AN ABSTRACT OF THE THESIS OF

Harrison M. Brookes for the degree of Master of Science in Forest Ecosystems and Society presented on August 20, 2015.

Title: Evaluating High Release Rate MCH (3-methylcyclohex-2-en-1-one) Treatments for Preventing *Dendroctonus pseudotsugae* (Coleoptera: Curculionidae) Infestations

Abstract approved:

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Darrell W. Ross

The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) can kill large numbers of Douglas-fir trees (*Pseudotsuga menziesii* (Mirbel) Franco) across a landscape during periods of population outbreaks. High-value individual trees and small stands can be protected from Douglas-fir beetle infestation during outbreaks by applying the anti-aggregation pheromone, MCH (3-methylcyclohex-2-en-1-one). MCH treatments are economical and highly effective, but there are still opportunities to refine existing treatments to be even more cost effective. Current recommendations for applying MCH are to space individual releasers on a 12 x 12 meter grid throughout areas to be protected. Previous field studies and a theoretical study using a puff dispersion model to predict pheromone concentrations have shown that wider spacing of releasers emitting the pheromone at higher release rates may be equally effective compared with the established standard treatment. During 2012 and 2013, we tested higher release rates of MCH at corresponding wider spacings to keep the total amount of MCH released per unit area equal in all treatments. In 2012 near

Challis, Idaho, treatments included the established standard release rate and spacing, four and six times the standard release rate with correspondingly wider spacings, and an untreated control. In 2013 near Ketchum, Idaho, treatments included the established standard release rate and spacing, five and seven times the standard release rate with correspondingly wider spacings, and an untreated control. Results from both years indicated that all MCH treatments were equally effective in preventing Douglas-fir beetle infestation. Using higher release rate formulations at wider spacings will reduce labor costs of applying MCH treatments. In addition to reducing labor costs, the revised treatment protocol may increase the feasibility of treating areas that currently may not be possible due to treatment costs.

Evaluating High Release Rate MCH (3-methylcyclohex-2-en-1-one) Treatments for Preventing *Dendroctonus pseudotsugae* (Coleoptera: Curculionidae) Infestations

by
Harrison M. Brookes

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented August 20, 2015
Commencement June 2016

Master of Science thesis of Harrison M. Brookes presented on August 20, 2015

APPROVED:

Major Professor, representing Forest Ecosystems and Society

Head of the Department of Forest Ecosystems and Society

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Harrison M. Brookes, Author

ACKNOWLEDGEMENTS

Thank you to personnel of the Challis and Sawtooth National Forests for allowing us to conduct the research and aiding in the collection of insect trap samples. Additional thanks to Daniel Ott, Juan Pajares, and Philip Mocettini for their help in establishing and evaluating the research plots. Funding for this project was provided by the USDA Forest Health Protection Special Technology Development Program.

CONTRIBUTIONS OF AUTHORS

Iral Ragenovich, Harold Thistle, and Tara Strand contributed to the conceptual design of this study. Laura Lowery helped to locate field sites and install plots in 2012. Iral Ragenovich helped install plots in 2012.

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INTRODUCTION

The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) is the most significant insect pest of Douglas-fir (*Pseudotsuga menziessi* (Mirb.) Franco) in western North America (Furniss and Carolin 1977). The beetle completes one generation per year with overlapping broods and overwinters in the phloem beneath the outer bark of Douglas-fir trees. In the spring, generally between April and June, adult beetles emerge from beneath the bark and search for new host trees for the next generation (Furniss and Carolin 1977). The most suitable host trees are those that are injured or stressed or have recently been killed (McMullen and Atkins 1962; Furniss 1965; Rudinsky 1966; Furniss et al. 1981; Wright et al. 1984). These trees have little or no defensive response to colonization attempts in contrast to the vigorous response of healthy trees. However, the beetles require moist phloem as a food source, and as a result trees that have been dead for more than one year are no longer at risk of being infested.

Under normal conditions, healthy Douglas-fir trees are at low risk for Douglas-fir beetle infestation. However, natural or human caused disturbances, such as wildfire, windstorms, defoliating insect outbreaks, or logging can weaken and or kill trees leading to an abundance of suitable host material. The result can lead to Douglas-fir beetle population outbreaks, which can kill large numbers of healthy living trees over large areas (Johnson and Belluschi 1969; Furniss et al. 1979).

