Forest Ecology and Management 257 (2009) 1231–1236

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Aerially applied methylcyclohexenone-releasing flakes protect *Pseudotsuga menziesii* stands from attack by *Dendroctonus pseudotsugae*

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ARTICLE INFO

Article history:
Received 14 May 2008
Received in revised form 31 October 2008
Accepted 8 November 2008

Keywords:
Pheromones
Bark beetles
Scolytidae
Semiochemicals
Douglas-fir beetle
Scolytinae
Curculionidae

ABSTRACT

We tested methylcyclohexenone (MCH), an anti-aggregation pheromone for the Douglas-fir beetle (*Dendroctonus pseudotsugae*), for protection of Douglas-fir (*Pseudotsuga menziesii*) stands by applying MCH-releasing polymer flakes by helicopter twice during summer 2006 to five 4.05-ha plots in the State of Washington, USA. Five similar plots served as untreated controls. We assessed *D. pseudotsugae* flight into study plots using baited pheromone traps, and tallied *D. pseudotsugae* attack rates on all *P. menziesii* trees in 2005 and 2006. We also measured stand basal area and incorporated that as an explanatory variable in the analysis. Significantly fewer *D. pseudotsugae* were trapped in treated plots than in control plots, and significantly fewer *P. menziesii* trees were attacked in treated plots than in control plots. The attack rate in untreated stands was nearly 10 times that of treated plots, and stands with higher basal area were significantly more likely to be attacked by *D. pseudotsugae* than were stands of lower basal area. Attack rates in 2006 and 2005 were significantly correlated, regardless of treatment.

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1. Introduction

Dendroctonus pseudotsugae Hopkins, the Douglas-fir beetle, is the most damaging beetle pest of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, throughout its range in western North America (Furniss and Carolin, 1977; Sanchez Salas et al., 2003). Outbreaks are normally sporadic and often follow wind throw or wildfires, but losses can be extensive (Dodds et al., 2004, 2006). More recently, drought has been implicated as a risk factor for *D. pseudotsugae* damage (Powers et al., 1999) and climate predictions suggest that localized droughts are likely to increase (Breshears et al., 2005). Heavily stocked or old growth stands are particularly at risk (Negron, 1998; Bulaon, 2003; Dodds et al., 2004; Cunningham et al., 2005; Hood and Bentz, 2007), and such stands serve as crucial habitat for the Northern Spotted Owl, *Strix occidentalis* (Xantus de Vesey), and the endangered Marbled Murrelet, *Brachyramphus marmoratus* (Gmelin). The need to conserve habitat for such protected species requires reduced harvests to maintain old growth stand structure (Noon and Blakesley, 2006; Raphael, 2006), resulting in greater risk of *D. pseudotsugae* outbreaks. In addition, managers of forested public lands have recently begun to fell *P. menziesii* trees to provide down woody debris for wildlife, because sufficient habitat is not created naturally in intensively managed forests (Ross et al., 2006). This practice, however, exacerbates outbreaks of *D. pseudotsugae* by providing breeding material for beetle populations that then spread the following year to standing trees (Furniss and Carolin, 1977; Ross et al., 2006). Forest managers have therefore sought methods to manage this pest, especially following such stand disturbances as wildfire and storms resulting in extensive wind throw, which exacerbate the situation by increasing stand susceptibility and providing breeding material for rapid beetle population buildup. Many of the stands that require protection from *D. pseudotsugae* are steep and/or remote, presenting difficulties for access using ground-level tree protection treatments. Furthermore, beetle flight begins when roads in many areas are impassable, making the possibility of an aerially applied treatment highly desirable.

Several management techniques to control *D. pseudotsugae* have been tested, including silvicultural treatments (Ross et al., 2006), insecticide applications (Furniss, 1962; Ibaraki and Sahota,

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0378-1127/$ – see front matter. Published by Elsevier B.V.
doi:10.1016/j.foreco.2008.11.037

1976), peeling of beetle-infested bark (Shore et al., 2005), and pheromone-based strategies including aggregation pheromones deployed in trap-out or trap-tree approaches (Ross and Daterman, 1995, 1997, 1998; Dodds et al., 2000; Laidlaw et al., 2003) and antiaggregants to interrupt host-finding (Furniss et al., 1972, 1974, 1977, 1982; McGregor et al., 1984; Ross and Daterman, 1994, 1995; Ross et al., 1996; Dodds et al., 2000). Reducing stand basal area may be the single most effective treatment (Dodds et al., 2004, 2006), but forest management objectives, particularly on public lands, often require preservation of large old-growth trees for wildlife habitat (Noon and Blakesley, 2006). Insecticide applications are likewise frequently ruled out because of adverse effects on nontarget organisms (e.g. Loch, 2005; Kreutzweiser et al., 2008; Kwon, 2008). Treatments such as trap-out, trap trees, and bark peeling (Laidlaw et al., 2003) are promising for small, high-value stands, but are labor-intensive and are thus unlikely to be used over large areas. They are also most appropriate for stands that are either spatially or ecologically isolated (i.e. surrounded by immature or non-host forest).

