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# Release Rates of Methylcyclohexenone and Verbenone from Bubble Cap and Bead Releasers Under Field Conditions Suitable for the Management of Bark Beetles in California, Oregon, and Alaska

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## Errata

for PNW-RP-544

1. Equation 2 on page 3 is changed to the following:  $dy/dX=b + 2cX$
2. Text on page 6, paragraph 1, second to last sentence, should read:  
The slopes, however, were not significantly different between the four sites.



This publication reports research involving pesticides, it does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate state or federal agencies, or both, before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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## Abstract

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Devices releasing antiaggregation pheromones, such as MCH (3-methyl-2-cyclohexen-1-one) and verbenone (4-methylene-6,6-dimethylbicyclo(3.1.1)hept-2-ene), are used experimentally to manipulate destructive populations of bark beetles. Two slow release devices, bubble caps attached to boles of trees and granular beads placed on the ground, were tested in forests of California, Oregon, and Alaska to determine their release rates. The hypothesis was that ambient air and soil temperatures were major determinants in the release rates of the releaser devices. Release rates of both bubble caps and beads differed greatly. The fastest rate was for bubble caps at a warm, California pine (*Pinus* spp.) site where it was 15 times faster than the rate at a cool Sitka spruce (*Picea sitchensis* Bong. Carr.) site in Alaska. Beads released MCH quickly and were rendered ineffective in less than 2 weeks. Little or no release occurred thereafter, regardless of the amount of pheromone remaining in the bead, or litter layer temperature. Release rates determined under field conditions are useful for the field entomologist and are vital to the development of models for semiochemical dispersion.

Keywords: Semiochemicals, release rates, antiaggregation pheromones, bark beetles, temperature, MCH, verbenone.

## Summary

The data reported here are from studies on the release rates of MCH and verbenone from two commonly used release devices, bubble caps and beads. These studies were carried out in California, Oregon, and Alaska. Release rates of both bubble caps and beads varied greatly. Ambient air and litter layer temperatures were the major determinants in release rates of the releaser devices. The fastest release rates from bubble caps occurred at a warm California pine site and were 15 times the rate from a cool spruce site in Alaska. Bead releasers quickly released semiochemicals for about 2 weeks. Little or no release occurred thereafter, regardless of the amount of pheromone remaining in the bead, or litter layer temperature.

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## Introduction

In the past few decades, outbreaks of various types of bark beetles in western North America, including Alaska, have brought about renewed interest in these devastating forest pests. Spruce beetle (*Dendroctonus rufipennis* (Kirby)) infestations impacted more than 1 000 000 ha of forested land in south-central Alaska in the last decade (Matthews and others 1997). Many of these infested stands have over 90 percent tree mortality. The impact of these outbreaks and the anticipated impact of future outbreaks have stimulated the continuation of basic and applied research on the use of semiochemicals to manipulate populations of bark beetles (Holsten 1994, Shea 1995, Werner 1994, Werner and Holsten 1995).

Bark beetle semiochemical communication systems are complex, involving insect physiology, pheromone chemistry, and microclimate processes in the forest stand atmosphere. There have been many successful applications of semiochemicals to manage forest pests. An aerial application of verbenone in northwestern Montana significantly reduced the attack of lodgepole pine (*Pinus contorta* Dougl. ex Loud.) by the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) (Shea and others 1992). Antiaggregation pheromones, however, have periodically failed to reduce tree attack by the mountain pine beetle (Amman 1993, Borden 1995) and the spruce beetle (Holsten and Werner 1985, 1987; Zogas 2001). These failures could be caused by technical problems involving the deployment, consistent release, longevity of releasers, and dispersion of semiochemicals from the releaser, as well as the influence of the microclimate within the stand. Inconsistency in effectiveness of semiochemical applications could lead to a reluctance of manufacturers to produce semiochemicals for operational uses and cause forest pest managers to be hesitant to use these chemicals for pest management strategies (Borden 1995).

The inconclusive results of semiochemical field tests indicate a need to obtain systematic knowledge on release rates from releaser devices—rates that are hypothesized to be strongly controlled by temperatures in the field. This report describes the results of field tests on the release of MCH (3-methyl-2-cyclohexen-1-one) and verbenone (4-methylene-6,6-dimethylbicyclo(3.1.1)hept-2-ene) from bubble cap and bead releasers. MCH is the antiaggregation pheromone of the spruce beetle and the Douglas-fir beetle (*D. pseudotsugae* Hopkins). Verbenone is the antiaggregation pheromone of the mountain pine beetle, western pine beetle (*D. brevicornis* Hopkins), and the southern pine beetle (*D. frontalis* Zimmerman).

The pheromones MCH and verbenone, formulated in bubble caps and beads provided by Phero Tech, Inc. (Delta, British Columbia, Canada)<sup>1</sup> were placed at several field sites in California, Oregon, and Alaska.

## Materials and Methods

### Study Area Characteristics

**Darling Ridge, California**—This study site was located on a southwest facing slope in the Eldorado National Forest, about 1000 m elevation on the west side of the Sierra Nevada. The vegetation was a mixed stand of ponderosa pine (*Pinus ponderosa* Dougl. ex Loud.), white fir (*Abies concolor* (Gord. & Glend.) Lindl.), incense-cedar (*Calocedrus decurrens* (Torr.) Florin), and California black oak (*Quercus kelloggii* Newb.).

**Silver Forks, California**—This site was also located on the west side of the Sierra Nevada but at an elevation of 1700 m. The overstory was diverse, dominated by white fir, incense-cedar, and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) with sugar pine (*Pinus lambertiana* Dougl.) and ponderosa pine as minor species.

<sup>1</sup> The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

**Santiam Pass, Oregon**—This site was located in the Cascade Range at an elevation of 1000 m. The open canopy comprised mostly Douglas-fir 15 to 25 m tall.

**Enterprise, Oregon**—This site was located in the Wallowa Mountains in northeast Oregon at an elevation of about 1500 m. A closed canopy Douglas-fir stand dominated the site.

**Cooper Landing, Alaska**—This site was dominated by 100-year-old Lutz spruce (*Picea X lutzii* Little) (mean diameter-at-breast-height (d.b.h.) of 30 cm) located on a south aspect at an elevation of 300 m about 150 km south of Anchorage on the Sterling Highway. The stand canopy was closed with an understory of 12 cm d.b.h. paper birch (*Betula papyrifera* Marsh). The litter layer, about 3 cm thick, was composed primarily of birch leaves.

**Seward, Alaska**—The overstory of this site was a 150-year-old closed-canopy Sitka spruce stand (*P. sitchensis* (Bong.) Carr.) located on a flat area at about 300 m elevation 15 km north of Seward, Alaska, on the Kenai Peninsula. Mean d.b.h. of the spruce was 55 cm; the understory was sparsely scattered spruce seedlings and a layer of moss 7 cm thick.

## Experimental Design

We used MCH bubble caps with release rates<sup>2</sup> of 24 °C at all study locations. In addition, we used MCH bubble caps with release rates<sup>2</sup> of 17 °C at the two Alaska sites. These 17 °C caps are significantly more effective in the cooler Alaska temperatures because they have a thinner membrane and thus a faster release rate than the 24 °C caps (Werner 1994, Werner and Holsten 1995). Only verbenone releasers were placed at the California sites.

Bubble caps were placed 2 m above the ground on the north side of trees, except in Alaska where they were placed on the south side. Four to five bubble caps were collected every 2 weeks for laboratory analyses. Shipment was made directly to the Forestry Sciences Laboratory of the USDA Forest Service, Pacific Northwest Research Station, in Corvallis, Oregon. Some bubble cap samples were analyzed immediately to determine residual levels of MCH and verbenone; others were frozen and stored for later analyses.

In addition to the bubble cap studies, MCH beads were distributed at each site on the forest floor. Verbenone beads were distributed only at the Silver Forks and Darling Ridge sites in California. Ten beads were randomly selected every 2 weeks from each study site and shipped to the Forestry Sciences Laboratory.

