

Monitoring the seasonal population density of *Pandemis pyrusana* (Lepidoptera: Tortricidae) within a diverse fruit crop production area in the Yakima Valley, WA

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ABSTRACT

The population dynamics of *Pandemis pyrusana* (Kearfott) were studied in 60 contiguous orchard blocks (154 hectares) of mixed fruit production situated in the Yakima Valley, Washington. Grids of sex-pheromone-baited and liquid-food-baited traps were placed at a rate of one trap of each type per 2 hectares. Trees within 50 m of each trapping location were sampled for overwintering and summer generation larvae, and fruit injury prior to harvest. Larvae from both generations were found in a low proportion of apple (*Malus domestica* Borkh.), pear (*Pyrus communis* L.), and cherry (*Prunus avium* L.) orchards, but not in the peach/nectarine (*Prunus persica* (L.)), apricot (*Prunus armeniaca* L.), or prune (*Prunus domestica* L.) orchards. Larval densities between generations increased 5-fold in apple and 10-fold in cherry and non-bearing apple. Parasitism of field-collected larvae by tachinid parasitoids averaged 37% and 23% for each generation, respectively. Low levels of fruit injury (< 0.5%) by *P. pyrusana* were detected in only five apple and pear orchards. Cumulative moth catch was 10-fold higher in sex-pheromone than food-baited traps. Moth catch in both types of traps varied significantly among crops. In general, moth catches were highest in apple and cherry. Cumulative moth catch in both trap types in apple and pear during the first flight was weakly correlated with levels of fruit injury. In contrast, moth catch during the second flight was not correlated with fruit injury. The observed low predictive ability of traps was likely due to trap saturation and contamination with non-target moths and a general dispersal of moths among orchards throughout the region. The capture of female moths versus the total of both sexes caught in food bait traps did not improve the prediction of fruit injury in apple or pear.

Key words: *Pandemis*, leafrollers, sex pheromone traps, food bait traps, fruit crops

INTRODUCTION

Pandemis spp. (Lepidoptera: Tortricidae) leafrollers are important direct pests of apple, *Malus domestica* (Borkh.), from British Columbia to California (Newcomber and Carlson 1952; Madsen *et al.* 1984; Zalom and Pickel 1988). Two species of *Pandemis* overlap geographically, within this range with *P. limitata* Robinson predominating in northcentral Washington and British Columbia and *P. pyrusana* (Kearfott) in the Yakima Valley, Washington, Oregon, and California. Levels of fruit injury caused by *P. pyrusana* have increased following the adoption of sex-pheromone-based mating disruption of codling moth, *Cydia pomonella* L., and the concurrent decreased use of the broad-spectrum organophosphate insecticides in these programs in Washington (Knight 1995) and California (Walker and Welter 2001). Management of *P. pyrusana* has relied on either the use of organophosphate insecticides, endotoxins of *Bacillus thuringiensis* Berliner, (Knight *et al.* 1998) or the use of sex pheromones for mating disruption (Knight and Turner 1999).

Management decisions for *P. pyrusana* in apple involve larval sampling in the spring prior to bloom (Beers *et al.* 1993). However, this method is labor intensive and ineffective in

detecting low-density populations. The use of sex pheromone-baited traps to monitor *P. pyrusana* populations has been hampered by a poor relationship between moth catch and the within-orchard pest density, lack of knowledge of the drawing range of these lures, and limited understanding of the population dynamics and dispersal patterns of *P. pyrusana* (Brunner 1999). The adoption of low-load sex pheromone lures (Brunner 1999) and food baits that can catch both male and female moths may improve the predictive ability of traps (Landolt 2000).

Pandemis leafrollers have a broad host range that includes both cultivated and uncultivated plant species (Brunner 1983; Vakenti *et al.* 2001). Fruit injury has been reported in a range of tree fruits in Washington including apple, pear (*Pyrus communis* L.), cherry (*Prunus avium* L.), apricot (*Prunus armeniaca* L.), prune (*Prunus domestica* L.), and peach/nectarine (*Prunus persica* (L.)) (Newcomer and Carlson 1952; Brunner 1983). Reduced insecticide sprays in cherry after harvest and within blocks of non-bearing apples can allow the establishment of refugia for *P. pyrusana* populations within a region (Brunner and Beers 1990). Development of an effective area-wide management scheme for tortricid leafrollers such as *P. pyrusana* may require the application of season-long control tactics in these crops.

