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Effectiveness of Permethrin Plus-C (Masterline®) and Carbaryl (Sevin SL®) for Protecting Individual, High-Value Pines (*Pinus*) From Bark Beetle Attack

Christopher J. Fettig, Tom E. DeGomez, Kenneth E. Gibson, Christopher P. Dabney, and Robert R. Borys

Abstract. Bark beetles (Coleoptera: Scolytidae) are commonly recognized as the most important mortality agent in western North American coniferous forests. High-value trees such as those located in residential, recreational, or administrative sites are particularly susceptible to attack. Regardless of landowner objectives, tree losses in these unique environments generally have a catastrophic impact. The value of these individual trees, the cost of removal, and the loss of aesthetics may justify protection until the main thrust of a bark beetle infestation subsides. This situation emphasizes the need for assuring that effective insecticides are available for individual tree protection. In this study, we assessed the efficacy of permethrin plus-C (Masterline®) and carbaryl (Sevin SL®) for protecting ponderosa, *Pinus ponderosa* Dougl. ex. Laws., lodgepole, *P. contorta* Dougl. ex Loud., and pinyon, *P. edulis* Engelm., pines from bark beetle attack during two field seasons. Masterline® was effective for protecting *P. contorta* from mountain pine beetle, *Dendroctonus ponderosae* Hopkins, attack for one field season. However, Sevin SL® was efficacious for two field seasons. An insufficient number of *P. ponderosa* and *P. edulis* control trees were killed to make definitive conclusions regarding efficacy in those systems. The data reported here regarding Masterline® is the first published report on its effectiveness for preventing bark beetle attack on standing trees. Masterline® appears to be an effective individual tree protection tool, but repeated applications will be necessary if multiyear control is desired.

Key Words. Carbaryl; permethrin; *Dendroctonus brevicomis*; *Dendroctonus ponderosae*; *Ips confusus*; ponderosa pine; lodgepole pine; pinyon pine.

The Scolytidae is a large and diverse group of insects consisting of approximately 550 species in North America and over 6,000 species worldwide (Wood 1982). Most feed on the phloem or xylem tissue of woody plants, and a few species are recognized as the most destructive of all forest insect pests. The western pine beetle, *Dendroctonus brevicomis* LeConte (Coleoptera: Scolytidae), is a major cause of ponderosa pine, *Pinus ponderosa* Dougl. ex. Laws., mortality in the western United States and particularly in California (Furniss and Carolin 1977). Under certain conditions, this species can aggressively attack and kill apparently healthy trees of all ages and size classes (Miller and Keen 1960). In recent years, the amount of *D. brevicomis*-caused tree mortality reached unprecedented levels in the mountains of San Bernardino and Riverside counties, California, where approximately 61,000 ha (150,731 ac) were infested (USDA Forest Service 2002).

The mountain pine beetle, *D. ponderosae* Hopkins, is the most destructive bark beetle in western North America. The species ranges throughout British Columbia, Alberta, most of the western United States, and into northern Mexico and colonizes several pine species, most notably lodgepole, *P. contorta* Dougl. ex Loud., *P. ponderosa*, sugar, *P. lambertiana* Dougl, and western white, *P. monticola* Dougl. ex D. Don. (Furniss and Carolin 1977). Large-scale infestations often occur in mature *P. contorta* stands in a near contiguous pattern and across extensive areas. In 2004 and 2005, unprecedented levels of *D. ponderosae*-caused tree mortality were recorded in British Columbia where an estimated 8.5 million ha (21 million ac) are infested (Wilent 2005).

The pinyon ips, *Ips confusus* (LeConte), is a major cause of pinyon, *P. edulis* Engelm. and *P. monophylla* Torr. & Frem., pine mortality throughout the southwestern United States (Furniss and Carolin 1977). In recent years, large infestations have been associated with extended periods of drought. In 2003, the USDA Forest Service estimated that 15% to 30% of pinyon had been killed on over 1.6 million ha (4 million ac) (USDA Forest Service 2004).