## Quantification of Release Rate

The initial amount of semiochemical in bubble caps was provided by the manufacturer. The best method for determining release of semiochemical from bubble caps was to weigh the fluid content of the bubble caps brought in from the field. Simply weighing intact bubble caps was not as accurate because contaminants such as dirt, water, or pitch could cause weight changes. The semiochemical weights were regressed against time. Representative samples of MCH and verbenone from bubble caps from each study site were extracted with hexane and analyzed qualitatively by gas chromatography and mass spectrometry to check for possible degradation to inactive compounds.

The MCH and verbenone beads were about 2.1 percent MCH and 2.6 percent verbenone, respectively; the remaining mass was polypropylene polymers. Each bead was sectioned in the laboratory with a razor blade and extracted with 1 milliliter of hexane. Concentrations of MCH and verbenone were determined by gas chromatography.

<sup>2</sup>Bubble cap release rates determined at these temperatures by the manufacturer.

A more appropriate way, perhaps, to analyze the data is to estimate the actual release rates. It is these rates that are expected to be strongly controlled by temperature. Release rates are estimated by first fitting a model to each data set and then calculating release rates by taking the first derivative or the slope of the line generated by the data-driven model. The model that is satisfactory for all data sets is the form

$$y = a + bX + cX^2 \quad (1)$$

where

X is days,

y is residual chemical in grams, and

a, b, c are parameters generated by fitting the model to the data.

The first derivative of this model is

$$dy/dX = b + 2cX \quad (2)$$

where dy/dX is the release rate in grams per day.

If the parameter c approaches zero, the release rate is b, or is constant with time. Any deviation from a constant release rate in the field is estimated from the value of the parameter c. Figure 18 in the appendix shows the fit of the model to each field data set for 24 °C bubble caps. Release rates are taken directly from the model lines derived for each field site. Figure 18 is a measure of the confidence expected in the calculated release rates.

## Temperature

Temperature measurements were made at each study site coincident with the releaser study. Each site had a weather station with an Omnidata data recorder (Omnidata International Inc., Logan, Utah) which received input from two exposed sensors; one placed on the tree bole at a height near the bubble caps and the other 2 to 3 cm below the surface of the litter layer. We thought litter layer temperatures were important factors controlling the release rates, especially in Alaska where the litter temperatures are much lower than in warmer climates for which the beads were originally formulated. Temperature data were collected at 2-hour intervals.

## Results and Discussion

### Release from Bubble Caps

In general, MCH release rates in 24 °C bubble caps were similar at study sites in Oregon and Alaska (Enterprise, Santiam Pass, Cooper Landing, and Seward), whereas MCH released faster at the Darling Ridge and Silver Forks sites in California (fig. 1). The residual MCH at the Darling Ridge site decreased especially fast compared to the other sites. The variation in the residual MCH for the 4 to 5 caps at Darling Ridge and Santiam Pass for each sampling period is shown in figure 17 (see app.); other sites have similar variations.

The 17 °C bubble caps began with higher amounts of MCH and declined faster than the 24 °C caps at the two Alaska sites (fig. 2). The residual MCH in the 17 °C caps at the Cooper Landing site decreased more rapidly than at the other sites, whereas the loss of MCH in the 17 °C bubble caps at the Seward site was markedly reduced after a rapid, initial loss.

In contrast to the MCH bubble cap data, verbenone appeared to decline in a well-defined linear fashion at the Darling Ridge and Silver Forks sites (fig. 3). The rate of verbenone loss appeared to be faster at the Darling Ridge site. The MCH loss approached an exponential decline compared to the linear decline in residual loss of verbenone at the Darling Ridge site (fig. 4).

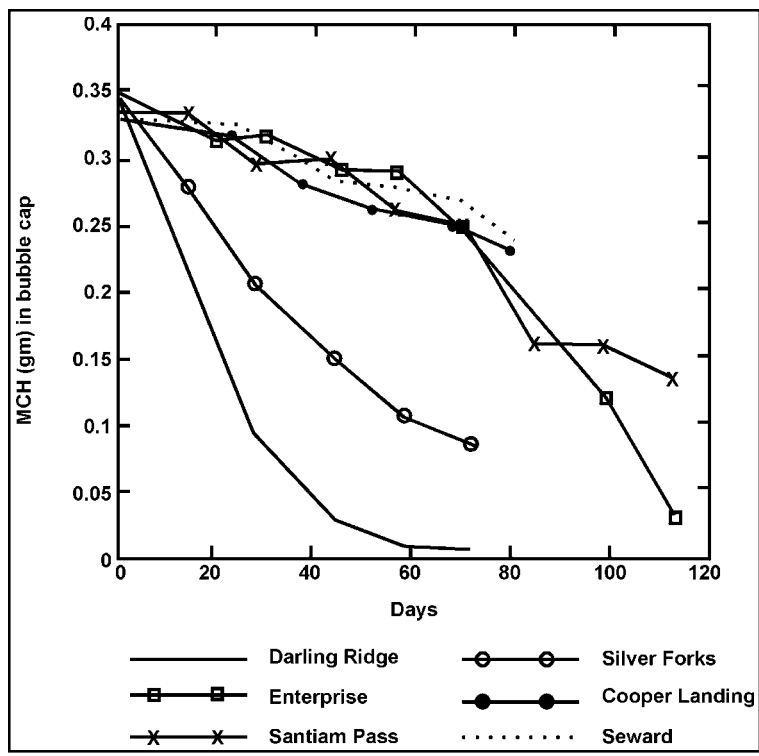


Figure 1—Depletion of MCH from 24 °C bubble caps at two sites each in California, Oregon, and Alaska. MCH was allowed to elute for 75 days in California and 115 days in Oregon and Alaska.

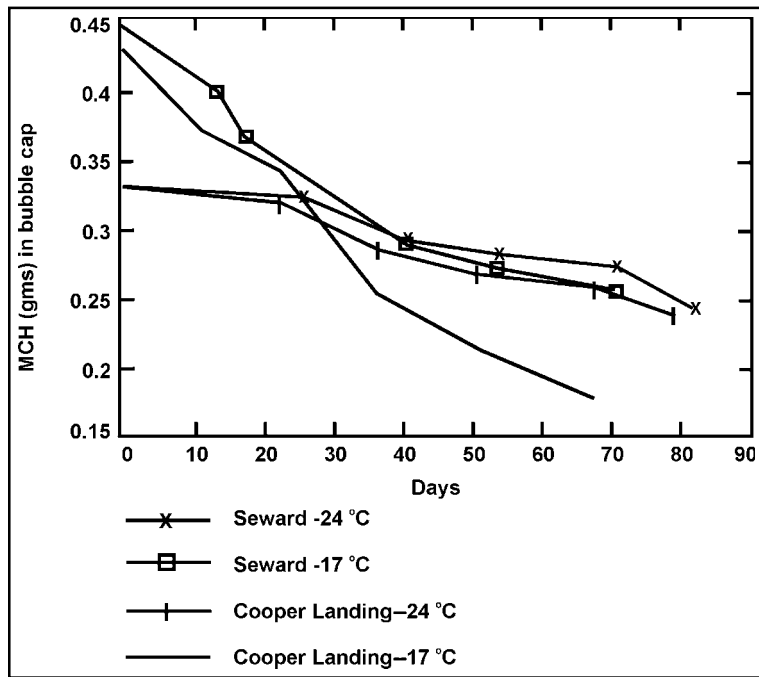


Figure 2—Depletion of MCH from 24 and 17 °C bubble caps at the two Alaska sites.