There are several options for reducing the severity and extent of Douglas-fir beetle caused tree mortality. Where it is consistent with forest management plans, thinning dense stands will increase the defensive capabilities of residual trees and reduce the chances of successful Douglas-fir beetle infestations (Williamson and Price 1971). Sanitation and salvage logging of recently attacked or dead trees and removal of large diameter slash following logging operations will also help to reduce beetle populations in nearby areas (Lejeune et al. 1961; Furniss et al. 1979). Salvage logging and thinning are effective tools for Douglas-fir beetle management, but may not be possible in some areas susceptible to infestation. Susceptible areas where salvage logging and thinning would be undesirable may include parks, riparian areas, old growth reserves, housing developments and recreation areas.

Another option available to land owners and resource managers is the use of insecticides. Insecticides are highly effective (Gibson 1957; Fettig et al. 2013), but require the lower and middle section of the bole to be completely covered. Cost, specialized equipment, difficulty of ensuring adequate coverage, and the transportation of spraying equipment through the forest makes insecticide treatments over large areas impractical. Consequently, insecticides are only used to protect high valued trees in residential areas, recreational sites, and other special use areas (Fettig et al. 2013).

Aggregation and anti-aggregation pheromones of the Douglas-fir beetle are another management option. Pheromones have been used for mass trapping, trap trees, and preventing infestations in high-valued stands. They can be used in areas where silvicultural options are not consistent with management objectives.

Components of the Douglas-fir beetle aggregation pheromone system include frontalin (1,5-dimethyl-6,8-dioxabicyclo[3.2.1]octane), seudenol (3-methylcyclohex-2-en-1-o1), and MCOL (1-methyl-cyclohex-2-en-1-o1) (Pitman and Vité 1970; Vité et al. 1972; Rudinsky et al.1974; Pitman et al. 1975; Libbey et al. 1983). Use of aggregation pheromones for trapping was found to be more effective when combined with ethanol, which can come from the beetle during feeding or the host tree itself (Pitman et al. 1975).

Trap tree techniques use live trees baited with aggregation pheromones that are harvested at the end of the Douglas-fir beetle flight period. Mass trapping is similar to using trap trees, but uses artificial traps in place of trees. Traps eliminate the need for harvesting, but require maintenance throughout the beetle flight period (Ross and Daterman 1994). Potential problems with mass trapping and trap trees include the unintended attack of nearby trees commonly referred to as spillover (Knopf and Pitman 1972; Pitman 1973; Ringold et al. 1975; Their and Weatherby 1991; Ross and Daterman 1994) and the mortality of beneficial predators that are also attracted by the aggregation pheromones (Pitman and Vité 1970; Furniss and Schmitz 1971; Rudinsky et al. 1972; Pitman 1973; Lindgren et al. 1988).

The Douglas-fir beetle anti-aggregation pheromone MCH (3-methylcyclohex-2-en-1-one) was first discovered by Kinzer et al. (1971) in the female hindgut of Douglas-fir beetles. MCH was originally thought to be released by the females after stridulation by males (Rudinsky 1969; Rudinsky 1973; Rudinsky et al. 1973). However, Pitman and Vité (1974) found contrary evidence that MCH is primarily released by the male beetles. Females unlike males, do not contain MCH at emergence from the bark or once they begin feeding (Pitman and Vité 1974). MCH was registered by the U.S Environmental Agency (EPA) in 1999 and has been used operationally to protect high-valued trees since 2000 (Ross et al. 2006).

Early work using MCH revolved around preventing the infestation of downed trees and subsequent population outbreaks using a plastic bead formulation (Furniss et al. 1974; Furniss et al. 1977; Clausen et al. 1981; McGregor et al. 1984). Applications of MCH in the bead formulation were shown to be highly successful in preventing the infestation of downed trees (Furniss et al. 1974; McGregor et al. 1984) but the bead formulation was never registered by the EPA or used in operational treatments.

Hedden and Pitman (1978) proposed a push-pull technique using both aggregation and anti-aggregation pheromones. The idea was to disperse the beetles to a population density which they could not successfully overwhelm a healthy tree's natural defenses. Lindgren et al. (1988) performed a similar study in felled trees using MCH bubble capsules and baited traps. Their results showed protection of felled trees, but the baited traps had no effect on infestation densities.