High-value trees such as those located in residential, recreational (campgrounds), or administrative sites are particularly susceptible to bark beetle attack as a result of increased amounts of stress associated with drought, soil compaction, mechanical injury, or vandalism (Haverty et al. 1998). Regardless of landowner objectives, tree losses in these unique environments can have a substantial impact (McGregor and Cole 1985). The value of these trees, the cost of removal, and the loss of aesthetics may justify protecting individual trees until the main thrust of an infestation subsides. This situation emphasizes the need for assuring that effective insecticides are available for individual tree protection.

Carbaryl is considered one of the most effective and environmentally safe insecticides used to prevent bark beetle attacks (Hastings et al. 2001). In the past, several formulations have been evaluated for protection of individual trees from attack by western bark beetle species, primarily *D. brevicomis* and *D. ponderosae*. The effectiveness and residual life of 1.0% and 2.0% carbaryl (Sevimol®; Bayer Environmental Science, Montvale, NJ) for preventing successful attack of *P. ponderosa* by *D. brevicomis* have been demonstrated (Hall et al. 1982; Haverty et al. 1985). The effectiveness of 2.0% carbaryl (same formulation) was also confirmed for protecting *P. contorta* from *D. ponderosae* attack (Gibson and Bennett 1985; Page et al. 1985; Shea and McGregor 1987). These and other studies (Smith et al. 1977; McCambridge 1982) led to the registration of 2.0% Sevimol® as a preventive spray. A 1.0% suspension of carbaryl (Sevimol® and Sevin SL®; Bayer Environmental Science, Montvale, NJ) was effective for protecting *P. contorta* from *D. ponderosae* attack in Montana for at least 1 year. A 2.0% suspension was effective in protecting *P. ponderosa* from *D. brevicomis* attack in southern Idaho for 1 year (Haverty et al. 1998). Shea and McGregor (1987) evaluated the efficacy of 0.5%, 1.0%, and 2.0% carbaryl (Sevimol® and Sevin XLR®) and found all concentrations and formulations were effective for protecting *P. contorta* from *D. ponderosae* attack for at least 1 year. In south central Alaska, Werner et al. (1986) reported that carbaryl protected white, *Picea glauca* (Moench) Voss, and Lutz, *P. glauca* X *lutzii* Little, spruce from spruce beetle, *D. rufipennis* Kirby, attack for three field seasons. Berisford et al. (1981) reported that 2.0% carbaryl was ineffective for preventing southern pine beetle, *D. frontalis* Zimmerman, attack, which later was linked to tolerance in that beetle associated with an efficient conversion of carbaryl into metabolites and a rapid rate of excretion (Zhong et al. 1995).

Several pyrethroid insecticides are effective for protecting individual trees from bark beetle attack. In laboratory and cut-bolt bioassays, permethrin was shown to be highly toxic to *D. brevicomis*, *D. frontalis,* and *D. ponderosae* (Hastings and Jones 1976; Hastings et al. 1981; Smith 1982). Shea et al. (1984) examined the effectiveness of permethrin (Pounce®; FMC Corporation, Philadelphia, PA) at three rates—0.1%, 0.2%, and 0.4%—for protecting *P. ponderosa* from *D. brevicomis* attack and reported that 0.2% and 0.4% provided protection for ≈4 months. Haverty et al. (1998) examined several rates of esfenvalerate and cyfluthrin for protecting *P. ponderosa* and *P. contorta* from *D. brevicomis* and *D. ponderosae* attacks, respectively. In the Sierra Nevada, esfenvalerate (Asana XL®; E.I. du Pont de Nemours and Company, Wilmington, DE) applied at 0.025% and 0.05% provided protection of *P. ponderosa* for a full summer (Haverty et al. 1998). In Montana, 0.006% and 0.012% esfenvalerate were found to be ineffective for protecting *P. contorta* from *D. ponderosae* attack. However, the 0.025% rate was effective for a single field season. Cyfluthrin (Tempo 20 WP®; Bayer Environmental Science, Montvale, NJ) applied at 0.025% provided protection of *P. ponderosa* for one field season in Idaho, but not in California (Haverty et al. 1998). All three cyfluthrin treatments, 0.025%, 0.05%, and 0.1%, were highly effective for protecting *P. contorta* for two field seasons (Haverty et al. 1998). DeGomez et al. (2006) reported that 0.19% permethrin plus-C (Masterline®; Univar USA, Inc., Austin, TX) and 0.06% bifenthrin (Onyx®, FMC Corporation, Philadelphia, PA) were effective for protecting *P. ponderosa* bolts from successful engraver beetle, *Ips* spp., attacks. Hall (1984) examined the efficacy of carbaryl, chlorpyriphos, fenitrothion, and permethrin for preventing red turpentine beetle, *D. valens* LeConte, attack and reported that only 2.0% and 4.0% carbaryl and 4.0% fenitrothion were effective.

