FINAL REPORT

WTFRC Project #CH-04-403 **WSU Project #13C-3643-3387**

Project title: Biology and management of bark beetles

PI: Jay F. Brunner
Organization: WSU Tree Fruit Research and Extension Center
Address, phone, e-mail: 1100 N. Western Avenue, Wenatchee, WA 98801
(509) 663-8181 ext. 238; jfb@wsu.edu

Co-PIs and affiliations: Tim Smith, WSU Extension, Chelan-Douglas County
Mike Doerr, WSU Tree Fruit Research and Extension Center

Contract administrator: Mary Lou Bricker (mdesros@wsu.edu) (509) 335-7667; or Tom Kelly (kellytj@wsu.edu) (509) 335-3691

Objectives:
1. Identify the bark beetle species attacking pome and stone fruit throughout the state. **(completed)**
2. Develop a clear understanding of the seasonal life history of bark beetles in Washington State and compare that with currently available information. **(completed)**
3. Examine methods of monitoring bark beetles. **(completed)**
4. Develop a means to predict beetle activity at any location. **(partially completed)**
5. Determine the distance bark beetles move from a source to attack healthy orchard trees. **(completed)**
6. Develop a laboratory rearing procedure for bark beetles. **(partially completed)**
7. Determine host suitability of various tree fruits **(completed)** and other deciduous trees **(partially completed)** for bark beetle reproduction. Identify other secondary decomposing beetles found in suspected bark beetle host material. **(not completed)**
8. Develop a bioassay technique for assessing relative toxicity of candidate insecticides. **(completed)** Validate insecticide bioassay results and evaluate new candidate insecticides for efficacy and longevity. **(completed)**
9. Document successful control strategies in heavily infested orchards. **(completed)**

Significant findings:
1. The dominant bark beetle found throughout central Washington was the shothole borer (SHB), *Scolytus rugulosus* Müller (Coleoptera: Scolytidae). An ambrosia beetle (AB), *Xyleborinus saxeseni* Ratzburg (Coleoptera: Scolytidae), was present in high numbers at only one location, a cherry orchard abandoned for several years. At most locations more than one species of scolytids were detected. Species identification was confirmed.
2. It is apparent that two distinct periods of SHB activity occur in Washington, the first beginning in late April and peaking in late May to mid-June. The second begins in mid-July and peaks in late July to early August. The pattern first noted in 2003 was observed again in 2004 and 2005. These data are inconsistent with some reported literature. It appeared that SHB was the species most implicated in damage to healthy trees.
3. Ambrosia beetle (AB) activity was noted throughout the entire growing season. It is likely that 2-3 generations occur each year, but there was overlap between them making clear demarcation of generations difficult. AB activity was first observed in late March, with a second activity period occurring in early June, and a possible third in July and August. Ambrosia beetle activity appeared to be limited to stressed or dying trees and was less likely to cause damage to healthy trees.

4. Traps were useful in identifying peak activity periods, but it was not clear whether they would be useful in setting thresholds for treatments. Yellow sticky traps (unbaited apple maggot traps) seemed to be the most appropriate trap to monitor SHB activity, but ethanol-baited intercept-style traps were necessary to monitor AB activity.
5. Woodpiles of cherry, apple and pear appeared to be the main sources of high beetle densities that caused injury to commercial orchards. However, one population of SHB was found developing on recently cut poplar or cottonwood (*Populus* spp.). Severe injury can result to either stressed or healthy cherry trees adjacent to heavily infested host material.
6. Movement of SHB into live orchards was closely associated with emergence from host material. SHB readily moved distances of 10-50 meters to attack healthy trees on orchard borders but did not move more than 2-3 rows into a healthy orchard.
7. Laboratory rearing of multiple generations on an artificial diet was not successful. Adult SHB survived a short time on a diet, but no reproduction occurred. Adults were reared and collected in large numbers from infested wood returned to the laboratory. Successive generations were then reared on current-year cuttings of apple and cherry.
8. Laboratory host-suitability tests showed variability in SHB development rates. Cherry is known to be a good host for SHB, but sap flow and mold development in rearing arenas limited reproduction. Apple and pear were clearly suitable hosts for SHB with reproductive rates being similar. Development appeared to be accelerated in apple relative to pear.
9. Many insecticides caused mortality of SHB in field-aged bioassays. The pyrethroid Asana was the most active through 21 days after treatment. Guthion and malathion provided good suppression through 14 days. Variable results were noted with the chloronicotinyls Actara and Assail, but there is evidence that this class of insecticide has potential to suppress SHB in the field. Thiodan and possibly Avaunt were also shown to be possible options. Proclaim, Sevin, Success and Carzol all caused mortality but not at levels expected to provide adequate control.
10. Orchard sanitation was the most important factor in contributing to a reduction in SHB densities and damage to live cherry trees. Sanitation involved removing potential host material (e.g. weakened limbs, recent prunings) from the orchard and eliminating any host material outside the orchard. Host material can be “eliminated” by burning wood or brush piles or thoroughly soaking the piles with an effective insecticide delivered by a handgun sprayer. The increased volume of water delivered by handgun applications appeared to be a significant factor in insecticide efficacy.

