Effect of sex pheromone and kairomone lures on catches of codling moth

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ABSTRACT

Field studies were conducted in sex pheromone-treated apple orchards to evaluate the performance of a clear 0.11 m^2 vertical interception trap coated with oil and baited with either (*E,E*)-8-10-dodecadien-1-ol (codlemone), ethyl (*E, Z*)-2,4-decadienoate (pear ester), or both attractants (combo) for adult codling moth, *Cydia pomonella* (L.). Interception traps baited with codlemone or pear ester caught significantly more males only or both sexes than unbaited traps, respectively. Interception and delta traps baited with codlemone caught similar numbers of males. Interception traps baited with pear ester caught up to 8-fold more males and 30-fold more females than similarly baited delta traps, respectively. Seasonal catches of females did not differ between light and pear ester-baited interception traps. Delta traps caught significantly more males, fewer females, and a similar number of total moths as the interception trap when both were baited with the combo lure. These data suggest that new clear trap designs can be developed to increase catches of female codling moth which may enhance seasonal monitoring and establish more useful predictive population models.

Key Words: apple, *Cydia pomonella*, traps, colour, monitoring

INTRODUCTION

Passive interception traps constructed of clear plastic, coated with an oil film, and hung vertical in the canopy were developed to study the behaviors of male and female codling moths *Cydia pomonella* (L.), in orchards treated with sex pheromone (Weissling and Knight 1994). While, moth catches on individual interception traps were not comparable to either sex pheromone-baited or light traps, two of the key attributes of these passive traps were the capture of nearly equal numbers of each sex and in providing an unbiased estimate of the proportion of mated females (Knight 2000). Passive interception traps have been used to experimentally demonstrate the occurrence of mating delay (Knight 1997) and to estimate the level of mating in sex pheromone-treated orchards (Knight 2006). These traps have also been used to study the distribution of moths within an orchard canopy (Weissling and Knight 1995) and to examine patterns of adult movement into sex pheromone-treated orchards (Knight 2007a). In addition to their use as a research tool, passive interception traps have been evaluated as monitoring aides to predict the seasonal phenology of female codling moth (Knight 2000). Their use demonstrated that female versus male moth captures can improve the prediction of the start of egg hatch and were more closely correlated with levels of fruit injury at both mid-season and prior to harvest.

Yet, despite these many benefits derived from using interception traps to monitor codling moth, a number of drawbacks have limited their adoption by growers; such as their relatively low moth capture rate compared with sex pheromone-baited traps, their non-specificity, the short useful life of the oil coating, especially during hot or wet periods, and an overall greater level of difficulty and higher cost of servicing these

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traps versus the standard plastic or cardboard traps. Alternative trap and lure designs that could alleviate some of these issues could enhance the benefits provided to growers from monitoring female codling moths within their orchards. One approach may be to use the bisexual attractant, ethyl (*E, Z*)-2, 4-decadienoate (pear ester) to further increase the catch of female moths on interception traps. Capture of female codling moth in delta traps baited with pear ester have been reported to improve prediction of first egg hatch and result in more accurate action thresholds (Knight and Light 2005a, b). However, the performance of pear ester relative to codlemone with standard traps has been inconsistent across a number of geographical regions with a broad range in its attractiveness for females reported (Ioriatti et al. 2003, Thwaite et al. 2004, Il`ichev 2004, Trimble and El-Sayed 2005, Kutinkova et al. 2005, Mitchell et al. 2008).

Growers within the western United States have widely adopted a lure (combo lure) loaded with both pear ester and (*E,E*)-8-10-dodecadien-1-ol (codlemone) because of its higher male and total moth catch than codlemone lures (Knight et al. 2005). Unfortunately, the combo lure catches a low proportion of female moths and few pest managers have been willing to identify the sex of trapped moths (Hawkins 2008). Thus, the full potential value of utilizing pear ester to monitor female codling moth has not been realized. Studies are reported here that evaluated the effectiveness of baiting interception traps with codlemone, pear ester, or both attractants. Results suggest that opportunities exist with codling moth to develop more efficacious monitoring systems that include adult female densities.

