Seasonal Flight Patterns of Codling Moth (Lepidoptera: Tortricidae) Monitored with Pear Ester and Codlemone-baited Traps in Sex Pheromone-Treated Apple Orchards

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ABSTRACT Traps baited with ethyl (*E*, *Z*)-2, 4-decadienoate (pear ester) or (*E*, *E*)-8,10-dodecadienol (codlemone) were used to monitor codling moth, *Cydia pomonella* L., (Lepidoptera: Tortricidae) in 102 apple, *Malus domestica* Borkhausen, orchards. All orchards were treated with 500–1,000 Isomate-C PLUS dispensers/ha during 2000–2002. Traps baited with pear ester caught their first moth significantly later on average than the paired codlemone-baited traps, but timing of peak moth catch during each moth flight coincided with both types of lures. The timing of first male moth capture in pear ester–baited traps was significantly earlier than the first female moth; and the percentage of male moths in the total numbers of moths captured ranged from 55 to 60% over the three seasons. The percentage of female moths caught by pear ester–baited traps that were mated exceeded 80% each year. Pear ester–baited traps caught similar numbers of moths as codlemone-baited traps during 2000. However, the density of sex pheromone dispensers per hectare was increased in most orchards in 2001–2002; and pear ester outperformed codlemone-baited traps in both years.

KEY WORDS *Cydia pomonella*, apple, monitoring, mating disruption

AN IMPORTANT PREREQUISITE FOR SUCCESSFUL management of codling moth, *Cydia pomonella* L. (Lepidoptera: Tortricidae), in apple, *Malus domestica* Borkhausen, has been the implementation of an intensive monitoring program (Vickers and Rothschild 1991). Male moth catch in traps baited with (*E*, *E*)-8,10-dodecadienol (codlemone) has been used to infer population density (Riedl and Croft 1974) and to predict timing of first egg hatch (Riedl et al. 1976). Careful monitoring of codling moth in orchards treated with sex pheromone mating disruption (MD) is critical because of the influence of moth density on the success of disruption and the potential for undetected moth immigration into treated orchards (Cardé and Minks 1995). Typically, high-dose codlemone lures and placement of traps higher in the canopy have been used to improve monitoring in MD orchards (Knight 1995). In addition, a higher density of traps has been recommended, i.e., one per hectare (Gut and Brunner 1996).

A pear-derived kairomone for codling moth (*E*, *Z*)-2,4-decadieonoate (pear ester) attracts both sexes of codling moth (Light et al. 2001). A gray halobutyl septum loaded with 3.0 mg pear ester placed in a standard sticky trap has in some cases been more attractive than high-dose codlemone lures for codling moth (Thwaite et al. 2004, Knight et al. 2005). However, a number of factors influence the performance of this kairomone in pome fruits, including crop, cultivar, application of sex pheromone dispensers, lure loading, trap size, occurrence of fruit injury, and trap placement within the canopy (Knight and Light 2005a). Efforts to standardize the use of pear ester to effectively monitor codling moth, similar to those successfully implemented to monitor codling moth with codlemone lures (Riedl et al. 1986), could likely accelerate the adoption of this attractant.

Here, we report the results of monitoring codling moth with pairs of traps baited with pear ester or codlemone lures in 102 apple orchards treated with sex pheromone dispensers during a 3-yr period. Seasonal differences were found in the response of codling moth to these two lures. Several factors associated with the implementation of pear ester–baited traps to monitor codling moth in sex pheromone–treated apple orchards are discussed.

Materials and Methods

Studies were conducted in 22, 50, and 30 apple orchards during 2000, 2001, and 2002, respectively. All orchards were situated within a 64-km^2 area near Brewster, WA (48° N, 119° W). Orchards were 8- to 16-ha and planted at 500–1,000 trees/ha, and tree heights ranged from 3.0 to 5.1 m. Orchards typically contained a mixture of cultivars, with the dominant

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Table 1. Summary of the dominant apple cultivars and the density of sex pheromone dispensers applied per hectare within apple orchards monitored during the 3-yr study