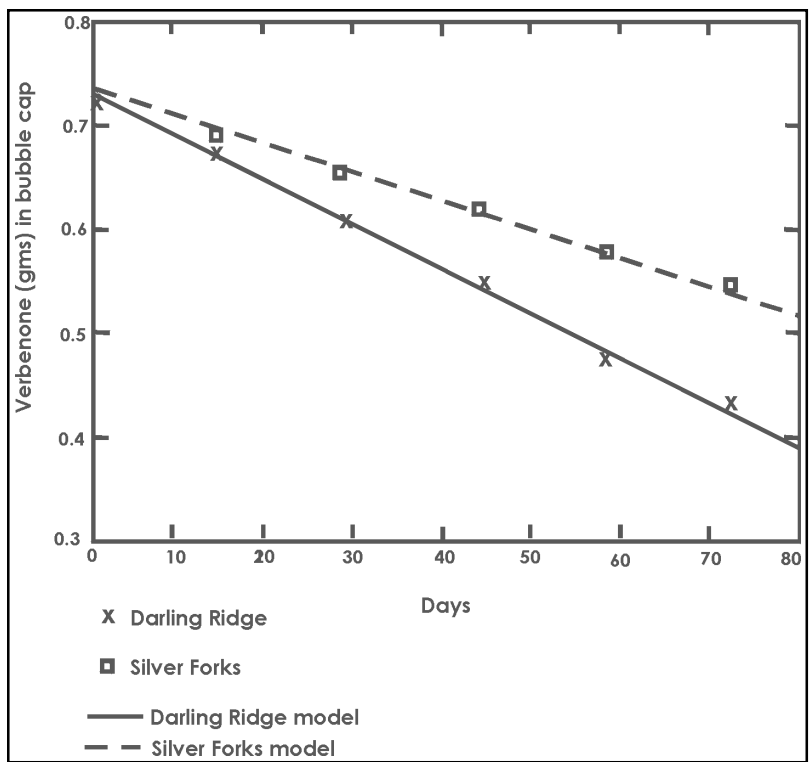


Figure 3—Depletion of verbenone from 24 °C bubble caps at the two California sites.

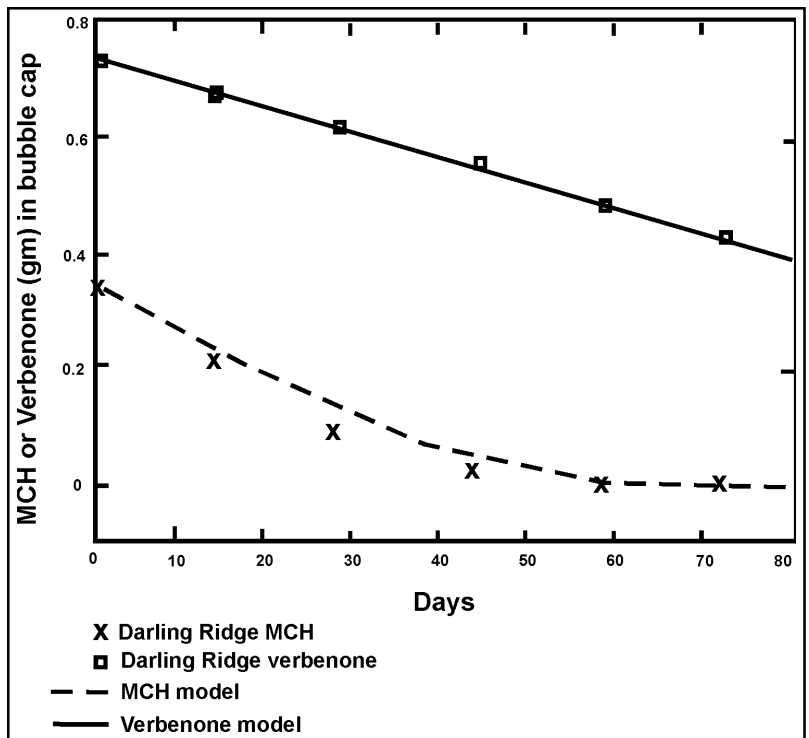


Figure 4—Depletion of MCH and verbenone in 24 °C bubble caps at the Darling Ridge, California, site over a 70-day release period.

Release rates of 24 °C MCH bubble caps at the Enterprise, Santiam Pass, Seward, and Cooper Landing sites have similar residual chemical dynamics (fig. 5). Estimated release rates for Santiam Pass and Cooper Landing are identical, hence only three curves are shown in figure 5. Release rates at all four sites increased during the sampling period. The slopes, however, were not significantly different between the four sites. Initial release rates (fig. 5) were estimated at 0.7 mg per day (per bubble cap) for all four sites, and each increased to 1.5 mg per day at the end of the sampling period, about a twofold increase.

In contrast to the increase in the MCH release rates shown in figure 5, there was a steep decline in MCH release rates for Darling Ridge and Silver Forks (fig. 6). The rate of decline was especially striking for the Darling Ridge study site. Both sites had higher initial release rates than the sites at Enterprise, Santiam Pass, Cooper Landing, and Seward. The initial rate for Darling Ridge was 10 mg per day (15 times greater than the 0.7 mg per day for sites in fig. 5). This initial rate of 10 mg per day declined to near zero at the end of the sampling period. The initial release rate for Silver Forks was 5 mg per day; it was estimated to be 2 mg per day at the end of the sampling period.

The release rates from 17 °C MCH bubble caps decreased at Cooper Landing and Seward (fig. 7). The initial rates were different, but the rate of decline was nearly equal. The initial release rate for the Cooper Landing site was 5 mg per day. The rate for the Seward site, however, was slightly lower at 4 mg per day. Near the end of the sampling period, the rates were sharply reduced to 1.5 mg per day for the Seward site and 2.5 mg per day for the Cooper Landing site. These initial rates of 4 to 5 mg per day for 17 °C caps contrasted to initial rates of 0.7 mg per day for 24 °C caps at the same sites, although the release rate for 24 °C caps rises slightly, whereas the rate for the 17 °C caps declined during the same sampling period (fig. 5).

Release rates for verbenone bubble caps were linear during the sampling period as rates were 3 mg per day for Silver Forks and slightly higher at 4 mg per day for the Darling Ridge site (fig. 3).

The release rate of bubble caps was expected to be strongly controlled by the temperature inside the cap. The most likely mechanism is that the chemical placed in the bubble cap initially as a pure liquid vaporizes into the atmosphere within the bubble cap and then releases through the membrane into the stand atmosphere. Vaporization may possibly occur on the exterior membrane surface. This, however, was not explored. The vapor pressure inside the bubble cap was close to the saturation vapor pressure, whereas the vapor pressure outside the membrane was negligible because the chemical was quickly removed by atmospheric turbulence, especially during the warm turbulent periods when beetle flight occurred. Release rates, therefore, were controlled by the saturation vapor pressure and the conductance of the membrane. Membrane conductance remained constant unless the membrane integrity was somehow disrupted, but the saturation vapor pressure increased exponentially with temperature.

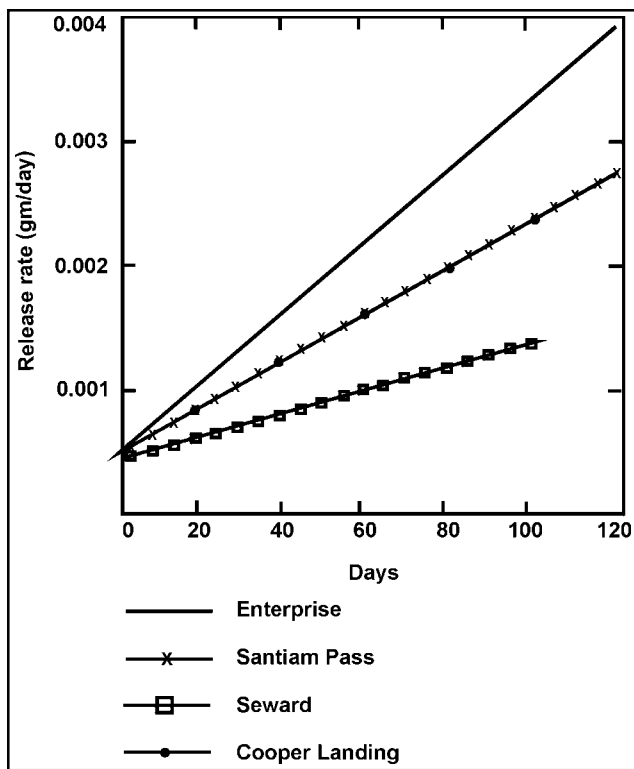


Figure 5—Model results of release rates from 24 °C MCH bubble caps at the Oregon and Alaska sites over a 100-day release period.