Grids of monitoring traps along with intensive larval sampling have been used successfully to study the area-wide population dynamics of other tortricids among various crop and non-crop hosts (Knight and Croft 1987; Knight and Hull 1988). These studies have demonstrated the patchwork pattern of overwintering pest populations and have clarified patterns of seasonal adult dispersal across crop types. A similar protocol was used in this study. The objectives of this study, conducted in 1999, were to measure the population density of *P. pyrusana* overwintering and developing during the summer within a variety of tree fruit crops within a contiguous region in the Yakima Valley, Washington, and to compare the usefulness of either a low-load sex-pheromone-baited or liquid-food-baited trap to monitor populations and predict larval densities and fruit injury levels in apple and pear orchards.

MATERIALS AND METHODS

This study was conducted in a 3 km² contiguous area of tree fruit production (Parker Heights) situated in the Yakima Valley of Washington (46° 29'N, -120° 24'W). *Pandemis pyrusana* had been reported to be an important pest for several apple and pear growers in this area during 1998. We identified 60 orchard blocks comprising 154 ha of apple, pear, cherry, peach, apricot, peach/nectarine, and prune production (Table 1). Apple orchards were planted with four cultivars (% of area): 'Gala' (46%), 'Golden Delicious' (19%), 'Red Delicious' (19%), and 'Fuji' (18%). All orchards received typical seasonal spray programs during the season (Olsen 2001).

Blocks were sampled for first generation larvae twice, in late May and early June, and again in August for second generation larvae. Five shoots from 10 trees within 50 m of each trap site were inspected on each date. Pole pruners were used to sample shoots randomly from the upper canopy. Rolled leaves were partially opened to determine if larvae were present. Infested shoots were placed in small paper bags, and returned to the laboratory. Recovered larvae were placed on artificial pinto bean diet (Shorey and Hale 1965) and reared under constant light at 24°C until adult eclosion to determine species and parasitism rate. Parasitoids were identified by Robert Pfannenstiel (USDA, ARS, Weslaco, TX). Apple and pear blocks were sampled for fruit injury just prior to harvest. Thirty fruit selected randomly on 20 trees within 50 m of each trap site were visually examined.

Two types of traps placed in a regular array (100 – 200 m spacing) were used to monitor adult *P. pyrusana*. Low-load (10% of the proprietary standard load) sex-pheromone-impregnated red septa (Trécé Inc., Salinas, CA) were used in delta traps (Pherocon 6, Trécé Inc., Salinas, CA). Food bait traps consisted of plastic dome traps (Scenturion Inc., Clinton,

WA) loaded with 150 ml of 1.0% glacial acetic acid and brown food coloring. All traps were placed in the field the last week.

Table 1

Composition and density of tree fruit orchards within the Parker Heights study site and the number of sampling sites associated with sex-pheromone and food-bait traps.

Crop	No. orchard blocks	No. hectares	No. trapping sites
Apple	19	66.0	68
Pear	18	36.4	48
Cherry	14	22.0	28
Peach	4	17.4	20
Non-bearing apple	2	5.4	6
Apricots	3	5.2	6
Prune	1	1.2	2
Total	61	153.6	178

of May. Each trap type was placed in orchard blocks at a rate of one trap per 2 hectares for a total of 178 trap sites. Traps were placed about 2-m high in the canopy. Traps were checked weekly from early June to early August (first flight) and late August to early October (second flight). Moths caught in bait traps were returned to the laboratory for identification and *P. pyrusana* moths were sexed under a dissecting microscope. Sex-pheromone septa were replaced every 4 weeks. Sticky trap liners used in delta traps and the liquid bait solution in the dome traps were replaced as necessary.

