Bugs in the System: Development of Tools to Minimize Ponderosa Pine Losses from Western Pine Beetle Infestations[1]

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Abstract

The western pine beetle, *Dendroctonus brevicomis* LeConte, is a major cause of ponderosa pine, *Pinus ponderosa* Dougl. Ex Laws., mortality in the western USA and particularly in California. Under certain conditions, the beetle can aggressively attack and kill apparently healthy trees of all ages and size classes. The average loss is substantial, and has been estimated at 1 billion board feet annually. The availability of pest management techniques for preventing and suppressing infestations is rather limited. Currently, we are conducting several studies on the development of chemical, silvicultural and semiochemical-based management tactics for minimizing the negative impacts associated with *D. brevicomis* infestations. This paper describes the status of four such studies. Efficacy of the insecticide bifenthrin for protecting individual, high-value trees, and of the anti-aggregation pheromone verbenone for protecting small stands, is described. In a trapping bioaasay, nine nonhost angiosperm volatiles significantly augmented the effect of two release rates of verbenone, reducing trap catches to levels significantly below that of either release rate of verbenone alone. These results suggest that the addition of nonhost angiosperm volatiles to verbenone could be important for developing successful semiochemical-based management techniques for *D. brevicomis*. In another study, we examined and described the effect of mechanical fuel reduction treatments on the activity of bark beetles in ponderosa pine stands. Many of the results presented here are preliminary in nature.

Keywords: western pine beetle, *Dendroctonus brevicomis*, ponderosa pine, *Pinus ponderosa*, insecticides, verbenone, nonhost angiosperm volatiles, semiochemicals, fuel reduction, forest health

Introduction

The western pine beetle (*Dendroctonus brevicomis* LeConte) is a major cause of ponderosa pine mortality in the western USA and particularly in California. Under certain conditions, the beetle can aggressively attack and kill apparently healthy trees of all ages and size classes. The total annual loss ranges from 500 million to 3.5 billion board feet. The average loss is substantial, and has been estimated at approximately 1 billion board feet annually (Miller and Keen 1960). Much of this mortality occurs within the larger diameter classes. Currently, the availability of pest management techniques for preventing or suppressing infestations is limited to prevention thinning or insecticide treatments.

Severe droughts, such as those occurring in California from 1975 to 1977 and from 1988 to 1993, are often accompanied by excessive amounts of *D. brevicomis*-

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caused tree mortality in both managed and unmanaged stands. High-value trees, such as those located in residential, recreational, or administrative sites, are particularly susceptible to attack as a result of increased amounts of stress associated with drought, soil compaction, mechanical injury, or vandalism (Haverty and others 1998). Regardless of landowner objectives, tree losses generally have a catastrophic impact. For example, the value of a mountain home may be severely reduced by the mortality of adjacent shade and ornamental trees (McGregor and Cole 1985). The mortality of trees located in campgrounds or other administrative sites can have long-range management impacts. The value of these individual trees, the cost of removal, and the loss of aesthetics may justify protecting individual trees with insecticides until the main thrust of an infestation subsides. This situation emphasizes the need for assuring that effective insecticides are available for individual tree protection in the future.

Several formulations of carbaryl have been evaluated and found effective for protection of individual trees from attack by western bark beetle species (Gibson and Bennet 1985, Hall and others 1982, Haverty and others 1985, Shea and McGregor 1987). These and other studies (McCambridge 1982, Smith and others 1977) led to registration of 2 percent Sevimol® for this use. In 2003, only two formulations of carbaryl, permethrin, and injected metasystox-R were registered for protection of ponderosa pine from the western pine beetle. Metasystox-R has been shown to be rather ineffective and is not recommended for use (Haverty and others 1997). Given the uncertain future availability of an effective preventative spray, I believe it is important to develop alternative insecticides for this important forestry use.