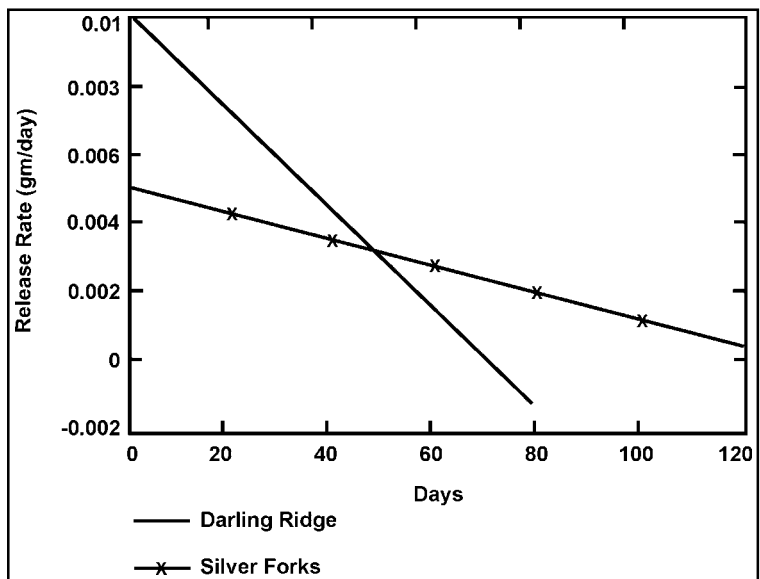


Figure 6—Model results of release rates from 24 °C MCH bubble caps for the two California sites.

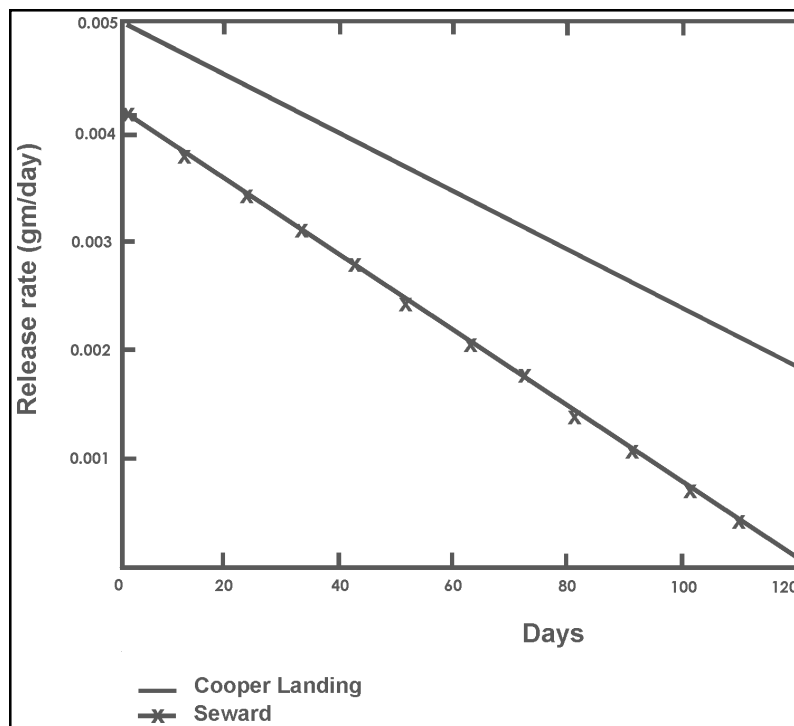


Figure 7—Release rates from 17 °C MCH bubble caps from the two Alaska sites.

**Table 1—Comparison of mean (+ standard deviation) litter layer and air temperatures for all study sites<sup>a</sup>**

Site	Date 1996	Air temperature	Litter temperature
----- Degrees centigrade -----			
Darling Ridge	6/23 to 9/1	23.6 + 5.1	21.3 + 2.6
Silver Forks	6/23 to 9/1	18.4 + 7.5	16.3 + 3.1
Santiam Pass	5/6 to 8/25	14.2 + 6.1	13.5 + 4.0
Enterprise	4/28 to 6/9	9.2 + 5.7	7.7 + 2.7
	8/4 to 9/19	15.4 + 5.7	14.0 + 2.9
Seward	5/17 to 8/11	10.3 + 4.7	8.8 + 2.7
Cooper Landing	5/17 to 8/10	11.9 + 4.5	9.8 + 3.1

<sup>a</sup> Means and standard deviations calculated from data collected every 2 hours.

The hypothesis is that the differences in the field release rates (shown in figs. 1 through 7) can be explained by temperature differences. Table 1 is a compilation of the average daily air and litter layer temperatures for the six study sites. The sites in California (Darling Ridge and Silver Forks) had considerably warmer temperatures than the other sites, 23.6 and 18.4 °C, respectively. These temperatures explained the high initial release rates at these sites because release rates increased exponentially with temperature. The Oregon Douglas-fir sites had lower temperatures than the California pine sites, but somewhat higher temperatures than the Alaska spruce sites. Oregon and Alaska sites had release rates that were not significantly different from each other, although the average temperatures seem to be significantly different. At lower temperatures, release rates varied less with temperature. Rates were still affected by temperature, but the magnitude was more difficult to demonstrate with field data.

A more detailed analysis can be done by using the air temperature data collected every 2 hours at each location. Darling Ridge and Cooper Landing sites had the largest differences in temperature (fig. 8, 9). For Darling Ridge (fig. 8), there was no discernible seasonal trend. Temperatures remained between 15 and 35 °C during the sampling period (including day and night measurements). At the Cooper Landing site (fig. 9), there was an increase in temperature during the May, June, and July sampling periods. This probably explained the observed increase in release rates (fig. 5). For Darling Ridge, the high initial release rates (fig. 6) were likely the result of high temperatures; the decrease in release rates occurred although the temperature remained high. This decline probably occurred because the chemical in the bubble cap was being depleted to a level where the vapor pressure inside the cap was diminished, thereby causing a reduction in the vapor pressure deficit between that inside the cap and the atmosphere external to the membrane. The Silver Forks site had temperatures similar to the Darling Ridge site, and the same analysis applies. The Seward, Santiam Pass, and Enterprise sites were similar to the Cooper Landing site in their dynamics.

It is significant that the release rates of verbenone at the Darling Ridge and Silver Forks sites were constant over the sampling period, whereas the MCH bubble cap release rates declined dramatically. Both releasers experienced the same temperature regime. The difference was that nearly twice as much chemical was initially placed in the verbenone releaser as in the MCH releaser. This suggests that the low release rates of MCH near the end of the sampling period at the two California sites were caused by high temperatures, which in turn caused rapid initial release rates and depleted the MCH, subsequently causing lower release rates later in the season. Another possibility is that there was a difference in volatility between the two compounds that could affect release rates.

The 17 °C MCH bubble caps at the Cooper Landing and Seward sites also exhibited a decline in release rates, while at the same time there was an increase in release rate of the 24 °C MCH bubble caps that were at the same site with the same temperature regime. The 17 °C release device has a thinner membrane than the 24 °C release device. Again, this may have been the result of rapidly declining levels of MCH within the bubble cap, therefore reducing the release rate in the later stage of the study. This reduction in release rate would not be expected to be linear over the course of the study, but the field sampling frequency may not have been sufficient to define the nonlinearity.

