Simultaneous disruption of pheromone communication and mating in *Cydia pomonella, Choristoneura rosaceana* and *Pandemis limitata* Lepidoptera:Tortricidae) using Isomate-CM/LR in apple orchards

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ABSTRACT

Simultaneous disruption of pheromone communication and mating of codling moth, *Cydia pomonella* (L), and four leafroller (Lepidoptera:Tortricidae) species, *Choristoneura rosaceana* (Harris), *Pandemis limitata* (Robinson), *Archips rosanus* (L.) and *Archips argyrospilus* (Walker) using an incomplete mixture of their individual pheromone components was studied in organic apple orchards, in Cawston, BC, 1997. Multi-species disruption with a single 500 'rope' dispenser / ha application of Isomate-CM/LR was compared to a single 500 dispenser / ha application of Isomate-C. Season-long disruption was assessed using synthetic pheromone traps and laboratory-reared females in mating tables. Mean seasonal recaptures of sterile male *C. pomonella,* using 10 mg codlemone lures in orchards receiving releases of 1000 males / ha / week, were not significantly different in half-orchard plots (0.5 - 1 ha) of Isomate-CM/LR or Isomate-C. Mating of *C. pomonella* in Isomate-C- and Isomate-CM/LR-treated plots was negligible. Isomate-CM/LR significantly reduced catches of *C. rosaceana* and *P. limitata* relative to catches in Isomate-C-treated plots. Few *A. rosanus* and no *A. argyrospilus* were caught in any orchard. Mating of *C. rosaceana* and *P. limitata* in Isomate-CM/LR-treated plots was significantly less than in Isomate-C-treated plots. Our results indicate Isomate-CM/LR will disrupt mating of *C. pomonella* equivalent to Isomate-C and may provide sufficient disruption of leafrollers to supplement biological control in organic orchards. Further studies are needed to show impacts of mating disruption on leafroller populations and damage when applied to larger areas and for several seasons sequentially.

Key Words: Codling moth, leafrollers, mating disruption, Isomate, organic apples

INTRODUCTION

Disruption of pheromone communication and mating of moths by releasing synthetic pheromones into the atmosphere is being employed worldwide as a highly-specific alternative to insecticides (Jutsum and Gordon 1989; Ridgway *et al.* 1990; Cardé and Minks 1995). While the specificity of pheromone controls is appealing for integrated programmes, this specificity undermines use in crops where secondary pests may become primary pests when use of insecticides is reduced (Croft and Hoyt 1983). Apple production in the Pacific Northwest is a good example of where pheromone-based mating disruption (Howell 1992; Judd *et al.* 1996) as a replacement for broad-spectrum insecticides to control codling moth, *Cydia pomonella* (L.), has resulted in increasing damage from several species (Brunner *et al.* 1994; Knight 1995; Gut and Brunner 1998) that are controlled to some degree by insecticides targeting codling moth (Madsen and Proctor 1985).

One solution to this problem is to broaden the range of action of mating-

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disruption products by combining pheromone components common to more than one species, or by mixing uncommon pheromone components from different species. There are few published examples of multi-species mating-disruption (Ridgway *et al.* 1990; Cardé and Minks 1995) but where this has been attempted it usually involves pheromone components common to closely related species (Pfeiffer *et al.* 1993; Deland *et al.* 1994; Evenden *et al.* 1999a,b). For example, four species of leafrollers (Lepidoptera:Tortricidae) found infesting apple orchards in BC (Madsen and Madsen 1980), the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), threelined leafroller, *Pandemis limitata* (Robinson), European leafroller, *Archips rosanus* (L.) and fruit-tree leafroller, *Archips argyrospilus* (Walker), all use (*Z*)-11-tetradecenyl acetate (*Z*11-14:Ac) as the major component in their multi-component pheromone blends (Arn *et al.* 1982). In small-plot studies, Deland *et al.* (1994) demonstrated that pheromone communication in *C. rosaceana*, *A. rosanus,* and *A. argyrospilus* could be disrupted with a 93:7 blend of *Z*11-14:Ac and (*E*)-11-tetradecenyl acetate (*E*11-14:Ac), and Evenden *et al.* (1999b) showed it was possible to simultaneously disrupt mating of *C. rosaceana* and *P. limitata* with a 98:2 blend of *Z*11-14:Ac and *E*11-14:Ac. Effectiveness of unattractive, generic pheromone blends as mating disruptants for these species is probably related to the fact that attraction to pheromone dispensers, i.e. false-trail following (*sensu* Bartell 1982), may not be necessary to achieve a high percentage of disruption (Knight *et al.* 1998; Evenden *et al.* 1999a,b,c; Knight and Turner 1999).

The alternative idea of using one dispensing system to release pheromone components uncommon to all species being targeted has been around for some time (Deventer *et al.* 1992), but there are few examples or commercial products. Isomate-CM/LR is a multi-species mating-disruption product that was registered in 1997 for commercial use in the United States to control codling moth and leafrollers. Isomate-CM/LR was not registered in Canada at that time because efficacy data were lacking (Heather McBrien, personal communication) and to the best of our knowledge there are still no published data on its use in Canada. With a view towards registering mating-disruption products for simultaneous control of codling moth and leafrollers in BC we tested the utility of Isomate-CM/LR as a commercial mating-disruption product (Shin-etsu Chemical Company, Tokyo, Japan).