MATERIALS AND METHODS

General methods. Studies were conducted in 2003 and 2006 in a 20-ha commercial apple orchard, *Malus domestica* (Borkhausen) situated near Moxee, WA (46° 33’ N, 120° 23’ W). This orchard was a mixed planting of ‘Delicious’ and ‘Golden Delicious’ with a 4.0 – 4.5 m canopy height, and a 4.8 x 5.5 m (tree x row) spacing. The orchard was certified organic and no supplemental insecticide sprays were applied during either season, except for the use of 2 – 6 applications of 1.0% horticultural oil (Orchex 796, Exxon, Houston, TX). The orchard was treated with 500 – 1,000 Isomate™ C-Plus dispensers ha $^{-1}$ loaded as per label with 182 mg of a 53:30:6 blend of codlemone, dodecanol, and tetradecanol (Pacific Biocontrol, Vancouver, WA).

Interception traps (0.33 x 0.33 m) were cut from rolls of 0.25 mm semi-rigid UV-stabilized film (#10SR36150, W. J. Dennis Co., Elgin, IL). A 0.5 x 2.0 cm slit was cut in the top center of each trap 1.5 cm from the edge. A 17.0 cm piece of 1.4-cm wide yellow tie-strapping (Postal Products Unlimited, Milwaukie, WI) was threaded through this slit and used to attach each trap to an orange plastic clip (Suterra LLC, Bend, OR). Traps were coated with oil (STP Oil Treatment, STP, Fort Lauderdale, FL) using a standard paint roller (smooth texture). Interception traps were replaced every 3-7 d during studies. Interception traps were baited with proprietary codlemone, pear ester, or pear ester and codlemone lures provided by manufacturers. Septa were attached to interception traps by piercing lures with a standard paper clip and hooking the clip to the yellow strapping ca. 1-4 cm above the center top edge of the trap. The membrane lure was attached to the strapping with an adhesive pad provided on the back surface of the lure. White delta-shaped traps (28.5 x 20.0 cm) with sticky inserts (17.0 x 17.0 cm) were included in these studies for comparison (Trécé Inc., Adair, OR). Sticky liners were replaced either weekly or up to a 4-wk interval depending on their condition. Lures were replaced after 8 wks during the two seasonal studies in 2003 and 2006. All traps were placed in the upper third of the canopy, ca. 3-m. Interception traps were clipped with the use of a pole to small branches, while delta traps were attached to a 1.3 m schedule 40 pvc pipe (Knight et al. 2006). Traps within each study were evenly randomized and spaced 15 – 30 m apart in a grid. Moths were removed from traps in the field and sexed with the aid of a microscope in the laboratory.

Baiting interception traps. Two tests were conducted to evaluate the attractiveness of interception traps baited with codlemone during 2003. The first test was conducted from 10 – 18 July with a red rubber septum loaded with 10.0 mg codlemone (Pherocon® CM 10X, Trécé Inc.). The baited delta-shaped trap was replicated 6-times and 10 replicates of baited and unbaited interception traps were included. In addition, six unbaited delta traps were included in the study, but none of these traps caught any moths and these data were not included in the analysis. Delta trap liners and interception traps were replaced on 15 July. A second study was conducted from 19 – 29 July using a proprietary plastic membrane lure (Biolure® 10X, Suterra LLC, Bend, OR). Baited delta traps were replicated nine times and 15 baited and unbaited interception traps were included. Delta trap liners and interception traps were replaced on 22 July.

Seasonal evaluation, 2003. A portion of the orchard was subdivided into eight 100 x 100 m replicate blocks. Five baited (pear ester) and unbaited interception traps, one baited (pear ester) delta-shaped trap, and one light trap (6 W blacklight bulb) baited with Dichlorvos (18.6% active ingredient, No-pest Strip™, United Industries, St. Louis, MO) were randomly placed in a grid with a 25 x 25 m spacing within each block. The study was initiated on 13 June and all traps were checked 21 times (2-7 d intervals) until 29 August. Data were summarized across dates based on the accumulation of degree days (lower threshold of 10 ^{o}C) from first moth flight (5 May) to the completion of the first (456 degree days) and second moth flight (1044 degree days) (Knight 2007b). Moth catch recorded after 10 July was included in the second flight period.