Methods:

Seasonal life history and monitoring: The seasonal life history of SHB and AB was monitored at 18 locations in north-central Washington over a three-year period. SHB and AB emergence and movement were monitored by rearing adults from infested sources and by trapping adults near the source of infested wood. Infested wood from different locations was collected in the early spring, placed in darkened containers and held under constant temperature conditions. Cages were fitted with glass vials in one side. Emerging beetles (and parasitoids) were attracted to the light. Beetles entering the glass vial were collected 3 times per week. Traps were placed near infested woodpiles outside of orchard blocks and on the orchard border closest to the source. Commercially available intercept-style traps (Lindgren Funnel Trap, 8-funnnels, Phero Tech, Inc.; Pane Intercept Trap, IPM Technologies, Inc.) baited with or without ethanol lures were compared to unbaited yellow sticky traps (Pherocon AM, Trécé, Inc.) for their ability to monitor adult emergence from a source and subsequent migration into surrounding orchards. All insects emerging from infested wood in laboratory cages and all insects collected in the intercept-style traps were identified to family by WSU entomologists. Further, all scolytids and associated parasitoids were sent to Dr. Malcom Furniss, (Entomologist *Emeritus*, University of Idaho) for positive identification.

***Describe SHB movement from host material to healthy orchards*:** Orchards that were exhibiting severe SHB infestation and subsequent damage to healthy cherry trees were identified and monitored for SHB emigration from nearby host material. The host material serving as the source for SHB was determined and then emigration to healthy trees was monitored with yellow sticky traps at the source and the orchard border. Infestation or damage to healthy trees was monitored by visually inspecting trees in a grid-like pattern moving away from the source. Every tree was monitored along the border row and then every row was monitored moving into the orchard until no further SHB damage was noted. Twenty growing shoots were randomly selected from each tree, and the total number of shoots exhibiting wilting or flagging foliage was recorded. SHB emigration and infestation was monitored at four locations in central Washington.

***Laboratory rearing of SHB*:** SHB adults were collected from infested wood as described in the *Seasonal life history and monitoring* section. The majority of adults were collected following peak flight noted in June 2003. Adults were exposed to both drying wood (cherry or apple limbs of >4 inches in diameter, pruned during the previous winter) in a cage and to cups containing an artificial scolytid diet (Southern pine beetle diet # F9761B, Bio-Serv, Inc.). The rearing arenas were examined regularly for SHB feeding activity and any sign of reproduction.

***Host suitability*:** SHB were reared in limb sections of cherry, apple and pear. These limb sections were recently cut pieces of 2- to 5-year-old wood (6" long x 1" diameter) from trees that had received no insecticide treatments. Limb sections were exposed to newly emerged adult SHB in 32 oz. clear plastic deli cups (Prime Source PS232). Twenty-five cups were set up per host, and 5 SHB were added to each cup. The cups were held at 72°F (±2°F) and 16:8 L:D. The wood sections were examined at regular intervals for SHB survival and the emergence of new beetles. Further, SHB sources identified in field monitoring trials were categorized by species/cultivar and estimated age since cutting. Data from these observations were used to describe host material that was suitable for SHB reproduction.