Verbenone (4,6,6-trimethylbicyclo[3.1.1]-hept-3-en-2-one) is the primary antiaggregation pheromone of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), southern pine beetle (*Dendroctonus frontalis* Zimmermann), and western pine beetle. It was first identified in males of the southern and western pine beetles, and subsequently in the hindgut of emergent and feeding female mountain pine beetles. Verbenone is naturally derived from three sources: (1) the beetles themselves, (2) auto-oxidation of α-pinene and subsequently of cis- and trans-verbenol to verbenone (Lindgren and Borden 1989), and (3) auto-oxidation from cis- and trans-verbenol to verbenone by certain microorganisms that are associated with bark beetle species. It is assumed that verbenone reduces the negative impacts of intraspecific competition by reducing the overcrowding of developing brood within the host tree.

In recent years, verbenone has been evaluated as a tool for mitigating stand losses due to bark beetle infestations. In the southern USA, verbenone is used once an infestation (termed "spot") has formed to reduce future spot growth (Clarke and others 1999). In general, by placing elution devices containing synthetic verbenone on all freshly attacked trees and a suitable buffer of uninfested trees at the active margin (termed "head") of the spot, emerging and reemerging beetles are forced to disperse in search of unoccupied hosts. Spot growth is often reduced and sometimes completely suppressed. Verbenone is now available commercially in a slow-release polyethylene pouch (Phero Tech Inc., Delta, BC) that has received U. S. Environmental Protection Agency (EPA) registration for use in forest stands containing southern pines (EPA Reg. No. 56261-CN-1 (1999)).

In the western USA, efforts have concentrated on using verbenone for small-scale stand protection. Most field evaluations have concentrated on *D. ponderosae* populations, and results have often been favorable. Verbenone released from multiple points in stands of lodgepole pine significantly reduced infestation levels in some studies (Amman and others 1989, 1991; Lindgren and others 1989, Gibson and others 1991, Shea and others 1992, Shore and others 1992, Lindgren and Borden 1993), but not others (Gibson and others 1991). In general, the application of verbenone has been unsuccessful in reducing the number of *D. ponderosae*-attacked trees in ponderosa pine (Bentz and others 1989, Lister and others 1990, Gibson and others 1991). To my knowledge, no studies have been published on the efficacy of verbenone for prevention or suppression of *D. brevicomis* infestations in ponderosa pine stands.

Volatile stimuli associated with host and non-host trees are important in mediating behavioral responses of phytophagous insects (Visser 1986). Bark beetles are believed to use a combination of host kairomones and aggregation pheromones to locate suitable host material (Borden 1985). Rejection may occur on the basis of absence of host cues or presence of non-host cues such as green leaf volatiles or angiosperm bark volatiles collectively termed nonhost angiosperm volatiles (NAVs). NAVs have been the focus of several recent studies which show that these compounds are capable of reducing aggregation in several scolytid species including *D. frontalis*, *D. ponderosae*, and *D. pseudotsugae* Hopkins (Zhang and Schylter 2004). In general, NAVs (except conophthorin) have only been effective for reducing aggregation if presented as combinations of two or more volatiles. One study has examined the effects of NAVs on *D. brevicomis* attraction, but was limited in scope to green leaf volatiles only (Poland and others 1998). I believe the system has promise for prevention and suppression of *D. brevicomis* infestations in ponderosa pine stands, and merits further investigation.

Under the National Fire Plan, the hazardous fuel treatment program has, and likely will, continue to increase in the future. One of the key goals of this program is the reduction of hazardous fuels within the wildland urban interface. In FY 2002, the goal was to treat 1.0 million hectares, and in consideration of the recent fire activity throughout the West, the protection of these communities and management of adjacent fuel loads has become paramount. At present, much of the biomass that has been removed is not merchantable as markets have yet to be developed for small dimensional timber. On many Forest Service districts in the Southwest, this material is chipped, and/or cut and lopped, and distributed on site. As a result increased amounts of host material (slash), and host volatiles (slash and chips) can attract and concentrate bark beetles within these areas. Populations can then reach high enough densities to threaten adjacent, apparently healthy trees. Trees that are killed by bark beetles after fuel reduction treatments increase fuel loads in areas not likely to be re-treated for many years. Furthermore, the cost of removal, regeneration, and long-term aesthetic losses justify the development of guidelines to mitigate such losses.

