Predation on eggs of codling moth (Lepidoptera: Tortricidae) in mating disrupted and conventional orchards in Washington

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ABSTRACT

Predation on eggs of codling moth, *Cydia pomonella* L., was assessed in Washington in June and August, 1995 in eight apple orchards treated with organophosphate insecticides (OPs), four orchards treated with mating disruption (MD) and some OPs, and four treated with MD but not with OPs. Sentinel codling moth eggs laid by caged moths on 10 shoots in each orchard were scored as alive, dead, or missing after 7 d, and beating tray samples of arthropod predators were collected at the beginning and end of each trial. Levels of egg predation (dead + missing eggs) did not differ significantly among orchard types in June but varied among orchard types in August (MD alone > MD + OPs > OPs). The percentage of dead eggs in August was significantly higher in the orchards receiving only MD than in orchards treated only with OPs. The percentage of missing eggs was significantly lower both months in orchards not treated with MD. Densities of spiders and all predators on both sample dates and for earwigs in August were significantly higher in orchards not treated with OPs. Densities of heteropteran predators did not vary significantly by orchard type. No significant correlations were found among predator densities and egg mortality within an orchard type. However, the percentages of dead eggs and dead plus missing eggs were significantly and positively correlated with densities of earwigs, spiders, and all predators in tray samples across the 16 orchards.

Key words: Codling moth, eggs, predation, mating disruption, biological control

INTRODUCTION

Within six years of registration, the sex pheromone for mating disruption (MD) of codling moth, *Cydia pomonella* L., is being used on nearly 20% of the apples produced in Washington (Alway 1997). Successful use of sex pheromones to manage codling moth has relied on low initial moth densities and intensive population monitoring. Adoption of MD has reduced the use of the broad spectrum organophosphate insecticides (OPs) against codling moth in apples by 75 - 85% (Gut and Brunner 1994, Knight 1995). The use of MD in Washington's apple orchards has replaced between 1 and 3 applications of the OP, azinphosmethyl. However, 77% of orchards treated with MD are still sprayed with OP for codling moth (Alway 1997).

The effects of reducing the use of OPs in MD orchards on the biological control of secondary pests, such as leafrollers, leafminers, aphids, and leafhoppers have been documented (Gut and Brunner 1994, Knight 1995). In general, the effectiveness of biological control has increased after the adoption of MD, but in many cases, supplemental use of insecticides has still been required. For example, Knight (1995) found that growers reduced their use of sprays for these pests by only 18% during three years of MD. Interestingly, the effects of implementing MD in Washington's apple orchards on the biological control of codling moth itself have been overlooked.

Many parasitoids and predators are known to attack the various life stages of codling moth,

including its egg (Falcon and Huber 1991). Previous studies of egg mortality of codling moth in Washington reported that parasitism by *Ascogaster quadridentatus* Wesmael occurs widely in unmanaged sites (crabapple and abandoned apple orchards) at low levels (< 20%), but was not detected in a survey of certified-organic orchards in the Yakima area before the adoption of MD (Knight 1994). In a more recent survey of conventional and organic orchards, egg parasitism by *Trichogramma* spp. was not observed (A.L.K., unpubl. data). These findings are consistent with a report by Yothers *et al.* (1935) that *Trichogramma* was not present 60 years ago in insecticide-managed apple orchards near Wenatchee, WA, even before the use of OPs.

There are no reports of predation on codling moth eggs in managed apple orchards in Washington. However, Ferro *et al.* (1975) found that 22% of eggs laid in an abandoned orchard near Ellensburg, WA were either nonviable, diseased, or presumed eaten by predators. Studies of egg predation in unsprayed orchards or in "integrated" or "biological control" orchards which were treated with a limited number of outdated materials, i.e., ryania, DDT, or lead arsenate, from other areas of the U.S., Canada, and Europe have found similar patterns. The major predators of codling moth eggs are anthocorids, mirids, earwigs, lacewings, and predatory thrips (Falcon and Huber 1991). Predation of codling moth eggs in unsprayed orchards generally removes 10 - 20% of eggs laid on leaves (Summerland and Steiner 1943, Westigard *et al.* 1976, Wood 1965), and 40 - 70% of eggs placed artificially (glued on leaves, shoots, and fruits) in the orchard (Glen 1975, 1977, Subinprasert and Svensson 1988). In comparison, egg predation in orchards sprayed with oil and early-season use of arsenical or botanical insecticides was usually 5 - 16% lower (Jaynes and Marucci 1947, MacLellan 1962, Wood 1965), but not always (Summerland and Steiner 1943). Levels of codling moth egg predation in orchards treated with OPs have not been reported.

