

Mating Disruption of Two Sympatric, Orchard-Inhabiting Tortricids, *Choristoneura rosaceana* and *Pandemis limitata* (Lepidoptera: Tortricidae), with Pheromone Components of Both Species' Blends

M. L. EVENDEN,^{1, 2} G.J.R. JUDD,³ AND J. H. BORDEN¹

J. Econ. Entomol. 92(2): 380-390 (1999)

ABSTRACT In British Columbia, several pheromone blends were tested as possible mating disruptants for 2 sympatric, orchard-inhabiting leafrollers (Lepidoptera: Tortricidae), the oblique-banded leafroller, *Choristoneura rosaceana* (Harris), and the threelined leafroller, *Pandemis limitata* (Robinson). Z9-tetradecenyl acetate (Z9-14:OAc), a minor pheromone component of the *P. limitata* pheromone and known pheromone antagonist of *C. rosaceana*, was tested alone and in combination with Z11-tetradecenyl acetate (Z11-14:OAc), the major pheromone component of both species, and additional minor components of the *C. rosaceana* pheromone, as mating disruptants of both species. Disruption of mating, assessed using tethered virgin females of both species, was tested in 0.1-ha plots (33.3 by 33.3 m), using fiber-tape dispensers releasing ≈ 10 mg/ha per hour. Z9-14:OAc applied alone did not significantly disrupt mating of either species. All treatments containing Z11-14:OAc and Z9-14:OAc in a $\approx 1:1$ ratio equally reduced mating of both species. Furthermore, an $\approx 91:6$ ratio of Z11-14:OAc : Z9-14:OAc, which is highly attractive to *P. limitata*, was no more effective than a less attractive pheromone blend containing a $\approx 1:1$ ratio of these components. Unattractive blends combining the major component, Z11-14:OAc and the inhibitor, Z9-14:OAc, disrupted mating of *C. rosaceana* as effectively as the major component alone. These results indicate that false-trail following was not an important mechanism of mating disruption for either of these species in this experimental setting. We conclude that Z11-14:OAc could be used alone or in combination with Z9-14:OAc to disrupt mating in both leafrollers simultaneously.

KEY WORDS *Choristoneura rosaceana*, *Pandemis limitata*, leafroller, mating disruption, pheromone, orchard

ALTHOUGH THE TWO sympatric leafrollers (Lepidoptera: Tortricidae) the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), and the threelined leafroller, *Pandemis limitata* (Robinson), are secondary pests of pome fruits in the Okanagan and Similkameen Valleys of British Columbia they are important. Implementation of a sterile insect release program to control *Cydia pomonella* (L.) (Dyck et al. 1993), the key insect pest of pome fruits, will likely cause these and other leafroller species to become more serious pests (Judd and McBrien 1994) that will require a noninsecticidal management strategy if growers are to increase organic or insecticide-free fruit production.

The pheromone blend of western Canadian populations of *C. rosaceana* has been identified as a 100:2:1.5:1 ratio of Z11-tetradecenyl acetate (Z11-14:OAc), E11-tetradecenyl acetate (E11-14:OAc), Z11-tetradecenyl alcohol (Z11-14:OH), and Z11-tetradecenyl aldehyde (Z11-14:Ald), respectively (Vakenti et al. 1988, Thomson et al. 1991). Female *P. limitata* share

Z11-14:OAc as the major pheromone component with *C. rosaceana*, but release it with Z9-tetradecenyl acetate (Z9-14:OAc) in a 91:9 blend; but a 94:6 blend of these components was optimally attractive to male *P. limitata* in trapping experiments (Roelofs et al. 1976).

Pheromone-based mating disruption has been used successfully to control several species of insect pests (Cardé and Minks 1995), but there are few examples of successful multiple-species mating-disruption systems (Ridgway et al. 1990). Sympatry of *C. rosaceana*, *P. limitata*, and other leafroller species in British Columbia requires an integrated approach to the development of a multiple-species mating-disruption system (Judd and McBrien 1994). One approach to achieving this goal is the use of common pheromone components (van Deventer and Blommers 1992, Pfeiffer et al. 1993, Deland et al. 1994), but another might be the use of interspecific antagonists (Bengtsson et al. 1994).

Z9-14:OAc, the minor pheromone component of the *P. limitata* pheromone, was demonstrated to be a pheromone antagonist for populations of *C. rosaceana* in western Canada (Evenden et al. 1999a) and has also been cited as a pheromone antagonist for eastern North American populations (Cardé and Baker 1984). Although pheromone antagonists alone have not been effective mating disruptants (Kaae et al. 1974, Roths-

¹ Centre for Pest Management Department of Biological Sciences, Simon Fraser University, Burnaby, BC, Canada V5A 1S6.

² Current address: Department of Entomology, College of Agriculture, S-225 Ag Science Building N, University of Kentucky, Lexington, KY 40546-0091.

³ Agriculture and Agri-food Canada, Pacific Agri-food Research Centre, Summerland, BC, Canada V0H 1Z0.

child 1974, Daterman et al. 1975) the stimulate cross species attraction (St 1983). In combination with pheromone released from the same dispenser t mating disruption (Bengtsson et al. 1996), for instance, by causing treated areas (Bengtsson et al. 1996) search showed that complex and si blends, independent of attractiveness, effective as mating disruptants again indicating that false-trail following other mechanisms (Bartell 1982, (vided by less attractive formulation setting (Evenden et al. 1999b). Addi to the pheromone blend of *C. rosaceana* response of males of both *C. rosaceana* to traps baited with virgin females (1999a), indicating the potential of pheromone components from both species as mating disruptant for both species.

In this study, we tested Z9-14:OAc in combination with Z11-14:OAc, the major component of both species, and Z9-14:OAc components for *C. rosaceana*, to develop a blend that could be used for the factory disruption of mating in both species.