The primary objective of this study was to test the hypothesis that codling moth pheromone could be mixed in the same reservoir and released with pheromone components of leafrollers without compromising disruption of this 'key' pest of apples which can be controlled with registered single-species disruption products like Isomate-C (Judd *et al.* 1996,1997). Secondly, we wanted a season-long assessment of communication and mating disruption of leafrollers with Isomate-CM/LR in commercial orchards, because previous work was conducted for short test periods, in small plots, with noncommercial dispensers (Deland *et al.* 1994; Evenden *et al.* 1999a,b,c). Our third objective was to begin gathering efficacy data on Isomate-CM/LR for Canadian registration agencies which was lacking in 1997.

MATERIALS AND METHODS

Test Orchards. Experiments were conducted in five, commercial organic apple orchards located in the Similkameen Valley, Cawston, BC (Judd *et al.* 1997). Orchards ranged in size from 1 - 2 ha and were composed of mixed apple varieties planted at densities of 600 - 900 trees / ha with tree × row spacings of 2.4 - 4.6 × 4.6 - 5.5 m, respectively. Trees ranged in height from 2.5 - 3.5 m and were pruned using a pyramid shape training system. Wild populations of codling moth were very low in these orchards due to successful use of mating disruption since 1990 (Judd *et al.* 1997) and benefits derived from release of sterile moths by the Okanagan-Kootenay Sterile Insect Release (SIR) programme (Dyck and Gardiner 1992). During the current study, SIR programme staff were releasing 1000 mixed sex (1:1 male:female ratio) sterile codling moths in each ha of every orchard two times each week. These standardized releases ensured there were approximately equal numbers of codling moths present in all orchards where we could assess disruption. No insecticides were applied to these orchards during this study.

Pheromone Disruption Treatments. Each orchard was divided into approximately equal halves (0.5 - 1 ha). One half was treated with Isomate-C and the other with Isomate-CM/LR. Both of these products are 'rope-type' twist-tie dispensers marketed by Pacific Biocontrol Corp., Vancouver, WA. Isomate-C is a translucent polyethylene dispenser containing a 155 mg blend of 58.8% (*E,E*)-8,10-dodecadien-1-ol (codlemone), 29.5% dodecanol, 5.3% tetradecanol and 6.4 % inert ingredients. Isomate-CM/LR is a brownish red polyethylene dispenser containing a 285 mg blend of 36.9% codlemone, 1.8% isomers of codlemone, 6.0% dodecanol, 1.2% tetradecanol, 43.5% *Z*11-14:Ac, 2.4% *E*11-14:Ac, and 8.2% inert ingredients, with similar design and release-rate characteristics as Isomate-C$^+$ which has superceded Isomate-C as a commercial product but which contains the same active ingredients (Don Thomson, personal communication).

All pheromone dispensers were deployed at a rate of 500 / ha between 1 May and 6 May. Dispensers were attached to branches in the upper third of the tree canopy ca. 0.5 - 1.0 m below the tip of the central leader or on the first lateral branch down from the tip.

Disruption of Pheromone Communication. Disruption of pheromone communication in codling moth was assessed by comparing catches of SIR-released sterile male moths in synthetic pheromone-baited traps in the two disruption treatments. Two Pherocon 1-CP style closed wing traps (Phero Tech Inc., Delta, B.C.) baited with 10 mg of codlemone (99% isomeric and chemical purity, Shin-etsu, Fine Chemicals Division, Tokyo, Japan) were deployed in each pheromone-treated plot (two traps / half-orchard treatment). Traps were hung ca.1.5 - 2.0 m above ground near the centre of each treatment on 8 May and were checked weekly until 18 September. Trap bottoms were replaced weekly and lures were changed every third week. Sterile codling moths were identified by an internal red dye sequestered from the artificial diet used to rear them (Dyck and Gardiner 1992).

Trap catches in pheromone-treated orchards were compared with catches in adjacent, paired conventional orchards also receiving sterile moths. These insecticide-treated, but non-pheromone-treated orchards, are hereafter referred to as "non-treated". Two wing traps baited with 1 mg of codlemone were deployed as above in each non-treated orchard. Weekly catches in these orchards provide a seasonal record of sterile moth activity in the absence of pheromone-disruption treatments.

Disruption of pheromone communication in leafrollers was assessed by comparing catches of male *C. rosaceana*, *P. limitata*, *A. rosanus*, and *A. argyrospilus* in the two pheromone-treated halves of each organic orchard. Two Pherocon 1-C style open (5 cm spacer) wing traps (Phero Tech Inc., Delta, B.C.) baited with 3 mg (Deland *et al.* 1994) of each species' pheromone were deployed in the middle of each pheromone-treatment (two traps / species / disruption treatment × four species). One trap for each species was hung ca.1.5 - 2.0 m above ground on different sides of the same tree, in each of two separate trees, ca. 20 m apart in the centre row of each plot. Positions for all traps remained fixed throughout the season. Traps were checked weekly from June 6 until September 18 when moths were removed and counted. All pheromone lures were changed at three-week intervals and trap bottoms were replaced as needed.