The objectives of this study were to: 1) confirm the efficacy of the registered rate of carbaryl (Sevin SL®) for protecting *P. ponderosa* from *D. brevicomis* attack (California) and *P. contorta* from *D. ponderosae* attack (Montana); 2) assess the efficacy of Sevin SL® for protecting *P. edulis* from *I. confusus* attack (Arizona); and 3) assess the efficacy of permethrin plus-C (Masterline®) for protecting individual, high-value trees from bark beetle attack.

MATERIALS AND METHODS

This study was conducted at three locations: 1) Shasta County, California (40.88°N, 121.65°W; 975 m [3,199 ft] elevation), 2) Beaverhead-Deerlodge National Forests, Montana (45.92°N, 121.37°W; 1966 m [6,450 ft] elevation), and 3) Coconino County, Arizona (35.23°N, 111.51°W; 2104 m [6,902 ft] elevation). At each site, four treatments were applied to each of 24 (AZ) and 30 (CA and MT) randomly selected trees: 0.2% a.i. permethrin plus-C (Masterline®), 1.0% (AZ) and 2.0% (CA and MT) a.i. carbaryl (Sevin SL®), and two separate untreated controls. One control group was used to assess bark beetle pressure during each of two field seasons (2004–2005). In Arizona, a single set of control trees was used during both field seasons. Once insecticides were mixed in the sprayer, and before treatments began, two tank samples were collected and returned to the laboratory for subsequent analysis if questionable failures of efficacy were observed.

Insecticides were applied with an ATV (AZ) and trailor-mounted (CA and MT) hydraulic sprayer, which allowed treatment of the entire bole of each tree, until runoff, to a height of ≈12 m (39.4 ft). This technique has been shown to result in at least 80% of the insecticide being applied to the tree bole (Haverty et al. 1983). The amount of insecticide (and water carrier) applied to each tree varied with diameter and species, the latter primarily as a result of differences in bark and crown architecture. On average, we applied 17.8 (4.7 gal), 19.5 (5.2 gal), and 3.8 L (1.0 gal) per tree for *P. ponderosa*, *P. contorta*, and *P. edulis*, respectively. All treatments were applied between 0630 and 1300 when wind speeds were <11 kph (6.8 mph). In California, insecticides were applied on 18 to 19 May 2004 to individual *P. ponderosa* (mean dbh = 39.9 cm [15.7 in]) when temperatures ranged from 4.0°C (39.2°F) to 15.5°C (60°F). In Montana, insecticides were applied to individual *P. contorta* (mean dbh = 27.7 cm [10.9 in]) during 15 to 17 June 2004 when temperatures ranged from −2.0°C (28.4°F) to 10.0°C (50°F). In Arizona, insecticides were applied to individual *P. edulis* (mean dbh = 14.8 cm [5.8 in]) during 13 to 15 April 2004 when temperatures ranged from −1.0°C (30.2°F) to 16.0°C (60.8°F).

Sample trees were confirmed uninfested and located in areas with recent bark beetle activity. The spacing between adjacent trees was >100 m (328 ft) to enhance the likelihood that a sufficient number of beetles would be in the vicinity of each tree to rigorously test the efficacy of these treatments. All sample trees and the first set of untreated control trees were baited with appropriate species-specific lures (Phero Tech Inc., Delta, British Columbia, Canada) for 6 to 24 weeks (Tables 1 to 3) depending on beetle pressure in the area. The surviving treated trees in each treatment (if <7 were killed in 2004) and the second set of untreated controls (CA and MT) were rebaited in 2005.