We report the levels of predation of codling moth eggs and predator population densities in 16 apple orchards in Washington in 1995 treated with one of three regimes: conventional OP-based spray programs, MD supplemented with early-season OPs, or MD alone.

MATERIALS AND METHODS

Sixteen orchards in central Washington were selected in 1995 based on their use of insecticides. Eight conventional orchards were treated with a typical broad spectrum insecticide spray program for apple in Washington (Beers and Brunner 1991). Insecticides used included: a delayed-dormant spray of chlorpyrifos (DowElanco, Indianapolis, IN) and superior-type oil, 3 - 5 sprays of azinphosmethyl (Bayer AG, Kansas City, MO) beginning at 250 degree days (temperature threshold = $10°C$) after the first sustained codling moth catch; and, for secondary pests, an average of two neurotoxic insecticide sprays of one of the following compounds: phosphamidon (CIBA-GEIGY, Greensboro, NC), endosulfan (FMC Corp., Middleport, NY), formetanate hydrochloride (AgrEvo, Wilmington, DE), carbaryl (Rhone Poulenc Ag. Co., Research Triangle Park, NC), oxamyl (Dupont Inc., Wilmington, DE), phosmet (Gowan Co., Yuma, AZ), methyl parathion (Pennwalt Chemical Co., Philadelphia, PA) and dimethoate (American Cyanamid Co., Princeton, NJ). Eight MD orchards were treated with 1,000 ISOMATE-C+ dispensers per ha (Shin-etsu, Tokyo, Japan). The four MD plus insecticide orchards were treated with chlorypyrifos plus superior-type oil at the delayed-dormant stage and one spray of azinphosmethyl in late May. Secondary pests were controlled with either a commercial formulation of *Bacillus thuringiensis* Berliner (for leafrollers) or soap (for aphids and leafhoppers). The four MD orchards were either left unsprayed or treated only with superior-type oil at the delayed-dormant stage. All orchards were given several spray applications of micronutrients.

Egg predation was assessed in each orchard using sentinel eggs laid by moths from a laboratory colony. Cylindrical mesh sleeve cages (20 x 40 cm) were placed on one shoot on each

of 10 trees in each orchard. Three female moths (presumed mated) from a laboratory colony were placed in each cage for 1-2 d. Sleeves were removed, leaves with eggs were flagged, and a diagram of egg locations was drawn for each leaf. Leaves were removed from some shoots to ensure that no more than 10 eggs were present. Shoots were clipped after 7 d and examined in the laboratory. Eggs were scored as alive, dead, or missing. Dead eggs were characterized as being shriveled and flat in appearance. Field assays were started on 3 - 10 June and 10 - 17 August, 1995. Assays in the insecticide-treated orchards were done 7 or more days after the last insecticide application. Percent egg mortality was transformed (arcsin(sqrt(x + 0.5))) and subjected to analysis of variance (ANOVA) using month (June, August) as a repeated measure (Hintze 1987). If the 'month by treatment' interaction proved to be significant, a one-way ANOVA was used to compare treatments on each date. Fisher's LSD was used to separate significant treatment means. A paired t-test was used to compare the percentage of missing versus dead eggs among treatments on each date. Correlation statistics were calculated for the percentage dead and missing eggs both across and within treatments.

Tray samples were taken from a tree adjacent to each of the 10 assayed on the days when sleeves were attached and removed, and the mean of these two samples is reported. Branches were jarred sharply three times with a rubber club above a cloth screen (45 by 45 cm). Branches were hit less hard in August than in June because fruit loads were heavy in August. Predators were placed in vials containing 70% ethanol, then counted and sorted in the laboratory. Predators were grouped as heteropterans, earwigs (*Forficula auricularia* L.), and spiders. Heteropteran species included both anthocorids (*Orius tristicolor* (White), and *Anthocoris* spp.), mirids (*Deraeocoris brevis piceatus* (Knight) and *Campylomma verbasci* (Meyer)), and nabids (*Nabis* spp.). Predatory species such as ants, coccinellids, neuropterans, and a predatory red velvet mite, *Anystis* sp., were uncommon in our tray samples, and were therefore grouped as an additional category (other) included in the total predator density. A repeated measure ANOVA (by month) was used to compare densities of predators across treatments. When there was a significant date by treatment interaction, a one-way ANOVA compared treatments on each date. Fisher's LSD was used to separate significant means. Correlation statistics were used to compare the association of each predator group with the percentage of dead, missing, and dead + missing eggs for all orchards and within each treatment on both dates.