Synthetic pheromone baits for each leafroller species were prepared with chemical components (Aldrich Chemical Company Inc., Milwaukee, Wisconsin, USA) of known purity, as confirmed by gas-chromatographic analysis (*Z*11-14:Ac, 98% with 2% *E*11-14:Ac; *Z*11-14:Ald, 96%; *Z*11-14-:OH, 97%; Z9-14:Ac, 96%, and 12:Ac, 97%) using published ratios (Roelofs *et al.* 1976a,b; Vakenti *et al.* 1988; Deland *et al.* 1993).

In making pheromone lures for all five species, a 200 μl solution of each pheromone blend was dissolved in dichloromethane and loaded into separate red rubber septa (Aldrich Chemical Company Inc., Milwaukee, Wisconsin, USA). After loading, septa were air dried for ca. 18 h at 23 °C in a fume hood and stored at 0 °C until pinned to the inner side of trap lids in the field.

Disruption of Mating. Disruption of mating was assessed using virgin female moths in mating tables described by McBrien and Judd (1996). Only mating of *C. pomonella*, *C. rosaceana*, and *P. limitata*, was assessed because these were the only species we had in rearing. *C. pomonella* were reared on an artificial diet (Dyck and Gardiner 1992) at 27 °C under a 16:8 h L:D photoregime and *C. rosaceana* and *P. limitata* were reared on a modified pinto bean-based diet (Shorey and Hale 1965) at 24 °C and 16:8 h photoregime. Female pupae of each species were placed individually in 150-ml plastic cups provided with a wet cotton wick until adults eclosed. Female moths aged 24 - 72 h were immobilized at 0.5 °C and one forewing and a tarsal tip were clipped with fine forceps before transporting them to field sites in refrigerated containers.

Individual females of these three species were placed in the same tree, in the upper third of the canopy, in each of five trees laid out in a die pattern centred in each pheromone-treated plot. Females were several trees removed from their respective species-specific pheromone traps. Availability of female *C. pomonella* allowed us to deploy mating tables in non-treated orchards for comparison, but shortages of leafrollers prevented this deployment. All female moths were placed in the field in the afternoon and removed the following morning to minimize predation and escape. Females recovered from the field were returned to the laboratory and each *bursa copulatrix* was dissected and examined for the presence of a spermatophore which indicates they had mated. Females were omitted from the data if they were dead when recovered.

Female *C. pomonella* were placed in the field on two nights, every second week from 19 May until 6 September. Female leafrollers were placed in the field on 2 to 4 nights, every week for three consecutive weeks starting 3 July and 12 August which corresponded to peak flight periods of first and second generation, respectively.

Harvest Fruit Damage. Although our experiments were not designed to evaluate crop protection specifically, a sample of 2500 fruit was taken from each pheromone-treated plot in each of the five organic orchards in order to establish background levels of leafroller damage for future reference. Samples were taken during normal harvest dates as fruit maturity and growers dictated. All fruit were examined for damage from codling moth, including stings and deep entries, and early and late season leafroller feeding. Each half-orchard treatment was sampled by walking a "W" pattern from corner to corner and edge to edge and systematically choosing 25 trees, 5 edge and 20 interior trees. One hundred fruit were removed from each sample tree by picking 50 low and 50 high fruit from south-side branches.

Statistical Analyses. For each species, moth captures from both traps in each pheromone treatment in the same orchard were pooled and transformed ($\log_{10} [x + 1]$) to normalize the data. Mean seasonal cumulative moth catches in the two pheromone treatments were compared using an analysis of variance (ANOVA) appropriate for a randomized block design (Zar 1984), where orchards are blocks (n = 5) and there are 2 pheromone treatments assigned randomly to either half orchard. Statistical comparisons were not made between codling moth catches in pheromone-treated and non-treated orchards because the latter orchards were treated with insecticides that could confound any comparison. In addition, different strength lures were used to monitor codling moth in pheromone-treated and non-treated orchards. However, catches of sterile codling moths from non-treated orchards are presented for comparisons of their relative seasonal activity. Low recovery of females in mating tables meant mean percentage mating per orchard could not be estimated reliably, therefore recovered females were pooled across orchards by treatment and χ^2 tests were used to compare the frequency of mating in the two pheromone treatments. A randomized block ANOVA was used to compare mean damage estimates from the two treatments after an arcsine $\sqrt{p}$ transformation of the data.