This paper describes the status of four studies conducted to develop tools for mitigating the amount of bark beetle-caused tree mortality in ponderosa pine stands. The results presented here are largely preliminary in nature.

Methods

Insecticide study.

This study was conducted on the eastern slope of the Sierra Nevada between 1400-1700 m elevation in Lassen County, California. Four treatments (insecticides) were analyzed for protecting ponderosa pine from *D. brevicomis*-attack: bifenthrin at

0.03, 0.06 and 0.12 percent AI (Onyx™); carbaryl at 2.0 percent AI (Sevin SL®); and two separate untreated controls. One control group was used to assess beetle pressure during the first summer, and the second used to assess pressure during the second summer post-treatment.

All insecticides were applied in mid-May 2003 using a trailer-mounted hydraulic sprayer (300 psi), which allowed treatment of the entire bole of each tree, until runoff, to a height of >10m (Haverty and others 1983). Two tank samples were collected and returned to the laboratory to be analyzed for concentration and purity. Treatments were applied between 0600 and 1100 when wind speeds are diminished.

Test trees were located in areas with recent beetle activity and isolated from other sample trees. Trees selected were 28 to 52cm dbh, and within 75m of an access road to facilitate treatment. Experimental trees were separated by >160m to ensure that a sufficient number of beetles would be in the vicinity of each tree to rigorously test the efficacy of these treatments (Shea and others 1984). The surrounding cover type was Ponderosa-Jeffrey (Yellowpine) Series. Forest composition, in order of decreasing abundance, was ponderosa pine, Jeffrey pine, *Pinus jeffreyi* Grev. & Balf., white fir, *Abies concolor* (Gond. and Glend.) Hildebr., and incense-cedar, *Calocedrus decurrens* Torr.

All test trees and the first set of untreated check trees were baited with *D. brevicomis* aggregation pheromone (*exo*-brevicomin, frontalin, and myrcene; WPB Tree Bait®; Phero Tech Inc., Delta, BC) for a period of 4 weeks in August 2003. The surviving treated trees in each treatment (if there are no more than 7 killed by the bark beetle challenge), and the second set of check trees were baited again in June 2004. Untreated check trees were monitored biweekly until 60 percent exhibit signs of successful attack, at which time the baits were removed from all trees.

Each treatment was randomly allocated to 35 trees (n = 210). The only criterion used to determine the effectiveness of the insecticide treatments was whether or not individual trees succumbed to attack by western pine beetle. Tree mortality was assessed in June 2004 (first baiting) and October 2004 (second baiting). The period between pheromone removal and mortality assessment was sufficient for crowns to "fade", an irreversible symptom of pending mortality. Treatments were considered to have sufficient beetle pressure if >60 percent of the untreated control trees die from beetle attack. Insecticide treatments were considered efficacious if <7 treated trees die as a result of bark beetle attack. These criteria were established based on a sample size of 30-35 trees/treatment and the test of the null hypothesis, H_O:S (survival ≥ 90 percent). These parameters provided a conservative binomial test (α = 0.05) to reject H_O when more than six trees die (Shea and others 1984).

Verbenone study

This study was conducted over a 3 yr-period. The experimental design was a randomized complete block with two treatments (verbenone-treated and untreated) and six replicates (3 reps/treatment/block). Plots were 2 ha, square in shape, and predominately (>60 percent BA) ponderosa pine. Adjacent plots were separated by >400 m. Three replicates of each treatment were evaluated on the McCloud RD, Shasta-Trinity National Forest, and three on the Placerville RD, Eldorado National Forest.

Verbenone pouches (Phero Tech Inc., Delta, BC) were deployed twice annually on June 1 and July 1 (2002-2004) on a grid, approximately 9.1 by 9.1 m. Individual pouches were stapled at approximately 2 m in height on the bole of 250 trees per plot. Pouches from the June application were removed when the second application was made in July. On weekly intervals, one verbenone pouch per plot was removed, and stored in a deep freeze for verification of chemical purity and determination of release rates. Each pouch that was removed was immediately replaced with a fresh pouch. Western pine beetle tree baits (Phero Tech Inc., Delta, BC) were placed at the center of each plot (verbenone-treated and untreated) to create additional beetle pressure and a robust examination of this treatment (Amman and others 1989).