The first published research on protecting live trees using MCH was done by Ross and Daterman (1994). They placed a combination of bubble capsule dispensers containing 400 mg of MCH around the perimeter of 1-ha circular plots and traps baited with aggregation pheromones placed around the outside of the protected area. The results indicated that live, susceptible trees could be protected using MCH and pheromone baited traps compared to a control with no MCH. A subsequent study found that MCH alone without pheromone baited traps was effective at protecting high risk stands from infestation (Ross and Daterman 1995).

Further testing of MCH was done to determine the optimal dose (Ross et al. 1996) defined as the least amount of MCH that would impart protection of high risk Douglas-fir. Ross and Daterman (1994; 1995) used between 45 – 76 g/ha and on average 150 bubble capsules (400 mg) per hectare. The results of the subsequent optimal dose study showed amounts as low as 20 g/ha (50 bubble capsules) were effective. However the authors recommended a slightly higher dose for operational treatments to provide a buffer and insure protection from Douglas-fir beetles (Ross et al. 1996).

More recent studies have attempted to refine the operational MCH treatment by increasing the release rate at more widely spaced release points to reduce treatment application time and cost. Ross et al. (2002) compared three different release rate and spacing combinations on 1-ha circular plots. They found that a three times higher release rate (3X) at correspondingly wider spacing to keep the total amount of MCH released per unit area the same was equally effective to the standard treatment. However, a nine times higher release rate (9X) was not as effective as the standard treatment.

When protecting areas larger than 1 hectare, it is recommended that MCH releasers be placed on a grid pattern throughout the area (Ross et al. 2006). Ross and Wallin (2008) tested the standard and 3X elution rates on 2 hectare plots using a grid layout for the MCH. The results were the same as Ross et al. (2002) in that both the standard and 3X elution rates provided similar levels of protection which were significantly different than the control.

Strand et al. (2012) used a puff dispersion model to simulate the MCH pheromone plumes produced in the previous studies by Ross et al. (2002) and Ross and Wallin (2008). Results from the simulations suggested that release rates as high as 6 times the standard elution rate would be effective.

The purpose of the following study was to test intermediate release rates from 4X to 7X to see if release rates higher than 3X would be effective at protecting Douglas-fir from Douglas-fir beetle infestation.

Evaluating High Release Rate MCH (3-methylcyclohex-2-en-1-one) Treatments for Preventing *Dendroctonus pseudotsugae* (Coleoptera: Curculionidae) Infestations

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Journal of Economic Entomology

Entomological Society of America

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Abstract

The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) can kill large numbers of Douglas-fir trees (*Pseudotsuga menziesii* (Mirb.) Franco) across a landscape during periods of population outbreaks. High-value individual trees and small stands can be protected from Douglas-fir beetle infestation during outbreaks by applying the anti-aggregation pheromone, MCH (3-methylcyclohex-2-en-1-one). MCH treatments are economical and highly effective, but there are still opportunities to refine existing treatments to be even more cost effective. Current recommendations for applying MCH are to space individual releasers on a 12 x 12 meter grid throughout areas to be protected. Previous field studies and a theoretical study using a puff dispersion model to predict pheromone concentrations have shown that wider spacing of releasers emitting the pheromone at higher release rates may be equally effective compared with the established standard treatment. During 2012 and 2013, we tested higher release rates of MCH placed with correspondingly wider spacings between release points, but kept the total amount of MCH released per unit area equal in all treatments. In 2012 near Challis, Idaho, treatments included the established standard release rate and spacing, four and six times the standard release rate with correspondingly wider spacings, and an untreated control. In 2013 near Ketchum, Idaho, treatments included the established standard release rate and spacing, five and seven times the standard release rate with correspondingly wider spacings, and an untreated control. Results from both years indicated that all MCH treatments were equally effective in preventing Douglas-fir beetle infestation. Using

higher release rate formulations at wider spacings will reduce labor costs of installing MCH treatments. In addition to reducing labor costs, the revised treatment protocol may increase the feasibility of treating areas that currently may not be possible due to treatment costs.