RESULTS AND DISCUSSION

Disruption of Pheromone Communication in *C. pomonella*. In non-treated orchards the mean (± SE) seasonal catch of sterile codling moths / trap (1051.7 ± 307.2) was several times greater than catches in either pheromone-treatment (Table 1). Comparing catches of *C. pomonella* in this way likely underestimates the level of disruption achieved by pheromone treatments, because traps were baited with different strength lures and insecticides may have reduced catches of sterile moths in non-treated orchards. While the SIR programme dictated use of 1 mg lures in conventional orchards, we chose to use 10 mg lures in pheromone-treated plots because they ensured sufficient moth captures to detect differences in pheromone treatments. Disorientation of *C. pomonella* would likely appear greater had we used 1 mg lures in pheromone-treated orchards, because they catch very few moths in this situation relative to 10 mg lures (Judd *et al.* 1996). Correcting for this difference in relative attraction we calculate from catches in Table 1, that Isomate-C caused 91% and Isomate-CM/LR caused 90% disorientation relative to the 1051 moths caught / trap in non-treated orchards.

There was no significant difference ($P > 0.05$) in the mean seasonal number of sterile moths caught / trap in plots treated with Isomate-C (274.5 ± 44.4) or Isomate-CM/LR (311.9 ± 126.2). This result indicates that both pheromone treatments disrupted orientation of codling moth to a similar extent and therefore, the release of leafroller pheromone components from Isomate-CM/LR had no detrimental affect on disruption of codling moth pheromone communication (Table 1).

Mean weekly catches of sterile *C. pomonella* pooled across pheromone-treated orchards (Fig. 1A) reveals few weekly differences between rates of recapture in plots treated with Isomate-C or Isomate-CM/LR, suggesting both dispensers were equally disruptive under varied weekly weather conditions. Weekly catches of sterile moths under both pheromone treatments was low early in the season and began to increase near 3 July (Fig. 1A). This increase is more likely caused by a general increase in the activity of sterile moths, or response to traps as the season progressed, than by decreasing effects of disruption treatments. This conclusion is based on the fact that catches of sterile males in non-treated orchards also doubled in weeks 9 - 16 compared with weeks 1 - 8 (Fig. 1A).

Disruption of Pheromone Communication in Leafrollers. Mean seasonal catches of *C. rosaceana* and *P. limitata* were both significantly ($P < 0.05$) lower in the Isomate-CM/LR treatment than in the Isomate-C treatment (Table 1). Almost no *Archips spp.* were caught in any orchards, supporting the view that these species are generally found further north and more

Table 1.
Seasonal cumulative catches of male moths in synthetic pheromone-baited traps and mating of sentinel females in mating tables for each of four species in each half of five organic apple orchards treated with different commercial pheromone dispensers, Cawston, BC, 1997.

Moth species[1]	Commercial pheromone disruption treatment (500 dispensers / ha)	Mean (± SE) number of moths / trap[2]	% of females mating[3]
C. pomonella	Isomate-C	275.5 ± 44.4a	0.0a
	Isomate-CM/LR	311.9 ± 126.2a	0.9a
C. rosaceana	Isomate-C	752.7 ± 356.8a	25.9a
	Isomate-CM/LR	124.2 ± 187.6b	7.8b
P. limitata	Isomate-C	542.7 ± 241.5a	32.6a
	Isomate-CM/LR	84.7 ± 103.7b	5.6b
A. rosanus	Isomate-C	2.0 ± 0.8 nt	0.0 nt
	Isomate-CM/LR	0.0 ± 0.0	0.0
A. argyrospilus	Isomate-C	0.0 ± 0.0 nt	0.0 nt
	Isomate-CM/LR	0.0 ± 0.0	0.0

[1] All *C. pomonella* caught were sterile moths released (1000 males / ha / orchard / week) by the Okanagan-Kootenay Sterile Insect Release Programme.
[2] Means of seasonal cumulative catches in two traps in each of five orchards. Paired means within a species followed by different letters are significantly different ($P < 0.05$) by Randomized Block ANOVA. nt = no test.
[3] Paired percentages within a species followed by different letters are significantly ($P < 0.05$) different by χ^2 tests on observed frequencies of mating.

frequently in the Okanagan than in the Similkameen Valley (Madsen and Madsen 1980).

Weekly catches of *C. rosaceana* are shown in Fig. 1B. Catch curves in both treatments reflect a large first-generation and small second-generation flight. This pattern is typically seen in insecticide-treated orchards and is thought to occur because insecticides applied during first generation reduce second-generation populations (Madsen and Madsen 1980). This cannot explain our results because organic orchards were not treated with insecticides. A small second-generation flight may arise because first-brood larvae often enter diapause early in this region. Therefore, control of this first generation is important because it prevents an escape of insects that give rise to an overwintering population with potential to undermine long-term control.

Weekly catches of *C. rosaceana* were reduced 70.9 - 100% in the Isomate–CM/LR treatment relative to the Isomate-C treatment (Fig. 1B), and reductions averaged 90.3% for the season across all orchards (Table 1). Deland *et al.* (1994) reported a similar 89 - 91% average disorientation of *C. rosaceana* to synthetic pheromone traps in 0.1 ha plots treated with 1000 - 2000 Hamaki-con (Shin-etsu Chemical Company Ltd., Tokyo, Japan) dispensers per ha, releasing a 93:7 blend of *Z*11-14:Ac and *E*11-14:Ac at ca. 20 - 40 mg / ha / h (Deland 1992). Given that a single Isomate-CM/LR dispenser releases ca. 1 mg *Z*11-14:Ac / day in the Okanagan Valley (GJRJ, unpublished data), 500 Isomate-CM/LR dispensers would release ca. 21 mg / ha / h. Therefore, using more than 500 Isomate-CM/LR dispensers per ha to disrupt *C. rosaceana* would seem unwarranted.