Materials and Methods

General protocol. All experiments were conducted in Cawston, British Columbia (B.C.) using a small-plot protocol (Roelofs and Evenden et al. 1999a) (Fig. 1). Experimental plots (33.3 by 33.3 m) were established in managed orchards. Plots were at least a minimum of 10 m from the edge of the orchard. Treatments were assigned to plots in a randomized design and rerandomized so that each plot was occupied for a maximum of 1 year. A control plot was included in each orchard. Five atmospheric semiochemicals (Z9-14:OAc, E9-14:OAc, Z11-14:OAc, Z11-14:OH, and Z11-14:Ald) were applied using Conrel fiber-tape dispensers (Ecogen, Billings, MT). The small-plot protocol used Z11-14:OAc and E9-14:OAc in blend. The dispensers were inescapable by-products of the synthesis of the pheromone isomers. In each plot, dispenser density was maintained at 1 dispenser per 3rd of the tree canopy on the edge of the tree. Dispenser density was maintained at 1 dispenser per 3rd of the tree canopy. Except where otherwise mentioned, the release rate was ≈ 10 mg/ha per hour (Roelofs and Weatherston et al. 1985). Mating disruption was deployed at the beginning of each year and assessed the effect of each treatment on mating disruption.

Disruption of mating was assessed using virgin female *C. rosaceana* and *P. limitata* in a laboratory at 24°C and a photoperiod of 16L:8D on a modified pintobean-based diet (Roelofs et al. 1996). Pupae were sexed and reared individually in 150-ml cups and provided with a source. Females aged 6-96 h were used for mating disruption.

Inhabiting Tortricids, *tata* (Lepidoptera: Both Species' Blends

BORDEN¹

tested as possible mating dis-
ructic Tortricidae), the oblique-
leafroller, *Pandemis limitata*
component of the *P. limitata*
ed alone and in combination
nponent of both species, and
g disruptants of both species.
cies, was tested in 0.1-ha plots
our. Z9-14:OAc applied alone
containing Z11-14:OAc and
rthermore, an ≈91:6 ratio of
no more effective than a less
onents. Unattractive blends
:OAc, disrupted mating of *C.*
licate that false-trail following
e species in this experimental
mbination with Z9-14:OAc to

er, mating disruption, phero-

he major pheromone component with
t release it with Z9-tetradecenyl ace-
ts) in a 91:9 blend; but a 94:6 blend of
ing experiments (Roelofs et al. 1976).
ased mating disruption has been used
ontrol several species of insect pests
iks 1995), but there are few examples
ultiple-species mating-disruption sys-
et al. 1990). Sympatry of *C. rosaceana*
other leafroller species in British Co-
an integrated approach to the devel-
ultiple-species mating-disruption sys-
l McBrien 1994). One approach to
goal is the use of common pheromone
van Deventer and Blommers 1992,
993, Deland et al. 1994), but another
e of interspecific antagonists (Bengt-

he minor pheromone component of
pheromone, was demonstrated to be a
agonist for populations of *C. rosaceana*
ada (Evenden et al. 1999a) and has also
a pheromone antagonist for eastern
n populations (Cardé and Baker 1984).
omone antagonists alone have not been
g disruptants (Kaae et al. 1974, Roda-

child 1974, Daterman et al. 1975) they are reported to
stimulate cross species attraction (Stadlebacher et al.
1983). In combination with pheromone components
released from the same dispenser they could cause
mating disruption (Bengtsson et al. 1994, Suckling and
Shaw 1995, Suckling and Burnip 1996, Witzgall et al.
1996), for instance, by causing emigration from
treated areas (Bengtsson et al. 1994). Previous re-
search showed that complex and simple pheromone
blends, independent of attractiveness, were equally
effective as mating disruptants against *C. rosaceana*,
indicating that false-trail following did not augment
other mechanisms (Bartell 1982, Cardé 1990) pro-
vided by less attractive formulations in a small plot
setting (Evenden et al. 1999b). Addition of Z9-14:OAc
to the pheromone blend of *C. rosaceana* disrupted the
response of males of both *C. rosaceana* and *P. limitata*
to traps baited with virgin females (Evenden et al.
1999a), indicating the potential of combining phero-
mone components from both species as a mating dis-
ruptant for both species.

In this study, we tested Z9-14:OAc alone and in
combination with Z11-14:OAc, the main pheromone
component of both species, and minor pheromone
components for *C. rosaceana*, to determine whether a
blend could be developed that would provide satisfac-
tory disruption of mating in both species.

Materials and Methods

General protocol. All experiments were conducted
in Cawston, British Columbia (B.C.) during 1994-1997
using a small-plot protocol (Roelofs and Novak 1981,
Evenden et al. 1999a) (Fig. 1). Experimental 0.1-ha
plots (33.3 by 33.3 m) were established in organically
managed orchards. Plots were at least 40 m apart and
a minimum of 10 m from the edge of each orchard.
Treatments were assigned to plots after a Latin-square
design and rerandomized so that each treatment occu-
pied each plot for a maximum of 14 d. A nontreated
control plot was included in each replicate.

Five atmospheric semiochemical treatments (Table
1) were applied using Conrel fiber-tape dispensers
(Ecogen, Billings, MT). The small percentages of E11-
14:OAc and E9-14:OAc in blends 4 and 5 (Table 1)
were inescapable by-products of synthesis of the Z
isomers. In each plot, dispensers were hung in the
upper 3rd of the tree canopy on the north side of the
tree. Dispenser density was maintained at 1,000/ha.
Except where otherwise mentioned, semiochemical
release rate was ≈10 mg/ha per hour at ≈20°C (Eco-
gen; Weatherston et al. 1985). New dispensers were
deployed at the beginning of each replicate, at least
48 h before assessing the effect of atmospheric treat-
ments on mating disruption.

