Research Article

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Efficacy of two insecticides for protecting loblolly pines (*Pinus taeda* L.) from subcortical beetles (Coleoptera: Curculionidae and Cerambycidae)

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Abstract

BACKGROUND: Tests were conducted on two insecticides (carbaryl and bifenthrin) for excluding subcortical beetles (Coleoptera: Curculionidae and Cerambycidae) from loblolly pine trees (*Pinus taeda* L.). Two trap designs (single- and double-pane windows) and two trapping heights (1.5 and 4 m) were also evaluated for maximizing beetle catches.

RESULTS: In July 2009, 15 loblolly pine trees were double girdled and were either left unsprayed or sprayed with carbaryl or bifenthrin. A total of 28 473 bark beetles were caught in window traps, including *Ips avulsus* Eichoff, *I. grandicollis* (Eichhoff), *I. calligraphus* (Germar) and *Dendroctonus terebrans* (Olivier). Both insecticides significantly reduced colonization of the trees by bark and woodboring beetles by 300–400%, with no differences in efficacy observed between the two insecticides. About 59% more *I. avulsus* were caught in double- than in single-pane window traps, with no differences for any other species. Traps at 4 m caught more *I. avulsus* and *I. grandicollis* (290 and 153% respectively), while traps at 1.5 m caught more *D. terebrans* (215%).

CONCLUSIONS: Either bifenthrin or carbaryl can be used to exclude subcortical beetles from loblolly pine trees. Trapping data reflect known vertical partitioning on the bole by these insects. Double-pane traps were slightly more effective than single-pane traps in catching subcortical beetles.

Keywords: bark beetles; bifenthrin; carbaryl; insecticides; loblolly pine; woodboring beetles

1 INTRODUCTION

Bark (Coleoptera: Curculionidae and Scolytinae) and woodboring beetles (Coleoptera: Cerambycidae) are diverse and abundant groups of subcortical insects that are ecologically and economically important in the southern United States.[1,2] They assist in decomposition and nutrient cycling of dead wood in forests, but they may also cause large-scale tree decline and mortality.[1] For example, the Georgia Forestry Commission reported a total of $254 295 101 in timber losses from 1972 to 2007 in Georgia from the southern pine beetle (*Dendroctonus frontalis* Zimmerman) alone.[3] The larvae of bark beetles feed primarily in phloem tissue, whereas those of woodboring beetles feed on phloem and xylem tissues.[4] Feeding and construction of galleries by larvae and adults girdle the tree, thus disrupting photosynthate transfer and resulting in the eventual decline and death of the tree.[5]

Forests in residential and recreational areas are important in providing environmental, aesthetic and economic values. Coincidentally, trees located in urban and semi-urban sites are often susceptible to subcortical beetle attack owing to stressful conditions associated with localized drought, overwatering, soil compaction, air pollution and mechanical injury to either stems or roots.[6,7] Although bark beetles such as pine engravers (*Ips* spp.) and black turpentine beetle [*Dendroctonus terebrans* (Olivier)] usually do not colonize healthy uninjured trees, they do colonize and kill pine trees in urban areas where they can build up in slash, weakened, damaged and drought-stressed trees.[8,9] Three major species of *Ips* are abundant in the southern pine forests, including *I. avulsus* Eichoff, *I. grandicollis* (Eichhoff) and *I. calligraphus* (Germar), which can attack apparently healthy high-value trees and create a public safety hazard in urban areas.[9,10] The high cost of removing these trees and the aesthetic impacts on the property often make protection of trees with insecticides an economically viable option.[11]

A number of studies have tested the efficacy of carbaryl and bifenthrin in the protection of different species of pines trees from various bark beetle species.[11–18] Most tests on the efficacy of carbaryl and bifenthrin in the southeastern and western