Weekly catches of *P. limitata* are shown in Fig. 1C. Unlike catches of *C. rosaceana*, which showed two distinct peaks in the Isomate-C treatment (Fig. 1B), catches of *P. limitata* remained high all season in the Isomate-C treatment (Fig.

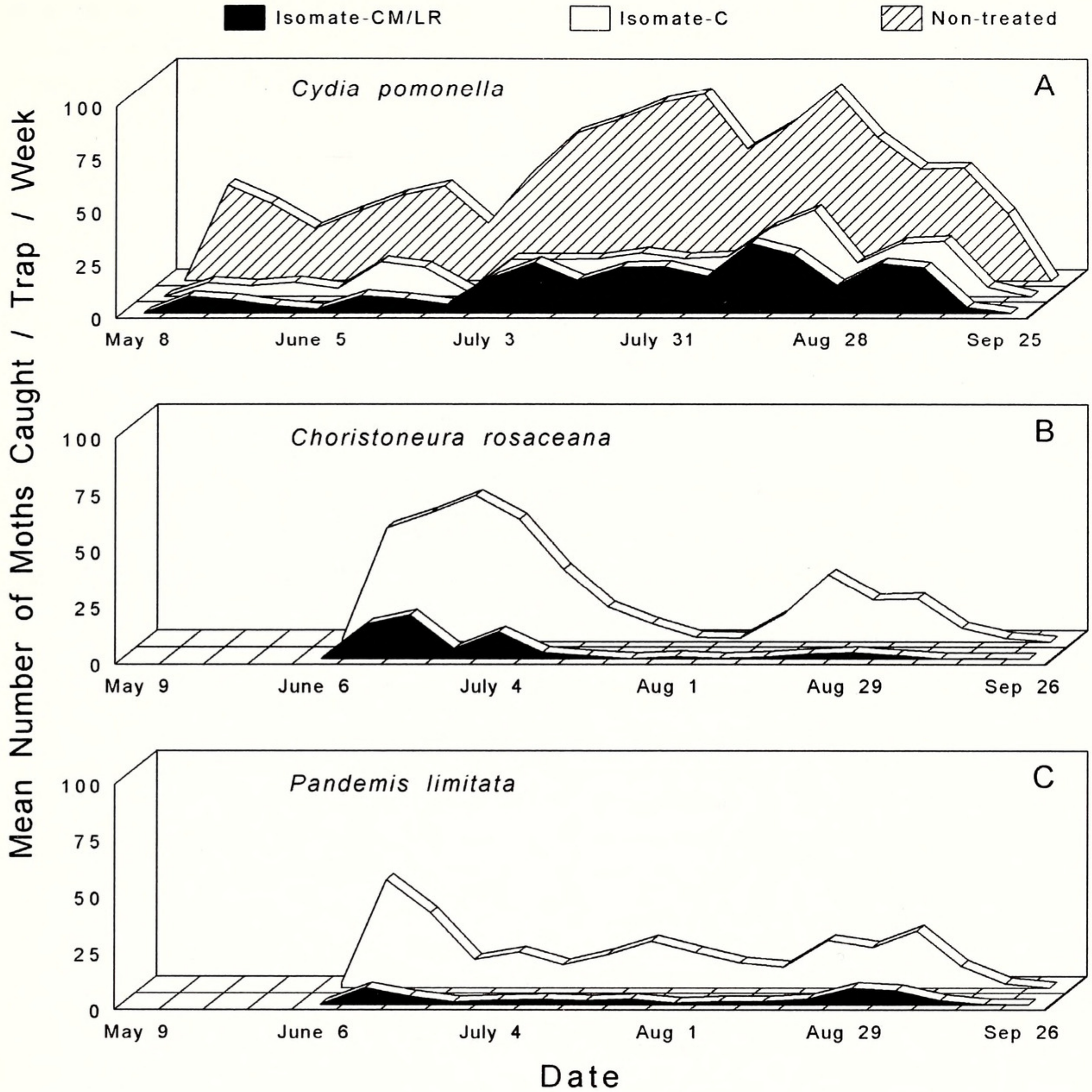

Figure 1. Mean weekly catches of mass-reared, sterile male *Cydia pomonella* released by the Okanagan-Kootenay SIR Programme (**A**), wild male *Choristoneura rosaceana* (**B**) and wild male *Pandemis limitata* (**C**) in their respective species-specific synthetic pheromone-baited traps hung in non-treated conventional apple orchards (*C. pomonella*) and in Isomate-C- and Isomate-CM/LR-treated halves of organic apple orchards (all species) in Cawston, BC, 1997.