Year	Dispenser density/ha	No. orchards of each cultivar				
		Delicious	Golden Delicious	Gala	Fuji	Granny Smith
2000	500	10	1	0	1	10
2001	750–1,000	10	10	10	10	10
2002	750–1,000	0	0	10	10	10

cultivar comprising >75% of the area. The cultivar composition of the orchards monitored among the 3 yr of the study is shown in Table 1. All orchards were treated with Isomate-C PLUS dispensers (Pacific Biocontrol, Vancouver, WA) loaded with 182.3 mg of a 60:33:7 blend of (*E, E*)-8–10-dodecadien-1-ol, dodecanol, and tetradecanol. The density of dispensers applied to orchards varied among years (Table 1). Management of codling moth in most orchards was supplemented with one to three spray applications of the organophosphate insecticides (azinphosmethyl; Micro Flo Co., Memphis, TN and phosmet; Zeneca Ag Products, Wilmington, DE) or the insect growth regulator (IGR), methoxyfenozide (Dow AgroSciences, Indianapolis, IN). Insecticides were applied either to the entire orchard or only along borders.

Two plots separated by 150 m were established within each orchard. Two traps baited with either a high-load codlemone lure (Pherocon Megalure CM; Trécé, Adair, OK), or a pear ester lure (Pherocon CM-DA; Trécé) were placed in each plot spaced 50 m apart and 25 m from the physical edge of the orchard. Delta-shaped traps with removable sticky liners were used with both lures. Traps were attached to PVC poles and hung in the upper third of the canopy. Traps were placed in orchards on 26 April 2000, 3 May 2001, and 1 May 2002 and monitored for 18 wk until September. All traps were checked weekly except during week 9 in 2001 and the first week in 2002. Moths were removed from traps and sexed, and females were dissected to determine their mating status. Incidental nontargets such as large hymenopterans and dipterans and plant debris were removed from traps each week, and sticky trap liners were replaced every few weeks. Lures were replaced once during each season after 9 wk.

Moth catches for each lure type were summarized for the 9-wk first and second moth flights and for the entire 18-wk season. All count data were square root $[(x + 0.01)^{0.5}]$ transformed before conducting *t*-tests and analysis of variance (ANOVA) (Analytical Software 2000). Means were separated using a least significant difference (LSD) test when the ANOVA was significant at $P < 0.05$. Differences in the timing of first moth catch between codlemone- and pear ester–baited traps and differences in the timing of a trap's catch of the first male versus female moth in a pear ester–baited trap in 2000 and 2001 were compared with paired *t*-tests (Analytical Software 2000). Data on the timing of first moth catch were included in these analyses of lure types only from plots where both lure types caught moths and in plots where pear ester–baited traps caught both sexes. Data for timing of first moth catch were not analyzed for 2002 because traps were not checked the first week after placement in the field.

Results

Codlemone-baited traps caught their first moth significantly earlier (2.9 ± 0.4 wk) than pear ester–baited traps (4.2 ± 0.4 wk) in 2000 ($F_{1,73} = 4.89$, $P < 0.05$). Traps were placed in orchards 7 d later in 2001 than in 2000, and no significant difference in the timing of first moth catch was detected between the two lures ($F_{1,68} = 0.60$, $P = 0.44$). Male codling moths were caught significantly earlier than female moths in pear ester–baited traps in both 2000 (4.2 ± 0.4 versus 5.6 ± 0.5 wk, respectively; $F_{1,56} = 5.43$, $P < 0.05$) and 2001 (2.2 ± 0.3 versus 3.2 ± 0.3 wk, respectively; $F_{1,66} = 6.68$, $P < 0.05$).

Pear ester–baited and codlemone-baited traps tracked the two moth flights similarly during all three seasons (Figs. 1–3). In 2000, the peak in moth catch during the first moth flight was narrow and occurred during week 3, whereas peak moth capture during the second flight occurred from week 14 to 16 (Fig. 1A). Peak moth catch in 2001 and 2002 occurred over a 3-wk period. Moth catches in the second flight were very low after week 14 in 2001 (Fig. 2A), whereas a broad, relatively large second peak occurred in 2002 (Fig. 3A). The occurrence of peak moth catch during a flight was sometimes shifted later with the pear ester lure than with the sex pheromone lure, e.g., second flight in 2000 (Fig. 1A) and both flights in 2002 (Fig. 3A).