Disruption of mating was assessed using tethered
virgin female *C. rosaceana* and *P. limitata* reared in the
laboratory at 24°C and a photoperiod of 16:8 (L:D) h
on a modified pintobean-based diet (Shorey and Hale
1965). Pupae were sexed and females were placed
individually in 150-ml cups and provided with a water
source. Females aged 6-96 h were immobilized at

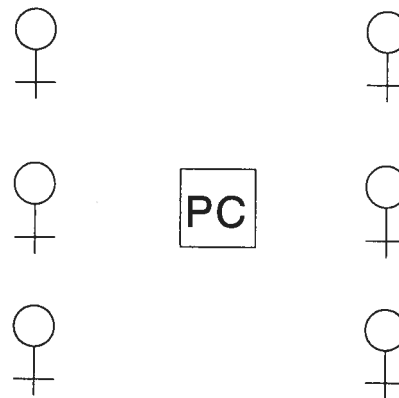


Fig. 1. Plot design used to test mating disruption in ex-
periments 1-6. Four 0.1-ha plots were established in each
experiment in organically managed orchards in Cawston, BC.
PC, plot center. ♀, position of 2 tethered females (of each
species in experiments 4-6), one high and the other low in
the canopy, except for experiment 1 in which females were
placed only high in the canopy.

0.5°C, tethered with a loop of polyester thread secured
around 1 forewing, and transported to field sites in-
dividually in plastic cups housed in refrigerated con-
tainers. Females of both species were placed at both
high (upper 3rd of canopy) and low (head height)
positions in the tree canopy at each of 6 locations near
the plot center (Fig. 1) during late afternoon and
collected early the following morning. Females were
placed on a leaf and secured by taping the thread to
a branch. Placement of each female was marked with
flagging tape. Females recovered from experimental
plots were dissected to reveal the presence (mated) or
absence (virgin) of a spermatophore in the bursa
copulatrix. Females were omitted from the data set if
they were dead and not mated upon recovery. Teth-
ered females were placed in experimental plots on 2-3
nights in each replicate to ensure that the proportion
of females mating was based on 15-30 live females per
treatment per replicate. In 2 instances in experiment
1 (see below), extremely high mortality rates caused
proportions to be based on 9 and 7 individual females.

Experiments. Experiments 1-3 were conducted to
test the hypothesis that blends containing the major
pheromone component of both species and minor
components of the *C. rosaceana* pheromone, blends
that are all effective mating disruptants for *C. rosa-
ceana* (Evenden et al. 1999b), would disrupt mating by
P. limitata. Experiment 1, conducted from 18 July to 15

Table 1. Blend compositions used in mating-disruption experiments against *C. rosaceana* and *P. limitata*

| Experiment number | Blend no. | % component in blend | | | | | |
|-------------------|-----------|----------------------|------------|-----------|------------|-----------|------------|
| | | Z11-14:OAc | E11-14:OAc | Z11-14:OH | Z11-14:Ald | Z9-14:OAc | E9-14:OAc |
| 1, 2, 3, 4 | 1 | 95.7 | 1.9 | 1.4 | 1.0 | — | — |
| 1, 4 | 2 | 96.7 | 1.9 | 14 | — | — | — |
| 1, 4, 5, 6 | 3 | 98.0 | 2.0 | — | — | — | — |
| 5 | 4 | 91.4 | 2.4 | — | — | 6.1 | — |
| 4, 5, 6 | 5 | — | — | — | — | 97.8 | 0.2 2.2 |

Compositions of blends 1-3 were as determined by Ecogen and verified by gas chromatograph (GC) analysis. Contents of blends 4 and 5 were as determined by GC analysis.

September 1994, tested blend 1, a four-component pheromone of *C. rosaceana*, and simpler partial blends 2 (lacking Z11-14:Ald) and 3 (Z11-14:OAc + E11-14:OAc) (Table 1). In this experiment, females were placed only at high levels in the canopy on open platforms with a square cardboard base of 42 cm² and a circular roof of 64 cm².

Experiments 2 and 3 tested blend 1 at various release rates to determine the optimum dose required to disrupt mating in *P. limitata*. In experiment 2, conducted from 7 June to 4 August 1995, dispensers with 25, 50 and 100 fibers per dispenser provided approximate release rates of 2.5, 5, and 10 mg/ha per hour, respectively, at ≈20°C (Ecogen; Weatherston et al. 1985). In experiment 3, conducted from 20 June to 28 July 1996, disruption dispensers with 1, 6, and 13 fibers per dispenser produced release rates of ≈0.1, 0.6, and 1.3 mg/ha per hour, respectively.

Experiments 4-6 were conducted to determine the minimum number of components in the pheromone of *C. rosaceana*, that alone, or in combination with Z9-14:OAc, would provide simultaneous mating disruption of both *C. rosaceana* and *P. limitata*. Experiment 4, conducted from 21 June to 24 July 1996, compared atmospheric treatments of blends 1, 2, and 3 in combination with Z9-14:OAc in a ≈1:1 ratio. Dispensers with 100 fibers of blends 1, 2, or 3 were attached to disruption dispensers containing 100 fibers of Z9-14:OAc (blend 5) producing an approximate combined release rate of 20 mg/ha per hour, 10 mg from each dispenser type.

In experiment 5, conducted from 12 August to 30 August 1996, treatments included the major component of both species with E11-14:OAc (blend 3) plus Z9-14:OAc (blend 5) in a 1:1 ratio, and blend 4, an attractive blend to *P. limitata* containing Z11-14:OAc, E11-14:OAc, Z9-14:OAc, and E9-14:OAc in a 91.4:2.4:6.1:0.2 ratio (Table 1). In treatment 1, fiber-tape disruption dispensers with 100 fibers of blend 3 were attached to dispensers containing 100 fibers of blend 5 with a release rate of ≈10 mg/ha per hour from each dispenser.

In experiment 6, conducted from 14 June to 19 July 1997, the 3 treatments were 100 fibers of blend 3, 100 fibers of blend 5, and 100 fibers each of blends 3 and 5 in a 1:1 ratio. Release rates were ≈10 mg/ha per hour for each blend.