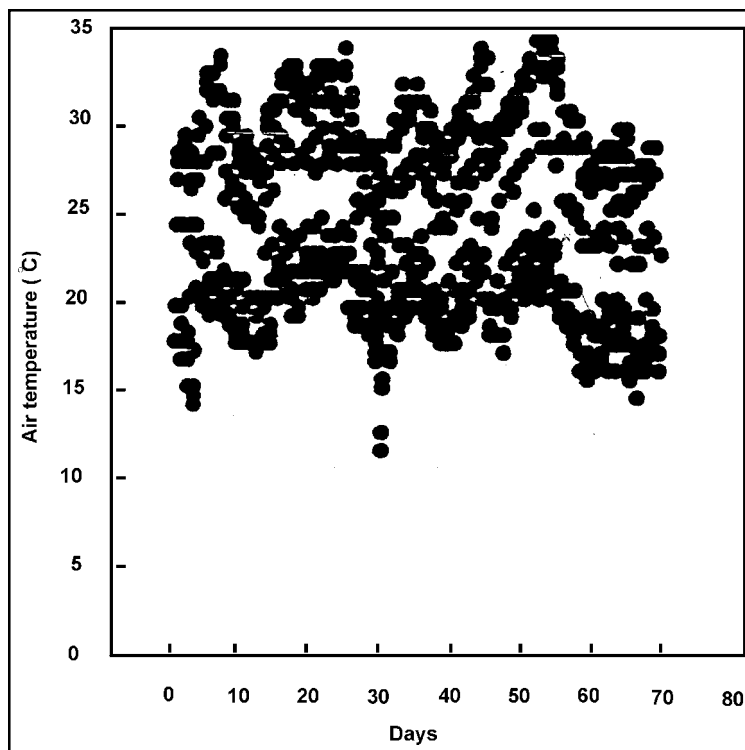


Figure 8—Air temperature (°C) at 2-hour intervals, Darling Ridge, California.

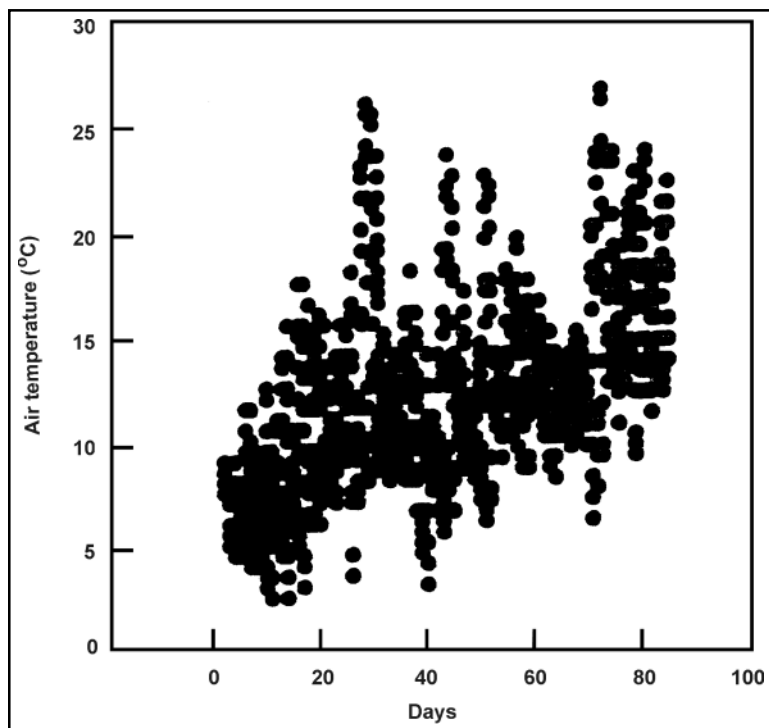


Figure 9—Air temperature (°C) at 2-hour intervals, Cooper Landing, Alaska.

## Release from Beads

There was no residual verbenone found in beads analyzed after 2 weeks in the field from either the Darling Ridge or Silver Forks sites. Either the active compound released completely from the bead during this period or degraded down to an inactive derivative. This is in contrast to the results obtained from an aerial application of verbenone beads in northwestern Montana (Shea and others 1992). In this study, more than half the verbenone was available for release from the beads after 2 weeks.

The seasonal decline in residual MCH in the beads for each of the six study sites was more variable than the MCH or verbenone bubble cap data, primarily because the initial concentration of MCH in the beads had a much higher variation than in the bubble caps (figs. 10, 11, and 12). The mean initial mass of MCH per bead was 0.835 mg + 0.181 mg at one standard deviation—the lowest amount observed was 0.384 mg and the highest was 1.16 mg. This large variation did not, however, mask the rapid initial decline in MCH content at all study sites. Figure 10 compares the warmest California site, Darling Ridge, with the Alaska Cooper Landing spruce site. In both cases, there was a rapid initial decline in the amount of MCH in the beads, followed by a constant amount of MCH. That is, the rapid initial decline was exponential in nature; the leveling off indicates there was no release after this rapid decline. The same dynamics occurred at the other study sites, with some variation in the decline rate and the amount of MCH remaining in the bead (figs. 11 and 12).

To help quantify these results, an exponential model has been fitted to the data. The lines in figures 10 through 12 are the fit of the model to the data. The model form is:

$$Y = A + B * \exp(-C * X) \quad (3)$$

where

Y = residual MCH in milligrams,

X = days after bead dispersion,

A, B, C, are estimated parameters,

A + B estimates the initial MCH in the beads (mg),

A estimates the residual MCH after the rapid initial decline (mg), and B and C determine the release rate; B is the scaling parameter (mg), and C is the exponential parameter (per day).

This model form appears to adequately represent the MCH residual dynamics for all six study sites. Table 2 is a summary of the estimated parameters for each site.

The exponential parameters, which are indicators of the initial decline rate, are the most negative for the warm California sites, Darling Ridge and Silver Forks, thereby indicating the most rapid rate of loss. The remaining four sites have loss parameters that are nearly equal. These four sites, Enterprise, Santiam Pass, Seward, and Cooper Landing, had litter layer temperatures considerably below those at the California sites (table 1).

The initial amount of MCH in the beads was measured directly at the beginning of each experiment and is reflected in the model by the sum of the constant (A) and scaling (B) parameters. This sum has only the variation found inherent in the MCH content of beads provided by the manufacturer.

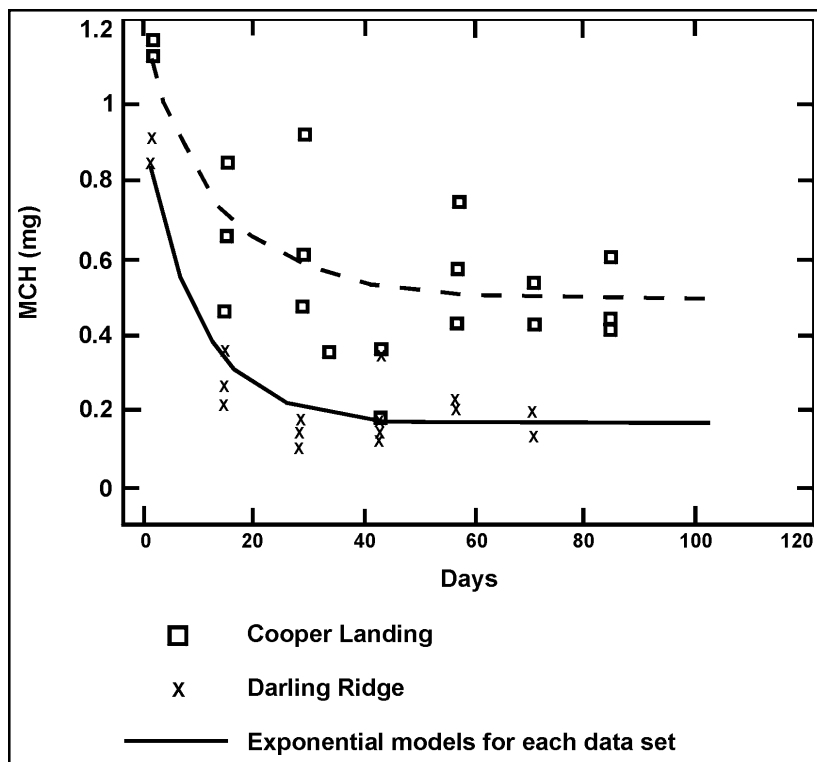


Figure 10—Depletion of MCH from beads from Darling Ridge, California, and Cooper Landing, Alaska, for 100 days.