Mean moth catches per trap during the first flight in 2000 were significantly higher in codlemone- than pear ester–baited traps, but this was reversed in both 2001 and 2002 (Table 2). Mean moth catch in pear ester–baited traps did not vary during the first flight among the 3 yr of the study, but significant yearly differences occurred for the codlemone-baited traps. Significantly more moths were caught during 2000 than the other 2 yr, and catch was higher in 2002 than 2001.

Mean moth catch in pear ester–baited traps exceeded codlemone-baited traps during the second moth flight and over the entire season in both 2001 and 2002 but not in 2000 (Table 2). Moth catches with both lure types were significantly lower during the second flight in 2001 versus the other 2 yr. No difference occurred in total moth catch in pear ester–baited traps among years over the entire season but significant yearly differences occurred with codlemone-baited traps. Mean moth catch over the entire year in these traps was significantly higher in 2000 than the other 2 yr and catch in 2002 exceeded that in 2001 (Table 2).

Pear ester–baited traps caught significantly more males than females during the first flight in 2000 (Fig. 1B) and 2001 (Fig. 2B) and during the entire year in 2001 (Table 2). No differences occurred in mean moth

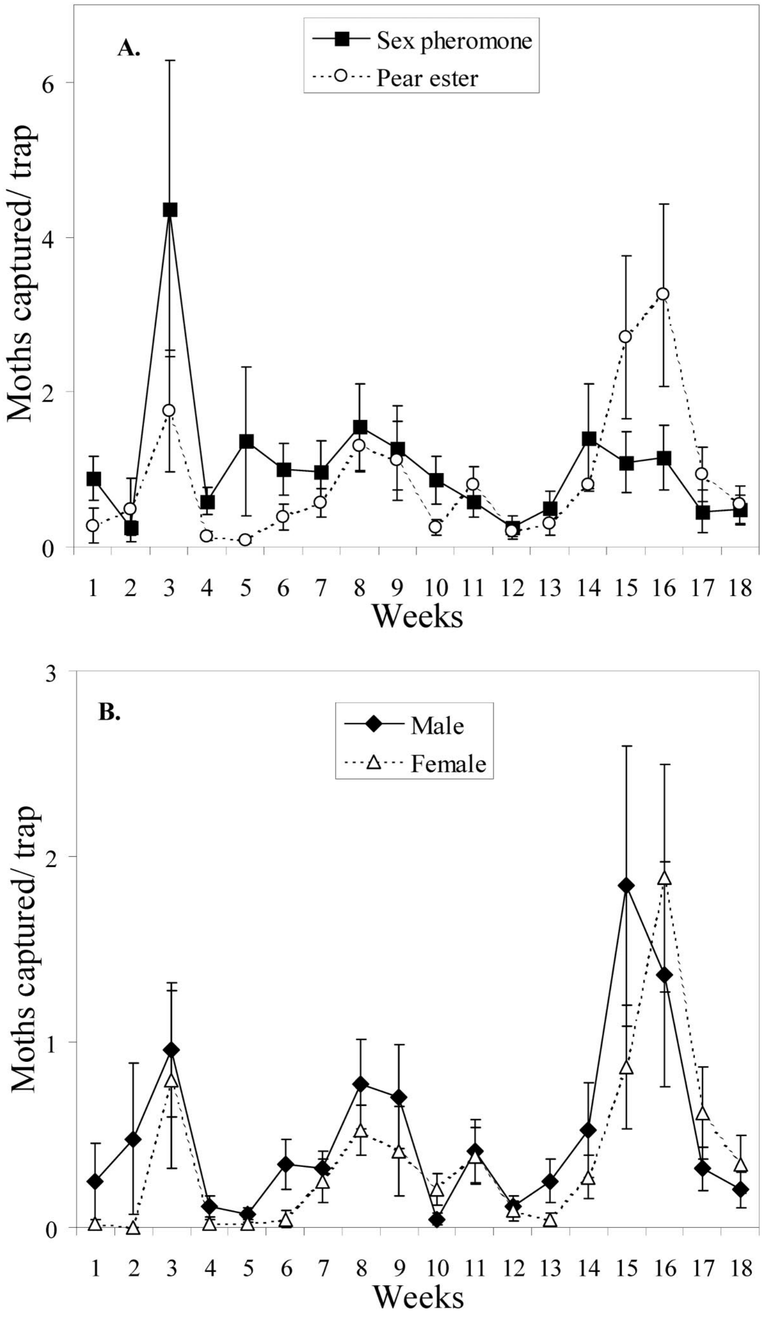

Fig. 1. Mean ± SE weekly catches of codling moth adults (A) in sex pheromone and pear ester–baited traps ($n = 44$) and catches of male and female moths (B) in pear ester–baited traps during 2000. Traps were placed in orchards on 26 April and checked weekly until 8 September.