Statistical Analyses. Proportional data generated in all mating disruption experiments were analyzed by

logistic regression techniques, a more powerful method of analyzing proportional data (Levesque 1990) than either chi-square tests or analysis of variance (ANOVA) on arcsine transformed data (Zar 1984). Selecting the most powerful method reduces the possibility of committing a type II error (i.e., accepting the null hypothesis when it is false [Zar 1984]). We used logistic regression models (GLIM 1985) [i.e., generalized linear models that determine the relationship between a binomially distributed response variable (p_i), of the form y/n , where y = number of successes (e.g., number of insects mating out of n = total number tested) and 1 or more explanatory variables x_i].

The model used has the form:

$$p_i = \exp(\beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki}) / 1 + \exp(\beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki})$$

where the relationship between p_i and the x_i is sigmoidal, but it can be shown (Collett 1989) that the logit (p_i) of this function is linearly related to x_i .

$$\text{logit}(p_i) = \log(p_i / (1 - p_i)) = \beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki}$$

Proportions of tethered female *C. rosaceana* that were mated after being exposed for 1 night in pheromone-treated or control plots were compared by a linear logistic regression model (GLIM 1985) in which disruption treatment was the explanatory variable, and replicates over time and plot position were treated as dummy variables. In experiment 2, 3, and 4 the dose of blend 1 could be considered as a continuous variable but a categorical model was used, because it allowed the dose at which mating disruption became ineffective to be identified. Fitting of the logistic regression model was followed by Z-tests to compare individual proportions using a procedure similar to a multiple comparisons test on means. The α -value was adjusted using the Bonferroni inequality to control for type I errors, which depend on the number of comparisons being made (Zar 1984). In all cases the experiment-wise $\alpha = 0.05$.

Results

Atmospheric treatment in experiment 1 with pheromone blends 1-3 containing Z11-14:OAc, the major component of both species and minor components of *C. rosaceana*, resulted in a 63-81% reduction in the

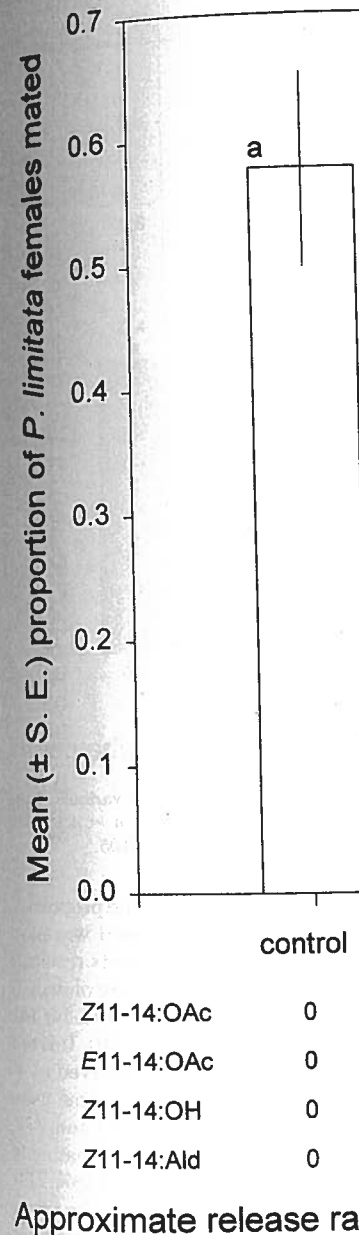


Fig. 2. Proportions of mated, tethered pheromone (blend 1) and 2 partial blends with the same letter are not significantly different.

proportion of mating among tethered *P. limitata* (Fig. 2). However, all 3 blends were equal in effectiveness. Mating disruption of *C. rosaceana*, was significant at release rates ranging from 0.6-10.0 mg/ha per hour (Fig. 3). Atmospheric treatment with 0.1 mg/ha per hour in experiment 5 resulted in a 63-81% reduction in the proportion of mating in female *P. limitata* with a nontreated control (Fig. 3).

a and *P. limitata*

| id | Z9-14:OAc | E9-14:OAc |
|--------|-----------|-----------|
| 14:Ald | — | — |
| — | — | — |
| — | 6.1 | 0.2 |
| — | 97.8 | 2.2 |

h (GC) analysis. Contents of blends 4 and 5

techniques, a more powerful
ing proportional data (Levesque
chi-square tests or analysis of vari-
n arcsine transformed data (Zar
ie most powerful method reduces
ommitting a type II error (i.e., ac-
hypothesis when it is false [Zar
logistic regression models (GLIM
lized linear models that determine
etween a binomially distributed re-
p_i), of the form y/n, where y =
ses (e.g., number of insects mating
umber tested) and 1 or more ex-
s x₁].

