel traps baited with the various test compounds to evaluate attraction to T. piniperda. The most attractive blends will be further tested to determine the optimal mixtures and doses for operational use and to compare the number of T. piniperda captured to the number of attacks on trap logs.

FHP PERSON WHO WILL LEAD THE PROJECT: James B. Hanson (NA-FHP, St.Paul)

JUSTIFICATION: Tomicus piniperda is a newly introduced insect in the United States, with potential to spread throughout all pine growing regions of North America. Despite the federal quarantine, T. piniperda will continue to spread by means of natural dispersal. Development of less costly and more effective means for detection, survey, inspection, and management of T. piniperda are critical for protecting the pine resource in both infested and uninfested areas of North America. Development of an improved attractive lure for the pine shoot beetle will benefit Federal and State agencies that monitor current distribution and spread of the pine shoot beetle. More specific and attractive lures would enhance trapping efficacy and thereby improve the detection of new infestations and reduce or replace the use of less efficient and cumbersome trap logs and intensive visual surveys. Moreover, improved attractive lures will also benefit Christmas tree growers and nursery managers by providing a means for mass trapping pine shoot beetles and thereby reducing pest populations as part of the National Compliance Management Program.

URGENCY: Information is urgently needed to develop an improved semiochemical-based means for detecting new introductions and managing currently established populations of T. piniperda. A delay in developing more efficient detection and management techniques could result in (1) undetected introductions of T. piniperda into unregulated areas of the US, (2) further spread of T. piniperda if pine materials are moved from unregulated areas where populations of the insect remain undetected, (3) increased costs for regulatory and inspection agencies in infested and uninfested areas of the US, (4) and further costs and burden for Christmas tree and nursery producers in infested areas of the US.

LINK TO NATIONAL FHP TECHNOLOGY DEVELOPMENT PRIORITIES: This study addresses one of the high priority objectives of the Special Technology Development Program, i.e., to develop or improve detection, analysis, and management of exotic pests. The development of an effective semiochemical trapping program will contribute to our ability to detect new introductions, monitor spread, and better manage currently established populations of T. piniperda.

SCOPE OF APPLICATION: This study will provide information applicable to all pine Christmas tree and nursery producers in the nine currently infested states and in Ontario, Canada. In addition, the information will be of value to inspection and regulatory agencies throughout the US, and ultimately to pine producers throughout North America, Europe, and Asia for improved management of established populations of T. piniperda

RESEARCH BASIS: Pheromone-baited funnel traps are widely used for bark beetle management. They have proven to be highly efficient for attracting and capturing many species of scolytid beetles (Lindgren 1983). Multiple funnel traps have been employed successfully for both monitoring, and mass-trapping programs for managing bark and ambrosia beetles for which highly attractive pheromones are available. For instance, mass-trapping with funnel traps baited with ethanol and lineatin, sulcatol, or retusol has been highly successful for managing populations and reducing degrade damage caused by the ambrosia beetles, Trypodendron lineatum, Gnathotrichus sulcatus, and G. retusus, respectively, in sawmills in coastal British Columbia (McLean and Borden 1977, 1979). Pheromone-baited multiple-funnel traps may be used to control the amount and distribution of tree mortality during outbreaks of the Douglas-fir beetle, Dendroctonus pseudotsugae (Ross and Daterman 1997). Mass-trapping has also been successful for the western pine beetle, Dendroctonus brevicomis, in southern California (Bedard and Wood 1974, 1981). In Europe, pheromone-baited pipe traps are used for mass trapping the European spruce beetle, Ips typographus (Raty et al. 1995).

Funnel traps baited with alpha-pinene have proven to be efficient at catching T. piniperda (Haack and Lawrence 1997). In general, species-specific pheromones greatly synergize attraction of bark beetles to attractive host volatiles. For instance, the pheromone frontalin significantly increased attraction of the spruce beetle, Dendroctonus rufipennis, and the Douglas-fir beetle to alpha-pinene. Therefore, incorporating attractive pheromones for T. piniperda with alpha-pinene could greatly enhance attraction by T. piniperda and result in a highly effective lure. In recent studies by Czokajlo (1998), using coupled gas-chromatographic

electro-antennal detection (GC-EAD), myrtenol and trans-verbenol were confirmed as attractive pheromones and alpha-pinene-oxide and nonanal were identified as new candidate pheromones for T. piniperda. These four compounds have shown considerable promise for development of an effective attractive lure, increasing attraction to alpha-pinene by up to 400% (Czokajlo 1998).

