Monitoring the Seasonal Flight Activity of *Cydia pomonella* and *Argyrotaenia velutinana* (Lepidoptera: Tortricidae) in Apple Orchards by Using Pheromone-Baited Traps

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ABSTRACT Codling moth, *Cydia pomonella* (L.), and redbanded leafroller, *Argyrotaenia velutinana* (Walker), are two key tortricid orchard pests in Minnesota. Field trials were conducted during 2001 and 2002 in Minnesota apple orchards to determine seasonal phenology of *C. pomonella* and *A. velutinana* and to evaluate two popular trap designs (Pherocon 1CP or 1C "Wing" trap versus Pherocon VI "delta" trap) for monitoring both species. Trap performance was determined by comparing the number of males captured, date of first moth capture, and the capture of nontarget beneficial insects. For *C. pomonella*, two distinct flight periods were recorded, suggesting two generations per year in Minnesota. Emergence and flight activity of first generation *C. pomonella* began at ≈110 degree-days (DD) base 10°F. This corresponded to apple bloom in southern Minnesota. The delta trap captured significantly more *C. pomonella* males than the wing trap (Pherocon 1CP version). For *A. velutinana*, three flight periods were recorded at all three locations in both years of the study. The first flight began at ≈55 DD base 10°F, around the tight cluster stage of apple in southern Minnesota. Both trap types captured approximately the same numbers of *A. velutinana* males in both years of this study. For both species, the dates of first moth capture were generally the same for both trap types, indicating that both types of traps are capable of detecting the first flights of *C. pomonella* and *A. velutinana* males. In general, the delta trap was less selective than the wing trap (Pherocon 1C), capturing significantly more nontarget beneficial insects, in particular bees.

KEY WORDS *Cydia pomonella,* codling moth, *Argyrotaenia velutinana*, redbanded leafroller, pest monitoring

PEST MONITORING IS A fundamental component of integrated pest management (IPM) programs. Monitoring helps to determine the occurrence and seasonal activity of pests and, if efficient, can provide reliable and valuable information for forecasting pest damage and can determine when to initiate pest management practices. Although several techniques (e.g., blacklight traps and sweep nets) can be used to monitor adult populations of insects, pheromone-baited traps are more routinely used to monitor the flight periods of several adult lepidopteran pests of field and fruit crops (Willson and Trammel 1980, Howell 1984, Durant et al. 1986, Knodel and Agnello 1990, Vincent et al. 1990, Delisle 1992). Passive interception traps also are increasingly used for orchard pest monitoring, in particular in sex pheromone-treated orchards (Weissling and Knight 1994, Knight 2000).

Several members of the lepidopteran family Tortricidae are important pests of apple orchards in North America with the potential to cause significant economic loss to commercial fruit growers. They include codling moth, *Cydia pomonella* (L.); oriental fruit moth, *Grapholita molesta* Busck; lesser appleworm, *Grapholita prunivora* Walsh; redbanded leafroller, *Argyrotaenia velutinana* (Walker); and obliquebanded leafroller, *Choristoneura rosaceana* (Harris). Larvae of *C. pomonella*, *G. molesta*, and *G. prunivora* feed on apple fruit, whereas larvae of *A. velutinana* and *C. rosaceana* are primarily foliage feeders (Chapman and Lienk 1971). Many apple growers in Minnesota have reported infestation and damage by tortricid pests. However, little is known about the occurrence, seasonal phenology, and pest status of key tortricid orchard pests in the different parts of the state.

A variety of commercial traps and lures are used to monitor lepidopteran orchard pests with varying degrees of performance and efficacy. With the increasing adoption of IPM-based strategies such as of action thresholds, mating disruption, and biological control, it is crucial that growers and consultants use the most sensitive, precise, and selective traps available. Evaluations of monitoring traps for key moth pests of apple in North America have been conducted mainly in the major apple-producing states, sometimes with varying results (Howell 1984, Knodel and Agnello 1990, Vin-

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cent et al. 1990, Knight 2000). For example, Knodel and Agnello (1990) evaluated the relative effectiveness of several sticky and nonsticky traps for monitoring major apple pests in New York and reported that trap efficacy varied with moth species and trap design. Of the six trap types evaluated, the delta trap captured the highest number of *C. pomonella* males outperforming the Multi-Pher 1 (a nonsticky trap) and other trap types tested. In contrast, Vincent et al. (1990) evaluated the performance two sticky and two nonsticky traps in Quebec and Ontario, Canada, and several parts of northeastern United States and reported that the Multi-Pher I trap had a higher frequency of maximum seasonal captures of *C. pomonella* than other trap types. The authors further reported that trap performance varied between sprayed and unsprayed orchards. These results suggest that pest phenology and response to pheromone traps may not only vary from region to region but also by orchard management type.