l has the form:
+ ... β_kx_{ki} / 1 + exp(β₀ + β₁x_{1i}
+ ... β_kx_{ki}),

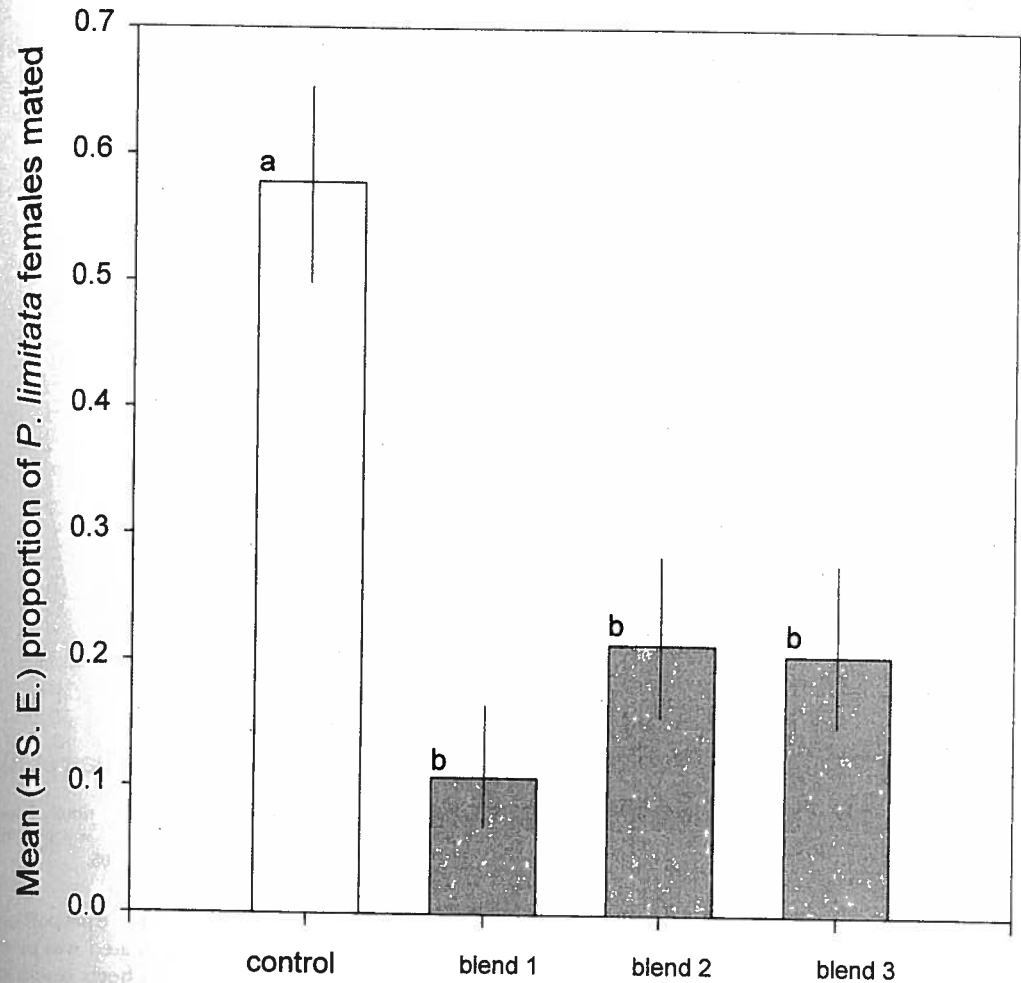
aship between p_i and the x_i is sig-
be shown (Collett 1989) that the
ction is linearly related to x_i,

$$p_i / (1 - p_i) = \beta_0 + \beta_1 x_{1i} + \dots + \beta_k x_{ki}$$

ered female *C. rosaceana* that were
exposed for 1 night in pheromone-
plots were compared by a linear
model (GLIM 1985) in which dis-
was the explanatory variable, and
e and plot position were treated as
In experiment 2, 3, and 4 the dose of
considered as a continuous variable
model was used, because it allowed
mating disruption became ineffec-
ed. Fitting of the logistic regression
by Z-tests to compare individual
; a procedure similar to a multiple
on means. The α-value was adjusted
oni inequality to control for type I
end on the number of comparisons
1984). In all cases the experimen-

Results

reatment in experiment 1 with pher-
3 containing Z11-14:OAc, the major
th species and minor components of
ulted in a 63–81% reduction in the



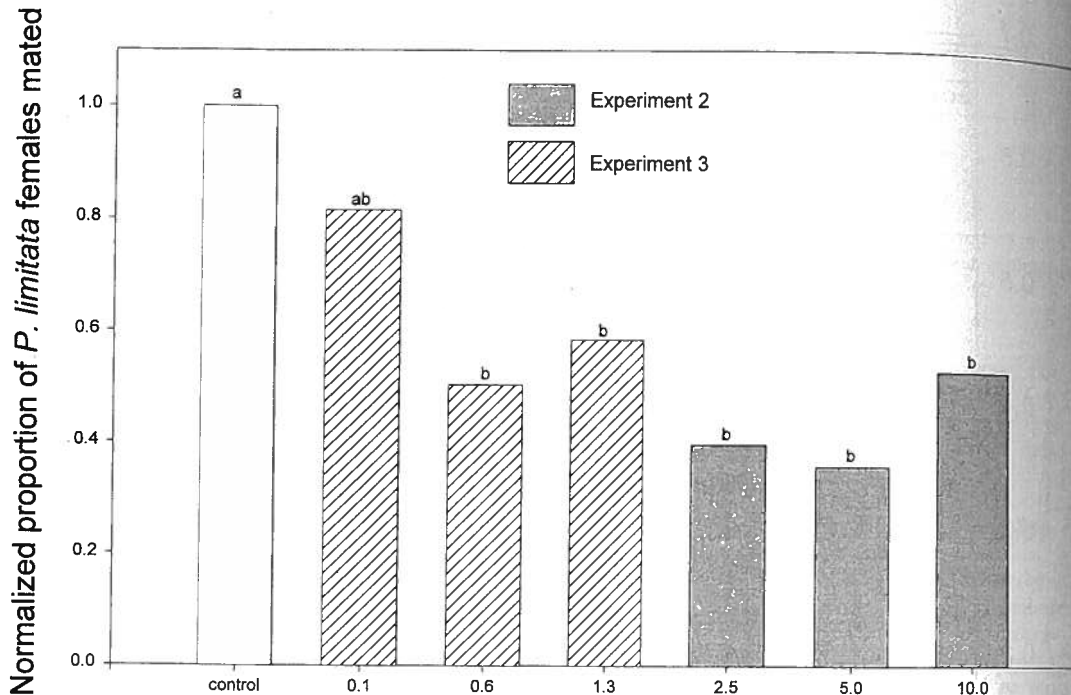
| | control | blend 1 | blend 2 | blend 3 |
|------------|---------|---------|---------|---------|
| Z11-14:OAc | 0 | 9.6 | 9.7 | 9.8 |
| E11-14:OAc | 0 | 0.2 | 0.2 | 0.2 |
| Z11-14:OH | 0 | 0.1 | 0.1 | 0 |
| Z11-14:Ald | 0 | 0.1 | 0 | 0 |