A 100 percent cruise was conducted pre- and post treatment on each plot in May and August (2002-2004) for the purpose of locating bark beetle infested trees. For all ponderosa pine >15 cm dbh, the number of *D. brevicomis*-attacked and -unattacked trees was recorded. All trees with evidence of bark beetle activity were geo-referenced by UTM coordinate.

Nonhost angiosperm volatile study

Twenty-seven (27) 16-unit multiple-funnel traps were deployed in a ponderosa pine forest on the McCloud RD, Shasta-Trinity NF, northern California in June 2004. Trap locations were separated by >20 m to avoid interference among adjacent treatments. Traps were hung on 3-m metal poles with collection cups approximately 1 m from the ground. A 3 x 3-cm time-released insecticidal Prozap Pest Strip (2,2-dichlorovinyl dimethyl phosphate (DDVP), Loveland Industries Inc., Greely, CO) was placed in the trap cup to kill arriving insects. Each trap location was randomly assigned one of nine treatments: 1) untreated control, 2) frontalin, *exo*-brevicomin, myrcene (WPB bait), 3) verbenone (4 mg/24h) + WPB bait, 4) (*E*)-2-hexen-1-ol , (*E*)-2-hexenal, (*Z*)-2-hexen-1-ol (**GLV**) + WPB bait, 5) **GLV** + verbenone + WPB bait, 6) benzyl alcohol, benzaldehyde, conopthorin, guaiacol, nonanal, salicylaldehyde (**BV**) + WPB bait, 7) **BV** + verbenone + WPB bait, 8) (*E*)-2-hexen-1-ol , (*E*)-2-hexenal, (*Z*)-2-hexen-1-ol + benzyl alcohol, benzaldehyde, conopthorin, guaiacol, nonanal, salicylaldehyde (**NAV**) + WPB bait, and 9) **NAV** + verbenone + WPB bait (Table 1). Treatment locations (trap and treatments) were re-randomized daily for 10 consecutive days.

Specimens were tallied, sexed, and identified using available keys (Wood 1982) and voucher specimens. The experimental design was completely randomized with nine treatments and 30 replicates per treatment. A test of normality was performed, and appropriate transformations were used when the data deviated significantly from a normal distribution. We performed a one-way analysis of variance on the pooled data (exclusive of the untreated control) collected from each trap using α=0.05 (SigmaStat Version 2.0, SPSS Inc.), and Tukey's HSD for separation of treatment means.

A second experiment was conducted in August 2004 using similar protocols. Each trap location was randomly assigned one of 12 treatments: 1) untreated control, 2) WPB bait, 3) verbenone (4mg/24h) + WPB bait, 4) verbenone (50mg/24h) + WPB bait, 5) NAV+C + Verb4 + WPB bait, 6) NAV+C + Verb50 + WPB bait, 7) NAV-C + Verb4 + WPB bait, 8) NAV-C + Verb50 + WPB bait, 9) ALD + Verb4 + WPB bait, 10) ALD + Verb50 + WPB bait, 11) ALC + Verb4 + WPB bait and 12) ALC + Verb50 + WPB bait (NAV+C includes conophthorin; NAV-C excludes conophthorin; ALD (aldehydes); ALC (alcohols)). The NAV alcohols were benzyl alcohol, guaiacol, (*E*)-2-hexen-1-ol, and (*Z*)-2-hexen-1-ol, and aldehydes were benzaldehyde, nonanal, salicylaldehyde, (*E*)-2-hexenal. The experimental design was completely randomized with 12 treatments and 30 replicates per treatment. Thirty-six (36) 16-unit multiple-funnel traps were used in this experiment.