Very little is known about the performance of pheromone-baited traps under Minnesota conditions or in many other parts of the upper Midwestern United States. In the absence of local scientific data on trap performance, fruit growers in Minnesota have been reluctant to use pheromone-baited traps. Studies have confirmed that *C. pomonella, A. velutinana,* and *C. rosaceana* are the predominant tortricid species found in Minnesota apple orchards (Fadamiro and Ciborowski 2003, Fadamiro 2004). The objectives of this study were to determine the seasonal phenology of *C. pomonella* and *A. velutinana* in Minnesota apple orchards and to evaluate the effectiveness and specificity of two common types of commercially available pheromone-baited traps for monitoring populations of both species in the region. Data from this study will be used to provide monitoring recommendations and guidelines for both apple pests in Minnesota.

Materials and Methods

The phenology of *C. pomonella* and *A. velutinana* in Minnesota was determined using trap data from three orchards located in different parts of Minnesota. A preliminary survey conducted in 2000 confirmed that both species predominate in Minnesota orchards. Experiments were conducted during the 2001 and 2002 field seasons at three commercial apple orchards (locations). The orchards were located in Elgin (southeast Minnesota), Hastings (east central Minnesota), and Fairhaven (west central Minnesota). The selected orchards were managed with the use of conventional practices typical of most commercial apple orchards in Minnesota. Of the three locations, Elgin was the southernmost location, whereas Fairhaven was the northernmost location.

Two types of sticky traps, Pherocon VI "delta" trap and Pherocon 1CP/1C "Wing" trap were evaluated for the two species. The two traps were selected because of their popularity among growers and other stakeholders. The Pherocon 1C/1CP (wing) type is probably the most widely used trap in North America (Riedl et al. 1986). However, the Pherocon VI (delta) type is favored by many because of its relative ease of deployment and maintenance. Both the delta and wing traps were made with a weather-resistant, white (delta) or off-white (wing) plastic material. The disposable, white, sticky-coated bottoms (liners) also were made with plastic. For *C. pomonella,* the Pherocon 1CP wing trap version was evaluated (being the common wing trap used for the species), whereas the Pherocon 1C was evaluated for *A. velutinana.* The two wing trap versions differ in dimension and size of the trap opening (the gap between the top and bottom parts of a trap). Pherocon 1CP is smaller in liner catch surface area (234 cm^2) than Pherocon 1C (394 cm^2). The top and bottom (liner) parts of Pherocon 1CP are fitted without the use of spacers, resulting in a close fit between the top and bottom parts, and relatively small trap openings (compared with Pherocon 1C in which spacers are used). All traps were manufactured by Trécé Inc. (Salinas, CA) and supplied by Great Lakes IPM Inc. (Vestaburg, MI). The experiment was a randomized complete block design replicated in four blocks per orchard. Each orchard was divided into four blocks where the experiment was replicated. In each block, two pheromone-baited traps (a delta and a wing trap) were deployed for each species (i.e., each orchard contained eight traps or four replicates of each trap design arranged in four parallel tree rows or blocks for each species). Each trap was baited with one pheromone rubber septum lure (Trécé Inc., 1-mg total pheromone dosage) for the target species. In addition, one unbaited (control) trap of each type was placed in each block. In each block, traps were randomly placed along a single row of apple trees at ≈1.5 m above the ground and spaced apart by at least 20 m. Traps were deployed in the third week of April 2001 and in the first week of May 2002.