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United States have been conducted on members of the genus *Dendroctonus*, which are considered to be major outbreak pests capable of killing live healthy trees. For example, Berisford *et al*.[13] found that carbaryl was not effective on southern pine beetle, *D. frontalis* Zimmerman, likely owing to metabolic processes that differ from those of most other bark beetles.[13] Fettig *et al*.[19] tested carbaryl and bifenthrin on multiple insect and tree species combinations, and found both to be effective in the prevention of attacks by western pine beetle (*D. brevicomis* LeConte). Grosman and Upton[20] and Grosman *et al*.[21] tested the efficacy of systemic insecticides for the protection of loblolly pines (*Pinus taeda* L.) from *Ips* spp., cerambycids and *D. frontalis* in the southern United States, and found that fipronil and emamectin benzoate were effective at varying levels in preventing mortality from subcortical insects. Similarly, Grosman *et al*.[22] reported that systemic insecticides can protect ponderosa pines (*P. ponderosa* Dougl. ex Laws.) for up to 3 years from *D. brevicomis* in California. However, systemic insecticides are expensive, bole injection can cause wounding on trees and there is a lag period between treatment and effective control, leaving trees vulnerable for a short time after application.[20]

Information is lacking on the use of non-systemic insecticides to prevent attacks by *Ips* and cerambycid beetles on mature loblolly pine trees in the southeastern United States. Further, fewer tests exist for standing trees, as opposed to cut bolts.[23] The present research objectives were: (1) to compare the relative efficacy of two sprayable insecticides with differing modes of action – carbaryl (acetylcholinesterase inhibitor) and bifenthrin (sodium channel disruption) – in preventing colonization by subcortical beetles on loblolly pines; (2) to compare the efficacy of single- versus double-pane window trap designs for capturing subcortical beetles arriving at trees; (3) to compare the efficacy of these two trap designs at two different heights on tree boles.

2 METHODS

2.1 Study sites

The study was conducted near Athens, Georgia (33°53′18″N, 83°22′21″W) within the Piedmont region of the state. The study site was a 15-year-old loblolly pine plantation with sweetgum (*Liquidambar styraciflua* L.), muscadine (*Vitis rotundifolia* Michx.), *Lespedeza* spp. and various species of grasses in the understory. The trees were growing in Madison clay sandy loam soil, and the mean annual precipitation in the region was ∼1124 mm.[24] Stands in the study area were on a 3 year prescribed burn cycle, with the last burn in the present study site applied in early spring of 2009.

2.2 Tree selection, preparation and monitoring

Fifteen mid-rotation loblolly pines were randomly chosen that were similar in size (mean DBH = 29.4 ± 0.9 cm) and age (∼15 years). Trees were spaced >15 m from each other to reduce the potential for drift contamination of nearby trees.[25] Three treatments randomly assigned to each of five pine trees were: (1) unsprayed control; (2) 2.0% carbaryl [Sevin® 80 WSP (EPA Reg. No. 432–1226), 80% carbaryl by weight; Bayer CropSciences LP, NC]; (3) 23.4% bifenthrin [Onyx® (EPA Reg. No. 279–3177); FMC Corp., Philadelphia, PA]. In mid-July 2009, each of the fifteen trees was girdled ∼0.5 m from the ground with a double girdle applied with a chainsaw. The lower girdle was then sprayed with ∼0.5 L of 53.8% glyphosate herbicide [Foresters'® (EPA Reg. No. 228–381); Nufarm Americas Inc., Burr Ridge, IL] to accelerate the death of the trees. The second girdle was used to prevent movement of the herbicide up the tree. The following day, insecticides were applied to the boles of the assigned trees to a height of 12–15 m, which was approximately the height of the lowest branches in the tree crown, using a hydraulic sprayer. Insecticide was applied until run-off was observed, and each tree received the maximum amount of active ingredient allowed by the labels of the respective products (Onyx®: 0.06% AI, ∼15 L spray tree^{-1}; Sevin®: 1.6% AI, ∼11 L spray tree^{-1}). A (+/−)-ipsenol and a (+/−)-ipsdienol bait pouch (ConTech Inc., BC, Canada) were hung on each tree at ∼1.5 and 4 m, for a total of four baits per tree. These semiochemicals were used to lure *Ips* engraver beetles into the general area to maximize colonization pressure on each tree.[26] Tree mortality based on percentage crown dieback was recorded every 2 weeks until 100% mortality was reached (due to girdling) for all trees in the third week of August 2009.