***Insecticide efficacy and longevity*:** In 2003-04, insecticides were evaluated using newly emerged first generation SHB adults. Mature Delicious apple trees at WSU-TFREC were treated with recommended rates of various insecticides. Treated apple branches were collected at 1, 7, 14 and 21 days after treatment (DAT) and returned to the laboratory. Approximately 6" long x 0.5" diameter sections of 2-year-old wood were added to 32 oz. deli cups (Prime Source PS232). Untreated apple branches were used as a control at each evaluation date. Five SHB adults were added to the deli cups, and survival was recorded after 3 days. Five rearing arenas were prepared for each treatment, and each treatment was replicated three times (25 SHB/treatment/DAT). Rearing conditions were 72°F, 16:8 L:D.

***Documenting successful control strategies*:** WSU entomologists worked closely with several growers to identify the source of severe SHB infestations, remove the source, and then document the efficacy of their clean-up efforts. The source of the infestation was determined through visual inspections as well as trapping of adult movement using yellow sticky traps. Sanitation involved cleaning up potential sources of infestation within the orchard by removing pruning cuts from the previous winter, removing weakened branches or limbs from infested trees, and finally removing any outside orchard sources. "Removal" of outside-orchard sources was accomplished through either insecticide applications or burning of host material.

Results and discussion:

***Seasonal life history and monitoring*:** Several hundred adult scolytids were collected from infested fruitwood and ethanol-baited intercept traps and preserved for identification. The dominant bark beetle found throughout Washington was the shothole borer (SHB), *Scolytus rugulosus* Müller (ver. Malcom Furniss). An ambrosia beetle, *Xyleborinus saxeseni* Ratzburg (ver. Malcom Furniss), was present in high numbers at only one location, a cherry orchard abandoned for several years. At most locations more than one species of scolytids were detected. A second *Scolytus* sp. (*S. multistriatus*) was found infesting a pile of cherry wood at one location. Cherry is not a reported host for *S. multistriatus,* and in this case *S. multistriatus* infested only the woodpile and was not detected moving into the neighboring cherry orchard. Many other wood decomposing beetles were reared from infested wood. In fact, the majority of beetles collected were associated with dry, dead wood (>18 months old). Buprestids, bostricids and powderpost beetles (Lyctidae) were the primary families of beetles associated with dry, dead wood. SHB and AB appeared to be the primary attackers of weakened trees or recent cuttings (<18 months old). SHB seemed to be the species most implicated in damage to healthy trees, whereas AB were found attacking only stressed or already damaged or weakened trees. Initial observations at the time of collection show that there was fairly significant parasitism (up to 50%) of SHB larvae by *Cheiropachus quadrum* (Hymenoptera: Pteromalidae) (ver. Malcom Furniss).

All traps tested were useful in identifying peak beetle activity periods. There did not appear to be any significant difference in commercially available intercept-style trap types (Fig. 1). Either the Pane Intercept Trap or the Lindgren Funnel Trap was a suitable trapping system to monitor both SHB and AB adult activity. Available ethanol attractants only slightly enhanced trap captures for SHB (Fig. 2). Adult SHB were more highly attracted to the yellow sticky traps than the dark silhouette of the intercept traps (Fig. 3). Although yellow sticky traps seemed to be the most appropriate trap to monitor SHB activity, the ethanol-baited funnel traps were necessary to monitor AB activity.

Two distinct periods of SHB activity occurred in Washington (Fig. 4). SHB activity was first noted in late April or early May and continued through June. The second adult flight was detected in mid- to late July and continued through August and into September. The pattern first noted in 2003 was observed again in 2004 and 2005. Adult SHB were trapped through the entire growing season from initial adult emergence

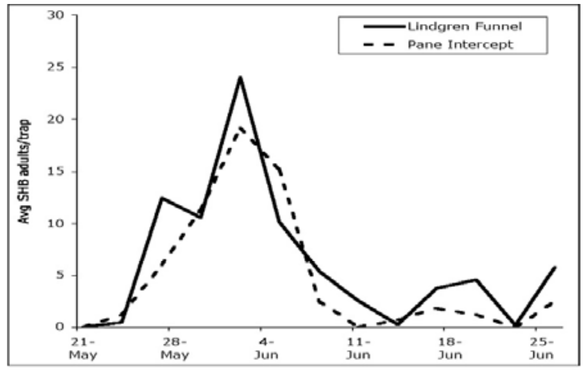

Figure 1: Monitoring SHB with commercially available intercept-style traps baited with an ethanol lure, 2003.