Keywords

Douglas-fir beetle, anti-aggregation pheromone, *Pseudotsuga menzeisii*

Introduction

The Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) is the most important insect pest of Douglas-fir (*Pseudotsuga menzeisii* (Mirb.) Franco) in western North America (Furniss and Carolin 1977). Douglas-fir beetle populations are usually maintained at low densities due to a limited amount of suitable breeding material, that is, recently dead trees or stressed live trees (McMullen and Atkins 1962; Furniss 1965; Rudinsky 1966; Furniss et al. 1981; Wright et al. 1984). Disturbances such as drought, wildfire, wind storms or defoliating insect outbreaks can result in an increase in suitable Douglas-fir beetle habitat, resulting in population increases. Large populations can successfully colonize and kill healthy trees, which would not have been susceptible when populations were at low densities (Johnson and Belluschi 1969; Furniss et al. 1979). During Douglas-fir beetle outbreaks, the anti-aggregation pheromone, MCH (3-methylcycolhex-2-en-1-one), can be used to prevent undesired tree mortality and minimize negative impacts on resource management objectives (Ross and Daterman 1994; Ross and Daterman 1995; Ross et al. 1996, 2002, 2006; Ross and Wallin 2008). When released by Douglas-fir beetles under natural conditions, MCH serves to prevent overcrowding of offspring by signaling to late arriving beetles that the tree has been fully colonized (McMullen and Atkins 1961; Hedden and Gara 1976). The current recommendation for MCH treatment is to place bubble capsule releasers on a 12 x 12 m grid pattern across the treated area in spring prior to beetle flight (Ross et al. 2006). Past studies have tested higher elution rates (3 and 9 times the standard rate, 3X and 9X) and correspondingly wider spacings to maintain the same amount of pheromone released per unit area while reducing the amount of time needed to apply the treatment (Ross et al. 2002; Ross and Wallin 2008). The results indicated that 3X the standard elution rate was equally effective to the standard treatment, while the 9X was not.

MCH has been commercially available since 2000 and used to protect individual trees and stands up to several hundred hectares (Ross et al. 2006). More recently, a puff dispersion model was used to simulate MCH concentrations at different elution rates and spacings (Strand et al. 2012). The results of this modeling exercise suggested that intermediate release rates between 3X and 9X may be as effective as the standard treatment.

The benefit of using a higher elution rate and correspondingly wider spacing is fewer release points of MCH throughout a treated area. Fewer release points result in less time walking through a stand to install the MCH dispensers to cover an area.

The net result is a reduction in labor time and costs. The reduction in labor costs may increase the feasibility of treating areas that currently may not be possible due to treatment costs.

The purpose of this study was to test higher elution rates and spacings in the field for preventing Douglas-fir tree mortality due to Douglas-fir beetle infestations under outbreak conditions

Materials and Methods

This study was conducted from May to September in both 2012 and 2013. Study sites were located near Challis, Idaho (44.5042° N, 114.2283° W) in 2012 and Ketchum, Idaho (43.6811° N, 114.3717° W) in 2013. Sites were chosen for their close proximity to relatively high Douglas-fir beetle populations. The same general methods were used in both years, the only change between years was the elution rates and spacings tested.

The study design each year was a randomized complete block design with five replications. Each block contained four treatments. In 2012, treatments were a control, the current standard (1X), and 4 and 6 times the standard release rate (4X and 6X). MCH releasers were spaced 12 m, 23 m, and 28 m apart for the 1X, 4X, and 6X treatments, respectively. Due to an insufficient number of MCH releasers, one block did not contain a 1X treatment. In 2013, treatments were a control, the current standard (1X), and 5 and 7 times the standard release rate (5X and 7X). MCH releasers were spaced 12 m, 26 m, and 31 m apart for the 1X, 5X, and 7X treatments, respectively. All plots within blocks and all blocks were spaced at least 100m apart. Plots were a 2-ha square. Plot locations were chosen based on the presence of a large component of mature Douglas-fir trees and no currently infested trees. In both studies, MCH was applied as Synergy Shield MCH Single Bubble formulation, Synergy Semiochemicals Corp., Burnaby, BC, Canada. To achieve the higher release rates, multiple dispensers were stapled at individual release points. The number of dispensers at each release point was equal to the number of times the elution rate was higher than the standard elution rate for that treatment. That is the 1X treatment used 1 dispenser per release point, the 4X treatment used 4, the 5X used 5, etc. A 16-unit multiple funnel trap (Lindgren 1983) was placed at the center of the plot. Each trap contained a lure of approximately 10 mg of frontalin (1,5-dimethyl-6,8-dioxabicyclo[3.21)octane) and 5 mg of seudenol (3-methylcyclohex-2-en-1-ol) impregnated in polyvinyl chloride cord (Daterman 1974). Release rates at 24ºC and chemical purities for frontalin and seudenol were 0.5 and 0.25 mg/d and 95.0 and 99.3%, respectively. Baited traps were placed at the plot centers to insure flying Douglas-fir beetles were attracted equally to all plots. A 3x3 cm piece of dichlorvos impregnated plastic was placed in trap collection cups to kill trapped insects.