2.3 Subcortical beetle sampling

Once the insecticide dried on the trees, single- and double-pane window traps were each installed at 1.5 and 4 m on the boles, for a total of four traps per tree. Traps were placed on each tree by randomly selecting a cardinal direction and then hanging the single-pane window traps on that side of the tree at each height. Double-pane window traps were then installed on the opposite side of the tree to reduce interactions between the two traps. Single-pane window traps consisted of a 17.6 × 26.4 cm panel of clear plexiglass with a 20 cm diameter collecting funnel (from a Lindgren funnel trap; Contech Inc., BC, Canada) attached to the bottom. A 9.5 cm diameter and 12 cm deep wet collection cup (also part of a Lindgren funnel trap) was attached to each funnel and filled with 5 cm of non-toxic propylene glycol RV antifreeze. Double-pane window traps were constructed similarly, but had an additional plastic panel slotted in the middle of the first panel at a right angle to form a +-shaped barrier, thus increasing the surface area. Traps were emptied every 2 weeks for 4 months from July to mid-October 2009. All *Ips* and *Dendroctonus* bark beetles and cerambycid beetles were identified to species using taxonomic keys.[1,2] Voucher specimens were deposited at the Georgia Museum of Natural History, University of Georgia, Athens.

Trees were sampled for evidence of beetle colonization 5 times during the study, every 2 weeks. During each sampling period, five 20 × 20 cm sections on each tree bole were selected at random heights and directions. These sections were inspected for evidence of insect colonization, which consisted of oviposition scars, entrance holes to galleries and boring dust and frass. Small (1–3 mm) round entrance/exit holes are typically created by bark beetles, and diamond-shaped oviposition scars and large round exit holes are typically created by woodboring beetles.[27] In October 2009, when the traps were removed, bark was peeled from selected trees for visual assessment of gallery formation by colonizing beetle larvae and the extent of phloem degradation.

2.4 Statistical analyses

Beetle colonization data were first checked for normality and constant variance across treatments. As these data were non-normal, various transformations were performed that did not improve normality. Hence, non-parametric Kruskal–Wallis tests of Wilcoxon rank-sum scores were used to assess differences in beetle colonization activity among the three treatments (unsprayed, carbaryl-sprayed and bifenthrin-sprayed trees).[28,29] The unit of replication was an individual tree ($N = 15$). Data points were the means of five samples taken at each sampling interval and pooled over the season. Analyses were performed separately for bark beetles and cerambycids. Means with 95% confidence intervals were calculated for each factor and compared graphically.

Beetle trap catches were pooled for each *Ips* and *Dendroctonus* species over the entire sampling season for analyses. The unit of replication was an individual trap per tree ($N = 60$). Data were first checked for normality and equal variance. The three main factors in the model were insecticide treatments, trap type and trapping height. A three-way analysis of variance test (ANOVA) was conducted to determine whether there were any significant interactions among the main factors.[29] As all the interaction terms were insignificant ($P > 0.05$), the analyses were repeated without the interaction terms.[28] Analyses were conducted separately on each bark beetle species under investigation: *I. avulsus, I. grandicollis, I. calligraphus* and *D. terebrans*.

The three most abundant species of Cerambycidae [*Monochamus* spp., *Xylotrechus sagittatus* Germar and *Acanthocinus obsoletus* (Olivier)] were tested separately using ANOVA. No significance was found for species-level trap data, so all Cerambycidae were pooled together and tested as a group using ANOVA.

3 RESULTS

Kruskal–Wallis non-parametric tests indicated that there were significant differences in colonization activities among the three treatments for both bark beetles (df = 2, $\chi^2 = 29.820$, $P < 0.001$) and cerambycid beetles (df = 2, $\chi^2 = 28.623$, $P < 0.001$) (Fig. 1). To quantify this difference, the means and their 95% confidence intervals were examined, and it was found that, for both taxonomic groups, untreated trees had significantly more attacks (ranging from 300 to 400% or more), and there was no significant difference between the two insecticides (Fig. 1). Visual assessment of the boles after peeling the bark revealed no measurable galleries owing to extensive phloem degradation by Cerambycid larvae and decay in untreated trees, and no galleries on treated trees. Treated trees had some evidence of attempted colonization (entrance/exit/vent holes and oviposition scars), but peeling the bark revealed no gallery formation, even in areas where holes were present.