The anti-aggregation pheromone for *D. pseudotsugae*, 3-methyl-2-cyclohexen-1-one (MCH), has been tested for decades for area-wide control in various release formulations (Furniss et al., 1972, 1974, 1977, 1982; McGregor et al., 1984; Ross and Daterman, 1994, 1995; Ross et al., 1996; Dodds et al., 2000). MCH is produced *in vivo* by some animals and is found in a variety of foods; it was approved by the Food and Drug Administration as a food additive (Syracuse Environmental Research, Inc., 1998) and is currently registered by the United States Environmental Protection Agency for use in forestry. Various release devices have been tested, including granular MCH-releasing formulations, 3 mm polymer beads coated with MCH, and MCH-containing bubble-capsules that are stapled to individual trees or dispersed throughout wind thrown trees. One type of polymer bead was shown to release MCH too quickly for operational use (Holsten et al., 2002), and the granular formulation was promising but was not implemented on a broad scale for logistical reasons (M. Furniss, personal communication). Bubble capsules are quite effective but are limited in their application to relatively small, accessible stands. A new "puffer" device that periodically emits MCH has shown promise for control of *Dendroctonus rufipennis* (Kirby) (Holsten et al., 2006), but this device may not be adaptable for area-wide treatments because of its bulk, weight, and high cost.

We chose to assess efficacy of MCH-impregnated laminated plastic flakes, an existing pheromone release device that has been used for decades in the USDA Forest Service's "Slow-the-Spread" program to control the invasive Gypsy Moth (Sharov et al., 2002). We selected this application system because of its favorable release patterns (Gillette et al., 2006), its favorable regulatory characteristics (it was already registered for pheromones of the Gypsy Moth and orchard pests) and because of its ease of application with existing aircraft adaptations (i.e. pods and hoppers for use with fixed-wing aircraft and helicopters). Although the current formulation does not biodegrade quickly, a new biodegradable formulation is now available and will be tested in the near future.

2. Materials and methods

2.1. Study location

We installed the study in early 2006 near Lake Chelan in northern Washington State, USA. The site was located in Chelan County, Washington, on the Chelan Ranger District, Okanogan-Wenatchee National Forest, T28N R20E, Willamette Meridian, eight air miles northwest of the town of Manson, WA. The area was part of the Pot Peak Fire Complex, which began on June 26, 2004 and burned a total of 47,000 acres. Numerous Douglas-fir beetle attacks on scorched Douglas-firs were noted in 2005, indicating a potential outbreak. We selected ten 4.05-ha plots, at least 400 m apart, with apparently similar basal areas and existing rates of *D. pseudotsugae* infestation (Table 1). We did not have sufficient resources to assess these variables both before and after the treatments; since we were able to quantify both of them after the pheromone application, we chose to do so then, and to incorporate them as covariates in the analysis so their effects would be accounted for and any potential differences would not affect our ability to assess a treatment difference. We randomly assigned treatment to half of the plots, reserving the remaining half as untreated controls. A core plot of 2.03 ha was established in the center of each of the ten plots so that treatment effects (beetle flight and rate of attack on trees) could be measured while avoiding edge effects.

2.2. Pheromone formulation

MCH-releasing flakes (Hercon Environmental Emigsville, PA, USA) were formulated to contain 15% MCH in a central layer of plastisol bounded by two layers of polymer laminate. This laminated formulation, which is prepared in sheets and then cut into small square "flakes," releases the active ingredient (AI) only at the perimeter (not from the upper or lower surfaces) of each 6.4 mm $\times$ 6.4 mm square flake. Each flake thus represents a small reservoir of MCH with limited pheromone-releasing surface-to-volume ratio; these attributes result in sustained release of the pheromone over time. For example, release rates calculated from laboratory tests indicate release of 0.31 mg/AI/cm^2 of flakes/day between day 7 and day 14 following application (personal communication, Norris Starner, Hercon Environmental, Emigsville, PA). MCH is a more compact and lower-molecular weight molecule than many beetle pheromones, however, with only seven carbons and a single branch, as compared to verbenone and ipsdienol, which have ten carbons and are multiply branched (www.pherobase.com). It may thus elute more rapidly than some other beetle pheromones, so we scheduled a second application in the event that the flakes might become depleted of pheromone before the end of beetle flight.

2.3. Application rate and timing

The first application was made on 5 May 2006 and the second on 29 June 2006 at the rates of 468 g AI/ha (1.3 kg of flakes/ha) and

Table 1
Stand structure characteristics and pre- and post-treatment attack rates in treated and control plots, Chelan, WA, 2006.

Treatment	Mean (SE) total basal area (m^2/ha)[a]	Mean (SE) *P. menziesii* basal area (m^2/ha)[a]	Mean (SE) number of stems/ha[a]	Mean (SE) number of *P. menziesii* stems/ha[a]	Mean (SE) number of *P. menziesii*/ha attackedin 2005[a]	Mean (SE) number of *P. menziesii*/ha attacked in 2006[a]	Mean (SE) DBH, all trees	Mean (SE) DBH, *P. menziesii* trees
Control	29 (2) a	26 (2) a	276 (37) a	253 (26) a	0.6 (0.4) a	6.23 (1.9) a	34.8 (2.6)a	34.7 (2.5) a
Treated	21 (4) a	17 (4) a	201 (44) a	175 (47) a	0.1 (0.1) a	0.30 (0.1) b	33.9 (0.7)a	33.7 (1.4) a
Control/treated	1.378	1.513	1.383	1.437	6.0	21	1.03	1.03
P-value	0.12	0.10	0.21	0.18	0.10	<0.0001	0.75	0.72

[a] Means (SE = standard error); means followed by the same letter are not significantly different at α = 0.05.