1C). This is quite different from the two distinct peaks Madsen and Madsen (1980) observed in insecticide-treated conventional orchards. Catches of *P. limitata* in the Isomate-CM/LR treatment showed early and late season peaks, but moths were always being caught in low numbers. A second peak in the Isomate-CM/LR treatment may indicate leafroller pheromone was running out late in the season as found by Knight *et al.* (2001). Given the date dispensers were deployed and a 1 mg / day release rate, dispensers were expected to run out of Z11-14:Ac between 24 - 30 August, exactly when the second peak of catches occurred (Fig. 1C). To make it a reliable product more data are needed on the release of various pheromone components from Isomate-CM/LR dispensers in relation to temperature.

Weekly catches of *P. limitata* were reduced 67 - 100% by treatment with Isomate-CM/LR (Fig. 1C) and reductions averaged 88.9% for the season across all orchards (Table 1), relative to the Isomate-C treatment.

Disruption of Mating in *C. pomonella*. Mating of *C. pomonella* in non-treated orchards receiving sterile moths averaged 48.7% during late May and June and 59% in July and August. In spite of very large numbers of sterile males being released in this study (1000 / ha / week), almost no sentinel female *C. pomonella* mated in either pheromone treatment, and there was no significant difference (χ^2 = 0.34, df = 1, $P > 0.05$) in the frequency of mating in the Isomate-C (0 / 223) and Isomate-CM/LR treatments (2 / 212). Mating frequency of *C. pomonella* in our Isomate-C treatment was quite low when compared with the frequencies of mating among feral codling moths reported by Knight (1996) using passive pane traps, or by Howell (1992) using black light traps, both in Isomate-C-treated orchards. While there may be discrepancy between different assessment methods, our evaluation of mating is suitable in this context because the relative difference in mating between the two pheromone treatments is of interest here. Given that Isomate-C is known to control populations of *C. pomonella* (Judd *et al.* 1996) and there appears to be little difference in levels of trap disorientation and mating disruption using Isomate-CM/LR, we expect the level of control with these two products to be similar.

Disruption of Mating in Leafrollers. On average, 25.9% (14 / 54) of female *C. rosaceana* and 32.6% (34 / 104) of female *P. limitata* mated when placed in the Isomate-C treatment having no leafroller pheromone, while only 7.8% (5 / 64) and 5.6% (6 / 107) of each species, respectively, mated in the Isomate-CM/LR treatment. Isomate-CM/LR significantly (χ^2 = 5.84, df = 1, $P < 0.05$) reduced mating of *C. rosaceana* by 70% and *P. limitata* by 83% (χ^2 = 23.4, df = 1, $P < 0.001$), relative to the Isomate-C treatment. Our seasonal level of mating disruption in *C. rosaceana* was somewhat lower than the 86% observed by Evenden *et al.* (1999b) using a similar blend (100:2 ratio of *Z*11-14:Ac and *E*11-14:Ac) and the same dispenser density (500 / ha) in 0.1 ha plots. Lower levels of disruption in our study may be due to higher population densities, or movement of *Z*11-14:Ac into the Isomate-C treatment used for comparison. Simultaneous release of codlemone from Isomate-CM/LR dispensers cannot explain any differences between these studies because *C. rosaceana* is not known to detect this chemical (GJRJ, unpublished electroantennograms).

Mating of *C. rosaceana* was similar in first (7.4%) and second generation (8.1%) and although catches of *P. limitata* increased during second generation (Fig. 1C), there was no increase in the frequency of their mating between first (7.5%) and second (2.4%) generation in Isomate-CM/LR-treated plots. Therefore, the amount of pheromone being released late in the season appears to have been adequate to control mating in leafrollers even if catches appeared to increase (Fig. 1C). Our 83% seasonal average mating disruption for *P. limitata* was similar to the 85% observed by Evenden *et al.* (1999b) when 1000 dispensers / ha were employed. Like *C. rosaceana* above, there may be little value in using more than 500 Isomate-CM/LR dispensers per ha to disrupt mating in *P. limitata*.

Fruit Damage. As expected given low levels of wild codling moths, release of sterile males, and treatment with pheromone, there was no detectable codling moth damage in any orchard. Leafroller damage was very high in these organic orchards and there was no significant ($P >$ 0.05) difference in the mean percentage of damage in plots receiving Isomate-C (10.9 ± 5.4%) or Isomate-CM/LR (8.7 ± 4.7%). These damage levels suggest densities of leafrollers were very high and crop protection can fail under high population densities even if measures of disruption are large (Judd *et al.* 1996, 1997). While we do not consider our experiment to be a fair evaluation of leafroller control by mating disruption, these data should provide a useful baseline for longer-term mating-disruption trials.

Our studies have demonstrated it is possible to simultaneously disrupt pheromone communication and mating in sympatric tortricid moths by releasing an incomplete mixture of their individual pheromone components. Levels of disorientation and reductions in mating of all species with Isomate-CM/LR were comparable to those seen in studies examining each species individually (Deland *et al.* 1994; Evenden *et al.* 1999a,b,c). Our data suggest control of codling moth with Isomate-CM/LR should be comparable to control with registered products like Isomate-C^{+} and Isomate-C (Judd *et al.* 1996). Isomate-CM/LR also has potential for supplementary control of leafrollers. These conclusions are supported by several studies using Isomate-CM/LR in Washington State (Knight *et al.* 1997; Knight 1998; Knight *et al.* 2001). These non-refereed reports suggest that when used on an area-wide basis for three years (1998 - 2000), orchards treated with Isomate-CM/LR and supplemental insecticides had 41% less leafroller damage, received one less spray per season and consistently had less codling moth damage than orchards receiving Isomate-C^{+} and supplemental sprays.