METHODS: Field trapping experiments will be conducted in 1999 in Michigan and Indiana in Scotch pine Christmas tree plantations that are heavily infested with T. piniperda. Twelve-unit multiple funnel traps will be suspended from iron rebar poles so that the bottom of the trap is approximately 0.3 m above the ground. Traps will be set up at least 15 m apart along the grass lanes between the rows of trees in each plantation. All competing sources of attraction such as fresh stumps, slash, and other brood material will be removed from the experimental area. Traps will be baited by hanging lures releasing the various test compounds from the sides of the funnel traps. A small piece of vapona no-pest strip will be placed in the collection cup of each trap to kill all insects captured. During the peak flight period, insects will be collected from each trap daily, and traps will be re-baited to conduct new experiments or additional replicates. All collected insects will be stored in bags and held at -16 C in the laboratory until identified, sexed, and counted. Each experiment will be laid out in a randomized complete block design with at least 10 replicates per treatment. All semiochemicals will be synthesized, purified, and formulated in standardized release devices and then purchased from IPM Technologies, Inc. or Pherotech, Inc.

Experiments 1-5 will be conducted concurrently during the initial part of the 1999 flight season. Experiment 1 will test alpha-pinene alone or combined with each of the four pheromone candidates (trans-verbenol, myrtenol, nonanal, and alpha-pinene oxide) individually and all combined. Similarly, Experiment 2 will test alpha-pinene alone or combined with each of the three other host volatiles ((+)-3-carene, -terpinolene, and ethanol) individually and all combined. Experiment 3 and 4 will test alpha-pinene with the six binary or four ternary combinations of the four pheromones, respectively, and compare attraction to alpha-pinene alone or combined with all four pheromones. Experiment 5 will test alpha-pinene alone or combined with the six binary combinations of the three other host volatiles or all three combined.

Based on the results of these five experiments, the most attractive combination of pheromones and of host volatiles will be determined. The most attractive pheromone and host-volatile combinations will be further tested in three additional experiments later in the 1999 flight season. Experiment 6 will test alpha-pinene alone or combined with the most

attractive blend of pheromones, the most attractive blend of host volatiles, or the blend of pheromones and host volatiles combined. Experiment 7 will test variable doses of the optimal blend from Experiment 6 to determine the most attractive release rate for operational use. Finally, Experiment 8 will test the optimal release rate and blend of host volatiles and pheromone components and compare trap catches to the number of attacks on trap logs during the same time period.

Trap logs to be employed in Experiment 8 will consist of 2-foot long bolts at least 8 inches in diameter, cut from freshly felled healthy Scotch pine trees. The bolts will be cut from the basal portion of the tree where the outer bark is rough. Trap logs will be set out randomly in the same area as the traps in Experiment 8. They will be set out at the initiation of Experiment 8 and collected when the experiment is terminated. Trap logs will be arranged in piles of three logs and, to allow full colonization, elevated approximately 2-5 inches above the ground on heavy-guage wire supports. Attack by T. piniperda on the trap logs will be assessed by counting entrance holes and debarking to confirm the identity of the attacking beetles. The number of attacks per pile of trap logs over the duration of the experiment will be compared to the number of insects captured per trap.

Statistical approach: The number of T. piniperda captured or attacking logs will be transformed in order to meet assumptions of normality and homoscedasticity and then analyzed by ANOVA and multiple comparison procedures in order to determine differences between treatments within each experiment.

QA/QC: Standard quality assurance/quality control (QA/QC) procedures will be utilized. For each task (e.g., setting up experiments, collecting, sorting, identifying and sexing captured insects) we will develop standard protocols and provide training to all field personnel. We will also conduct a 5% to 10% double check of each data-recording step (e.g., beetle identification, data entry). Data sets will be duplicated and maintained in two separate buildings, both in hard-copy and electronic format.