During July to mid-October 2009, a total of 28 473 *I. avulsus*, *I. grandicollis, I. calligraphus* and *D. terebrans* were caught (Table 1). *Ips avulsus* was the most abundant beetle, followed by *I. grandicollis, D. terebrans* and *I. calligraphus*. Insecticide treatment was not a significant factor for *I. avulsus* and *I. grandicollis*, but it was for *I. calligraphus* (df = 2, $F = 3.94$, $P = 0.025$) and *D. terebrans* (df = 2, $F = 5.09$, $P = 0.010$). For *I. calligraphus*, fewer individuals were caught on trees treated with carbaryl than controls, but were not different from trees treated with bifenthrin. Additionally, trees treated with bifenthrin were not different from controls. For *D. terebrans*, trees treated with carbaryl caught fewer individuals than trees treated with bifenthrin and controls. Double-pane window traps caught 1.43 times more *I. avulsus* (df = 1, $F = 4.44$, $P = 0.040$) than single-pane traps (Fig. 2A), while both trap designs were equally effective for the other three species (*I. grandicollis*: $P = 0.124$; *I. calligraphus*: $P = 0.617$; *D. terebrans*: $P = 0.129$) (Fig. 2A). Traps placed at 4 m caught 2.9 times more *I. avulsus* (df = 1, $F = 33.79$, $P < 0.001$) and 1.53 times more *I. grandicollis* (df = 1, $F = 8.07$, $P = 0.006$) than those at 1.5 m. (Fig. 2B). In contrast, traps at 1.5 m caught 2.15 times more *D. terebrans* (df = 1, $F = 23.48$, $P < 0.001$) than traps at 4 m (Fig. 2B). Trap height was not a significant factor in trapping *I. calligraphus* ($P = 0.510$) (Fig. 2B). None of the third- and second-order interactions was significant for these dominant bark beetle species.

In all traps, a total of 503 cerambycid beetles were caught. Trap height (df = 1, $F = 0.59$, $P = 0.445$) and trap design (df = 1, $F = 0.59$, $P = 0.418$) had no effect on trap catches of these beetles.

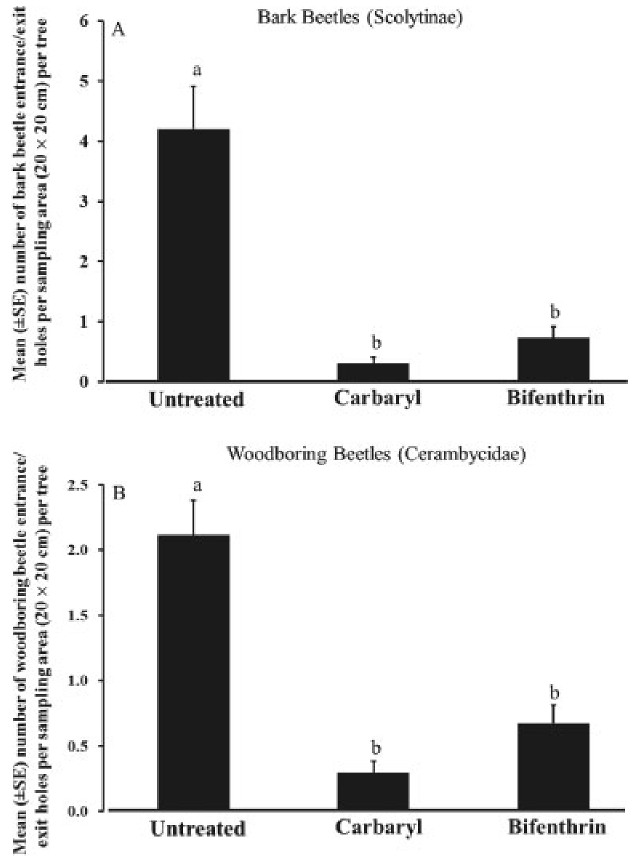

Figure 1. Mean (± SE) number of bark beetle (Scolytinae) (A) and woodboring beetle (Cerambycidae) (B) entrance/exit holes per sampling area (20 × 20 cm) per tree.