Lacking in these studies unfortunately, are data from Isomate-CM/LR-treated orchards receiving no supplemental insecticides. Ours is the only evaluation of Isomate-CM/LR where no insecticides were applied and the only one reporting actual mating data that we are aware of. These kinds of data are useful for registration of pheromones in Canada. Efficacy data based on fruit damage are also needed but our study lacks this assessment because the split-orchard design resulted in treatment areas too small to prevent movement of mated females or ballooning larvae between treatments. Therefore, it remains to be shown whether measures of disruption observed here will impact the population dynamics of these species and control damage effectively without use of insecticides. In this regard, Isomate-CM/LR may have a role to play in supplementing biological control of leafrollers in organic apple orchards where parasitism rates as high as 68% are common during summer in the Similkameen Valley (Cossentine *et al.* 2004).

During the revision of this manuscript Isomate-CM/LR was registered by the Canadian Pest Management Regulatory Agency (Heather McBrien, personal communication). Nevertheless, multiple-year mating-disruption trials still need to be conducted in larger orchards, or on an area-wide basis (Knight *et al.* 2001), and under lower population pressure than seen in this study, before any conclusions about the efficacy of mating disruption as a crop-protection tool for leafrollers in BC can be made.

ACKNOWLEDGEMENTS

We thank the Similkameen-Okanagan Organic Producers' Association (SOOPA) and its cooperating members for allowing us to conduct trials in their orchards. We also thank Nicole Verpaelst for technical field assistance. We especially thank Don Thomson from Pacific Biocontrol Corporation for making Isomate-CM/LR available for testing and sharing technical data on this product. This research was partially funded by the Washington State Tree Fruit Research Commission, SOOPA and the Agriculture and Agri-Food Canada Matching Investment Initiative.

REFERENCES

Arn, H., M. Tóth, and E. Priesner. 1982. List of sex pheromones of Lepidoptera and related attractants, 2nd Edition. International Organization for Biological Control, Montfavet.

Bartell, R.J. 1982. Mechanisms of communication disruption by pheromone in the control of Lepidoptera: a review. Physiological Entomology 7: 353-364.

Brunner, J.F., L.J. Gut, and A.L. Knight. 1994. Transition of apple and pear orchards to a pheromone-based pest management system. Proceedings of the Washington State Horticultural Association 88: 169-175.

Cardé, R.T. and A.K. Minks. 1995. Control of moth pests by mating disruption: successes and constraints. Annual Review of Entomology 40: 559-585.

Cossentine, J., L. Jensen, E. Deglow, A. Bennett, H. Goulet, J. Huber, and J. O'Hara. 2004. The parasitoid complex affecting *Choristoneura rosaceana* and *Pandemis limitata* in organically managed apple orchards. BioControl 49: 359-372.

Croft, B.A. and S.C. Hoyt (eds.). 1983. Integrated Management of Insect Pests of Pome and Stone Fruits. John Wiley and Sons Inc., New York.

Deland, J.-P. 1992. Mating disruption of fruittree leafroller, *Archips argyrospilus*, and effects on other leafroller species. Master of Pest Management Thesis. Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia, Canada. 78 pp.

Deland, J.-P., R. Gries, G. Gries, G.J.R. Judd, and B.D. Roitberg. 1993. Sex pheromone components of the fruittree leafroller, *Archips argyrospilus* (Walker) (Lepidoptera: Tortricidae), in British Columbia. Journal of Chemical Ecology 19: 2855-2864.

Deland, J.-P., G.J.R. Judd, and B.D. Roitberg. 1994. Disruption of pheromone communication in three sympatric leafroller (Lepidoptera: Tortricidae) pests of apple in British Columbia. Environmental Entomology 23: 1084-1090.

Deventer, van P., A.K. Minks, L.H.M. Blommers, U. Neuman, and K. Jilderda. 1992. Mating disruption utilizing lepidopterous sex pheromones: three years of testing in apple orchards in The Netherlands. Brighton Crop Protection Conference — Pests and Diseases. 3: 1193-1198.

Dyck, V.A. and M.G.T. Gardiner. 1992. Sterile-insect release programme to control the codling moth *Cydia pomonella* (L.) (Lepidoptera: Olethreutidae) in British Columbia, Canada. Acta Phytopathologica et Entomologica Hungarica 27: 219-222.

Evenden, M.L., G.J.R. Judd, and J.H. Borden. 1999a. Simultaneous disruption of pheromone communication in *Choristoneura rosaceana* and *Pandemis limitata* with pheromone and antagonist blends. Journal of Chemical Ecology 25: 501- 517.

Evenden, M.L., G.J.R. Judd, and J.H. Borden. 1999b. Mating disruption of two sympatric, orchard-inhabiting tortricids, *Choristoneura rosaceana* and *Pandemis limitata* (Lepidoptera: Tortricidae) with pheromone components of both species' blends. Journal of Economic Entomology 92: 380-390.