Approximate release rates (mg/ha per h) of semiochemical components

Fig. 2. Proportions of mated, tethered female *P. limitata* in nontreated plots or plots treated with the complete *C. rosaceana* pheromone (blend 1) and 2 partial blends (2 and 3) in experiment 1, 18 July–15 September 1994, Cawston, BC, n = 4. Bars with the same letter are not significantly different, Z-test, P > 0.05.

proportion of mating among tethered-female *P. limitata* (Fig. 2). However, all 3 blends were statistically equal in effectiveness. Mating disruption of *P. limitata* provided in experiments 2 and 3 by blend 1, the pheromone of *C. rosaceana*, was significant and equal at release rates ranging from 0.6–10.0 mg/ha per hour (Fig. 3). Atmospheric treatment with blend 1 released at 0.1 mg/ha per hour in experiment 3, did not alter the proportion of mating in female *P. limitata* compared with a nontreated control (Fig. 3).

Atmospheric treatment in experiment 4 with blends 1–3 in combination with Z9-14:OAc (blend 5) strongly reduced the proportion of mating among tethered female *P. limitata*, but only the combination of blends 2 + 5 resulted in a significant reduction in mating by *C. rosaceana* (Fig. 4). No treatment differences were detected for the 3 semiochemical blends tested in experiment 4 for either species. In experiment 5, blends 3 + 5, equivalent to an off-ratio pheromone blend for *P. limitata*, were tested against blend 4, a



Approximate release rate of atmospheric treatment with blend 1 (mg/ha per h)

Fig. 3. Proportions of tethered female *P. limitata* mating in nontreated plots or plots treated with blend 1 at various release rates in experiment 2 (7 June–4 August 1995) and experiment 3 (20 June–28 July 1996), Cawston, BC, $n = 4$ in both experiments. Within each experiment bars with the same letter are not significantly different, Z-test, $P > 0.05$.

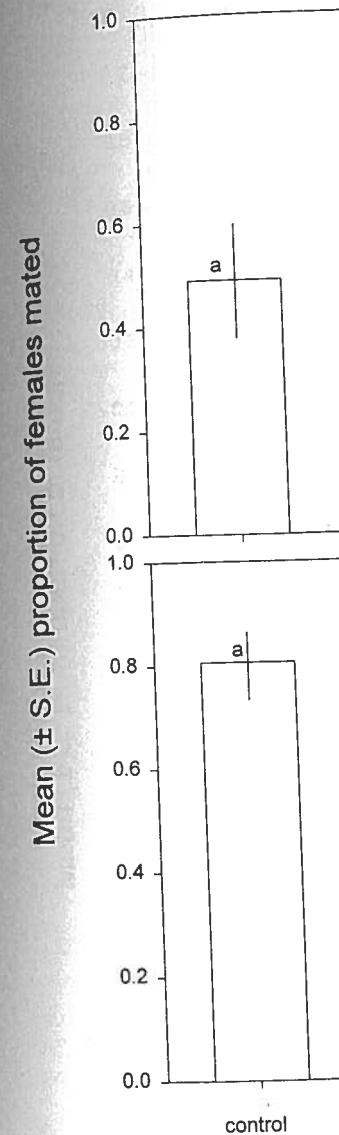
blend close to the *P. limitata* pheromone. As in experiment 4, treatments containing Z9-14:OAc produced a greater reduction in mating in *P. limitata* (81–83%) than *C. rosaceana* (Fig. 5). For *C. rosaceana*, only blends 3 + 5 resulted in a significant reduction (73%) in the proportion of females that mated.

In experiment 6, Z9-14:OAc alone (blend 5) the minor component of the *P. limitata* pheromone did not reduce mating in either species, whereas Z11-14:OAc (blend 3), the major component of both species, did (Fig. 6). Blends 3 + 5, the off-ratio blend of the *P. limitata* pheromone, were no more effective as a mating disruptant against *P. limitata* than Z11-14:OAc (blend 3) the major component alone. For *C. rosaceana*, treatment with blends 3 + 5 significantly reduced mating, but was no more effective than Z11-14:OAc alone (blend 3) (Fig. 6).

Discussion

Our data suggest that simultaneous disruption of mating in the sympatric species *C. rosaceana* and *P. limitata* can be achieved by treating the atmosphere with Z11-14:OAc, the compound that comprises the majority of the pheromone in both species or with a blend containing both Z11-14:OAc and Z9-14:OAc, the minor component for *P. limitata* and antagonist to *C. rosaceana*.

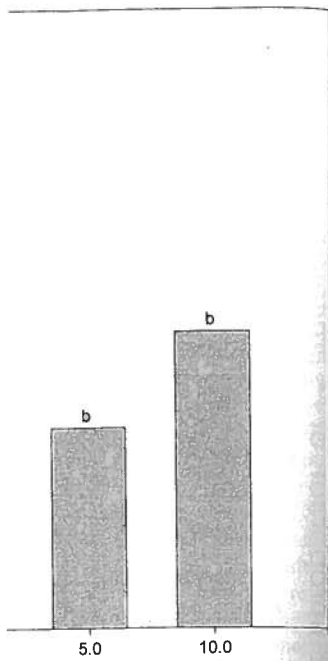
In experiments 1–3, the reductions in the proportion of tethered, female *P. limitata* that mated was most likely caused by neurophysiological effects resulting from exposure to Z11-14:OAc. Trap capture of male *P. limitata* is inhibited by the addition of 6% E11-14:OAc to its pheromone blend (Roelofs et al. 1976). It is not known if Z11-14:OH or Z11-14:Ald is perceived by *P. limitata* males and acts interspecifically in some manner. Blends 1 and 2, containing Z11-14:OH and Z11-14:Ald, were no more effective at reducing mating in *P. limitata* than blend 3, which contained 98% Z11-14:OAc with 2% E11-14:OAc. As Z9-14:OAc, the minor component of the *P. limitata* blend is required for attraction of males of this species (Roelofs et al. 1976) it is highly unlikely that disruption using any of blends 1–3 alone (Table 1) was the result of false-trail following. Although it may be possible to camouflage a plume with an incomplete pheromone blend (Minks and Cardé 1988), it is most likely that neurophysiological effects caused the observed reduction in mating of *P. limitata* in experiments 1–3. Preexposure or constant exposure to single pheromone components in the laboratory (Linn and Roelofs 1981, Liu and Haynes 1993a) and in the field (Flint and Merkle 1984, Judd et al. 1995) has resulted in upwind flight of males to off-ratio pheromone blends that is best explained by neurophysiological adaptation or habituation.