RESULTS AND DISCUSSION

Mean levels of egg mortality within orchard types ranged from 10.1 to 37.0% during the season (Table 1). Levels in individual orchards ranged from 7.2 to 52.5% (Fig. 1). In June, total egg mortality did not differ among treatments ($F = 2.6$; df = 2,13; $p = 0.12$), but in August, egg mortality was highest in orchards not treated with insecticides, and was significantly higher in the 'MD plus insecticide' than in the 'conventional insecticide' orchards ($F = 15.1$; df = 2,13; $p < 0.001$).

Table 1

Mean percentages (SE) of egg predation in 1995 in apple orchards treated with organophosphate (OP) insecticides, mating disruption (MD) with limited use of OPs, or with MD alone.

Month	% eggs dead			% eggs missing			% total egg mortality		
	OP	MD + OP	MD	OP	MD + OP	MD	OP	MD + OP	MD
June	10.8 (1.8)a	9.3 (1.0)a	14.8 (0.9)a	5.3 (1.5)a	13.9 (2.7)b	9.3 (2.9)b	16.1 (2.8)a	23.2 (2.3)a	24.2 (3.5)a
August	5.2 (1.5)a	9.0 (1.4)a	24.2 (3.1)b	4.9 (1.4)a	12.9 (4.5)b	12.8 (3.1)b	10.1 (1.7)a	21.9 (4.7)b	37.0 (6.2)c

Means for % eggs dead, % eggs missing, and % total egg mortality across treatments for each month followed by a different letter are significantly different (Fishers LSD, $p < 0.05$).

There were no significant differences in the percentage of dead eggs among orchard types in June ($F = 2.0$; df = 2, 13; $p = 0.17$). However, the percentage of eggs categorized as dead was highest in the 'MD alone' treatment compared with the two insecticide treatments in August ($F = 13.8$, df = 2,13, $p < 0.001$). These were significant differences among treatments in the percentage of eggs missing ($F = 6.6$; df = 2,13; $p = 0.01$). More eggs were missing in the orchards treated with MD than in those treated with insecticide only. There was no significant difference in the percentage of missing eggs between treatments in the June and August samples ($F = 0.01$; df = 1, 13; $p = 0.97$) and no significant correlations between the percentage of eggs missing and the percentage of dead eggs within orchards ($p > 0.05$). There were no significant differences in the mean percentages of the two types of egg mortality across all orchards or within each of the three orchard types, except for two cases. A significantly higher percentage of eggs was dead than missing in the insecticide-treated orchards in June ($t = 2.7$; df = 7; $p = 0.03$) and in August in the MD orchards ($t = 7.5$; df = 3; $p < 0.01$).

The mean number of predators was significantly different between orchard types ($F = 9.0$, df = 2, 13, $p < 0.01$) (Table 2). Predators were more numerous in the 'MD alone' orchards than in those treated with insecticides. There was no significant difference between the two types of insecticide-treated orchards and no significant difference in the density of predators between the June and August samples ($F = 0.6$, df = 1, 13, $p = 0.46$).

Table 2

Mean density (SE) of arthropod predators collected per 10 tray samples in 1995 from apple orchards treated with organophosphate (OP) insecticides, mating disruption (MD) with a limited use of OPs, and with MD alone.

	OP insecticides					MD + OP insecticides					MD alone				
Month	H	E	Sp	O	T	H	E	Sp	O	T	H	E	Sp	O	T
June	2.0a	0.0a	1.0a	0.0a	3.0a	0.2a	2.0a	0.2a	3.7b	6.1a	5.5a	1.9a	5.4b	3.1b	15.9b
	(0.6)	(0.0)	(0.4)	(0.0)	(0.8)	(0.2)	(1.0)	(0.2)	(2.0)	(2.0)	(1.2)	(1.4)	(1.8)	(1.0)	(2.7)
August	0.7a	0.3a	0.7a	0.1a	1.8a	4.1a	0.0a	3.8a	0.1a	8.0a	7.2a	2.0b	10.0b	0.7a	19.9b
	(0.3)	(0.2)	(0.4)	(0.1)	(0.7)	(1.0)	(0.0)	(2.6)	(0.1)	(2.2)	(5.0)	(0.6)	(4.0)	(0.7)	(8.6)

'H' = heteropterans; 'E' = earwigs; 'Sp' = spiders; 'O' = other (includes ants, red velvet mites, lacewing larvae and adults, and coccinellid larvae and adults); 'T' = total of all predators. Means for each predator group in each row followed by a different letter are significantly different, Fishers LSD, $p < 0.05$.