MEASURES OF SUCCESS: This project will be considered successful if (1) new knowledge about T. piniperda attraction to pheromones and host compounds is obtained, (2) the most attractive blend of pheromones and host compounds for T. piniperda is determined, and (3) an improved lure for T. piniperda can be developed based on these findings.

COOPERATORS:
1. Principal investigators:

Therese Poland, Research Entomologist, NC-4501, East Lansing
Robert Haack, Research Entomologist and Project Leader, NC-4501, East Lansing
Toby Petrice, Biological Technician, NC-4501, East Lansing
James B. Hanson, Field Representative, FHP, St. Paul

2. Currently identified cooperating investigators:
Steve Teale, State University of New York, Syracuse, NY
IPM Technologies, Portland, OR
Phero Tech, Inc., Delta, BC
Kellogg Forest
USDA APHIS
Michigan Department of Agriculture

PRODUCTS: The project will lead to new knowledge about T. piniperda attraction to pheromones and host-volatiles. The major product from this new knowledge will be the determination of the optimal blend of pheromone and host compounds for development of an improved lure for T. piniperda. Data collection will begin in spring 1999. Data analysis and report writing will be completed by the end of Fiscal Year (FY) 1999.

PUBLICATION: A project report will be completed by the end of FY99. The results from this study will be published in scientific and technical journals during FY00.

TECHNOLOGY TRANSFER: The products of this project will be transferred to regulatory officials, forest entomologists, and Christmas tree and nursery producers through publications, presentations, electronic-mail, and postings on the internet. In addition, due to the cooperation of IPM Technologies, Inc. and Phero Tech, Inc., all products will be transferred directly to industry so there will be no delay in commercial development of an improved lure for T. piniperda.

PROJECT DURATION: One year - FY99.

LONG TERM BUDGET: One year project; see below.

FY 1999 BUDGET REQUEST: 20k is being requested to complete this study. These funds will be used to purchase at least 200 funnel traps ($33 each), semiochemical lures including alpha-pinene (180 lures, $6 each), myrtenol, trans-verbenol, alpha-pinene-oxide, nonanal, (+)-3-carene, -terpinolene, and ethanol (80 lures of each compound, $6 each), re-bar to support the traps ($4 each), lab and field supplies (flagging, storage bags, labels, vials, and ethanol) salaries for two part-time student employees (GS-3 or GS-4), some travel expenses, and overhead

(NCRS policy is 10% overhead). The Insect Unit, NC-4501, will contribute at least 30k of in-kind contributions towards this project, including salaries of the NC-4501 investigators, vehicle charges, some travel costs, and publication costs. This project is expected to occupy 20% of one GS-11 Research Entomologist (Therese Poland), 10% of one GS-7 Biological Technician (Toby Petrice), and 5% of one GS-14 Research Entomologist (Robert Haack). In addition, in-kind contributions will be provided by staff at the Kellogg Forest, USDA APHIS Niles Biocontrol lab, and the Michigan Department of Agriculture who will assist in felling trees for trap logs and in monitoring traps.

	FHP	NC-4501
Procurements:		
Equipment and Supplies	$ 13,000.00	$ 2,000.00
Contracting	0.00	0.00
Administrative Items:		
Salary	3,000.00	21,000.00
Overhead	2,000.00	0.00
Other (Travel)	2,000.00	7,000.00
TOTAL FY 1999 REQUEST	$ 20,000.00	$ 30,000.00

BENEFIT AND COST:

STDP PRODUCTION FUNCTION

PROJECT NUMBER: NA-99-XX

PROJECT COST: $ 50,000.00

PROJECT OBJECTIVE: To evaluate responses by the pine shoot beetle, Tomicus piniperda (L.), to attractive semiochemicals (pheromones and host compounds) and determine the optimal mixture for an improved lure to be used in detection, survey, mass-trapping, and reducing the spread of T. piniperda.