4 DISCUSSION

The results show that carbaryl and bifenthrin were effective in preventing colonization by subcortical beetles on loblolly pine trees. While the present experiment was small scale (limited in the number of trees that could be killed on site), the results were highly significant, and trends were sufficiently clear to draw sound conclusions. Studies performed on pines in the western United States have shown similar results for carbaryl and bifenthrin on subcortical beetles, although most of these studies assessed colonization by *Dendroctonus* spp. and rarely by *Ips* spp.[6,11,15,19]

Fettig *et al.*[19] tested carbaryl and bifenthrin to protect trees against *I. confusus* LeConte and *Dendroctonus* spp. in Nevada, Colorado and Arizona, using tree mortality as the response variable. This allowed evaluation of multiyear efficacy, but was not effective in areas where beetle abundance was too low to cause mortality with baiting alone. However, beetle pressure was sufficient in Nevada to show that both products were effective for two seasons. Tests in Colorado showed that both insecticides were effective for the first season, but in the second season there was not enough pressure to challenge the treatments, as none

Table 1. Total numbers of the most abundant bark and woodboring beetles caught in 2009 on loblolly pine in both single- and double-pane window traps

Date	*Ips avulsus*	*Ips grandicollis*	*Ips calligraphus*	*Dendroctonus terebrans*	*Monochamus* spp.	*Xylotrechus sagittatus*
30 July 2009	8190	2406	46	193	69	43
13 August 2009	1675	1326	54	228	28	22
27 August 2009	3931	1141	53	113	42	29
10 September 2009	2816	440	84	45	57	16
24 September 2009	2177	74	76	27	71	11
9 October 2009	3317	30	28	3	30	8
Total	**22 106**	**5417**	**341**	**609**	**297**	**129**

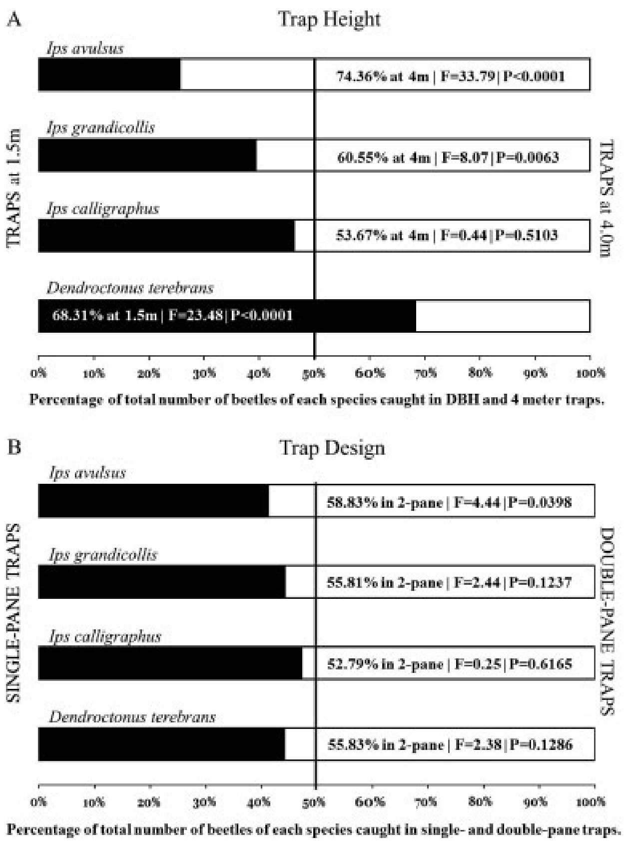

Figure 2. Percentage of each abundant bark beetle species caught at two trap heights (1.5 and 4 m) (A), and trap designs (single- and double-pane window trap) (B).

of the untreated trees died from *I. confusus* attack. The tests in Arizona had to be discontinued owing to low beetle pressure and low tree mortality. For this reason, it was decided to girdle and bait the trees to ensure adequate levels of beetle colonization. This also meant that efficacy could not be tested beyond one growing season (as all the trees were dead), but it ensured that there would be enough pressure to challenge the treatments adequately. The total numbers of the most abundant bark beetle species in the present traps (Table 1) suggest that the present pressure was many times more than the natural level, even after a large disturbance, e.g. Hanula *et al.*[30] Untreated trees were highly infested by beetles, and the bark came off in large (~0.5 m^2) sections without any effort at the end of the sampling period. Trees that were treated with insecticides had essentially undamaged boles with intact phloem, and the bark had to be removed with a draw knife, in spite of the fact that the crowns were dead with no live needles.