The Leaf Wetness & Temperature logger (Spectrum Technologies, Inc., Plainfield, IL) was used to relate pest emergence to degree-day (DD) accumulations. One logger was placed in each orchard at the end of March each year, when the average temperatures were still too low for any accumulation of degree-days at base 10°C (Riedl et al. 1976, Pitcairn et al. 1992). Data from each logger was downloaded weekly onto a computer laptop via a cable. Using the product software, the degree-day (at base 10°C) summary was generated from the daily temperature data for each orchard.

Traps were checked weekly by counting and recording the number of males of each target species per trap. Captures of nontarget beneficial insects (i.e., ladybird beetles, wasps, lacewings, and bees) also were counted and recorded for each trap to determine trap selectivity. The position of each trap was rerandomized biweekly to minimize potential effect of trap position on capture. Pheromone lures were replaced every 4 wk in accordance with manufacturer's recommendation, and trap liners were cleaned after each weekly count and replaced as necessary. Actual capture in pheromone traps was calculated by subtracting captures in unbaited control traps of each type from

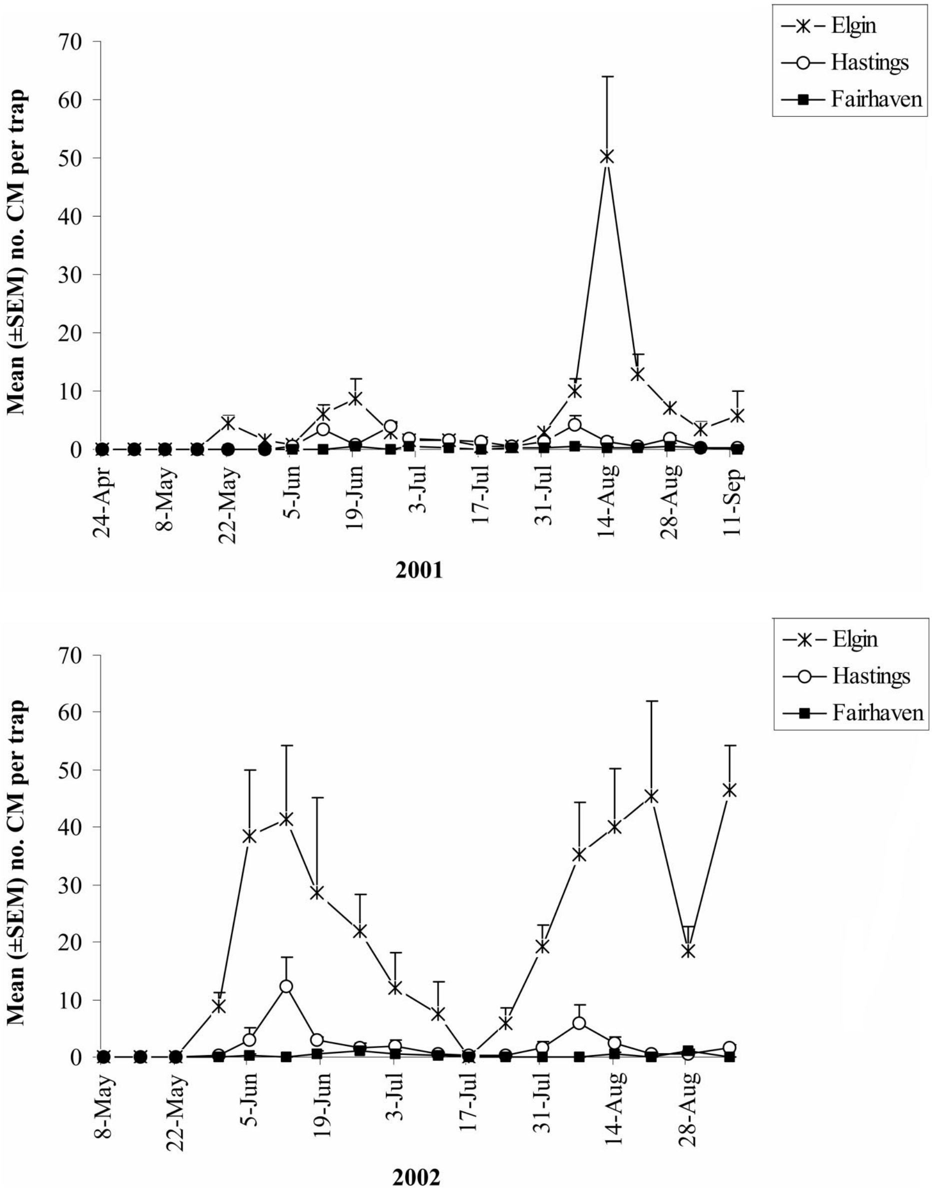

Fig. 1. Seasonal phenology of codling moth, *C. pomonella* (CM) in Minnesota. Figure shows mean (±SEM) weekly capture of *C. pomonella* in pheromone-baited delta traps during 2001 and 2002 field seasons at three locations in Minnesota.

captures in pheromone-baited traps. Weekly trap catch data were normalized by using the square-root transformation ($\sqrt{x + 0.5}$). Data for each species, location, and year were analyzed separately. For each orchard and during each year, seasonal mean capture per week was calculated for each block (replicate), and this value was then used to calculate the seasonal mean capture for each trap type (means of four replicates per trap type). The date of first moth capture also was noted for each trap. Seasonal mean captures were compared by using analysis of variance (ANOVA, JMPIN version 4.0.2, SAS Institute 1985) to test for the effects of treatment (trap types) and block (replicates). Significant differences were established at the 95% confidence level ($P < 0.05$).