The Challis study was installed May 1-10, 2012. Trap samples were collected every 1-2 weeks during the beetle flight period. The Ketchum study was installed May 2-6, 2013 and trap samples were collected approximately every 4 weeks. Trap collections were stored in a freezer until they were processed in the laboratory. All

Douglas-fir beetles and associated predators (*Thanasimus undatulus* (Say) and *Enoclerus sphegeus* F.) in each sample were counted and recorded.

Plots were surveyed (July 30 - August 01, 2012, and September 04-07, 2013) after the Douglas-fir beetle flight period was over. All Douglas-fir trees ≥ 20 cm dbh within a 1 ha circular plot at the center of each treatment plot were surveyed. The dbh and infestation status of each tree was recorded. A tree was determined to be infested if it was mass attacked and contained large amounts of boring dust on the lower bole. Basal area for all trees, ≥ 20 cm dbh was measured at plot center and approximately 25 m from the plot center in each cardinal direction. Basal area was recorded by species. Basal area data were used to calculate the percentage Douglas-fir composition of the stand.

Each data response was fitted with a linear mixed model. Years were analyzed separately. Blocks represented the random effect. Assumptions of normality and constant variance were checked graphically and were adequately met. If non-constant variance among group residuals was observed, variances were allowed to differ among groups (Zuur et al. 2009). For each response, an overall F-test for a difference among treatment means was conducted to test for treatment effects. If this showed a statistically significant difference (p-value < 0.05), pairwise comparisons were done for all treatment responses except percent infested using a Tukey adjustment for multiple comparisons (Lenth and HervÃ© 2015).

Percent mass attacked data for treatments receiving MCH were separated out and an overall F-test was done to look for differences among elution rates. A likelihood ratio test was done to compare a one mean reduced model and a two mean model (control and MCH treatments) to show the difference in percent infested between control and MCH treatment plots.

All statistical analyses were performed using the R (R Core Team 2014) software program via RStudio (RStudio Team 2015). Package nlme (Pinheiro et al. 2014) was used to fit linear mixed models and package lsmeans (Lenth and HervÃ© 2015) was used to obtain pairwise comparisons of interest. All plots were created using ggplot2 (Wickham 2009).

Results and Discussion

There were significant treatment differences in the mean number of Douglas-fir beetles collected in the pheromone-baited traps in 2012 (F= 8.69; df = 3, 11; P = 0.0031), but there were no significant treatment differences in mean number of Douglas-fir beetles collected in traps in 2013 (F = 1.59; df = 3, 12; P = 0.2424). Means by treatment and results of pairwise comparisons between treatments are reported in Table 2.1. Similar studies have generally shown a trend of higher numbers of Douglas-fir beetles being caught on control plots compared to plots treated with MCH (Ross and Daterman 1994; 1995; Ross et al 1996; Ross and Wallin 2008). This has been attributed to the higher number of infested trees on the control plots resulting in higher levels of aggregation pheromones from the natural sources in addition to the trap baits (Ross and Daterman 1995; Ross et al. 1996) and the effect of MCH on treated plots (Ross et al. 2002). Ross et al. (2002) found no differences in

Douglas-fir beetles caught between control and MCH treated plots which they attributed to removing traps before the end of the Douglas-fir beetle flight period (Ross et al. 2002). In this study, traps remained on the plots for the entirety of the flight period for both locations. A possible explanation for the significant treatment differences at one site one year and not at the other site in a different year is the difference in beetle population densities across year and site. During the year when there no significant differences among treatments, overall trap catches were higher than during the year when there were significant differences. However, generally similar Douglas-fir beetle trap catches on all treatments for both our study sites indicate comparable beetle pressure on all plots.