catches between sexes in 2002 (Fig. 3B). Moth catch of both sexes were significantly lower in 2001 than 2000 or 2002 for the second moth flight, but no differences occurred during the first moth flight. Male moth catch over the entire season was not significantly different among years, and female moth catch was significantly different only between 2001 and 2002.

A high proportion of females trapped in pear ester-baited traps were mated throughout the season in all 3 yr (Fig. 4). Weekly levels of mating generally exceeded 0.80 except during weeks 7–11 in 2000, weeks 6 and 15 in 2001, and week 16 in 2002. These time periods coincided with either the end or the beginning of moth flights.

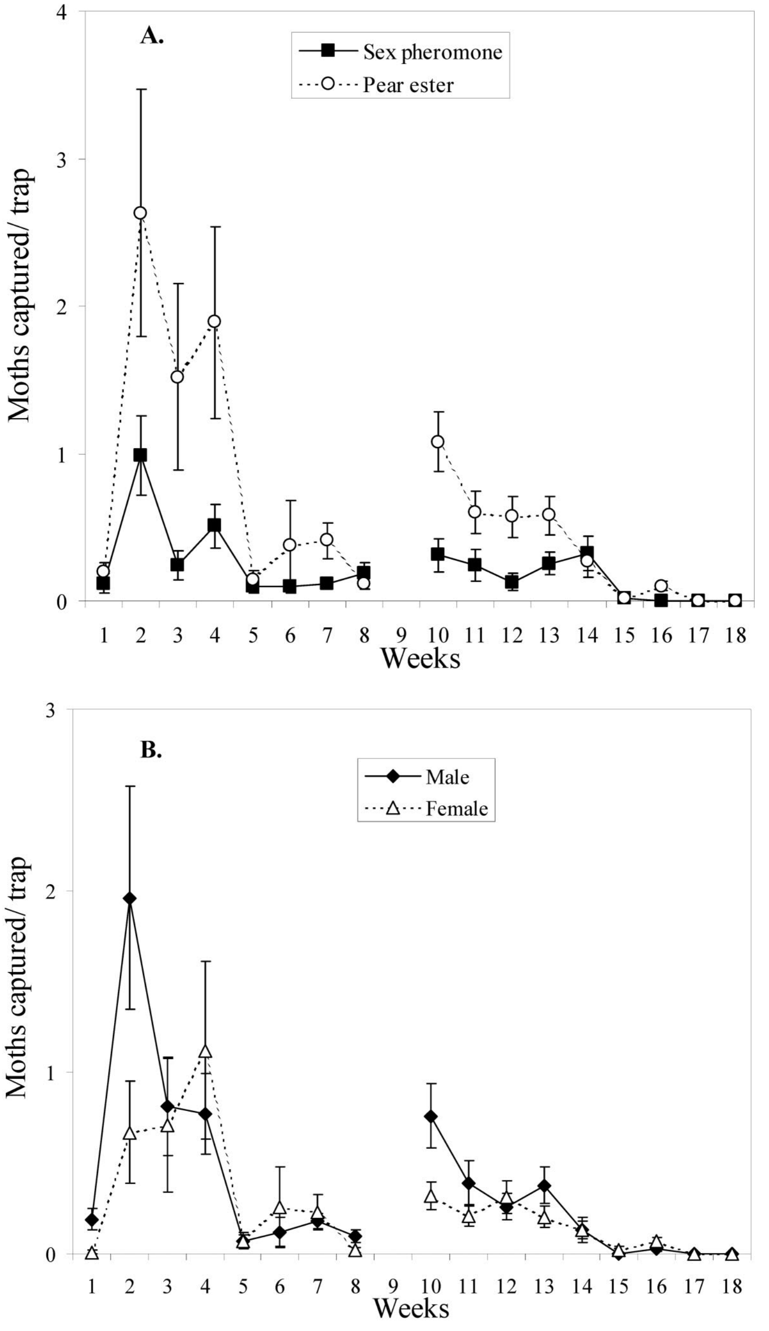

Fig. 2. Mean ± SE weekly catches of codling moth adults (A) in sex pheromone and pear ester–baited traps ($n = 100$) and catches of male and female moths (B) in pear ester–baited traps during 2001. Traps were placed in orchards on 1 May and checked weekly except for week 9 until 8 September.