Table 1*— Nonhost angiosperm volatiles used in Experiments 1 and 2.*

Volatile	Source	Release Device	Release (mg/24h)
benzyl alcohol	Fischer Scientific	Phero Tech bubblecap	1.3 (20 °C)
benzylaldehyde	Fischer Scientific	Phero Tech flexlure	3.5 (20 °C)
conophthorin	Phero Tech	0.4 ml polyethylene vial	3.0 (28 °C)
guaiacol	Sigma Aldrich	Phero Tech bubblecap	5.0 (20 °C)
nonanal	Sigma Aldrich	Phero Tech flexlure	3.5 (20 °C)
(*E*)-2-hexenal	Bedoukian Research	Phero Tech bubblecap	3.5 (20 °C)
(*E*)-2-hexen-1-ol	Bedoukian Research	Phero Tech bubblecap	3.8 (20 °C)
(*Z*)-2-hexen-1-ol	Bedoukian Research	Phero Tech bubblecap	3.8 (20 °C)
salicylaldehyde	Sigma Aldrich	Phero Tech bubblecap	5.0 (20 °C)
verbenone	Phero Tech	Phero Tech pouch	50.0 (30 °C)
frontalin *exo*-brevicomin myrcene	Phero Tech	250µL Eppendorf vial 250µL Eppendorf vial 1.8 mL X 2 Eppendorf	3.0 (24 °C) 3.0 (24 °C) 18.0 (24 °C)

Hazardous fuel reduction study

This study was conducted over a period of two years at three locations, and was not limited in scope to *D. brevicomis* as in the previous three studies. The experimental design was a randomized complete block with three blocks, six treatments, and 2 replicates/treatment/block. Blocking occurred on the basis of location. Plots were 0.4 ha, square in shape, and predominately (> 60 percent BA) ponderosa pine. Adjacent plots were separated by >100 m. Two replicates of each treatment were evaluated on the Tahoe National Forest, CA, Kaibab National Forest, AZ, and Prescott National Forest, AZ.

The following treatments were evaluated:

1) May chips, randomly dispersed within plot
2) May chips, raked 2 m from the root collar of all live residual trees
3) August chips, randomly dispersed within plot
4) August chips, raked 2 m from root collar of all live residual trees
5) May slash, scattered according to standard practices
6) August slash, scattered according to standard practices
7) Untreated control

A 100 percent cruise was conducted on each plot in 2003 and 2004 for the purpose of locating all bark beetle infested trees. For all pines >22.8 cm dbh, the number of bark beetle-attacked trees was recorded. Any tree containing successful bark beetle attacks was tagged, and the species and dbh were recorded. The primary variable of interest is the number of bark beetle-attacked trees occurring per unit area during the two-year period.

Results and Discussion

Insecticide study

A rigorous examination of the insecticide treatments occurred during the first baiting period as 22 of 35 untreated trees were killed by *D. brevicomis* attacks. This mortality rate exceeded the criterion established for a viable experiment (60 percent or 21 trees). Only the 0.03 percent AI bifenthrin treatment failed to meet the criterion for efficacy (12/34). The remaining treatments, specifically 0.06 percent AI bifenthrin (0/31), 0.12 percent AI bifenthrin (0/29), and 2.0 percent AI carbaryl (1/34), were effective for protecting ponderosa pine from *D. brevicomis* attacks during the first field season. Investigations are continuing to determine if efficacy remains during the second field season. This study has led to the registration and recommendation of 0.06 percent AI Onyx™ as a preventative spray.

Verbenone Study

No significant differences were observed between the number of *D. brevicomis*-killed trees in untreated and verbenone-treated plots, respectively (P = 0.84). In 2002, (mean ± sem) 6.8 ± 2.6 and 9.0 ± 3.3 trees were killed in untreated and verbenone-treated plots, respectively (P = 0.84). In 2003, 7.8 ± 2.7 and 4.8 ± 1.2 were killed in untreated and verbenone-treated plots, respectively (P = 0.33). Analysis of the 2004 data is currently ongoing and not available at this time. At present, we must conclude that the high release rate of verbenone (50 mg/24h) examined here, which represents a 6X increase over conventional release devices, does not increase the efficacy of this treatment for prevention and suppression of *D. brevicomis* infestations in ponderosa pine.