Data Analysis. All moth count data were transformed to stabilize variances [square root ($x \pm 0.01$)] prior to analysis of variance (Analytical Software 2000). Moth catches in the single trap of each type placed in the prune orchard were not included in these analyses. Means were separated with Fisher's LSD test where significant differences occurred ($P < 0.05$). Linear correlation coefficients were computed among the cumulative mean moth counts per trap during each flight period, larval densities, and percent fruit injury. A chi-square contingency test was used to compare the proportion of parasitized larvae among crops during each generation.

RESULTS

Larval Sampling. Overwintering larvae were found in only 10 blocks within the study site: apple (4), non-bearing apple (2), pear (2), and cherry (2); and were not found in any blocks of peach/nectarine, apricot, or prune. While non-bearing apples had the highest mean percentage of infested shoots (Table 2), the percentage of infested shoots ranged up to 5% in pear and 6% in apple. Parasitism of overwintering larvae by the tachinids, *Nemorilla pyste* Walker and *Nilea erecta* Coquillett, totaled 37% and varied significantly among crops ($\chi^2 = 11.47$, $df = 3$, $P < 0.01$): 12.5% in cherry, 37.8% in apple, 50.0% in pear, and 85.7% in non-bearing apple.

Larval population density within the study site was roughly 3-fold larger during the summer than the overwintering generation, but densities increased nearly 5-fold in apple and 10-fold in both non-bearing apple and cherry blocks (Table 2). Summer generation larvae were sampled in three blocks of apple, three blocks of non-bearing apple, and two blocks of cherry. These included four blocks in which an overwintering population was not previously detected. In addition, in five blocks, overwintering larval populations were detected but no second generation larvae were found. The highest mean percentage of infested shoots occurred in non-bearing apple (Table 2). There were no infested shoots found in pear orchards during the summer. Apple orchards with the highest densities of summer generation larvae were situated near two areas containing cherry and non-bearing apple. Tachinids parasitized 23% of the

Table 2

Correlations among the overwintering and summer larval densities and fruit injury for *P. pyrusana* within tree fruit crops in the Parker Heights study site.

Crop	% (+ SE) infested shoots			Correlation coefficients ^a		
	Overwintering larvae (OL)	Summer larvae (SL)	% (+ SE) fruit injury (FI)	OL-SL	OL-FI	SL-FI
Non-bearing apple	0.50±0.27	5.88±2.10	-	0.83**	-	-
Apple	0.45±0.18	2.07±0.68	0.06±0.02	0.38	0.18	0.83**
Pear	0.25±0.16	0.00±0.00	0.03±0.02	0.00	0.21	0.00
Cherry	0.28±0.14	2.64±1.28	-	0.15	-	-
Peach	0.0	0.0	0.0	-	-	-
Apricot	0.0	0.0	0.0	-	-	-
Prune	0.0	0.0	0.0	-	-	-

^a Correlation coefficients followed by ** were significant at $P < 0.01$.

field-collected summer generation larvae and no difference was found among crops ($\chi^2 = 3.45$, $df = 2$, $P = 0.18$).

Moth Flight. Moth catch in sex-pheromone-baited traps varied among crops during the first moth flight ($F = 3.55$; $df = 5, 82$, $P < 0.01$) and was higher in apple, pear and cherry than in peach (Table 3). During the first flight, moth catch in non-bearing apple and apricot did not differ from the other crops. Cumulative moth catch in sex-pheromone traps increased about 400% between generations but did not vary among crops during the second flight ($F = 0.76$; $df = 5, 82$; $P = 0.58$).

Moth catch in the food-bait traps was much lower than in sex-pheromone traps during both flights (Table 3). The male:female sex ratio was 0.60 and 2.26 during the two moth flights, respectively. Cumulative male catch varied significantly among crops during both the first ($F = 2.65$; $df = 5, 82$; $P < 0.05$) and second moth flight ($F = 3.00$; $df = 5, 82$; $P < 0.05$). Male moth catch was lowest in apricot during both flights. Male moth catch in cherry during the second flight was significantly higher than in all other crops except apple (Table 3). Cumulative female catch varied among crops during the first flight, ($F = 3.02$; $df = 5, 82$; $P < 0.01$) and counts were higher in apple and cherry than in peach and non-bearing apple (Table 3). Moth catch in food-bait traps increased about 250% between the two flights. Cumulative total moth catch in the bait traps varied among crops during both flights (first flight: $F = 2.81$; $df = 5, 82$; $P < 0.05$ and second flight: $F = 2.46$; $df = 5, 82$; $P < 0.05$). Cumulative moth catch in bait traps during the first flight in apple and cherry were significantly higher than peach, apricot and non-bearing apple (Table 3). Cumulative catch in bait traps during the second flight in cherry were greater than those in apricot and pear.