Discussion

Pear ester is an effective lure for both sexes of codling moth and has outperformed high-load codlemone lures in walnut (Light et al. 2001), apple (Thwaite et al. 2004), and pear (Knight et al. 2005) orchards treated with sex pheromone dispensers. A similar pattern was found in our study comparing the Megalure CM and pear ester lures in both 2001 and 2002. We hypothesize that the higher moth catches in codlemone- versus pear ester–baited traps in the first moth flight in 2000 was caused by a lower sex pher-

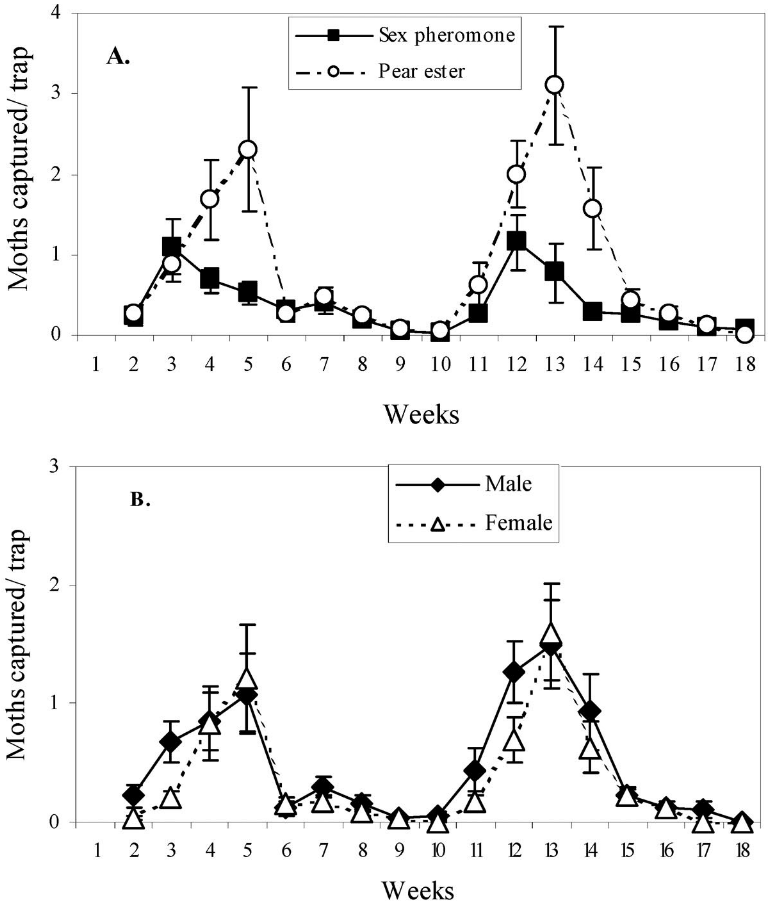

Fig. 3. Mean ± SE weekly catches of codling moth adults (A) in sex pheromone and pear ester–baited traps (n = 60) and catches of male and female moths (B) in pear ester–baited traps during 2002. Traps were placed in orchards on 1 May and checked weekly starting on 15 May until 3 September.