The mean density of heteropteran predators in tray samples was not significantly different between treatments ($p = 0.06$). The predominant heteropteran species were the two mirids, *D. brevis* and *C. verbasci*. Mirids were the major predators of codling moth eggs in Nova Scotia and England (MacLellan 1962, Glen 1975), however, levels of egg mortality were not correlated with their density. The population density of heteropteran predators is more often related to the densities of their major prey: phytophagous mites and aphids, the mix of surrounding vegetative habitats, orchard spray practices, and weather (MacLellan 1962, Glen 1977, Glen and Brain 1978, Thistlewood *et al.* 1990, Reding and Beers 1995, Horton *et al.* 1997). These factors can create large fluctuations in numbers of heteropterans between orchards and in different years (Horton *et al.* 1997). Recommendations to increase the density of predatory bugs in orchards have included providing alternative habitats in or near orchards, chemical attractants, and the use of selective insecticides (Horton *et al.* 1997). However, management of heteropteran egg predators in apple is seriously impaired by the feeding habits of *C. verbasci*. *Campylomma verbasci* overwinters in apple orchards and feeds early in the season on both arthropods and young developing fruits. An increasing number of apple orchards in Washington is being treated

for this pest, and its effective management relies on applications of OP or other broad spectrum insecticides at the prebloom or bloom stages (Reding and Beers 1995). Thus, while *C. verbasci* readily ate codling moth eggs in laboratory bioassays (A.L.K., unpublished data), its feeding habits limit its use as an egg predator.

Counts of earwigs in tray samples did not vary significantly between treatments in June (p = 0.07), but were significantly different in August (F = 8.9; df = 2,13; p < 0.01) (Table 2). Earwig density was significantly higher in the orchards treated only with MD compared with orchards treated with insecticides. Philips (1981) noted that earwigs are both pests and beneficial in apple orchards. Earwigs are reported to feed on aphids (Carroll and Hoyt 1984, Mueller *et al.* 1988); and studies in England (Glen 1975, 1977, Glen and Brain 1978) found that earwigs in cages readily eat codling moth eggs. Unfortunately, earwigs occasionally feed on fruits (J. Dunley, Wash. State Univ., personal communication), and this has limited both augmentative releases and conservation practices for this species in apple orchards.

Spiders were the most numerous predators in our samples, and their densities varied significantly between orchard types (F = 8.4; df = 2,13; p < 0.01) (Table 2). Spiders are good indicators of the ecological disturbance created by insecticide use in orchards (LeRoux 1960, Specht and Dondale 1960, Dondale *et al.* 1979, Madsen and Madsen 1982). In our study, spider densities were higher in orchards treated with MD than in those treated with insecticides. There was no difference between the June and August samples (F = 3.0; df = 1, 13; p = 0.11). Spiders are not likely to be a major predator of codling moth eggs, though there are a few reports of spiders feeding on lepidopteran eggs (Buschman *et al.* 1977, Jennings and Houseweart 1978). Spiders are more likely to prey on larvae. MacLellan (1973) found that spiders feeding on larvae helped to control populations of the tortricid leafroller, *Epiphyas postvittana*, in some apple orchards in Australia.

A number of other predators that may feed on codling moth eggs (Falcon and Huber 1991) were less common in our samples, such as mites (*Anystis* sp.) (1), ants (2), coccinellid larvae and adults (4), and lacewing larvae and adults (5). We found no predatory thrips. There were significantly more predators in the orchards treated with MD than with insecticides alone (F = 5.9; df = 2,13; p = 0.01), and significantly more in June than in August (F = 5.0; df = 1, 13; p = 0.04), perhaps because it was difficult to sample the mobile adult stages without dislodging fruit.

There were no significant correlations (p > 0.05) between any predator group or the total of all predators and egg mortality within each orchard type during either sampling period. However, across the 16 orchards, there were significant correlations between both the percentage of dead eggs and the percentage of dead plus missing eggs and the mean densities of earwigs, spiders, and total number of predators (r-values ranged from 0.51 - 0.59, *p's* < 0.05). The regression of total egg mortality (y) against the mean density of all predators (x) was described by the equation: y = 14.2 + 0.7x (R^2 = 0.32, p = 0.02; Fig. 1).