| | |
|------------|---|
| Z11-14:OAc | 0 |
| E11-14:OAc | 0 |
| Z11-14:OH | 0 |
| Z11-14:Ald | 0 |
| Z9-14:OAc | 0 |
| E9-14:OAc | 0 |

Approximate release

Fig. 4. Proportions of tethered female *C. rosaceana* treated with *C. rosaceana* pheromone. Cawston, BC, $n = 4$. Within each species proportions that approached 0 for which

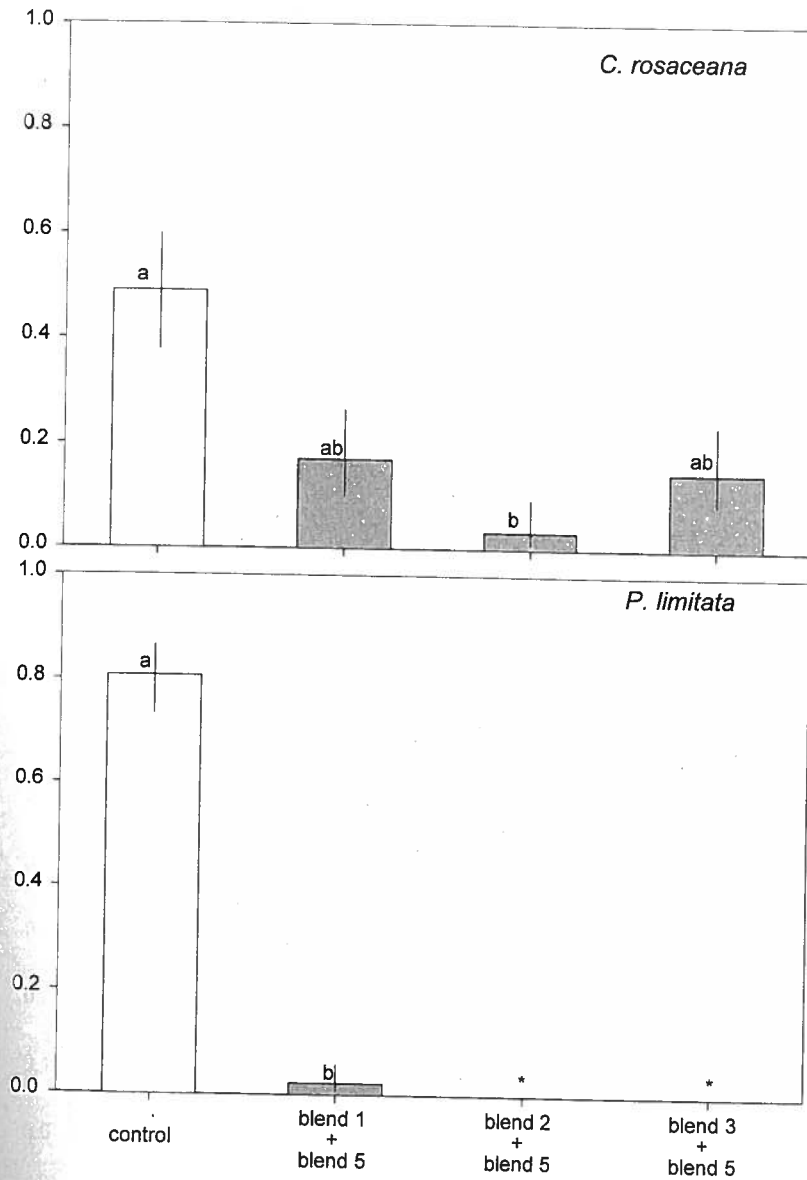


with blend 1 (mg/ha per h)

ots treated with blend 1 at various release rates (experiment 4, Cawston, BC, n = 4 in both years, Z-test, P > 0.05).

1-3, the reductions in the proportion of *P. limitata* that mated was most likely due to neurophysiological effects resulting from the addition of 6% E11-14:OAc blend (Roelofs et al. 1976). It is not clear if Z11-14:OH or Z11-14:Ald is perceived by *P. limitata*. Z11-14:OH acts interspecifically in some manner. Blend 2, containing Z11-14:OH and Z11-14:Ald, is more effective at reducing mating than blend 3, which contained 98% Z11-14:OAc. As Z9-14:OAc, the minor component of this species blend is required for disruption using any of blends 1-3, it may be possible to camouflage a pheromone blend (Minks et al. 1994), it is most likely that neurophysiological effects caused the observed reduction in mating in experiments 1-3. Preexposure or addition of single pheromone components (Linn and Roelofs 1981, Liu and Roelofs 1984) in the field (Flint and Merkle 1984) has resulted in upwind flight of males from pheromone blends that is best explained by physiological adaptation or habituation.