Evenden, M.L., G.J.R. Judd, and J.H. Borden. 1999c. Pheromone-mediated mating disruption of *Choristoneura rosaceana*: is the most attractive blend really the most effective? Entomologia Experimentalis et Applicata 90: 37-47.

Howell, J.F. 1992. Two years of commercial use of Isomate-C to disrupt mating for control of codling moth. Proceedings of the Washington State Horticultural Association 88: 176-181.

Gut, L.J. and J.F. Brunner. 1998. Pheromone-based management of codling moth (Lepidoptera: Tortricidae) in Washington apple orchards. Journal of Agricultural Entomology 15: 387-405.

Judd, G.J.R., M.G.T. Gardiner, and D.R. Thomson. 1996. Commercial trials of pheromone-mediated mating disruption with Isomate-C® to control codling moth in British Columbia apple and pear orchards. Journal of the Entomological Society of British Columbia 93: 23-34.

Judd, G.J.R., M.G.T. Gardiner, and D.R. Thomson. 1997. Control of codling moth in organically-managed apple orchards by combining pheromone-mediated mating disruption, post-harvest fruit removal and tree banding. Entomologia Experimentalis et Applicata 83: 137-146.

Jutsum, A.R. and R.F.S. Gordon (eds.). 1989. Insect Pheromones in Plant Protection. John Wiley and Sons Ltd., Chichester, United Kingdom. 369 pp.

Knight, A.L. 1995. The impact of codling moth (Lepidoptera:Tortricidae) mating disruption on apple pest management in Yakima Valley, Washington. Journal of the Entomological Society of British Columbia 92: 29-38.

Knight, A.L. 1996. Why so many mated female codling moth in disrupted orchards? Proceedings of the Washington State Horticultural Association 92: 213-214.

Knight, A.L. 1998. Development of mating disruption for leafrollers. *In* Proceedings of the 72nd Annual Western Orchard Pest and Disease Management Conference, Portland, Oregon, U.S.A. January 7-9, 1998. WOPDMC 72: 99.

Knight, A.L. and J.E. Turner. 1999. Mating disruption of *Pandemis* spp. (Lepidoptera: Tortricidae). Environmental Entomology 28: 81-87.

Knight, A., S. Cockfield, D. Thomson, and D. Neff. 1997. Developing mating disruption for leafrollers. *In* Proceedings of the 71st Annual Western Orchard Pest and Disease Management Conference, Portland, Oregon, U.S.A. January 8-10, 1997. WOPDMC 71: 112-114.

Knight, A.L., D.R. Thomson, and S.D. Cockfield. 1998. Developing mating disruption of obliquebanded leafroller (Lepidoptera:Tortricidae) in Washington State. Environmental Entomology 27: 1080-1088.

Knight, A.L., B.A. Christianson Jr., S. Cockfield, and J. Dunley. 2001. Areawide management of codling moth and leafrollers. Good Fruit Grower 52 (11): 31-33.

Madsen, H.F. and B.J. Madsen. 1980. Response of four leafroller species (Lepidoptera: Tortricidae) to sex attractants in British Columbia orchards. The Canadian Entomologist 112: 427-430.

Madsen, H.F. and P.J. Procter. 1985. Insects and mites of tree fruits in British Columbia. British Columbia Ministry of Agriculture and Food. 82-6. Victoria, B.C. 70 pp.

McBrien, H.L., and G.J.R. Judd. 1996. Teflon®-walled mating table for assessing the efficacy of pheromone-based mating disruption. Journal of the Entomological Society of British Columbia 93: 121-125.

Pfeiffer, D.G., W. Kaakeh, J.C. Killian, M.W. Lachance, and P. Kirsch. 1993. Mating disruption to control damage by leafrollers in Virginia apple orchards. Entomologia Experimentalis et Applicata 67: 47-56.

Ridgway, R.L., R.M. Silverstein, and M.N. Inscoe. 1990. Behavior-modifying chemicals for insect management, applications of pheromones and other attractants. Marcel Dekker, Inc., New York, U.S.A. 761 pp.

Roelofs, W., A. Cardé, A. Hill, and R. Cardé. 1976a. Sex pheromone of the threelined leafroller, *Pandemis limitata*. Environmental Entomology 5: 649-652.

Roelofs, W., A. Hill, A. Cardé, R. Cardé, H. Madsen, and J. Vakenti. 1976b. Sex pheromone of the European leafroller, *Archips rosanus*. Environmental Entomology 5: 362-364.

Shorey, H.H. and R.L. Hale. 1965. Mass-rearing of the larvae of nine noctuid species on a simple artificial medium. Journal of Economic Entomology 58: 522-524.

Vakenti, J.M., A.P. Guance, K.N. Slessor, G.G.S. King, S.A. Allan, H.F. Madsen, and J.H. Borden. 1988. Sex pheromone components of the oblique-banded leafroller, *Choristoneura rosaceana* in the Okanagan Valley of British Columbia. Journal of Chemical Ecology 14: 605-621.