Table 1. The effectiveness of permethrin plus-C (Masterline®) and carbaryl (Sevin SL®) for protecting *Pinus ponderosa* from *Dendroctonus brevicomis* attack for two field seasons after treatment, Shasta County, California (40.88°N, 121.65°W), 2004 to 2005.

Treatment[z]	2004[y] mortality/n	2005[x] mortality/n	Cumulative mortality/n
Masterline	2/30	1/28	3/30
Sevin SL	0/30	0/30	0/30
Untreated control	16/30	12/30	28/60

[z]Applied 18 to 19 May 2004.
[y]Assessed 22 October 2004. Trees actively baited with racemic frontalin (1–3 mg/24 h), racemic *exo*-brevicomin (1–3 mg/24 h), and myrcene (15–20 mg/24 h) for 42 d.
[x]Assessed 29 October 2005. Trees actively baited for 84 d.

Table 2. The effectiveness of permethrin plus-C (Masterline®) and carbaryl (Sevin SL®) for protecting *Pinus contorta* from *Dendroctonus ponderosae* attack for two field seasons after treatment, Beaverhead-Deerlodge National Forests, Montana (45.92°N, 121.37°W), 2004 to 2005.

Treatment[z]	2004[y] mortality/n	2005[x] mortality/n	Cumulative mortality/n
Masterline	2/30	14/27	16/29[w]
Sevin SL	0/30	1/30	1/30
Untreated control	30/30	22/30	52/60

[z]Applied 15 to 17 June 2004.
[y]Assessed 16 to 17 September 2004. Trees actively baited with 80%-(–)-*trans*-verbenol (1.5 mg/24 h) and racemic *exo*-brevicomin (0.3 mg/24 h) for 42 d.
[x]Assessed 27 to 28 September 2005. Trees actively baited for 42 d.
[w]One tree lost to wood cutting.

Tree mortality was assessed in April 2005 (AZ) and September (MT) and October (AZ and CA) 2004 to 2005. Treatments were considered to have sufficient beetle pressure if ≥60% of the untreated control trees died from bark beetle attack. Insecticide treatments were considered efficacious when <7 trees died as a result of bark beetle attack (Shea et al. 1984). These criteria were established based on a sample size of 22 to 35 trees/treatment and the test of the null hypothesis, Ho:S (survival ≥90%). These parameters provide a conservative binomial test ($\alpha = 0.05$) to reject Ho when more than six trees die. This experimental design is accepted as the standard for such evaluations and provides a very conservative test of efficacy (Haverty et al. 1998). Efficacy was monitored for two field seasons after insecticide treatment.

RESULTS

California: *D. brevicomis* and *P. ponderosa*

In 2004 and 2005, beetle pressure was insufficient to adequately challenge the treatments because <60% of untreated

Table 3. The effectiveness of permethrin plus-C (Masterline®) and carbaryl (Sevin SL®) for protecting *Pinus edulis* from *Ips confusus* attack for two field seasons after treatment, Coconino County, Arizona (35.23°N, 111.51°W), 2004 to 2005.

Treatment[z]	2004[y] mortality/n	2005[x] mortality/n	Cumulative mortality/n
Masterline	1/24	1/23	2/24
Sevin SL	0/23[w]	0/23	0/23
Untreated control	5/24	1/19	6/24

[z]Applied 13 to 15 April 2004.
[y]Assessed April 2005. Trees actively baited with racemic ipsenol (0.1–0.3 mg/24 h), racemic ipsdienol (0.1–0.3 mg/24 h), and 83%-(–)-*cis*-verbenol (1–2 mg/24 h) for 168 d.
[x]Assessed October 2005. Trees actively baited for 168 d.
[w]One tree lost to wood cutting.

controls died from *D. brevicomis* attack (Shea et al. 1984). During the initial field season, 6.7% of Masterline®-treated *P. ponderosa* died from bark beetle attack, whereas 53.0% mortality was observed in the untreated controls (Table 1). If two additional control trees had died, bark beetle pressure would have been sufficient to make definitive estimates of efficacy (Shea et al. 1984), and we would have concluded that both Masterline® and Sevin SL® were efficacious during the first field season. In 2005, only 3.6% of Masterline®-treated trees died, whereas 40% mortality was observed in the untreated control (Table 1). No Sevin SL®-treated trees died during the experiment.