Analysis of the 2003 data from Placerville as a separate, completely randomized design results in a significant treatment effect (P = 0.07). In fact, 2X more mortality occurred on untreated plots than verbenone-treated plots. These data support our initial hypothesis that efficacy will likely vary with differences in stand structure, composition and topographic features. Forest conditions which include mixed stands of susceptible and non-susceptible species (such as Sierra-mixed conifer), increased crown cover, and vertical stratification will likely result in higher efficacy.

Nonhost angiosperm volatile study

In Experiment 1, there was no significant interaction between treatment and the gender of *D. brevicomis* ($F_{7, 464}$ = 0.52; P = 0.82). A significant treatment effect was observed ($F_{7, 232}$ = 9.35; P < 0.001; Fig. 1), and no significant departures from residual normality or equal variance were apparent. Significantly more female than male *D. brevicomis* were collected (paired T-test, P < 0.001). The ratio of males to females was 0.52.

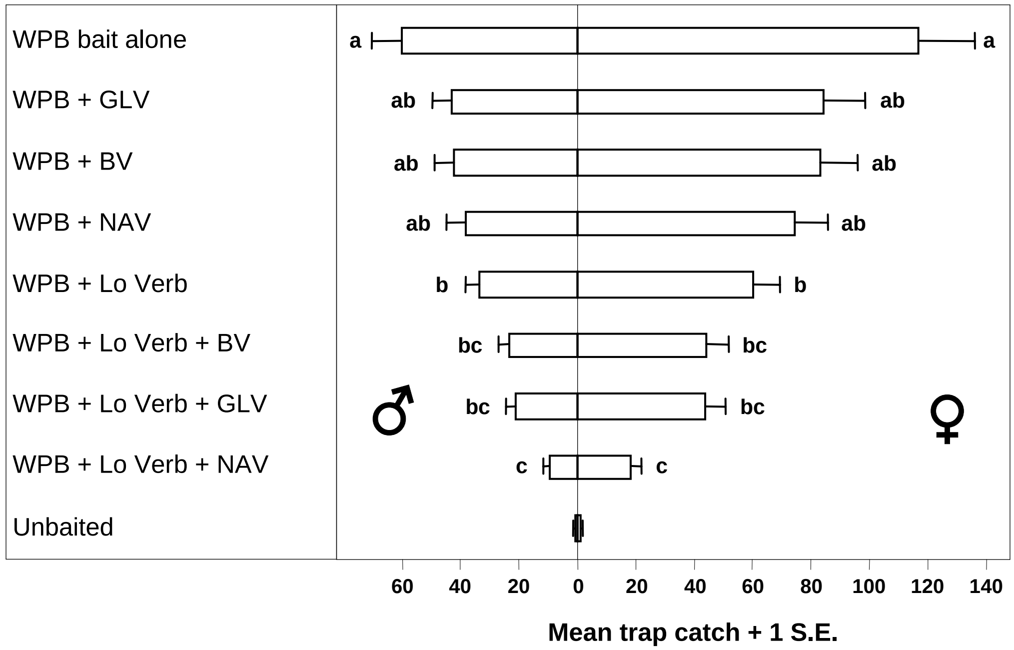

Figure 1—Disruption of western pine beetle, *Dendroctonus brevicomis* LeConte, attraction to baited (frontalin, *exo*-brevicomin, and myrcene) multiple-funnel traps during Experiment 1, McCloud Flats, Shasta-Trinity National Forest, California, June 2004. Means followed by the same letter are not statistically different ($P > 0.05$; Tukey's HSD (Honest Significant Difference) for means separation).

Based on these results, we chose to conduct a second experiment to determine: 1) if the NAV signal was overwhelmed by higher release rates of verbenone, 2) if components from the NAV blend could be removed without significantly affecting efficacy, and 3) if differences exist in the response of *D. brevicomis* to the alcohols and aldehydes in the NAV blend.