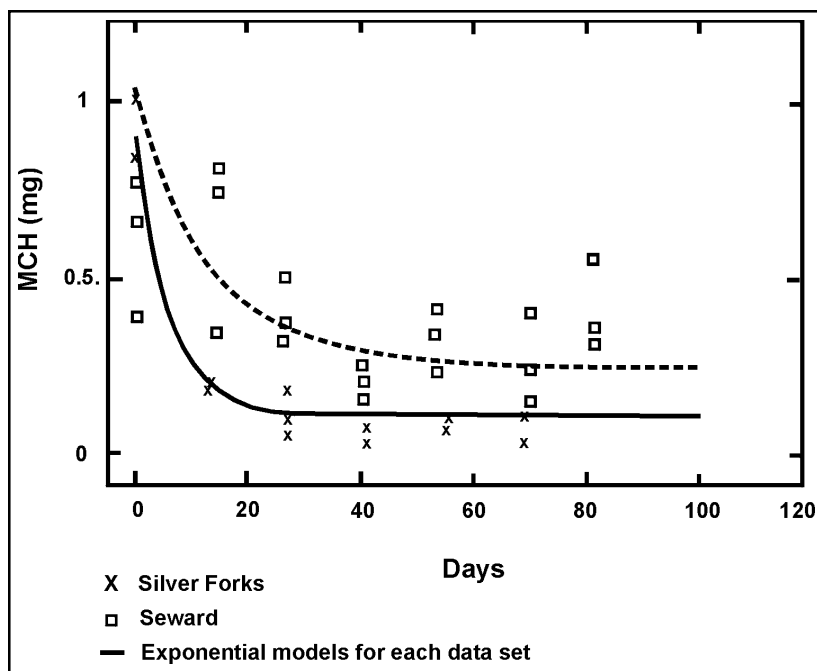


Figure 11—Depletion of MCH from beads from Silver Forks, California, and Seward, Alaska, for 100 days.



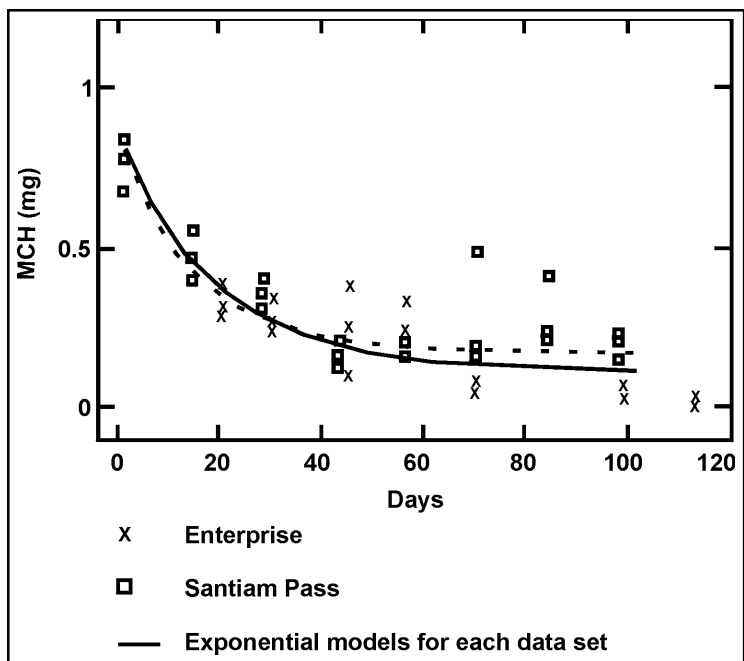


Figure 12—Depletion of MCH from beads from Enterprise and Santiam Pass, Oregon.

Table 2—Parameters<sup>a</sup> from models of residual MCH in beads

Site	Residual MCH (mg)	Scaling (mg)	Exponential (per day)
	A	B	C
Darling Ridge, CA	0.17	0.70	0.10
Silver Forks, CA	.10	.80	.15
Enterprise, OR	.12	.70	.05
Santiam Pass, OR	.18	.65	.065
Seward, AK	.25	.8	.07
Cooper Landing, AK	.5	.6	.07

<sup>a</sup> A estimates the residual MCH after the rapid initial decline (mg); B is the scaling parameter (mg); and C is the exponential parameter (per day).

The constant parameter (A) estimates the residual MCH found in the beads after the rapid initial decline; after this amount was reached, the data suggest there was no further release. The sites in California and Oregon had similar amounts, whereas the Alaska sites had higher amounts. The Cooper Landing spruce site showed high residual, 0.5 mg, which is about 50 percent of the initial MCH in the beads, similar to previous findings in Alaska (Holsten and Werner 1985). For some reason, the total amount of MCH in the beads was not releasing, and this amount seemed somewhat temperature dependent—lower temperatures resulted in a higher amount of MCH not available for release. This conclusion should be considered preliminary because there is considerable variation in the data. With the bead and similar plastics, MCH is within a substrate composed of a framework of interlocking polymer molecules that expand in higher temperatures and contract at lower temperatures. The beads are loaded by heating them in the lab and then soaking or spraying them with MCH<sup>3</sup>. This would be consistent with the high variation noted in the pheromone load of the beads and the higher retention of residual MCH in colder environments. Thus the short-term release of a pheromone from beads followed by no release may be a function of the initial amount of pheromone on the bead surface and not from the polymer matrix.

In analyzing the effect of temperature on release rate of beads, it was apparent that only the litter layer temperatures during the first 20 days were controlling the release of MCH. The average litter layer temperature for each site for the first 20 days of each study is presented in table 3. (See table 1 for the appropriate calendar period). To estimate release rates for this 20-day period, the original model (equation 3) is modified by taking the first derivative. The result is a variable release rate for each site with the highest rates occurring immediately after the beads have been dispersed. The release rate then declines in an exponential fashion. In quantitative terms, beads released MCH proportional to the amount of MCH in the bead—as the amount of MCH in the bead declined, the release rate declined. Rates, calculated for 50 percent of total MCH released, were between 0.01 and 0.04 mg MCH per day. There was a positive temperature effect between the release rate relative to average litter layer temperature (table 3), but the relation was marginal; the correlation coefficient was 0.6 (fig. 13). Higher temperatures resulted in higher release rates, with an increase in release rate of 0.0008 mg per degree.

This study revealed that beads release their contents only during the first 2 to 3 weeks following their dispersal, and this may, or may not, coincide with bark beetle flight. Figures 14 to 16 show the period of active beetle flight for Seward, Cooper Landing, and Enterprise. Insect activity periods are defined as those periods when the air temperature is above 16 °C (these periods are indexed as 1 in figs. 14 through 16). For the Alaska sites, the index indicated no bark beetle activity for the first 10 days, whereas at Santiam Pass, there were periods during most days when temperatures exceeded 16 °C. (Enterprise, Darling Ridge, and Silver Forks were similar to Santiam Pass.) For the Alaska sites, it seemed that the period of the most rapid release of MCH from the beads probably would not have coincided with bark beetle flight. At the other sites, the beads could only be potentially effective for short periods after dispersion.

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<sup>3</sup> Daterman, Gary. 2001. Personal communication. Entomologist, Pacific Northwest Research Station, Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331.