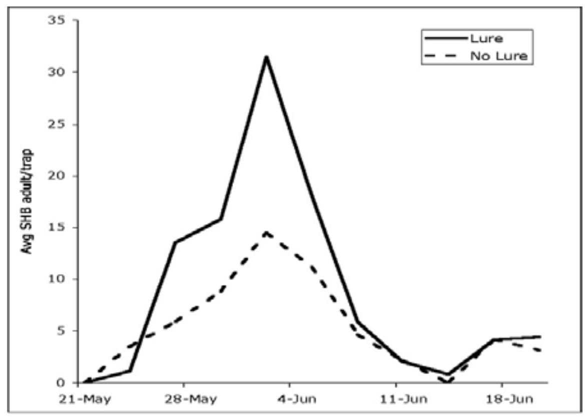

Figure 2: Additive effect of an ethanol lure on SHB captures with an intercept style-trap, 2003.

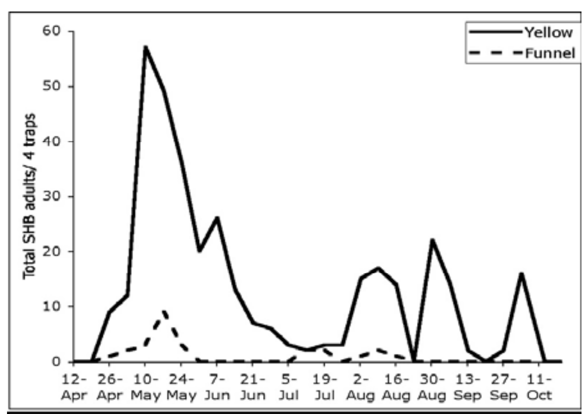

Figure 3: SHB captures in intercept-style funnel traps and yellow sticky cards, 2004.

through the end of October. Visual observations of laboratory and field behavior suggested that adult dispersal to suitable hosts and subsequent oviposition occurred shortly after emergence with subsequent activity centered on tending to the maternal galleries.

Traps were useful in identifying peak activity periods of SHB, but it was not clear whether they would be useful in setting thresholds for treatments. We experienced difficulty in locating SHB sources of various population sizes near neighboring cherry orchards that were allowed to remain untreated. However, our observations indicated that if a SHB source was located near a cherry orchard and any significant emergence was detected with yellow traps some control intervention was probably necessary to prevent damage.

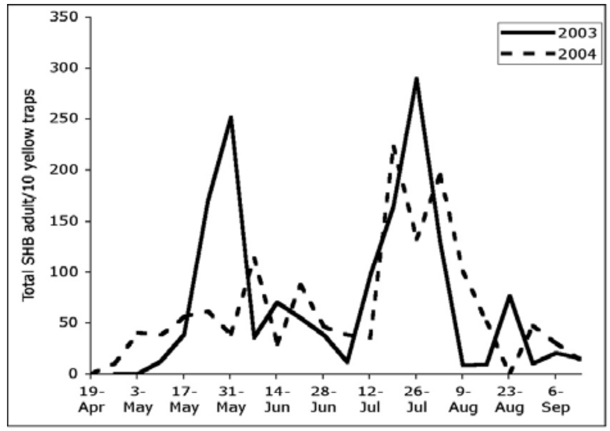

Figure 4: Seasonal life history of SHB, 2003-04.

AB activity was initially noted in late March or early April in 2004 (Fig. 5). AB activity was detected throughout the entire growing season, with 2 to 3 generations likely. It appeared that a second peak of activity might have occurred in early June, with a possible third generation in July and early August. A similar pattern of summer activity was noted in 2003, but traps were not in place early enough to detect the first flight.