Table 2. Comparison of mean ± SE moth catches during first and second moth flights and over the entire season in traps baited with codlemone and pear ester lures

Year	No. moths per baited trap		Statistics[a]		No. moths per pear ester–baited trap		Statistics[b]	
	Pear ester	Codlemone	t	P	Male	Female	T	P
First flight								
2000	3.7 ± 1.1	9.7 ± 3.0a	3.06	<0.01	2.5 ± 0.7	1.3 ± 0.6	−2.57	<0.05
2001	6.8 ± 1.5	2.3 ± 0.5c	−3.35	<0.001	4.0 ± 0.8	2.7 ± 0.8	−2.23	<0.05
2002	6.1 ± 0.9	3.4 ± 0.7b	−2.02	<0.05	3.4 ± 0.5	2.7 ± 0.5	−1.15	0.25
ANOVA[b]	F = 1.15, P = 0.32	F = 19.3, P < 0.0001			F = 0.47, P = 0.63	F = 2.53, P = 0.08		
Second flight								
2000	9.5 ± 2.6a	5.8 ± 1.8a	−1.06	0.29	5.1 ± 1.6a	4.4 ± 1.1a	−0.07	0.94
2001	3.4 ± 0.5b	1.3 ± 0.3b	−4.70	<0.0001	2.1 ± 0.3b	1.3 ± 0.2b	−1.81	0.07
2002	8.0 ± 1.1a	3.1 ± 0.8a	−4.39	<0.0001	4.5 ± 0.7a	3.5 ± 0.5a	−1.20	0.23
ANOVA[b]	F = 7.72, P < 0.01	F = 9.85, P < 0.0001			F = 5.92, P < 0.01	F = 8.90, P < 0.001		
All season								
2000	13.2 ± 3.0	15.6 ± 3.8a	0.86	0.39	7.5 ± 1.9	5.7 ± 1.2ab	−0.78	0.44
2001	10.1 ± 1.7	3.6 ± 0.7c	−4.38	<0.0001	6.1 ± 0.9	4.0 ± 0.9b	−2.20	<0.05
2002	14.1 ± 1.8	6.5 ± 1.3b	−3.45	<0.001	7.9 ± 1.1	6.2 ± 0.9a	−1.28	0.22
ANOVA[a]	F = 2.64, P = 0.07	F = 20.4, P < 0.0001			F = 1.72, P = 0.18	F = 3.52, P < 0.05		

Column means followed by a different letter were significantly different, P < 0.05. LSD test.
[a] Degrees of freedom in t-tests were 44, 198, and 118 for 2000, 2001, and 2002, respectively.
[b] Degrees of freedom for all the one-way ANOVAs were 2,201.

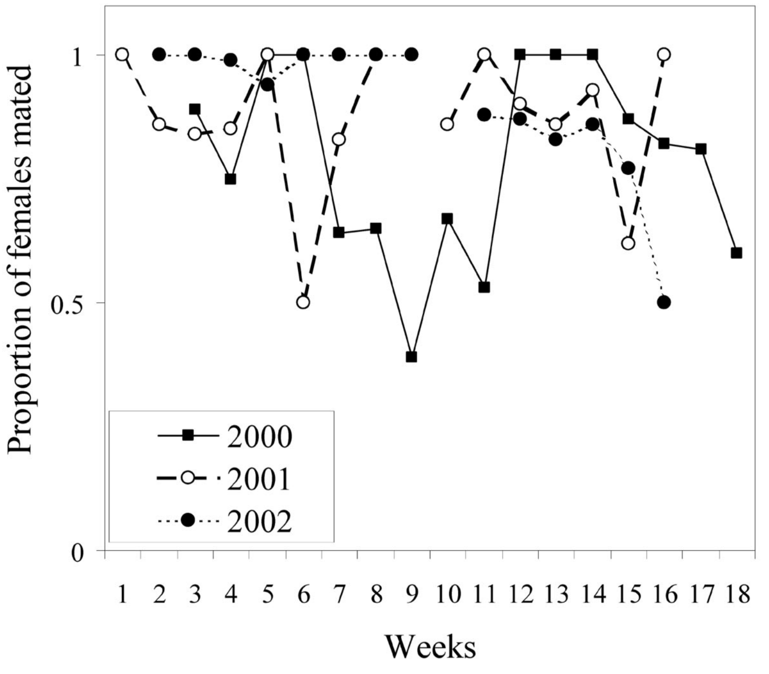

Fig. 4. The proportion of female codling moths captured in pear ester–baited traps that were mated during 2000–2002. Data are not graphed for weeks when female moths were not collected.

omone dispenser density compared with the other 2 yr in the study. Similarly, the ratio of moth catch in paired traps baited with pear ester versus codlemone was significantly higher in apple orchards in 2003 treated with 500 versus 1,000 isomate dispensers per hectare (Knight 2004).