Seasonal evaluation, 2006. The orchard was divided into six 100 x 100 m blocks. Unbaited interception traps and interception and delta-shaped traps baited with either pear ester or the combo lure were compared. One delta-shaped trap with each lure and three interception traps of each type were placed within each block in a grid with a 30 x 30 m spacing. Traps were initially placed in orchards on 13 June and checked 20 times during the season. Cumulative moth counts for each flight were based on the accumulation of degree days from the start of moth flight (4 May). Moth catch after 6 July was included in the second flight.

Statistical analysis. The mean moth catches from each group of interception traps placed within each block (5 traps per block in 2003 and 3 traps per block in 2006) were calculated and used in the subsequent comparison with other trap types. Count data were transformed with a square root transformation and proportional data with the angular transformation to stabilize variances (Snedecor and Cochran 1967). Analysis of variance (ANOVA) was used to compare the main treatment effect for the various trap and lure combinations (Analytical Software 2003). Tukey's method was used to detect significant ($P < 0.05$) pair-wise comparisons within significant ANOVA's.

RESULTS

Baiting interception traps. Significant differences in catches of both sexes and total numbers of moths occurred among the three trap-lure combinations in tests with two different codlemone lures (Table 1). Codlemone-baited delta and interception traps caught similar numbers of male and total moths. Both traps caught significantly more male and total moths than the unbaited interception trap. The baited and

Table 1.
Comparison of mean (SE) codling moth catches in (2003) unbaited and baited interception and baited delta traps using high-load codlemone lures.

		Mean (SE) moth catch per d[1]		
Lure	Trap	Male	Female	Total
Red septa	Baited delta	5.8 (0.5)a	0.0 (0.0)b	5.8 (0.5)a
	Unbaited interception	1.4 (0.3)b	1.0 (0.1)a	2.4 (0.3)b
	Baited interception	5.6 (1.7)a	0.9 (0.1)a	6.5 (1.7)a
	ANOVA: df = 2,23	$F = 8.75$, $P < 0.01$	$F = 111.5$ $P < 0.0001$	$F = 6.62$, $P < 0.01$
Membrane	Baited delta	4.8 (0.4)a	0.02 (0.01)b	4.8 (0.4)a
	Unbaited interception	0.5 (0.1)b	1.1 (0.2)a	1.6 (0.3)b
	Baited interception	3.4 (0.9)a	0.7 (0.2)a	4.1 (1.1)a
	ANOVA: df = 2,36	$F = 33.7$ $P < 0.0001$	$F = 24.2$ $P < 0.0001$	$F = 10.5$ $P < 0.001$

[1] Column means for each lure followed by a different letter were significantly different, $P < 0.05$, Tukey's.

unbaited interception traps caught significantly more females than the baited delta trap. Results were similar in tests using either a rubber septum or membrane lure (Table 1).

Seasonal evaluation, 2003. Significant differences in the cumulative male, female, and total moth catches during each moth flight occurred among four trap-lure combinations (Table 2). Light traps caught significantly more male and total numbers of codling moth than interception and delta traps baited with pear ester and unbaited interception traps. Pear ester-baited interception and light traps caught similar numbers of females. The baited interception traps caught significantly more female and total moths than the pear ester-baited delta traps. The unbaited interception trap caught significantly more moths than the delta trap during the first but not the second flight. The interception traps baited with and without pear ester caught similar numbers of male moths in the first flight but the baited trap caught significantly more female and total moths in the second flight. The proportion of females caught by the different lure-trap combinations varied significantly, $F_{3, 28} = 3.45$, $P < 0.05$. The light trap caught a significantly lower proportion of female moths than the baited interception trap over the entire season. The unbaited interception and delta traps caught an intermediate proportion of female moths.