Fruit Injury. Fruit injury by *P. pyrusana* was detected in only one pear and four apple blocks within the study site and ranged from 0.1 to 0.5%. Surprisingly, no overwintering or summer generation larvae were detected in samples collected from three of these five blocks. All orchards with fruit injury were adjacent to or near blocks of cherry and non-bearing apple.

Correlations Among Population Measures. The overwintering density of larvae in both apple and pear orchards was not correlated with levels of fruit injury ($P = 0.79$ and $P = 0.77$, respectively) (Table 2). However, summer larval densities in apple were well correlated with fruit injury ($P < 0.001$). The percentage of shoots infested by overwintering larvae was not significantly correlated with percentage of shoots infested with summer larvae in apple ($P = 0.27$) or cherry ($P = 0.90$). However, larval densities in non-bearing apple blocks were significantly correlated ($P < 0.01$) (Table 2).

The correlations of cumulative moth catch per trap during each flight period with other

Table 3
 Cumulative *P. pyrusana* moth catch (\pm SE) in sex-pheromone-baited and liquid-food-baited traps for the first (May – June) and second (July – August) moth flight within tree fruit crops in the Parker Heights study site.

Crop	Sex-pheromone traps		Liquid-bait traps					
	1 st flight	2 nd flight	Male		Female		Male + female	
			1 st flight	2 nd flight	1 st flight	2 nd flight	1 st flight	2 nd flight
Apple	68.5 \pm 15.0b	207.1 \pm 23.0a	5.7 \pm 1.5c	13.4 \pm 4.3bc	8.2 \pm 2.1b	8.0 \pm 2.3a	13.9 \pm 3.4b	21.4 \pm 6.6ab
Pear	81.0 \pm 16.3b	210.5 \pm 26.8a	4.3 \pm 1.3bc	3.4 \pm 0.8a	5.4 \pm 1.3ab	4.2 \pm 1.6a	9.8 \pm 2.5ab	7.7 \pm 2.3a
Cherry	53.3 \pm 12.5b	226.1 \pm 31.5a	3.8 \pm 1.4abc	27.4 \pm 14c	8.9 \pm 3.5b	18.1 \pm 7.3a	12.7 \pm 4.8b	45.2 \pm 21.4b
Peach	9.8 \pm 3.7a	177.4 \pm 21.2a	0.7 \pm 0.3ab	3.6 \pm 2.2a	1.1 \pm 0.3a	5.2 \pm 3.5a	1.8 \pm 0.4a	8.8 \pm 4.6ab
Non-bearing apple	39.3 \pm 10.2ab	182.7 \pm 32.4a	1.0 \pm 0.7ab	10.3 \pm 3.8ab	0.9 \pm 0.3a	5.4 \pm 4.0a	1.9 \pm 1.0a	15.7 \pm 5.4ab
Apricot	18.0 \pm 3.8ab	92.7 \pm 17.4a	0.0 \pm 0.0a	1.0 \pm 0.7a	1.5 \pm 0.5ab	4.5 \pm 1.5a	1.5 \pm 0.6a	5.5 \pm 1.5a
Prune	16.0	78.0	0.0	0.0	0.0	1.0	0.0	1.0

Column means followed by a different letter are significantly different at $P < 0.05$, Fishers LSD. Moth catch from the single prune orchard was not used in these statistical analyses.

measures of population density varied for each trap type in apple and pear (Table 4). Cumulative moth catch from both trap types during the first flight was significantly correlated with fruit injury in apples and pears but this relationship was weak (r 's < 0.50 ; Table 4). Restricting the cumulative moth counts to the first 3 or 4 weeks of the season did not improve these correlations (r 's < 0.45). In comparison, moth catches during the second flight were not correlated with fruit injury (Table 4). Cumulative moth catch per trap during the first and second flight were correlated for each type of trap. However, moth catch in sex-pheromone-baited traps during both flight periods was not correlated with either overwintering or summer larval densities. In comparison moth catch in the food-bait traps during the first flight period was correlated with overwintering larval density and summer larval density; and moth catch during the second flight was correlated with summer larval density (Table 4). Correlations of cumulative moths and cumulative female moths for each flight with larval densities and fruit injury were similar (Table 4).