Results and Discussion

C. pomonella. Two distinct flight activity periods of *C. pomonella* males were recorded at Elgin and Hastings during both 2001 and 2002 seasons, indicating two generations of *C. pomonella* per year at the two locations (Fig. 1). In both years of the study, trap captures of *C. pomonella* at the third location (Fairhaven) were too low to indicate any flight peaks. Two generations per year also have been reported for *C. pomonella* in

Table 1. Seasonal mean capture of codling moth and beneficial insects per week in delta and wing traps baited with *C. pomonella* sex pheromone lures during 2001 and 2002 field seasons at three locations in Minnesota

Location	Yr	Trap	Mean (±SEM) trap capture/wk		
			CM	Bees	BNF
Elgin	2001	Delta	7.10 ± 0.92	0.66 ± 0.17	0.96 ± 0.19
		Wing	3.51 ± 0.52	0.41 ± 0.11	0.67 ± 0.12
		F	12.5	0.6	0.8
		df	1, 3	1, 3	1, 3
		P	0.04	0.49	0.44
	2002	Delta	24.63 ± 2.24	0.35 ± 0.08	0.42 ± 0.09
		Wing	10.43 ± 1.78	0.0 ± 0.0	0.0 ± 0.0
		F	19.6	12.7	21.1
		df	1, 3	1, 3	1, 3
		P	0.02	0.04	0.02
Hastings	2001	Delta	1.35 ± 0.16	0.93 ± 0.33	1.21 ± 0.34
		Wing	0.74 ± 0.13	0.04 ± 0.09	0.23 ± 0.10
		F	1.8	3.9	3.4
		df	1, 3	1, 3	1, 3
		P	0.27	0.14	0.16
	2002	Delta	2.33 ± 0.42	0.76 ± 0.24	0.93 ± 0.25
		Wing	1.27 ± 0.21	0.04 ± 0.07	0.08 ± 0.08
		F	13.0	8.5	9.2
		df	1, 3	1, 3	1, 3
		P	0.04	0.06	0.05
Fairhaven	2001	Delta	0.21 ± 0.05	0.82 ± 0.18	0.94 ± 0.18
		Wing	0.24 ± 0.05	0.04 ± 0.06	0.10 ± 0.07
		F	0.2	19.3	20.5
		df	1, 3	1, 3	1, 3
		P	0.65	0.02	0.02
	2002	Delta	0.27 ± 0.07	0.38 ± 0.08	0.50 ± 0.09
		Wing	0.25 ± 0.07	0.01 ± 0.03	0.13 ± 0.05
		F	0.08	6.1	4.9
		df	1, 3	1, 3	1, 3
		P	0.80	0.09	0.11

BNF, all beneficial insects (i.e., lady beetles, wasps, lacewings, and bees); CM, codling moth.