Montana: *D. ponderosae* and *P. contorta*

In 2004 and 2005, beetle pressure was sufficient to adequately challenge these treatments (Shea et al. 1984). Masterline® provided one field season of efficacy (6.7% mortality), but in 2005, a significant number of Masterline®-treated trees died from *D. ponderosae* attacks (58.5% mortality) (Table 2). Sevin SL® was efficacious during both field seasons with 0% and 3.3% mortality observed in 2004 and 2005, respectively. Bark beetle pressure was extremely heavy during this evaluation as indicated by the mortality levels reported for the untreated controls (Table 2).

Arizona: *I. confusus* and *P. edulis*

In 2004 and 2005, beetle pressure was insufficient to adequately challenge the treatments because <60% of untreated controls died from *I. confusus* attack (Shea et al. 1984). In 2004, 4.2% of Masterline®-treated *P. edulis* died from bark beetle attack, whereas 20.8% mortality was observed in the untreated control (Table 3). During the second field season, 4.3% of Masterline®-treated *P. edulis* died from bark beetle attack, but only 5.3% mortality was observed in the untreated control (Table 3). No Sevin SL®-treated trees died during the experiment.

DISCUSSION

Carbaryl is considered by many to be the most effective and environmentally safe insecticide used to prevent bark beetle attacks on individual trees (Hastings et al. 2001). In this study, 2.0% a.i. carbaryl (Sevin SL®) was effective for protecting *P. contorta* from *D. ponderosae* attack for two field seasons, which agrees with results from other authors (Gibson and Bennett 1985; Page et al. 1985; Shea and McGregor 1987). Furthermore, in both Arizona and California, no mortality was observed on Sevin SL®-treated trees. The Arizona data are the first report of the effectiveness of carbaryl for preventing *I. confusus* attack and suggest that 1.0% a.i. may be effective for protecting *P. edulis*. Carbaryl remains a good choice for control purposes because of its effectiveness, residual activity, low cost, and moderate mammalian toxicity (Hastings et al. 2001).

Pyrethroid insecticides offer an excellent alternative to carbaryl. They cause fewer environmental disruptions, have lower mammalian toxicities, and are effective in very small quantities (Haverty et al. 1998). Masterline® is a rather novel and unique formulation of permethrin containing methyl cellulose (i.e., “plus-C”). The process is thought to increase efficacy and stability by reducing drift, evaporation, and photo, chemical, and biologic degradation of the permethrin molecule. The Masterline® emulsifiable formulation contains 38.0% permethrin, which is slightly higher than that of Astro® (36.8%). However, Masterline® is registered for use on conifers at rates significantly below that of Astro® (i.e., 0.2% versus 0.5%, respectively).

The data contained here regarding Masterline® is the first published report on its effectiveness for preventing bark beetle attack on individual trees. Our results suggest that one field season of efficacy can be expected even under the most significant of infestations (Table 2), which is similar to that described for other formulations of permethrin (Shea et al. 1984). Based on these results, claims regarding increased efficacy over conventional permethrin formulations such as Astro® should be viewed with skepticism until such trials are conducted. We conclude that Masterline® is an effective individual tree protection tool, but repeated annual applications will be necessary if multiyear control is desired.

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Christopher J. Fettig (corresponding author)
Pacific Southwest Research Station
USDA Forest Service
1107 Kennedy Place, Suite 8
Davis, CA 95616, U.S.
cfettig@fs.fed.us

Tom E. DeGomez
University of Arizona
211 Southwest Forest Science Complex
Northern Arizona University
P.O. Box 15018
Flagstaff, AZ 86011, U.S.