In our study and in work reported by Trimble and El-Sayd (2005), pear ester– and codlemone-baited traps tracked the peak codling moth flights during each summer generation similarly. However, significant differences also occur with these two lure types. For example, codlemone-baited traps caught their first moth >1 wk earlier than pear ester–baited traps in 2000. In addition, pear ester–baited traps caught males significantly earlier than females because of the occurrence of protandry in codling moth (Howell 1991). Thus, the cumulative degree-day totals used to predict the timing of egg hatch after the start of either sustained male or female moth catches in pear ester–baited traps is likely to differ from the totals currently used with codlemone-baited traps (Beers and Brunner 1992). Development of a predictive model for codling moth egg hatch based on female moth catches in pear ester–baited traps could be an important contribution to its effective management (Knight 2002).

A large number of factors can influence the capture of codling moth in traps baited with pear ester (Knight and Light 2005a). These can include lure dosage, trap size, and trap placement in the canopy. Here we propose a standardized monitoring program that is based on the use of the Pherocon CM-DA dispenser placed in a large delta-style trap and replaced after 9 wk. The trap is attached to a PVC pole that enables them to be more easily placed in the upper third of the canopy (Knight et al. 2002). The use of the pole also allows the trap to be hung at some distance from foliage and fruit, which can significantly increase the catch of female codling moths (Knight and Light 2005a).

The influence of dosage of pear ester in gray halobutyl septa on catches of codling moth has been well studied, and differences among lures loaded with 0.1–40.0 mg have often been minimal (Light et al. 2001, Ioriatti et al. 2003, Knight and Light 2005b, Trimble and El-Sayd 2005). However, Knight and Light (2005b) found that, within this range, a lure loading of 3.0 mg caught the greatest proportion of female moths (0.6). Based on these findings, this rate was used in further studies developing female-based action thresholds for codling moth (A.L.K., unpublished data). However, several studies seem to confound our results. While Ioriatti et al. (2003) did not test a 3.0-mg lure, they did catch similar proportions of females in traps baited with either 0.1- or 20.0-mg lures. Studies by Il'ichev (2004) and Trimble and El-Sayd (2005) caught a very low proportion of female moths (<0.2) regardless of lure rate. Whether these differences are caused by geographical differences in the response of codling moth populations to pear ester or were caused by contamination of trapping materials with sex pheromone remains unclear. At present, the Pherocon CM-DA dispenser has been the most widely adopted lure and provides a reasonable compromise in longevity, cost, and effectiveness (Knight and Light 2005b).

Trap location within an orchard has consistently been an important factor affecting catch of codling moth in codlemone-baited traps placed in untreated (Vakenti and Madsen 1976) or sex pheromone–treated orchards (Knight 1995). Codlemone-baited traps placed in trees on orchards' borders can catch more codling moths because of moth immigration (Knight et al. 1995). In MD orchards, increased catch at the orchard edge can also be caused by a reduction in the atmospheric concentration of sex pheromone at this interface (Milli et al. 1997). Although a comparative study of the influence of trap location within the orchard on moth catches in pear ester traps has not been reported, we recommend that pear ester–baited traps be positioned 25 m from the edge of the orchard.

The density of monitoring traps baited with pear ester lures is another factor that should be standardized with the use of pear ester. Growers commonly use codlemone-baited traps at densities of one per 2–4 ha (Knight 1995), however, Gut and Brunner (1996) recommended one trap per ha in MD orchards. The range of attraction of pear ester is largely unknown, though recapture rates of marked moths in sex pheromone-treated orchards suggest that it is less than that for codlemone (Knight and Light 2005a). Pear ester lures could be used in a high-density grid of traps to monitor codling moth in problem areas, such as orchard borders, near bin piles, and in areas of orchards where codlemone-baited traps have previously generated false-negative moth catches. Greater experience using a standardized protocol with pear ester–baited traps to monitor codling moth within entire apple orchards is needed to fully implement an effective program.

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