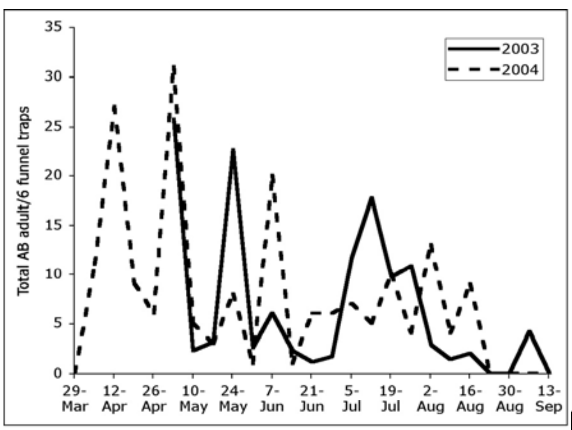

Figure 5: Seasonal life history of AB, 2003-04.

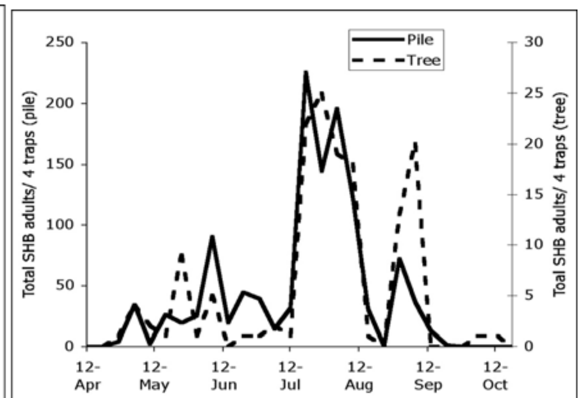

Figure 6: Emigration of SHB from woodpile source to healthy orchard trees, 2004.

***Emigration of SHB from source to healthy orchards*:** Movement of SHB into orchards was closely associated with emergence from host material, generally a pile of recently pruned or cut wood. SHB activity was easier to monitor in the host material than in live trees, as a very large number of adults emerged from a relatively small area. The first impression was that little activity was noted in live orchard trees. However, plotting adult captures in live trees on a second *y*-axis with a different scale (Fig. 6) showed that relative activity in the host material and live orchard trees was very similar. These data suggested that recently emerged SHB adults were highly dispersive and readily moved distances of 10 to 50 meters from host material to live trees. SHB feeding damage in orchards was most commonly associated with movement from infested sources (Fig. 7). Generally, SHB damage was in close proximity to a source. It appeared that SHB moved readily along a border but did not move more than 2 to 3 rows into a healthy orchard.

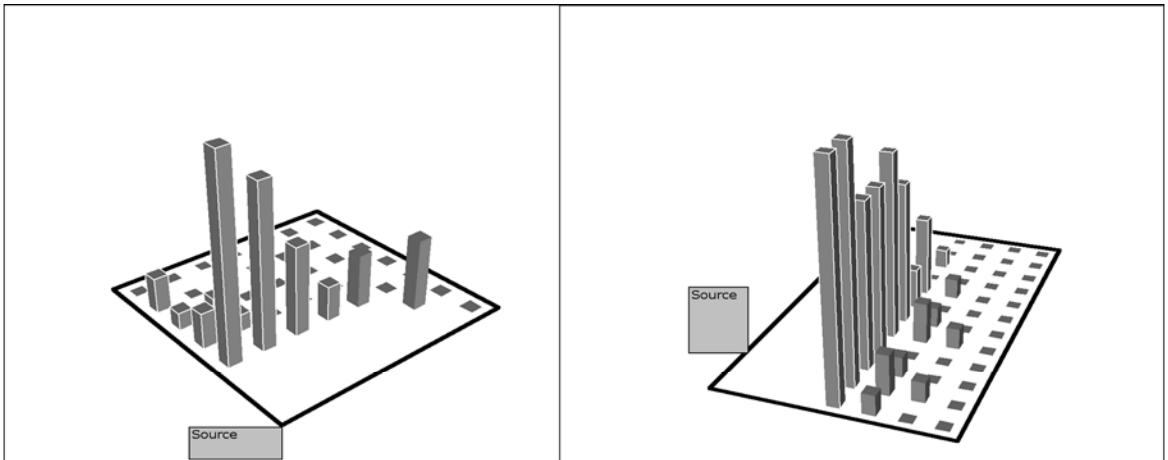

Figure 7: Relative SHB injury levels in orchard trees near an SHB source. Each bar represents a cherry tree sampled in a 20 x 20 ft grid.