many parts of North America (Spuler 1930, Madsen and Sanborn 1962, Knodel and Agnello 1990, Varela et al. 1993, Knight 2000). Knight (2000) recorded two generations per year for *C. pomonella* in Washington. In California, *C. pomonella* is reportedly multivoltine with two generations occurring in the colder regions and up to four generations in the warmest growing regions (Pitcairn et al. 1992). However, Roberts and Hagley (1986) recorded one and a partial second generation for *C. pomonella* in Ontario, Canada. First capture of *C. pomonella* males began at ≈110 DD base 10°C, which corresponded to apple bloom in southern Minnesota. At Elgin (the southernmost location), this occurred around the third week of May 2001 and last week of May 2002. Spring emergence was delayed 1–2 wk at Hastings (central location) and Fairhaven (the northernmost of the three locations) (Table 3).

The seasonal mean captures of *C. pomonella* in pheromone-baited traps are shown in Table 1. The delta trap captured significantly more *C. pomonella* males than the wing trap (Pherocon 1CP) at Elgin in 2001 and 2002, and at Hastings in 2002. Although, the delta trap captured almost twice the number of *C. pomonella* per week than the wing trap at Hastings in 2001, this number was not significant. No significant difference in trap capture of *C. pomonella* was recorded at Fairhaven in 2001 or 2002, possibly because trap captures were generally low at this location. Significant differences were recorded in the numbers of bees and all beneficial insects captured at some locations (Table 1). The delta traps baited with *C. pomonella* pheromone captured significantly more bees and non-target beneficial insects than *C. pomonella* pheromone-baited wing traps at Elgin in 2002, at Hastings in 2002, and at Fairhaven in 2001. The higher trap efficacy of the delta trap (liner surface area 379 cm^2) over the Pherocon 1CP wing trap (liner surface area 234 cm^2) may be related to its larger liner catch surface area, or to differences in trap design. The dates of first moth capture were generally the same for both trap types, except in two instances (Table 3), indicating that both traps are capable of detecting the first flights of *C. pomonella* males. The wing trap is the most widely used trap for *C. pomonella* (Riedl et al. 1986). However, the delta trap captured twice as many males as wing trap in this study, suggesting that the delta trap is more efficient in terms of the number of *C. pomonella* captured. This is in agreement with the result of Knodel and Agnello (1990) in which the delta trap captured more *C. pomonella* males than the wing trap and the other types of trap evaluated. The delta trap is slightly more expensive ($4.68 per set) than the wing trap ($3.35 per set), but this initial higher cost may be offset because the delta type is more durable and can be reused over multiple seasons.

A. velutinana. The phenology of *A. velutinana* is shown in Fig. 2. Three flight periods of *A. velutinana* were recorded at each location in both years of study