The results from Experiment 2 suggest that conophthorin can be excluded from the NAV blend without suffering a reduction in efficacy. This result disagrees with observations by other authors regarding the response of congenerics to NAV blends (Fig. 2; Zhang and Schlyter 2004). This observation is extremely important in that conophthorin is difficult to procure and is rather costly compared to the other NAVs. Future studies are planned to determine the effects of these treatments for protecting individual trees.

Hazardous fuel reduction study

The following results pertain to the Tahoe block specifically. Several bark beetle species appeared to be preferentially attracted to chipped sites. Most notable were the red turpentine beetle, *D. valens* LeConte, *D. brevicomis*, and *Ips paraconfusus* Lanier. Bark beetle activity was greater in chipped plots (19 percent of residual stems) than chipped and raked plots (12 percent). This was particularly evident in regard to the spring treatments where we observed a 48 percent reduction in tree mortality associated with raking the chips away from the base of residual trees. There was relatively little subsequent bark beetle activity in lop and scatter (3.5 percent) and untreated control (4 percent) plots. Most of the attacks in the untreated control were confined to rust-infested sugar pine, *P. lambertiana* Dougl.

Our preliminary results suggest that chipping may result in unacceptable levels of tree mortality in the Sierra Nevada, particularly when associated with hazardous fuel reduction treatments in the wildland urban interface.

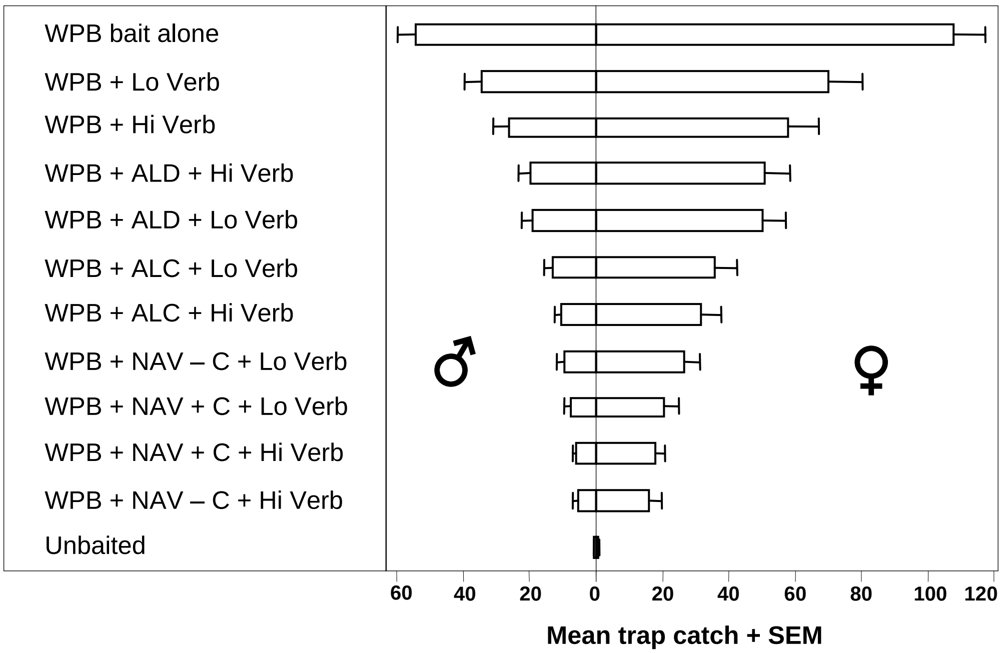

Figure 2—Disruption of western pine beetle, *Dendroctonus brevicomis* LeConte, attraction to baited (frontalin, *exo*-brevicomin, and myrcene) multiple-funnel traps during Experiment 2, McCloud Flats, Shasta-Trinity National Forest, California, August 2004. Final statistical analyses are not yet available.

Summary

This paper discusses four studies associated with the development of tools to reduce undesirable levels of tree mortality. At present, management options are rather limited in this regard. It is our hope that continued development and refinement of these techniques will eventually result in useful products for minimizing ponderosa pine losses from western pine beetle infestations.

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