These results show that the importance of predators in the biological control of codling moth has been overlooked in Washington apple orchards. Glen (1982), modeling predation of codling moth eggs in an unsprayed orchard in England, found that fruit injury would have been 6-fold higher in the absence of egg predators. Coupled with even higher levels of mortality of young larvae (MacLellan 1962, Westigard *et al.* 1976) by similar predators (Falcon and Huber 1991), predation in the absence of insecticides can reduce codling moth populations during the summer (MacLellan 1977, Ferro *et al.* 1975). However, natural mortality of codling moth eggs and young larvae is low in apple orchards where there is little diversity of predaceous species (Geier 1964, Wood 1965, Wearing 1979). In our study, using only OPs early in the season, reduced biological control of codling moth significantly (Table 1).

Integration of pest management tactics in apple as first proposed by Pickett (1959) and more recently termed 'second-stage' IPM (Prokopy *et al.* 1990) must rely on early season control of
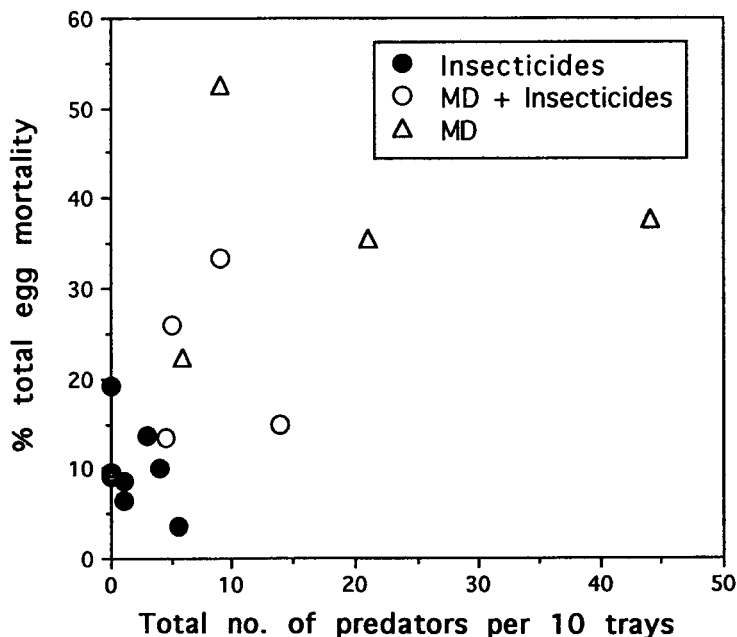
Figure 1. Percent total egg mortality (dead plus missing eggs) (y) plotted against mean density of all predators (x) per 10 beating-tray samples in August, 1995 for 16 apple orchards treated either with insecticides only, mating disruption (MD) for codling moth plus limited use of insecticides, or with MD alone. $y = 14.2 + 0.7x$, $R^2 = 0.32$, $p = 0.02$.

pest populations with maximal use of behavioral, cultural, and biological control during the remainder of the season. Mating disruption of codling moth is the keystone for this IPM program in western U.S. orchards. However, studies of MD of codling moth in organic or unsprayed orchards have shown that this technique alone cannot reliably control codling moth (Pfeiffer *et al*. 1993, Trimble 1995, Judd *et al*. 1997). In fact, current use of MD in conventional orchards reduces the number of orchards treated with OPs for codling moth by only 23% (Alway 1997). We show that natural control of codling moth is reduced when OPs are used to supplement control of codling moth or to manage secondary pests. Further reductions in the use of broad spectrum insecticides are needed to achieve the full potential of biological control.

Integration of ecological approaches and consideration of arthropod community structure may allow a new level of apple IPM (Gruys 1982, Liss *et al*. 1986, Kogan 1988). Previous field studies in apple have found a significant decrease in the number and diversity of predators as human disturbance increases from unsprayed to organic to conventional orchards (LeRoux 1960, MacLellan 1972, Madsen and Madsen 1982, Brown and Aller 1989). However, even if insecticides are used less, natural enemies in small, isolated MD orchards might not affect all codling moth populations (Knight 1995). Effective biological control of codling moth may require area-wide reductions in the use of broad spectrum insecticides and establishing specific cultural conservation practices within and surrounding orchards (Horton *et al*. 1997).

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