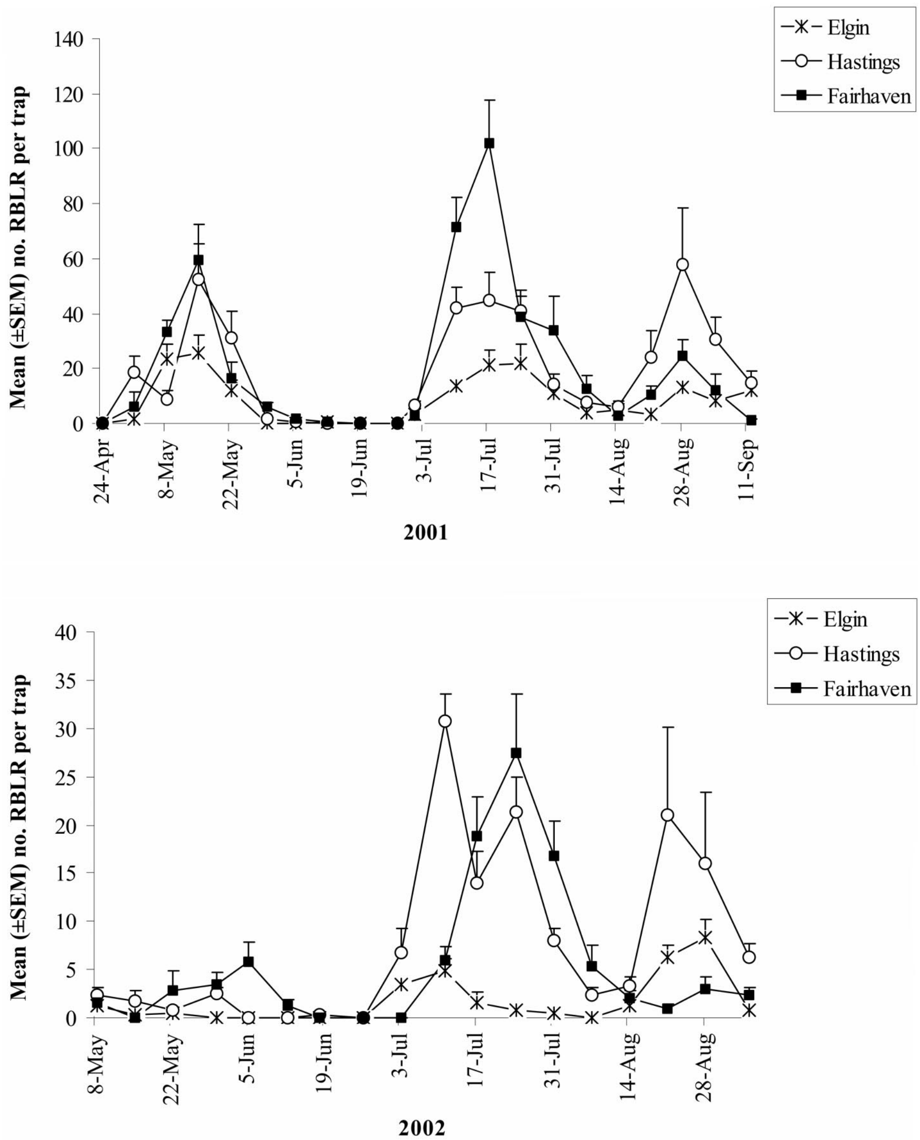

Fig. 2. Seasonal phenology of redbanded leafroller (RBLR) in Minnesota. Figure shows mean (±SEM) weekly capture of redbanded leafroller in pheromone-baited wing traps during 2001 and 2002 field seasons at three locations in Minnesota.

(Fig. 2), suggesting three generations of *A. velutinana* per year in Minnesota. *A. velutinana* is known to produce two to three generations per year in North America (Chapman and Lienk 1971, Willson and Trammel 1980, Rock et al. 1993). Judging from trap capture data, *A. velutinana* was the most abundant tortricid moth and the first to commence spring flight in Minnesota orchards during both years of this study. There was little variation in the phenology of *A. velutinana* between locations. The first flight of *A. velutinana* males began around the last week of April 2001 (≈55 DD base 10°C, tight cluster stage of apple) and reached a peak around the second week of May (Fig. 2). The second flight began around the first week of July and reached a peak around the middle of July. The peak of the third flight occurred around the end of August at the three locations. Similar results were recorded in 2002, except that moth pressure was lower in 2002 than 2001. The relatively lower population pressure recorded for *A. velutinana* in 2002 may be the result of the relatively colder 2001–2002 winter temperatures, which may have resulted in increased mortality of overwintering larvae.

The seasonal mean captures of *A. velutinana* in pheromone-baited traps are shown in Table 2. In general, no significant differences were recorded in captures of *A. velutinana* in both types of trap. However, *A. velutinana* pheromone-baited delta traps captured significantly more bees and nontarget beneficial insects than pheromone-baited wing traps at Hastings in

Table 2. Seasonal mean capture of redbanded leafroller and beneficial insects per week in delta and wing traps baited with *A. velutinana* sex pheromone lures during 2001 and 2002 field seasons at three locations in Minnesota