***Laboratory rearing*:** Laboratory rearing of multiple generations on an artificial diet was not successful. Adult SHB survived a short time on the diet, but no reproduction occurred. Adults were reared and collected in large numbers from infested wood returned to the laboratory. Successive generations were then reared on current-year cuttings of apple and cherry. However, in order to rear enough adults to conduct research experiments upon, a large space commitment was necessary. Further, newly emerged SHB adults were highly dispersive and would escape all rearing arenas tested. The most efficient means of rearing SHB may very well be establishing a colony on a pile of recently cut fruitwood and then add new cuttings to the woodpile each year. This would allow for observations of insect behavior under "normal" conditions as well as providing an area where insects could easily be collected.

***Host suitability*:** Host suitability tests showed variability in SHB development and reproductive rates between cherry, apple and pear (Fig. 8). Cherry is known to be an excellent host for SHB development, but copious amounts of sap flow acts to inhibit SHB reproduction, a defensive response in the tree. In our rearing arenas excessive moisture from the cherry cuttings resulted in significant mold development. Mold apparently reduced SHB reproduction in the cherry rearing experiment. The first emergence of new SHB was noted at 50 days in apple, with emergence from an individual arena occurring over a 3 to 4 week period. The first emergence in pear and cherry was noted at 64 days. The emergence pattern in pear was similar to apple but was delayed by 14 days. It was apparent from this study that apple and pear were suitable hosts for SHB with reproductive rates being similar. Development was accelerated in apple relative to pear.

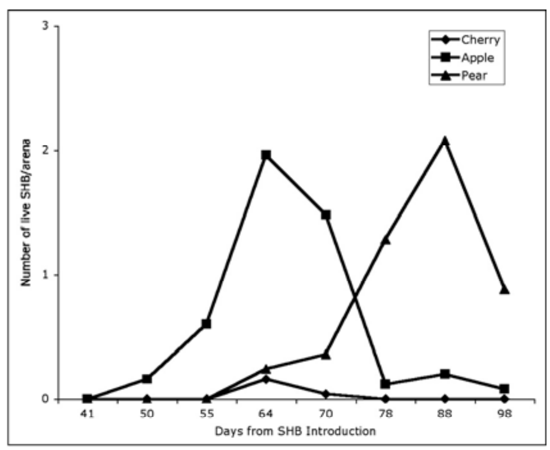

Figure 8: SHB host suitability of various fruitwood types, 2004.

It was generally reported that pome and stone fruits (*Prunus* spp., *Malus* spp., and *Pyrus* spp.) were the primary hosts of SHB. In nearly all of our monitoring trials, fruitwood was discovered to be the source material for the SHB population. This was probably the result of our trials being focused on areas very near orchards. Prunings from the previous winter were most often discovered to be the primary reproductive material. Large pieces of scaffold wood may dry more slowly and provide sufficient habitat for reproduction for a longer period of time, but generally cuttings greater than 18 months old were not suitable for SHB reproduction. We did monitor a recently cut pile of poplar or cottonwood (*Populus* spp.) placed along an orchard border. SHB moved to the cuttings immediately and were able to successfully reproduce on the 3-month old cuttings. Other studies have reported that SHB will occasionally attack ash, elm, and hawthorn, as well as other deciduous trees. It was apparent that at least the potential existed for SHB to colonize many types of deciduous hardwood trees. Thus, efforts focused on locating sources of SHB infestations may need to be directed not only to fruitwood but to other potential hosts as well.

***Field-aged bioassays*:** A preliminary protocol was developed for screening insecticides against SHB adults. The average survival of SHB adults introduced to rearing arenas with untreated sections of wood was above 80% through the 3 days of observation. This level of survival indicates that any significant mortality noted in the rearing arenas could be attributed to pesticide exposure and not to a problem with the protocol.

Table 1. Field-aged bioassay data from candidate insecticide, 2003-04.