This study provided an opportunity to test different trapping methods for subcortical beetles on standing mature pine trees. Traps at different heights (1.5 and 4 m) caught different numbers of *Ips avulsus, I. grandicollis, I. calligraphus* and *D. terebrans*. It has been well documented that these beetles exhibit vertical partitioning behavior on the boles of pine trees to limit interspecific competition.[10] The present trapping data reflected this behavior, as higher numbers of *I. avulsus* were caught in traps at 4 m, and more *D. terebrans* in traps at 1.5 m. *Ips avulsus*, the smallest of the *Ips* species in this complex, is usually found in the branches and upper bole where the phloem is thinner. *Ips grandicollis* was also trapped with greater frequency in the 4 m traps. As it is only slightly larger than *I. avulsus*, it is also usually found in the upper area of the bole and in larger branches. *Dendroctonus terebrans* is the largest beetle of the group and is found in the lower bole and base of the tree where the phloem is thickest.[10] If the objective is to sample only *Ips* spp., then the 4 m trapping height would be more accurate. However, with the inclusion of *D. terebrans* in the target group, a lower trap may be needed to get a more accurate sample of this species.

Double-pane window traps caught significantly more *I. avulsus*, but both traps were equally effective for the other species. To maximize the number of beetles caught when using window traps attached to trees, it is recommended that the double-pane as opposed to the single-pane design be used, as differences in material costs and construction times are negligible.

The present results could have been confounded by two factors: (1) volatiles produced from insecticide-treated trees may have been different from those of untreated trees, thus affecting trap catches; (2) potential colonizers of trees were removed during the trapping, which may have affected results of the insecticide treatment. If the first confounding factor had been true, then significant interactions between insecticide treatment and trap types would have been observed. For total catches of bark beetles, none of the second- and third-order interactions was significant ($P = 0.351-0.960$). At species level, the treatment terms were significant only for *I. calligraphus* and *D. terebrans* ($P = 0.025$ and 0.010 respectively), but the interaction terms were not significant ($P = 0.251-0.845$). Considering that these species accounted for only ~3% of total catches, it is hard to draw final conclusions about their response to insecticides. In terms of the second confounding factor, it is not possible to test whether the traps skewed the colonization of beetles on trees and thus affected the insecticide results. Exactly the same trap designs and sampling periods were used on all trees, allowing for comparison across treatments, and, furthermore, the observations concerning insecticides are similar to those found in other studies that did not use traps on trees.[19,25]