Location	Yr	Trap	Mean (±SEM) trap capture/wk		
			RBLR	Bees	BNF
Elgin	2001	Delta	8.65 ± 0.70	0.35 ± 0.08	0.57 ± 0.09
		Wing	8.55 ± 0.59	0.30 ± 0.16	0.65 ± 0.17
		F	0.0002	0.11	0.13
		df	1, 3	1, 3	1, 3
		P	0.99	0.76	0.74
	2002	Delta	1.92 ± 0.17	0.56 ± 0.16	0.58 ± 0.16
		Wing	1.64 ± 0.19	0.11 ± 0.06	0.33 ± 0.09
		F	2.0	4.2	0.5
		df	1, 3	1, 3	1, 3
		P	0.25	0.13	0.52
Hastings	2001	Delta	14.32 ± 0.96	0.45 ± 0.10	0.64 ± 0.12
		Wing	19.05 ± 1.46	0.20 ± 0.07	0.39 ± 0.09
		F	3.8	2.2	0.9
		df	1, 3	1, 3	1, 3
		P	0.15	0.23	0.42
	2002	Delta	6.56 ± 0.61	0.71 ± 0.10	0.81 ± 0.10
		Wing	7.61 ± 0.68	0.15 ± 0.07	0.39 ± 0.08
		F	6.8	39.3	13.0
		df	1, 3	1, 3	1, 3
		P	0.08	0.008	0.04
Fairhaven	2001	Delta	18.90 ± 0.96	0.61 ± 0.11	0.61 ± 0.11
		Wing	20.65 ± 1.34	0.07 ± 0.06	0.11 ± 0.06
		F	0.9	50.6	50.6
		df	1, 3	1, 3	1, 3
		P	0.42	0.006	0.006
	2002	Delta	6.04 ± 0.71	0.90 ± 0.36	0.92 ± 0.36
		Wing	5.40 ± 0.47	0.03 ± 0.09	0.07 ± 0.09
		F	0.2	1.9	1.8
		df	1, 3	1, 3	1, 3
		P	0.69	0.26	0.27

BNF, all beneficial insects (i.e., lady beetles, wasps, lacewings, and bees); RBLR, redbanded leafroller.

2002 and at Fairhaven in 2001. Both trap types have similar liner catch surface area (Delta "Pherocon VI," 379 cm^2; Wing "Pherocon 1C," 394 cm^2). The dates of first moth capture were the same for both trap types (Table 3), indicating that both traps are equally capable of detecting the first flights of *A. velutinana* males. The wing trap is currently the most widely used trap for *A. velutinana* (Riedl et al. 1986), and the results of this study suggest that this trap is at least as effective as the delta trap. In this study, the delta trap outperformed the wing trap for *C. pomonella,* but not for *A. velutinana.* Trap efficiency also has been reported to vary with pest species and trap design (Knodel and Agnello 1990, Vincent et al. 1990).

Table 3. Dates of first capture of moth pests in pheromone-baited delta and wing traps during 2001 and 2002 field seasons at three locations in Minnesota

Location	Yr	Trap	CM	RBLR
Elgin	2001	Delta	20 May*	30 April*
		Wing	20 May	30 April
	2002	Delta	30 May*	8 May*
		Wing	30 May	8 May
Hastings	2001	Delta	5 June*	1 May
		Wing	12 June	1 May*
	2002	Delta	31 May*	10 May
		Wing	31 May	10 May*
Fairhaven	2001	Delta	20 June*	2 May
		Wing	13 June	2 May*
	2002	Delta	3 June*	6 May*
		Wing	3 June	6 May

CM, codling moth; RBLR, redbanded leafroller.

* Indicates the trap that captured the highest number of moths per location per season.

Trap Selectivity. Of the two trap types, the delta trap was the least selective capturing significantly more nontarget beneficial insects, in particular bees, than the wing trap (Tables 1 and 2). The lower selectivity of delta trap may be related to its relatively larger openings than wing trap, or a subtle color difference. Bees are reportedly attracted to the bright color of white traps (Krause 1985, Knodel and Agnello 1990). The delta trap used in this study is white, whereas the color of the wing trap is better described as off-white. However, it is doubtful whether bees and other insects could actually detect this subtle color difference. Considering the high daily death rate of a healthy honey bee colony (Morse and Hooper 1985), capture rates of bees in delta traps (an average of 0.6 bees per trap per week) are insignificant. Nevertheless, delta trap should be used with caution, in particular during the bloom and postbloom stages of apple when bees are most active in the orchard. Further studies on the possible effect of trap deployment characteristics (e.g., height, site, and periphery versus middle of tree canopy) may improve the selectivity of delta trap without compromising trap efficiency.

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