Insecticide	Rate (form/a)	Average corrected % mortality-2004 (2003 data in parens)			
		1 DAT	7 DAT	14 DAT	21 DAT
Asana XL	8.0 fl oz	100.0 (100.0)	100.0 (86.1)	100.0 (100.0)	100.0 (77.7)
Actara 25W	4.5 oz	100.0 (91.7)	100.0 (44.4)	100.0 (---)	90.5 (---)
Assail 70W	3.4 oz	100.0 (50.0)	100.0 (30.6)	100.0 (29.9)	95.2 (22.2)
Avaunt 30W	6.0 oz	100.0 (66.7)	100.0 (2.7)	95.2 (0.0)	61.9 (33.3)
Carzol 92SP	1.25 lb	(58.3)	(16.7)	(---)	(---)
Guthion 50W	2.0 lb	100.0 (91.7)	100.0 (44.4)	85.7 (50.0)	42.9 (44.4)
Malathion 50%	1.5 qt	90.9 (100.0)	81.3 (72.2)	61.9 (---)	47.6 (---)
Proclaim 5SG	4.8 oz	50.0	81.3	100.0	66.7
Sevin XLR	1.0 qt	(41.7)	(2.8)	(---)	(---)
Success 2SC	6.0 fl oz	31.8 (75.0)	43.8 (30.5)	52.4 (39.9)	23.8 (11.1)
Thiodan 3E	3.0 qt	(87.5)	(16.7)	(39.4)	(55.6)

Many insecticides caused mortality of SHB in field-aged bioassays (Table 1). The pyrethroid Asana XL (esfenvalerate) was the most active through 21 days after treatment. Guthion (azinphos-methyl) and malathion provided good mortality through 7 days. Variable results were noted with Thiodan (endosulfan), Actara (thiamethoxam), Assail (acetamiprid), Avaunt (indoxacarb), and Proclaim (emamectin benzoate). However, there was evidence to suggest that these insecticides have potential to suppress SHB. Sevin (carbaryl), Success (spinosad) and Carzol (formetanate hydrochloride) all caused mortality but not at levels expected to provide adequate control. The variability of these data may show a weakness in our method (e.g. limited replication), variability based on age of collected adults, or variability among populations. Thus, more insecticide work is necessary to understand the full potential of each insecticide to control SHB under field conditions.

Significant mortality was noted with many of these products for up to 7 days, and their repeated use during the growing season may contribute to maintaining SHB populations below damaging levels in most commercial orchards, especially during the first SHB generation when cherry fruit fly sprays are being applied at regular intervals. Cherry orchards may become more susceptible to injury in the postharvest period when insecticide programs for cherry fruit fly and leafroller have ceased and second generation SHB adults are able to move into unprotected orchards.

Orchard sanitation**:** In the winter of 2003 we monitored a concentrated effort to clean up a large SHB source that had resulted in significant damage to young, healthy cherry trees. Serious damage was noted along the orchard border despite several insecticide applications, including repeat applications of methyl parathion and endosulfan. The source was a firewood pile and a brush pile that was replenished each year with new prunings and not burned. The source was identified in September 2003, and a damage evaluation was made at that time. Damage was high but fairly isolated to the rows adjacent to the source (Fig. 9). During the winter of 2003-04 the orchard was pruned heavily, removing all weakened or damaged branches. Previous year's prunings (2002-03) and current season prunings (2003-04) were returned to the laboratory and placed in emergence cages. Enough wood to fill a 2' x 2' x 1' (L x W x D) emergence cage was collected from each year's prunings. The 2002-03 prunings produced 191 SHB adults, and the 2003-04 prunings produced 6 SHB adults. These data indicated that the majority of SHB were being generated by 1-year-old prunings but also that some reproduction was occurring in the live trees. The grower made a concentrated effort to clean up all source material (firewood and brush piles and prunings) and maintain a clean area near the infested orchard. In 2004 the orchard was monitored with yellow sticky traps, ethanol-baited funnel traps, and visual inspection of damaged shoots. Insecticide applications were going to be timed with increased trap captures. However, only a total of 4 SHB adults and 9 AB adults were trapped in 5 yellow traps and 2 funnel traps over the entire season. No specific SHB insecticide applications were needed in 2004. No SHB damage was noted at any time in the 2004 season (Fig. 9).