ASSUMPTIONS:

- We believe that the benefits and costs calculations presented below are based on very conservative estimates and assumptions. For instance, we only considered the impact of lower detection costs and reduced spread of T. piniperda for a single year. However, these benefits will continue for many years as inspection agencies continue to monitor the spread of this insect and pine growers and producers will continue to benefit from improved management and slower spread. It is likely that in the first year, the presence of T. piniperda

will be detected in several new counties due to the improved efficacy of detection utilizing an improved lure. However, in all subsequent years the spread of T. piniperda will be reduced. Fewer infestations will remain undetected; therefore, appropriate management and quarantine measures will be implemented to reduce inadvertent introductions of T. piniperda from infested to uninfested areas. In addition, improved semiochemical-based management will help to reduce T. piniperda populations in infested areas to a level that will greatly reduce damage and the risk of spreading the insect.

- Implementation of semiochemical-based detection and management for T. piniperda utilizing the improved lure will result in a decline in the spread of T. piniperda by at least 3 counties per year. For instance, in 1998, T. piniperda was detected in 19 new counties; if an improved lure had been available the rate of spread could have been reduced to 16 new counties, representing a 16% decrease in the rate of spread.
- An improved lure for T. piniperda will cost $ 4.00 more per lure than the current alpha-pinene lures.
- Most Christmas tree and nursery producers sell their trees to local markets; however, within each county it is assumed that there are at least 3 producers who export a significant number of trees and will require inspection; it is further assumed that at least 1 grower will not pass inspection.
- It is assumed that within each county there are at least 10 Christmas tree growers or nursery producers who will participate in the National Compliance Management Program.

BACKGROUND DATA:

- Currently, detection surveys for establishment of T. piniperda are conducted in at least 10 counties per state in at least 13 states including Minnesota, Wisconsin, Iowa, Missouri, Illinois, Indiana, Kentucky, Ohio, West Virginia, Maryland, Pennsylvania, New York, and Vermont. Approximately half of these 130 counties are monitored with trap logs, while the remaining counties are monitored with alpha-pinene-baited multiple funnel traps
- Counties are monitored with either 5 funnel traps per county, or 5 piles of trap logs with 3 trap logs per pile
- Funnel traps cost 33.00 each and can be used for at least 15 years (probably much longer with minor repairs); therefore, the annual cost of purchasing a trap is approximately $ 2.20.
- Standard alpha-pinene lures cost $ 6.00 per trap.
- Assuming a maximum of 120 traps can be transported at one time in a pickup truck, the average distance per round trip to set up and take down traps within neighboring counties in a given state is 300 miles, and travel costs are $ 0.23 per mile, transportation costs for

setting up and collecting traps are approximatley $ 0.58 per trap.

- Costs for processing insects sampled in traps are $ 4.80 per trap based on 4 person-days of time at $ 15 per hour ($ 120 per day) to set up, take down and process insects from 100 traps.
- The total cost to purchase, bait, transport, set up and take down traps and to completely process sampled insects is $ 13.58 per trap.
- Assuming a maximum of 100 trap logs can be transported at one time in a pickup truck, the average distance per round trip to set up and take down trap logs within neighboring counties in a given state is 300 miles, and travel costs are $ 0.23 per mile, transportation costs for setting up and collecting trap logs are approximately $ .69 per log.
- Costs for processing insects in logs are $ 24.00 per log based on 20 person days of time at $ 15 per hour ($ 120 per day) to set up, take down and debark logs and process insects from 100 trap logs.
- The cost of trap logs is $ .38 per log based on 132 trap logs per cord and $ 50.00 per cord for pine logs.
- Contracting costs to cut and deliver trap logs are $3.00 per trap log based on $ 300.00 per day (100 trap logs per day) for wages/benefits/compensation insurance and supplies for professional tree fallers.
- The total cost to obtain, transport, set up and take down trap logs and to completely process them is $ 28.07 per trap log.
- Inspection of Christmas tree or nursery plantations requires 1 person day for inspection at a cost of $200.00 including wages, transportation, processing samples, identification and confirmation of insects, and completing inspection certificates.
- The costs for fumigating trees or losses for cancelling export contracts are at least $4,000.00 per grower who does not pass field inspection for T. piniperda.
- Average management costs for Christmas tree and nursery producers who participate in the National Compliance Management Program are at least $ 1,500.00 per grower including the cost of enrolling in the program, renting chippers, additional labor costs for removing stumps, and cull trees, setting out and removing trap logs, and applying an early season foliar cover spray.
- Each pine producing county in the North Central Region of the US exports on average at least 8,000 cords of pine to mills outside of the T. piniperda infested area.
- Current Federal Quarantine regulations prohibit movement of pine logs from infested counties for 8 months of the year (i.e., from November 1 to June 30).
- The average price of pine timber is $ 50 per cord.
- The increased cost of competing for and transporting the limited supply of pine timber from non-local markets is estimated at $ 5 per cord.