Only two predators were identified in trap catches, *T. undatulus* and *E. sphegeus*. *E. sphegeus* made up <1% of the total predators for both Challis and Ketchum and those data were not subjected to statistical analyses. There were no significant differences among treatments in catches of *T. undatulus* in 2012 ($F = 1.99$; df = 3, 11; $P = 0.1737$) or 2013 ($F = 3.26$; df = 3, 12; $P = 0.0596$) (Table 2.1). These results are similar to those reported in previous studies (Ross et al. 1996; 2002; Ross and Wallin 2008) further illustrating that MCH doesn't inhibit *T. undatulus* response to aggregation pheromones as much as it inhibits Douglas-fir beetle response.

In 2012, there were no significant differences in mean basal area ($F = 1.70$; df = 3, 11; $P = 0.224$), percent of total basal area ($F = 2.68$; df = 3, 11; $P = 0.0987$), tree density ($F = 0.93$; df = 3, 11; $P = 0.459$) or DBH ($F = 2.91$; df = 3, 11; $P = 0.0821$) of Douglas-fir trees ≥ 20 cm DBH among treatments (Table 2.2). In addition to

Douglas-fir, other tree species ≥ 20 cm found on the plots in Challis were lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm), subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm).

In 2013, there were no significant differences in mean basal area (F = 1.74; df = 3, 12; P = 0.2127), percent of total basal area (F = 0.39, df = 3, 12; P = 0.765), tree density (F = 1.62; df = 3, 12; P = 0.2374) or DBH of Douglas-fir trees ≥ 20 cm DBH among treatments (F = 0.41; df = 3, 12; P = 0.7466) (Table 2.2). In addition to Douglas-fir, other tree species ≥ 20 cm DBH found on the plots in Ketchum were lodgepole pine and quaking aspen (*Populus tremuloides* Michx). The lack of significant differences in any of the measured tree or stand characteristics within each plot was anticipated and demonstrates that plots were located and treatments randomly assigned without bias.

There were significant differences among treatments in the mean percent of Douglas-fir trees ≥ 20 cm DBH mass attacked by the Douglas-fir beetle in both years (Challis: F = 4.09; df = 3, 11; P = 0.0354, and Ketchum: F = 3.43; df = 3, 12; P = 0.0523) (Table 2.2). Results for both years were similar with the control having a significantly higher percentage of Douglas-fir trees mass attacked than the three MCH treatments.

There were no significant differences in percent of trees mass attacked among the MCH treatments in 2012 (F = 1.50; df = 2, 7; P = 0.2867) or 2013 (F = .45; df = 2, 8; P = 0.6507). When compared using one mean for all groups and a two mean group model (Control vs Standard, 4X and 6X) neither Challis or Ketchum showed a significant difference ($F = 3.04$; df = 2, 9; $P = 0.2187$), ($F = 1.07$; df = 2, 9; $P = 0.5859$) respectively.

The combined results of both studies indicate that all of the higher MCH release rates with wider spacings (4X – 7X) were as effective at preventing Douglas-fir beetle mass attacks as the currently recommended standard treatment. This confirms the hypotheses of Strand et al. (2012) using a puff dispersion model that intermediate release rates between 3X and 9X the standard elution rate may be equally as effective as the current standard.

Using higher MCH elution rates at fewer points in a treatment area will reduce the time and, therefore, cost of MCH treatments to protect susceptible stands. By reducing time and cost land managers may be able to treat larger areas on fixed budgets or areas that would not have been economically feasible previously.

Acknowledgements

Thank you to the personnel of the Challis and Sawtooth National Forests for allowing us to conduct the research and aiding in the collection of insect trap samples. Additional thanks to Daniel Ott, Juan Paiares, and Philip Mocettini for their help in setting up and evaluating the research plots. Funding for this project was provided by the USDA Forest Health Protection Special Technology Development Program.

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Table 2.1 Mean number ± SEM of Douglas-fir beetles and clerid predators, *Thanasimus undatulus*, caught in traps baited with aggregation pheromones on MCH-treated and control plots.