Kenneth E. Gibson
Forest Health Protection
USDA Forest Service
P.O. Box 7669
Missoula, MT 59807, U.S.

Christopher P. Dabney
Pacific Southwest Research Station
USDA Forest Service
1107 Kennedy Place, Suite 8
Davis, CA 95616, U.S.

Robert R. Borys
Pacific Southwest Research Station
USDA Forest Service
1107 Kennedy Place, Suite 8
Davis, CA 95616, U.S.

Zusammenfassung. Borkenkäfer (Coleoptera: Scolytidae) sind wohl allgemein die wichtigste Todesursache in Nadelwäldern. Wertvolle Bäume, besonders die Solitärbäume in bewohnten Gebieten, sind besonders anfällig. Unabhängig von den Eigentümerbelangen haben Baumverluste an diesen einzigartigen Standorten katastrophale Auswirkungen. Der Wert dieser Solitäre, die Kosten der Entfernung und der Verlust an ästhetischem Wert mögen eine Schutzbehandlung rechtfertigen, bis der Hauptansturm eines Borkenkäferbefalls überstanden ist. Diese Situation verdeutlicht den Bedarf an effektiven Insektiziden für individuellen Baumschutz. In dieser Studie untersuchten wir die Wirkung von Permethrin plus-C und Carbaryl bei *Pinus ponderosa*, *contorta* und *edulis*, die über 2 Feldperioden Käferattacken zu erleiden hatten. Permethrin war effektiv beim Schutz von *P. contorta* gegen *Dendroctonus ponderosae* in einer Feldsaison. Carbaryl war in beiden Perioden effektiv. Eine ungenügende Anzahl von *P. ponderosa* und *P. edulis*-Kontrollbäumen wurde getötet, um definitive Schlussfolgerungen bezüglich der Effektivität dieser Mittel zu ziehen. Die hier erhobenen Daten bezüglich Permethrin sind die ersten veröffentlichten Berichte über die Effektivität, Borkenkäferattacken an Solitären zu verhindern. Permethrin erscheint hier als effektives Werkzeug, aber wiederholte Anwendungen werden nötig sein wenn eine mehrjährige Kontrolle angestrebt wird.

Resumen. Los escarabajos de la corteza (Coleoptera: Scolytidae) son comúnmente reconocidos como los más importantes agentes de mortalidad en los bosques de coníferas del oeste. Árboles de alto valor, tales como los localizados en sitios residenciales, recreativos o administrativos, son particularmente susceptibles al ataque. Independiente de los objetivos del propietario, la pérdida de árboles en estos ambientes únicos generalmente tiene un impacto catastrófico. El valor de estos árboles individuales, el costo de remoción, y las pérdidas de valores estéticos puede justificar la protección hasta que subsista el efecto principal de una infestación del descortezador. Esta situación enfatiza la necesidad de asegurar que la efectividad de los insecticidas esté disponible para la protección de árboles individuales. En este estudio se evaluó la eficiencia de permethrin más-C (Masterline®) y carbaryl (Sevin SL®) para proteger pino ponderosa Dougl. ex. Laws., *P. contorta* Dougl. ex Loud. y *P. edulis* Engelm., del ataque del escarabajo durante dos estaciones de crecimiento. Masterline® fue efectivo para proteger P. contorta del escarabajo, *Dendroctonus ponderosae* Hopkins, por una estación de crecimiento. Sin embargo, Sevin SL® fue eficaz por dos estaciones de crecimiento. Un insuficiente número de árboles de control de *P. ponderosa* y *P. edulis* fueron matados para hacer las conclusiones definitivas con respecto a la eficiencia en estos sistemas. Los datos reportados aquí con respecto a Masterline® son el primer reporte publicado sobre su efectividad para prevenir el ataque en árboles establecidos. Masterline® parece ser una herramienta efectiva de protección de árboles individuales, pero serán necesarias aplicaciones repetidas si se desea un control en muchos años.