Table 4

Correlations of cumulative moth catch during the 1st and 2nd moth flight of *P. pyrusana* in traps baited with either low-load sex-pheromone lures or a liquid-food bait with selected population measures across all apple and pear blocks within the Parker Heights study site.

Trap type	Flight period	Population measure	Correlation coefficient ^a
Low-load Sex-pheromone	1 st flight	Overwintering larval density	0.04
		Summer larval density	0.25
		2 nd moth flight	0.41**
		% fruit injury	0.45**
	2 nd flight	Overwintering larval density	0.02
		Summer larval density	0.21
Liquid-food bait ^b	1 st flight	% fruit injury	0.18
		Overwintering larval density	0.40* (0.44**)
		Summer larval density	0.60** (0.61**)
		2 nd moth flight	0.32* (0.36**)
	2 nd flight	% fruit injury	0.46** (0.37**)
		Overwintering larval density	0.17 (0.11)
		Summer larval density	0.40** (0.35**)
		% fruit injury	0.07 (0.07)

^a Correlation coefficients followed by * were significant at $P < 0.05$; coefficients followed by ** were significant at $P < 0.01$.

^b Correlation coefficients in brackets are for cumulative female moth catch only.

DISCUSSION

Establishing action thresholds based on the capture of male moths in sex-pheromone-baited traps has been difficult for many tortricid pests that occur in high densities within orchards (Madsen and Peters 1976; Minks *et al.* 1995; Walker and Welter 1999). Success has been achieved by reducing the effects of trap saturation by either using only early-season catches (Knight and Hull 1989) or by reducing the attractiveness of the lure (Faccioli *et al.* 1993). However, these approaches have not always improved the performance of sex-pheromone traps. A significant correlation of peak moth catch and larval density could not be established for the apple pest, *Argyrotaenia citrana* (Fernald) with traps baited with lures across a 1,000-fold range in their sex-pheromone load (Walker and Welter 1999).

The utility of sex-pheromone traps to accurately predict the population density of *P. pyrusana* may be limited. Walker and Welter (2001) found a significant but moderate

relationship ($r^2 = 0.59$, $P = 0.04$) between peak weekly moth catch of *P. pyrusana* during the first moth flight and summer larval density in California apple orchards. While Brunner (1999) suggested that the use of low-load (5%) sex-pheromone lures improved the accuracy of traps in predicting larval populations and fruit injury, these data have not been published. Results reported herein found that low-load (10%) sex-pheromone lures were, at best, weak predictors of local population densities estimated by either larval sampling or levels of fruit injury.

Many factors affect the performance of lure-baited traps and the correlation of moth catch with local larval population density. Moth capture within traps is influenced by operational factors including the lure's emission characteristics and the attractant's chemical stability, and the size, geometry, placement, and maintenance of the trap (McNeil 1991). Saturation of the trap's catch surface with moths and non-target species can also reduce the effectiveness of traps to reflect relatively high population densities (Brown 1984). An accurate estimate of low-density leafroller larval populations is difficult to achieve without extensive host sampling. Furthermore, *P. pyrusana* larvae were typically found feeding on shoot terminals in the upper canopy of trees, and the variability in tree height among orchards and crops may have created a sampling bias in the estimate of larval density. In general, a greater number of larvae were detected in apple orchards with smaller canopies - non-bearing apple and younger blocks of Fuji. The relationship between moth catch and fruit injury is further impacted by a large number of horticultural and biological factors including cultivar and crop load, tree size and pruning, and spray practices. Orchards within our study site varied widely for many of these factors.