CALCULATIONS

EXPENDITURE AND OUTPUT VALUES (EOV) WITHOUT PROJECT:

Cost of Detection/Survey:
(65 counties sample with trap logs) * (15 trap logs per county) * ($28.07 per trap log) = $ 27,368.25
(65 counties sample with alpha-pinene baited traps) * (5 traps per county) * ($ 13.58 per trap) = $ 4413.50
total detection/survey costs: $ 31,781.75

Losses incurred because of increased costs of inspection, management, and restrictions on pine Christmas tree, nursery stock, and log movement in 3 additional newly infested counties per year:

Inspection Costs:
(3 counties) * (3 Christmas tree or nursery producers per county who export a significant number of trees outside of infested area) * (1 day of inspection per producer) * ($ 200.00 per inspection day) = $1,800.00

Management Costs:
(3 counties) * (10 Christmas tree or nursery producers per county who participate in compliance management program) * ($ 1,500.00 management costs per producer) = $ 45,000.00

Export restrictions:
(3 counties) * (1 grower per county who fails inspection) * ($4,000.00 in lost sales or contracts or fumigation costs) = $ 12,000.00

Log export restrictions:
(3 counties) * (8,000 cords of pine per county restricted from being exported to mills outside the infested area) * (.67 /yr during which restrictions apply) * (5 $ per cord additional costs to mills to obtain pine from other non-local markets) = $ 80,400.00

Total EOV without Project: $ 170,981.80

EXPENDITURE AND OUTPUT VALUES WITH PROJECT:

Cost of detection/surveys:
(130 counties sample with traps baited with new improved lure) * (5 traps per county) * (17.58 per trap) = $ 11,427.00

No losses incurred because of increased costs of inspection, management, or restrictions on pine Christmas tree, nursery stock or log movement in

3 counties which remain uninfested due to reduction in spread of Tomicus piniperda.

Total EOV with Project: $ 11,427.00

BENEFIT (CHANGE IN EOV) ATTRIBUTABLE TO PROJECT:
(- $ 11,427.00) - (- $ 170,981.90) = $159,554.80

BENEFIT/COST RATIO:
$ 159,554.80 / $ 50,000.00 = 3.19 in year 1

BENEFIT ATTRIBUTABLE TO STDP:
3.19 * $ 20,000 = $63,800.00

PNV OF PROJECT:
$ 159,554.80 - $ 50,000.00 = $ 109,554.80

PNV OF STDP:
$ 63,800.00 - $ 20,000.00 = $ 43,800.00

LITERATURE CITATIONS:

Bedard, W.D., and Wood. D.L. 1974. Programs utilizing pheromones in survey or control. Bark beetles - the western pine beelte. Pages 441-449 in Birch, M.C. (ed.) Pheromones. North Holland Publ. Co., Amsterdam.

Bedard, W.D., and Wood, D.L. 1981. Suppression of Dendroctonus brevicomis by using a mass-trapping tactic. Pages 103-114 in Mitchell, E.R. (ed.) Management of insect pests with semiochemicals. Plenum Press, New York.

Bouhot, L., Lieutier, F., and Debouzie, D. 1988. Spatial and temporal distribution of attacks by Tomicus piniperda L. and Ips sexdentatuts Boern. (Col., Scolytidae) on Pinus sylvestris. J. Appl. Entomol. 106: 356-371.

Byers, J.A., Lanne, B.S., Lofqvist, J., Schlyter, F., and Bergstrom, G. 1985. Olfactory recognition of host-tree susceptibility by pine shoot beetles. Naturwissenschaften 72: 324.

Czokajlo, D. 1998. Semiochemicals for the larger pine shoot beetle (Tomicus piniperda L.) and its clerid predators. Ph.D. Thesis. State University of New York, College of Environmental Science and Forestry.