Site, Year and Treatment	DFB (mean no. per trap)	*T. undatulus* (mean no. per trap)
Challis, ID 2012		
Control	363.7 ± 38.7a	191.5 ± 35.1
Standard	249.1 ± 97.0ab	189.5 ± 33.7
4X Standard	128.3 ± 46.3b	216.6 ± 16.2
6X Standard	217.9 ± 67.3ab	267.3 ± 34.9
Ketchum, ID 2013		
Control	518.4 ± 208.1	399.5 ± 157.1
Standard	520.2 ± 204.4	613.1 ± 193.5
5X Standard	338.8 ± 192.1	543.2 ± 49.4
7X Standard	352.0 ± 215.9	796.1 ± 366.7

Within a site and year, means followed by no letter or the same letter are not significantly different at $\alpha = 0.05$

Table 2.2 Mean ± SEM stand and tree characteristics for Douglas-fir ≥ 20 cm DBH on control and MCH-treated plots near Challis, ID in 2012 and Ketchum, ID in 2013.

Site, Year and Treatment	Basal area (m^2/ha)	% Basal area (% of total)	Tree density (stems/ha)	DBH (cm)	% Mass Attacked
Challis, ID 2012					
Control	16.3 ± 1.7	91.8 ± 4.7	59.2 ± 7.9	34.5 ± 1.2	17.9 ± 5.7a
Standard	16.4 ± 1.7	92.0 ± 5.6	48.8 ± 10.8	32.7 ± 1.1	3.6 ± 6.0b
4X Standard	12.4 ± 2.4	98.1 ± 4.9	48.8 ± 8.9	31.5 ± 2.2	1.7 ± 5.9b
6X Standard	15.5 ± 2.5	99.6 ± 4.7	63.4 ± 13.2	31.6 ± 1.0	0.5 ± 5.7b
Ketchum, ID 2013					
Control	24.4 ± 1.9	99.3 ± 0.7	80.0 ± 6.4	39.5 ± 1.5	14.0 ± 4.3a
Standard	25.3 ± 2.6	96.0 ± 4.1	75.0 ± 17.7	41.0 ± 3.2	0.5 ± 4.3b
5X Standard	20.3 ± 2.6	98.7 ± 1.5	65.4 ± 9.4	39.5 ± 1.8	1.0 ± 4.4b
7X Standard	25.2 ± 2.6	98.3 ± 1.5	83.8 ± 8.2	37.2 ± 2.8	0.7 ± 4.3b

Within a site and year, means followed by no letter or the same letter are not significantly different at $\alpha = 0.05$

CONCLUSION

The results of this study further demonstrate the effectiveness of MCH at preventing Douglas-fir beetle infestations during periods of population outbreaks. When implemented in a grid formation over areas greater than 1 acre, the results of this study and those of Ross and Wallin (2008) show that 3X, 4X, 5X, 6X, and 7X treatments were effective for protecting susceptible Douglas-fir trees.

A previous study by Ross et al. (2002) tested an elution rate of 9 times (9X) the current standard on circular 1 ha plots and found no difference in the percentage of trees mass-attacked compared to the control. This elution rate and spacing has not been tested in a grid pattern of releaser deployment, but the standard and 3X treatments have been tested on both circular 1 ha plots (Ross et al. 2002) and 2 ha square plots using a grid pattern for deployment (Ross and Wallin 2008) with results showing a lower percentage attacked trees compared to the control. These results compared with the puff dispersion simulations reported by Strand et al. (2012) indicate the upper limit of effective elution rate and spacing is below 9X.

Based on our results we recommend operational MCH applications using releasers eluting the pheromone at up to 5 times the current standard release rate at correspondingly wider spacing to keep the total amount of MCH released equal on an area basis. Even though the 6X and 7X treatments were found to be as effective as the lower release rates, we feel it is important to maintain a margin of error in operational treatments to avoid failures that might arise by pushing release rate and spacing to the threshold of effectiveness. Further operational use or research may provide sufficient evidence in the future to warrant more widespread use of release rates up to 7 times the standard.

Further increasing the elution rate reduces the number of MCH release points throughout a treatment area. More widely spaced release points requires less walking and fewer stops during treatment saving time and labor costs. Reductions in cost and time can help land managers treat marginal or larger areas then are currently possible while maintaining the same level of protection from Douglas-fir beetle infestations.

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