Seasonal evaluation, 2006. Significant differences in the catches of male, female, and total codling moths occurred between unbaited interception and interception and delta traps baited with either pear ester or the combo lure during both flights in 2006 (Table 3). The combo-baited delta trap caught significantly more male moths than all other trap types during both flights. The other four traps did not differ during the first moth flight in male moth captures. However, during the second moth flight the baited interception traps caught significantly more males than the unbaited interception and the pear ester-baited delta traps. The unbaited interception trap also caught significantly more male moths than the pear ester-baited delta trap.

The baited interception traps caught significantly more female codling moth than the baited delta traps during both flights (Table 3). The unbaited interception trap caught similar numbers of female moths as the pear ester-baited interception

Table 2.
Comparison of seasonal codling moth catches (2003) in interception and delta traps baited with pear ester and unbaited interception and light traps, n = 8.

	Cumulative mean (SE) moth catch per trap[1]					
	1st moth flight			2nd moth flight		
Lure - trap	Male	Female	Total	Male	Female	Total
Unbaited interception	15.8 (1.9)b	10.8 (1.5)a	26.5 (2.5)b	74.4 (6.30bc	44.4 (5.9)b	118.8 (7.9)bc
Baited interception	18.1 (1.3)b	19.9 (2.5)a	38.0 (2.7)b	159.1 (5.6)b	128.9 (15.3)a	288.0 (16.6)b
Baited delta	1.9 (1.0)c	0.8 (0.4)b	2.6 (0.9)c	21.0 (4.4)c	16.3 (4.5)b	37.3 (8.5)c
Unbaited light	71.6 (13.3)a	27.1 (8.1)a	98.8 (18.6)a	526.1 (138.9)a	172.1 (43.7)a	698.3 (179.0)a
ANOVA: df = 3,28	$F = 33.8$ $P < 0.0001$	$F = 16.9$ $P < 0.001$	$F = 34.2$ $P < 0.0001$	$F = 22.4$ $P < 0.0001$	$F = 17.8$ $P < 0.0001$	$F = 22.4$ $P < 0.0001$

[1] Column means followed by a different letter were significantly different, P < 0.05, Tukey's .

Table 3.
Comparison of seasonal moth catches (2006) in unbaited interception and baited interception and delta traps with pear ester and pear ester + codlemone (combo) lures, n = 6.

	Cumulative mean (SE) moth catch per trap[1]					
	1st moth flight			2nd moth flight		
Lure - trap	Male	Female	Total	Male	Female	Total
Unbaited interception	0.6 (0.2)b	0.8 (0.2)bc	1.3 (0.3)bc	9.0 (1.2)c	6.1 (0.8)b	15.1 (1.9)b
Pear ester-baited interception	1.0 (0.2)b	1.6 (0.4)ab	2.7 (0.5)ab	17.5 (1.7)b	27.4 (2.8)a	44.9 (4.2)a
Combo-baited interception	1.3 (0.3)b	1.8 (0.4)a	3.2 (0.6)ab	17.9 (1.7)b	23.5 (2.5)a	41.4 (4.0)a
Pear ester-baited delta	0.0 (0.0)b	0.2 (0.2)c	0.2 (0.2)c	2.0 (0.7)d	0.8 (0.5)c	2.8 (0.9)c
Combo-baited delta	7.5 (2.3)a	0.2 (0.2)c	7.7 (2.4)a	32.7 (6.5)a	3.7 (1.1)c	36.3 (7.5)a
ANOVA: df = 4,25	$F = 9.06$ $P < 0.0001$	$F = 5.27$ $P < 0.001$	$F = 9.01$ $P < 0.0001$	$F = 23.2$ $P < 0.0001$	$F = 45.0$ $P < 0.0001$	$F = 30.2$, $P < 0.0001$

[1] Column means followed by a different letter were significantly different, $P < 0.05$, Tukey's.

and both delta traps during the first moth flight. The unbaited interception trap caught significantly more female moths than either delta trap during the second flight.