Francke, Von W., and Heemann, V. 1976. The odour-bouquet of Blastophagus piniperda L. (Coleoptera, Scolytidae). J. Appl. Entomol. 82: 117-119.

Haack, R.A., and Lawrence, R.K. 1997. Highlights of Forest Service

research on Tomicus piniperda: 1992-1996. Pages 111-118 in 1997 Japanese beetle and the pine shoot beetle regulatory review: Proceedings, Louisville, Kentucky, 24-26 February 1997. USDA APHIS, Riverdale, Maryland.

Kangas, E., Oksanen, H., and Perttunen, V. 1970. Responses of Blastophagus piniperda L. (Coleoptera, Scolytidae) to trans-verbenol, cis-verbenol, and verbenone, known to be population pheromones of some American bark beetles. Ann. Entomol. Fenn. 36(2): 75-83.

Långström, B., and Hellqvist, C. 1991. Shoot damage and growth losses following three years of Tomicus -attacks in scots pine stands close to a timber storage site. Silva Fenn. 25(3):133-145.

Lanne, B.S., Schlyter, F., Byers, J.A., Lofqvist, J., Leufven, A., Bergstrom, G., van der Pers, J.N.C., Unelius, R., Baeckstrom, P., and Norin, T. 1987. Differences in attraction to semiochemicals present in sympatric pine shoot beetles, Tomicus minor and T. piniperda. J. Chem. Ecol. 13: 1045-1067.

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

Loyttyniemi, K., Heliovaara, K., and Repo, S. 1988. No evidence of a population pheromone in Tomicus piniperda (Coleoptera, Scolytidae): a field experiment. Ann. Entomol. Fenn. 54: 93-95.

McLean, J.A., and Borden, J.H. 1977. Suppression of Gnathotrichus sulcatus with sulcatol-baited traps in a commercial sawmill and notes on the occurrence of G. retusus and Trypodendron lineatum. Can. J. For. Res. 7:348-356.

McLean, J.A., and Borden, J.H. 1979. An operational pheromone-based suppression program for an ambrosia beetle, Gnathotrichus sulcatus, in a commercial sawmill. J. Econ. Entomol. 72: 165-172.

NAPIS. 1998. Website: http://www.ceris.purdue.edu:80/napis/pests/psb/.

Raty, L., Drumont, A., De Windt, N., Gregoire, J.C. 1995. Mass trapping of the spruce bark beetle Ips typographus L.: traps or trap trees? For. Ecol. Mangt 78: 191-205.

Ross, D.W., and Daterman, G.E. 1997. Using pheroone-baited traps to control the amount and distribution of tree mortality during outbreaks of the Douglas-fir beetle. For. Sci. 43:65-70.

Schonherr, J. 1972. Pheromone in the pine bark beetle, Myelophylus piniperda (Col., Scolytidae). Zeit. Ang. Entomol. 71: 410-413.

Schroeder, L.M., and Eidmann, H.H. 1987. Gallery initiation by Tomicus piniperda (Coleoptera, Scolytidae) on Scots pine trees baited with host volatiles. J. Chem. Ecol. 13(7): 1591-1599.

Schroeder, L.M., and Lindelöw, Å. 1989. Attraction of scolytids and associated beetles by different absolute amounts and proportions of alpha-pinene and ethanol. J. Chem. Ecol. 15:807-817.

Vité, J.P., Volz, H.A., Paiva, M.R., and Bakke, A. 1986. Semiochemicals in host selection and colonization of pine trees by

the pine shoot beetle Tomicus pinperda. Naturwissenschaften 73:39-40.

Ye, H. 1994. Influence of temperature on the experimental population of the pine shoot beetle, Tomicus piniperda (L.) (Coleoptera: Scolytidae). J. Appl. Entomol. 117: 190-194.

Zhou, N., Li, L., Jiang, Z. and Liu, H. 1997. Study on effect of chemical attractants to Tomicus piniperda. Memoir of Tomicus pinperda L. Research. Yunnan Forestry Science and Technology 2: 20-38 (published by Yunnan Academy of Forest Science, Kunming, Yunnan Province, China)