**Table 3—Mean litter layer temperatures for 20 days after bead dispersion**

Site	Temperature
	<i>Degrees centigrade</i>
Darling Ridge, CA	21.2
Silver Forks, CA	15.2
Santiam Pass, OR	9.3
Enterprise, OR	7.1
Seward, AK	4.5
Cooper Landing, AK	5.6

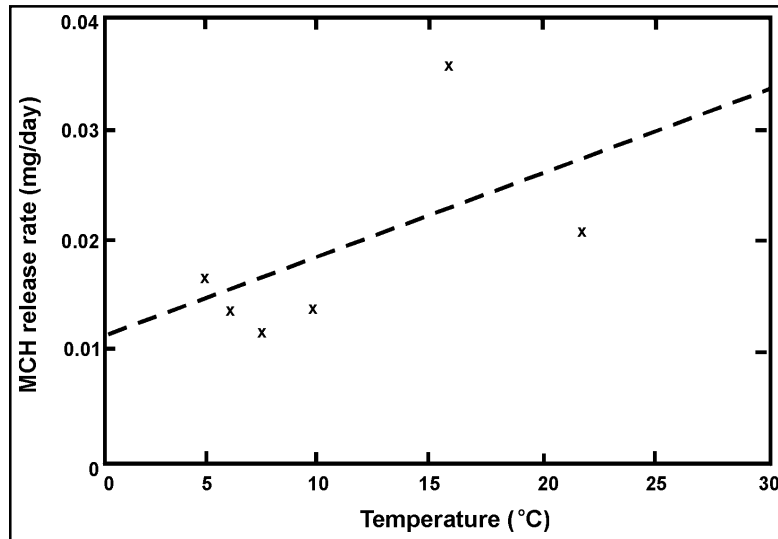


Figure 13—Release rate from beads related to average litter layer temperature (°C) for first 20 days after the beads were dispersed.

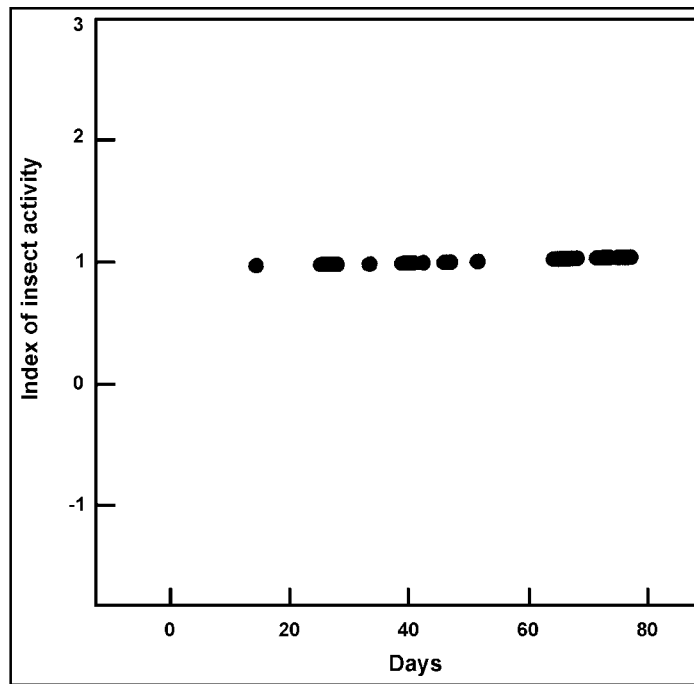


Figure 14—Estimated periods of insect activity at Seward, Alaska, related to the number of days after beads were distributed. Values of 1 are periods of temperature greater than 16 °C.

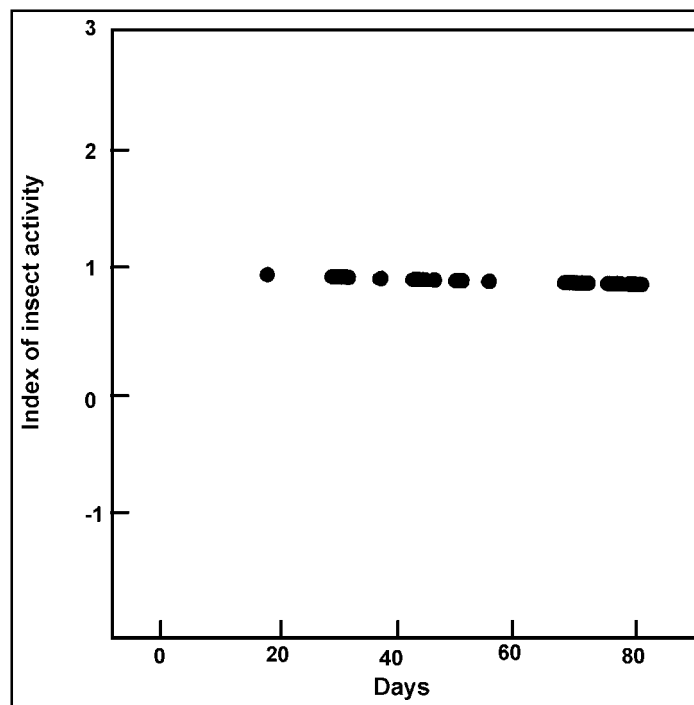


Figure 15—Estimated periods of insect activity at Cooper Landing, Alaska, related to the number of days after beads were distributed. Values of 1 are periods of temperature greater than 16 °C.

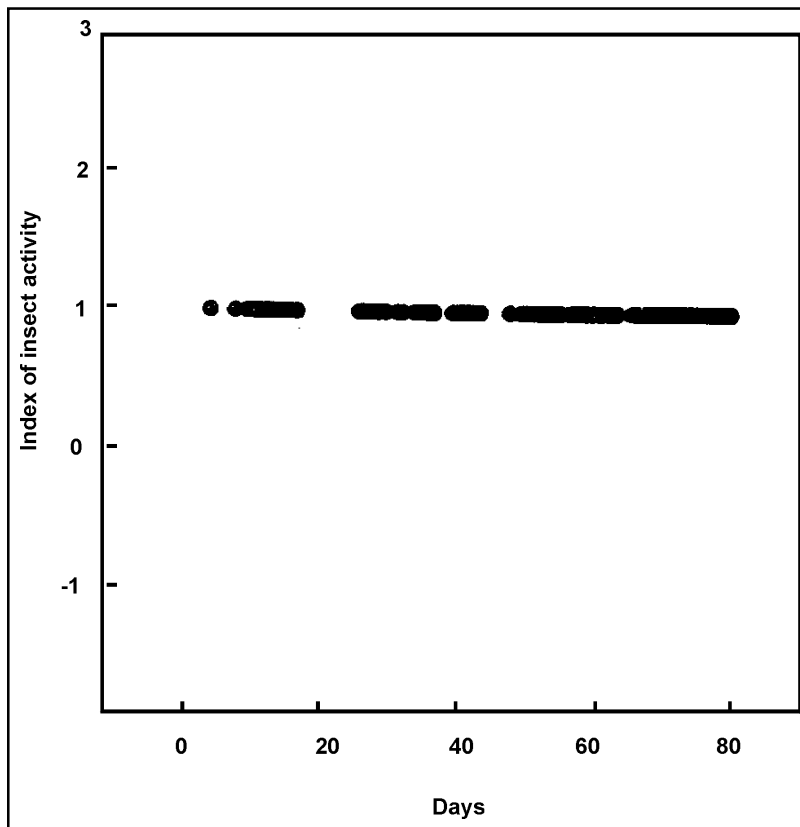


Figure 16—Estimated periods of insect activity at Santiam Pass, Oregon, related to the number of days after beads were dispersed. Values of 1 are periods of temperature greater than 16 °C.