The combo-baited delta trap caught similar numbers of total moths as the baited interception traps in both moth flights. The pear ester-baited delta caught significantly fewer total moths than these three traps during both moth flights. The unbaited interception traps caught an intermediate number of total moths: fewer moths than the combo-baited delta in the first flight and fewer moths than the baited interception and the combo-baited delta, but significantly more moths than the pear ester-baited delta in the second flight. The proportion of females caught by the different lure-trap combinations varied significantly, $F_{4,24}$ = 4.56, P < 0.01. The combo-baited delta trap caught a significantly lower proportion of female moths than either of the baited interception trap during 2006. The unbaited interception and pear ester-baited delta traps caught an intermediate proportion of female moths.

DISCUSSION

The clear, oil-coated unbaited interception trap has proved to be an effective tool to monitor the mating status of female codling moths and the density, distribution, and movement of both sexes in experimental orchards (Weissling and Knight 1994, 1997; Knight 1997, 2000, 2006, 2007a). Studies reported here demonstrate that baiting the interception trap with codlemone can increase male catches to levels comparable to standard delta traps and with the use of pear ester creates a more effective trap than the delta for monitoring female codling moth. Further studies with the interception trap should evaluate the use of the more potent, acetic acid and pear ester combination lure (Landolt et al. 2007).

Trap effectiveness is strongly influenced by the anemotactic flight and close-range behaviors of adult moths to both the lure and the physical structure of the trap (Foster and Muggleston 1993). Trap reflectance and moth vision appear to be critical factors influencing the capture of male codling moths in traps of various colours (Knight and Miliczky 2003, Knight and Fisher 2006). Multiple field observations of adult codling moth inside screened cages suggest that both sexes fly accidently into the clear interception trap while moving within and through tree canopies (unpubl. data). Surprisingly, an unbaited interception trap caught significantly more total moths than a delta trap baited with pear ester.

Flight tunnel studies have revealed that a significant proportion of male codling moths orienting to codlemone lures placed inside of various white sticky traps land on the outside of the trap first, walk inside, and then become stuck (Knight et al. 2002). Switching from white to orange-colour traps increased male moth catches in the field, and flight tunnel assays suggested this was primarily caused by increasing the proportion of males that flew directly inside the orange versus white trap, especially under low light conditions (Knight and Fisher 2006). Interestingly this difference in moth behavior between trap colours became greater as the light level was increased. This may reflect the male's response period to both codlemone and pear ester occurring primarily during scotophase (Knight and Light 2005c).

Female codling moths respond to trap colour differently than males. For example, orange and white delta traps baited with pear ester had similar catches of females in both field and flight tunnel experiments (Knight and Fisher 2006). While, direct observations of female's orientation and contact with pear ester-baited delta traps have not been reported, the diurnal response of females to pear ester-baited traps begins in the late afternoon and occurs on average earlier than the response of males (Knight and Light 2005c), and coincides with the peak timing of oviposition, 1800 – 2200 h (Riedl and Loher 1980). Thus, trap's reflectance over the UV or visible spectrum may be a more critical factor affecting female than male capture on interception traps.

The relatively high cost of maintaining interception traps likely will continue to interfere with grower adoption despite the enhanced benefits which can be derived from monitoring female codling moth. Reducing the size of traps and placing them lower in the canopy would improve their handling and servicing but would also significantly reduce moth catches (Ioriatti et al. 2003, Knight and Light 2005c). One alternative that should be explored is the use of clear delta traps. The operational advantages of a clear delta versus interception trap are that its profile is smaller so that traps can more easily be placed in the canopy and fewer non-target insects are caught, and that the sticky liner is placed horizontally inside the trap so the coating does not run off and is protected from precipitation. Clear delta traps with clear liners are available from at least one supplier in Europe (PRI, Wageningen, The Netherlands), but its use with pear ester for codling moth has not been reported. Studies are needed to assess whether a smaller horizontal sticky surface placed inside of a clear trap with a restricted opening would be as effective as the larger vertical surface of the interception trap.

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