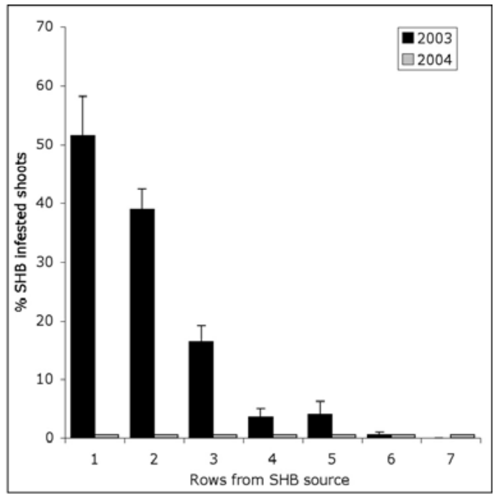

Figure 9: SHB damage in highly infested orchard before (2003) and after (2004) a sanitation program was initiated to remove host material.

In 2005, we identified three locations in Okanogan with easily identified sources of SHB located just outside of cherry blocks. Further, infested limbs and prunings were serving as host material within the cherry blocks. These locations were brought to our attention after first generation adults caused serious damage to orchard borders. Insecticidal control options were limited because one of the blocks was managed organically and the conventional blocks were experiencing damage levels of 50% shoot infestation despite a history of border sprays. Although yellow traps were placed near the end of first generation activity, captures in the first week averaged 116 SHB/trap in the source areas across all three sites (Fig 10). The grower immediately began a concerted effort to remove all

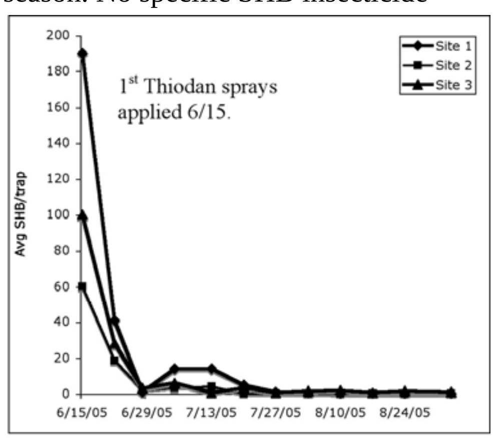

Figure 10: SHB captures from 3 high pressure locations following a sanitation program and an insecticide program targeting host material, 2005.

possible host material from within the orchard. This involved picking up the previous winter's cuttings and pruning out all weakened branches or limbs. This host material was added to the source material located outside the orchard. The grower then started an intensive spray program targeting the woodpiles. Thiodan was applied by handgun on a 10-to 14-day retreatment interval for the rest of the season. Care was taken to thoroughly soak the entire woodpile. Although the new host material was added to the woodpiles, no second-generation activity was noted at any of the three sites.

Our experience with SHB management indicated that orchard sanitation was the most important factor in contributing to a reduction in SHB densities and damage to live cherry trees. Sanitation programs must include removing potential host material (weakened limbs, recent prunings) from within the orchard and eliminating any host material outside the orchard. Host material can be "eliminated" by burning the wood or thoroughly soaking the wood with an effective insecticide delivered by a handgun sprayer. The increased volume of water delivered by handgun applications was an important factor in insecticide efficacy.

Budget:
Project title: Biology and management of bark beetles
PI: Jay F. Brunner
Project duration: 2 years
Current year: 2004-05
Project total (2 year): $32,000

Year	**Year 1 (2004)**	**Year 2 (2005)**
Total	**16,000**	**16,000**

Current year breakdown

Item	**Year 1 (2004)**	**Year 2 (2005)**
Salaries[1]	**4,178**	**4,345**
Benefits (29%)	**1,212**	**1,260**
Wages[2]	**7,000**	**7,000**
Benefits (16%)	**1,120**	**1,120**
Equipment	**0**	**0**
Supplies[3]	**1,000**	**1,000**
Travel[4]	**1,490**	**1,275**
Miscellaneous	**0**	**0**
Total	**16,000**	**16,000**

1 Mike Doerr – one month salary – conduct bioassays and supervise rearing.
2 One person for four months to conduct field sampling.
3 Supplies include rearing materials, traps and preservation materials for beetles. Cell phone charges are allowed under this grant.
4 Travel – one vehicle for 3-4 months at $350/month plus fuel to collect field samples.

This research proposal is protected property of Washington State University. Please see the statement on the inside front cover of this book.