Moth catch of *P. pyrusana* in both types of traps during first flight was a better predictor of larval populations and fruit injury than moth catch during second flight. This result is similar to data previously reported for tufted apple bud moth *Platynota idaeusalis* (Walker) (Knight and Hull 1988) and *A. citrana* (Knight and Croft 1987). Both of these studies used grids of sex pheromone-baited traps within a diverse agricultural setting. Both leafroller pests overwintered primarily within managed agricultural sites and early-season male moth catches reflected this local distribution. However, the adults of both species are highly mobile and male moth catches of the summer generation flight were more homogeneous within the region. Similarly, counts of male *P. pyrusana* during second flight were uniformly high among 56 of the 60 orchards in Parker Heights.

While, moth catches during first flight in food bait traps were more closely associated with spring and summer larval densities than moth catches in sex-pheromone-baited traps, both trap types were similar in predicting fruit injury. Interestingly, the counts of female moths in the food bait traps did not improve the prediction of local population density. Liquid-food-bait traps had a greater number of problems associated with their use than the sex-pheromone traps. First, the acetic acid mixture evaporated rapidly during the warmer weather in August and required frequent servicing. The food-bait traps were not selective and caught a large number of non-target moths (Lepidoptera: Noctuidae) that saturated the traps. Identification and sexing of *P. pyrusana* individuals from a large decomposing mixture of insects was time consuming. The decomposition and fermentation of the mixture was also highly attractive to muscid flies and may have released volatile chemicals that may have reduced the attractiveness of the bait to *P. pyrusana*. Development of dry food baits placed in either sticky or insecticide-treated traps will likely reduce these problems (Landolt and Alfaro 2001).

Establishing effective management of a polyphagous pest such as *P. pyrusana* requires a concerted area-wide program across all potential hosts. Interestingly, populations of *P. pyrusana* in Parker Heights were not detected in the eight commercial orchards of peach/nectarine, apricot, and prune despite these crops' apparent host suitability (Brunner 1983). Its absence in these crops may have been due to the use of broad-spectrum insecticides for other key pests in these crops. For example, early-season and summer sprays for green

peach aphid, *Myzus persicae* (Sulzer), peach twig borer, *Anarsia lineatella* (Zeller), oriental fruit moth, *Grapholitha molesta* (Busck), and western flower thrips, *Frankliniella occidentalis* (Pergande), are widely used in these stone fruits (Olsen 2001). In contrast, *P. pyrusana* larvae were found in over a third of the cherry orchards. Cherry is sprayed early in the season for phytophagous mites and the black cherry aphid, *Myzus cerasi* (Fabricus), and receives a series of cover sprays through June for the western cherry fruit fly, *Rhagoletis indifferens* (Curran). However, Washington growers typically do not apply any insecticides to cherry after June. The role of cherry orchards in serving as refugia for leafrollers was also reported for *P. idaeusalis* in a typical mixed-fruit production area in Pennsylvania (Knight and Hull 1988).

Leafroller management in apple and pear tends to ignore the potential role of these extra-orchard habitats and this allows populations of *P. pyrusana* to remain established at high levels within a given region. Even leafroller populations in non-bearing apple blocks are generally not treated. Instead, leafrollers are managed by individual growers within-season in their respective orchards with one or more well-timed applications of efficacious sprays. Implementation of an effective leafroller management strategy, however, is often hampered by poor spring weather, poor spray timing, the survival of larvae feeding within protected leaf shelters, and insecticide resistance.

Conversely, the idea of growers working together to implement an effective area-wide pest management program that suppresses a pest population across all host habitats would seem to be more effective and has recently been demonstrated for codling moth, *Cydia pomonella* L. (Calkins 1998). Similarly, the obliquebanded leafroller, *Choristoneura rosaceana* Harris was effectively managed by 13 growers using sex-pheromone-based mating disruption and *B. thuringiensis* sprays (Knight *et al.* 2001). The effectiveness of the area-wide approach requires that the pest population density be reduced to low levels through an integration of selective tactics. The success of the codling moth project was predicated on the clean-up of all problem sites that harbored high pest populations (Knight 1999). Similarly, effective area-wide management of *P. pyrusana* will require that populations in the surrounding cherry and non-bearing apple blocks be managed successfully.

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