## Conclusions

The results of this study demonstrated that the release rates of MCH and verbenone bubble cap releasers are controlled by temperature and will vary significantly from warm sites to cool sites. Release rates from bubble caps were likely controlled by the membrane composition and thickness, along with internal vapor pressure. The latter was strongly correlated with ambient air temperature. The MCH and verbenone beads released their contents only during the first 2 to 3 weeks after their dispersal, regardless of the study location. To be effective, it is important that MCH and verbenone be in the atmosphere during beetle flight. Thus, more than one application of MCH or verbenone beads may be needed if the beetle flight period lasts more than 2 weeks. The results of this study demonstrate the importance of determining field release rates of pheromone dispensers. Limited understanding of field release rates will lead to inconclusive results and confusion in pheromone field tests that rely on these chemicals for pest management strategies.

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## English Equivalents

When you know:	Multiply by:	To find:
Celsius (°C)	1.8 and add 32	Fahrenheit
Centimeters (cm)	2.54	Inches
Hectares (ha)	2.47	Acres
Kilometers (km)	0.621	Miles
Meters (m)	3.281	Feet
Square meters (m <sup>2</sup> )	1.20	Square yards
Millimeters (mm)	0.254	Inches

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## Appendix

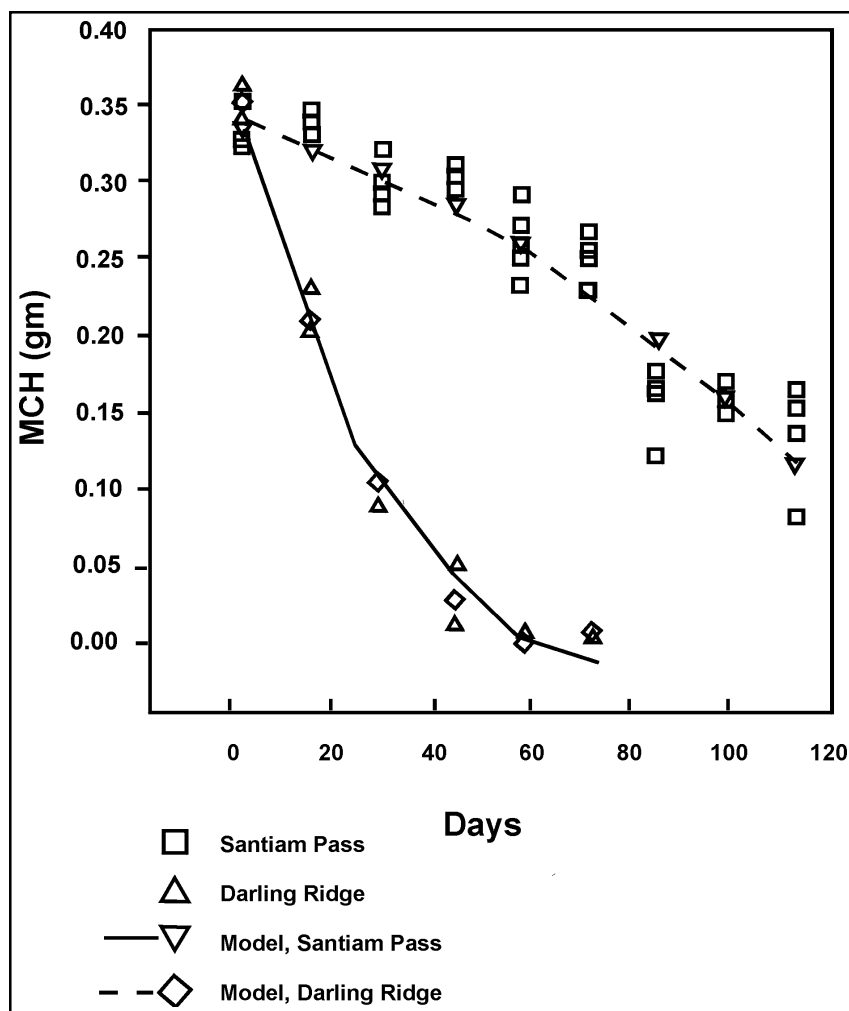


Figure 17—Two examples of data variation for MCH bubble cap release rates. Sites are Darling Ridge, California, and Santiam Pass, Oregon. Lines are model fit to the data.



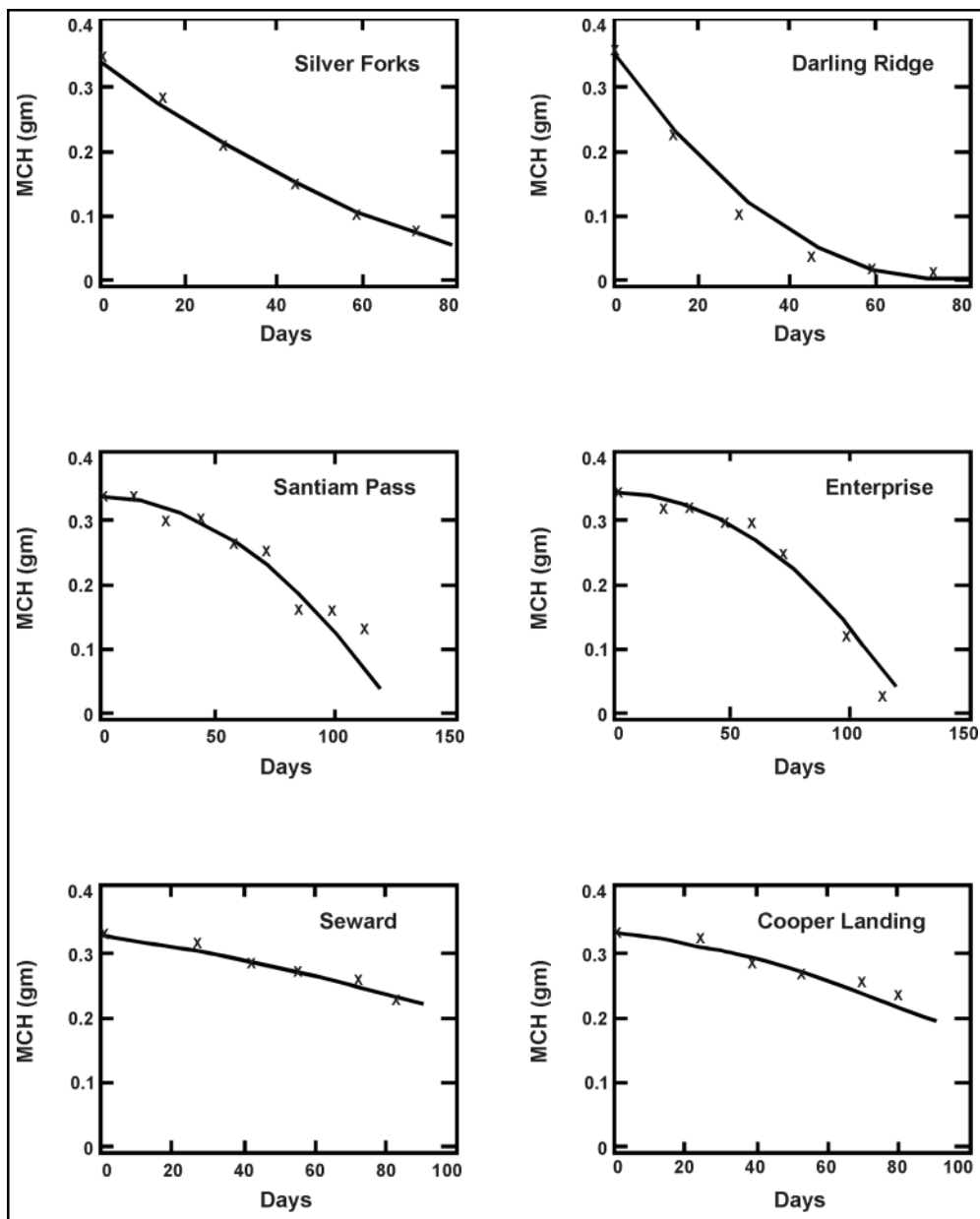


Figure 18—Comparison of MCH residue data in bubble caps and model fit for each of the six field sites.

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