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REFERENCES

1 Wood S, The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae). *Great Basin Naturalist Memoirs* **6**:(1982).
2 Lingafelter S, Illustrated key to the longhorned woodboring beetles of the eastern United States. *Coleopterists Bull* **206**:(2007).
3 *Southern Pine Beetle Historical Data for Georgia*. [Online]. Georgia Forestry Commission (2007). Available: http://www.gfc.state.ga.us/forestmanagement/documents/SPBHistoricalData2007.pdf [29 August 2011].
4 Linsley EG, Ecology of Cerambycidae. *Annu Rev Entomol* **4**:99–138 (1959).
5 Dunn JP and Lorio PL, Effects of bark girdling on carbohydrate supply and resistance of loblolly pine to southern pine beetle (*Dendroctonus frontalis* Zimm.) attack. *Forest Ecol Manag* **50**:317–330 (1992).
6 Haverty M, Shea P, Hoffman J, Wenz J and Gibson K, Effectiveness of esfenvalerate, cyfluthrin, and carbaryl in protecting individual lodgepole pines and ponderosa pines from attack by *Dendroctonus* spp. USDA/FS research paper 237 (1998).
7 Poland TM and McCullough DG, Emerald ash borer: invasion of the urban forest and the threat to North American ash resource. *J For* **104**:118–124 (2006).
8 Connor MD and Wilkinson RC, *Ips* bark beetles in the South. USDA/FS forest insect and disease leaflet 129 (1983).
9 Gandhi KJK and Miller DR, Southern pine engraver (*Ips*) beetles in your backyard. [Online]. WSFNR09-8 (2009). Available: http://www.treesearch.fs.fed.us/pubs/34390 [4 March 2011].
10 Insects of the eastern forest. USDA Forest Service miscellaneous publication No. 1426, USDA Forest Service, Washington, DC (1985).
11 Fettig C, DeGomez T, Gibson K, Dabney C and Borys R, Effectiveness of permethrin plus-C (Masterline) and carbaryl (Sevin SL) for protecting individual, high-value pines (*Pinus*) from bark beetle attack. *Arbocult Urban For* **32**:247–252 (2006).
12 Berisford CW and Brady EU, Duration of protection of loblolly pines from *Ips* bark beetles by lindane. *J Econ Entomol* **69**:357–358 (1976).
13 Berisford CW, Brady EU and Ragenovich IR, Residue studies, in *Field and Laboratory Evaluations of Insecticides for Southern Pine Beetle Control*, ed. by Hastings FL and Costner JE. USDA/FS Gen. Tech. Rep. SE 21, SE For. Exp. Sta., Asheville, NC (1981).
14 Hall R, Shea P and Haverty M, Effectiveness of carbaryl and chlorpyriphos for protecting ponderosa pine trees from attack by the western pine beetle (Coleoptera: Scolytidae). *J Econ Entomol* **75**:504–508 (1982).
15 Haverty M, Shea P and Hall R, Effective residual life of carbaryl for protecting ponderosa pine from attack by the western pine beetle (Coleoptera: Scolytidae). *J Econ Entomol* **78**:197–199 (1985).
16 Hastings F, Holsten E, Shea P and Werner R, Carbaryl: a review of its use against bark beetles in coniferous forests of North America. *Environ Entomol* **30**:803–810 (2001).
17 DeGomez T, Hayes C, Anhold J, McMillin J, Clancy K and Bosu P, Evaluation of insecticides for protecting southwestern ponderosa pines from attack by engraver beetles (Coleoptera: Curculionidae: Scolytinae). *J Econ Entomol* **99**:393–400 (2006).
18 Fettig CJ, Klepzig K, Billings R, Munson A, Nebeker T, Negrón J, *et al*, The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. *Forest Ecol Manag* **238**:24–53 (2007).
19 Fettig CJ, Allen KK, Borys RR, Christopherson J, Dabney CP, Eager TJ, *et al*, Effectiveness of bifenthrin (Onyx) and carbaryl (Sevin SL) for protecting individual, high-value conifers from bark beetle attack (Coleoptera: Curculionidae: Scolytinae) in the western United States. *J Econ Entomol* **99**:1691–1698 (2006).
20 Grosman D and Upton W, Efficacy of systemic insecticides for protection of loblolly pine against southern pine engraver beetles (Coleoptera: Curculionidae: Scolytinae) and woodborers (Coleoptera: Cerambycidae). *J Econ Entomol* **99**:94–101 (2006).
21 Grosman D, Clarke S and Upton W, Efficacy of two systemic insecticides injected into loblolly pine for protection against southern pine bark beetles (Coleoptera: Curculionidae). *J Econ Entomol* **102**:1062–1069 (2009).
22 Grosman DM, Fettig CJ, Jorgensen CL and Munson AS, Effectiveness of two systemic insecticides for protecting western conifers from mortality due to bark beetle attack. *West J App For* **25**:181–185 (2010).
23 Strom BL and Roton LM, A small-bolt method for screening tree protectants against bark beetles (Coleoptera: Curculionidae). *J Entomol Sci* **44**:297–307 (2009).
24 *Athens WSO Airport, Georgia: Monthly Total Precipitation*. [Online]. UGA Libraries. Available: http://www.sercc.com/cgi-bin/sercc/cliMONtpre.pl?ga0435 [2 September 2011].
25 Fettig CJ, Munson AS, McKelvey SR, Bush PB and Borys RR, Spray deposition from ground-based applications of carbaryl to protect individual trees from bark beetle attack. *J Environ Qual* **37**:1170–1179 (2008).
26 Miller DR, Asaro C and Berisford CW, Attraction of southern pine engravers and associated bark beetles (Coleoptera: Scolytidae) to ipsenol, ipsdienol, and Lanierone in southeastern United States. *J Econ Entomol* **98**:2058–2066 (2005).
27 Gandhi K, The responses of sub-boreal forest insects to a catastrophic wind disturbance event and subsequent fuel-reduction practices in northeastern Minnesota. *PhD Dissertation, Vols I and II*, University of Minnesota, MN (2005).
28 Dowdy S, Wearden S and Chilko DM, *Statistics for Research*. Wiley-Interscience, New York, NY (2004).
29 *SAS Version 9.2*. SAS Institute, Cary NC (2007).
30 Hanula JL, Meeker JR, Miller DR and Barnard EL, Association of wildfire with tree health and numbers of pine bark beetles, reproduction weevils and their associates in Florida. *For Ecol Manag* **170**:233–247 (2002).