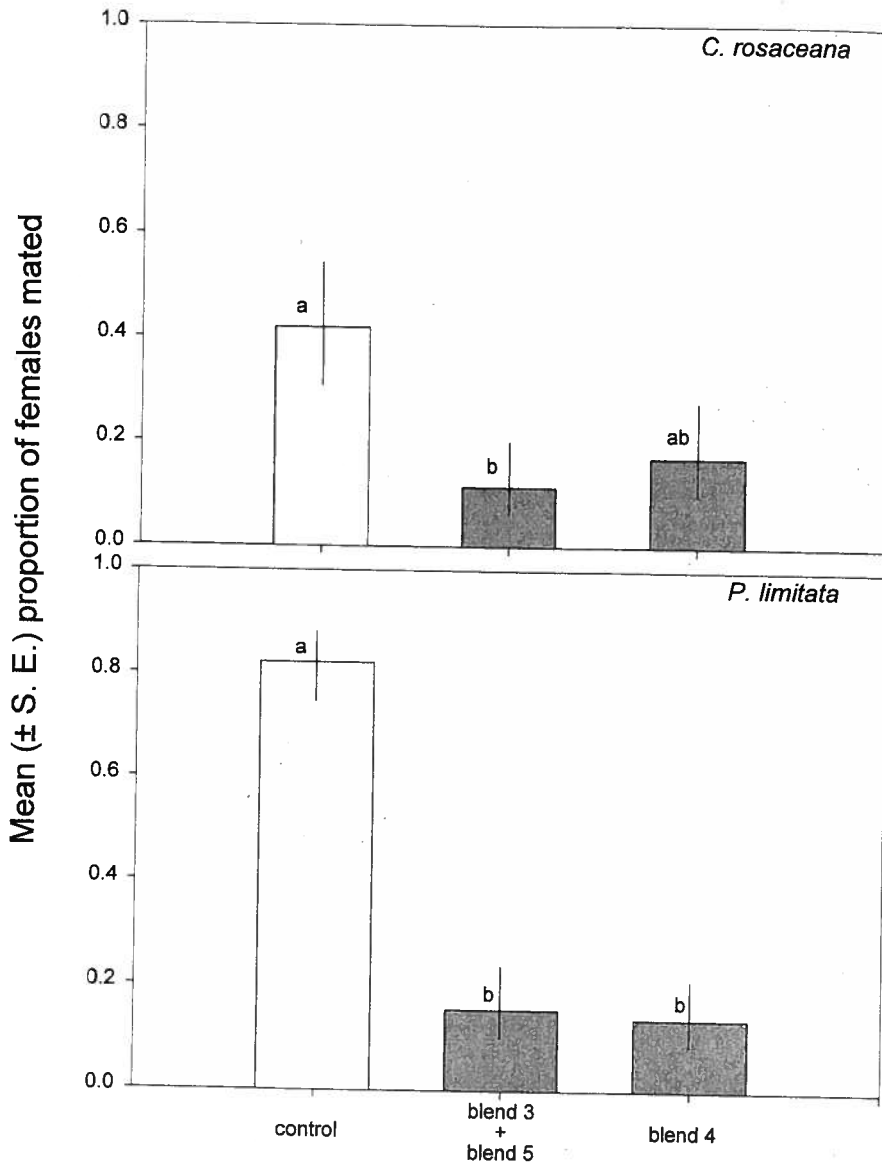
Mean (\pm S.E.) proportion of females mated



| | control | blend 1 + blend 5 | blend 2 + blend 5 | blend 3 + blend 5 |
|------------|---------|-------------------|-------------------|-------------------|
| Z11-14:OAc | 0 | 9.6 | 9.7 | 9.8 |
| E11-14:OAc | 0 | 0.2 | 0.2 | 0.2 |
| Z11-14:OH | 0 | 0.1 | 0.1 | 0 |
| Z11-14:Ald | 0 | 0.1 | 0 | 0 |
| Z9-14:OAc | 0 | 9.8 | 9.8 | 9.8 |
| E9-14:OAc | 0 | 0.2 | 0.2 | 0.2 |

Approximate release rates (mg/ha per h) of semiochemical components

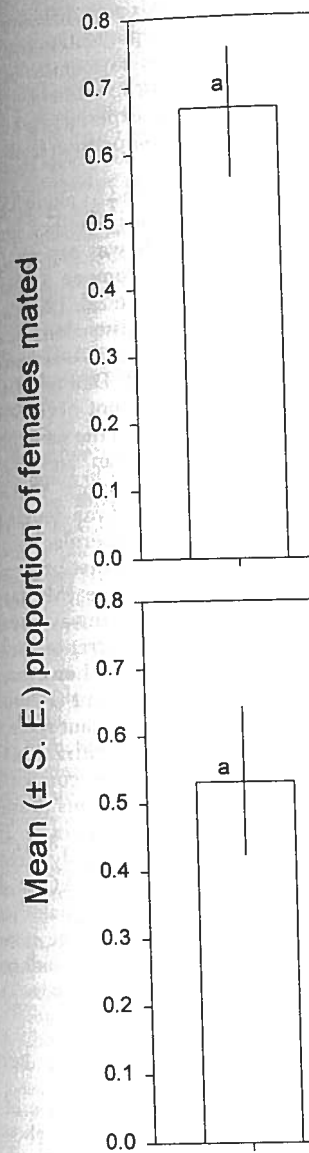
Fig. 4. Proportions of tethered female *C. rosaceana* and *P. limitata* mating in experiment 4 in nontreated plots or plots treated with *C. rosaceana* pheromone (blends 1-3) in combination with Z9-14:OAc (blend 5) in a 1:1 ratio, 21 June-24 July 1996, Cawston, BC, n = 4. Within each species, bars with the same letter are not significantly different, Z-test, P > 0.05. Asterisks indicate proportions that approached 0 for which standard errors could not be estimated by the logistic regression function.



| | control | blend 3 + blend 5 | blend 4 |
|------------|---------|-------------------|---------|
| Z11-14:OAc | 0 | 9.8 | 91.4 |
| E11-14:OAc | 0 | 0.2 | 2.4 |
| Z11-14:OH | 0 | 0 | 0 |
| Z11-14:Ald | 0 | 0 | 0 |
| Z9-14:OAc | 0 | 9.8 | 6.1 |
| E9-14:OAc | 0 | 0.2 | 0.2 |

Approximate release rates (mg/ha per h) of semiochemical components

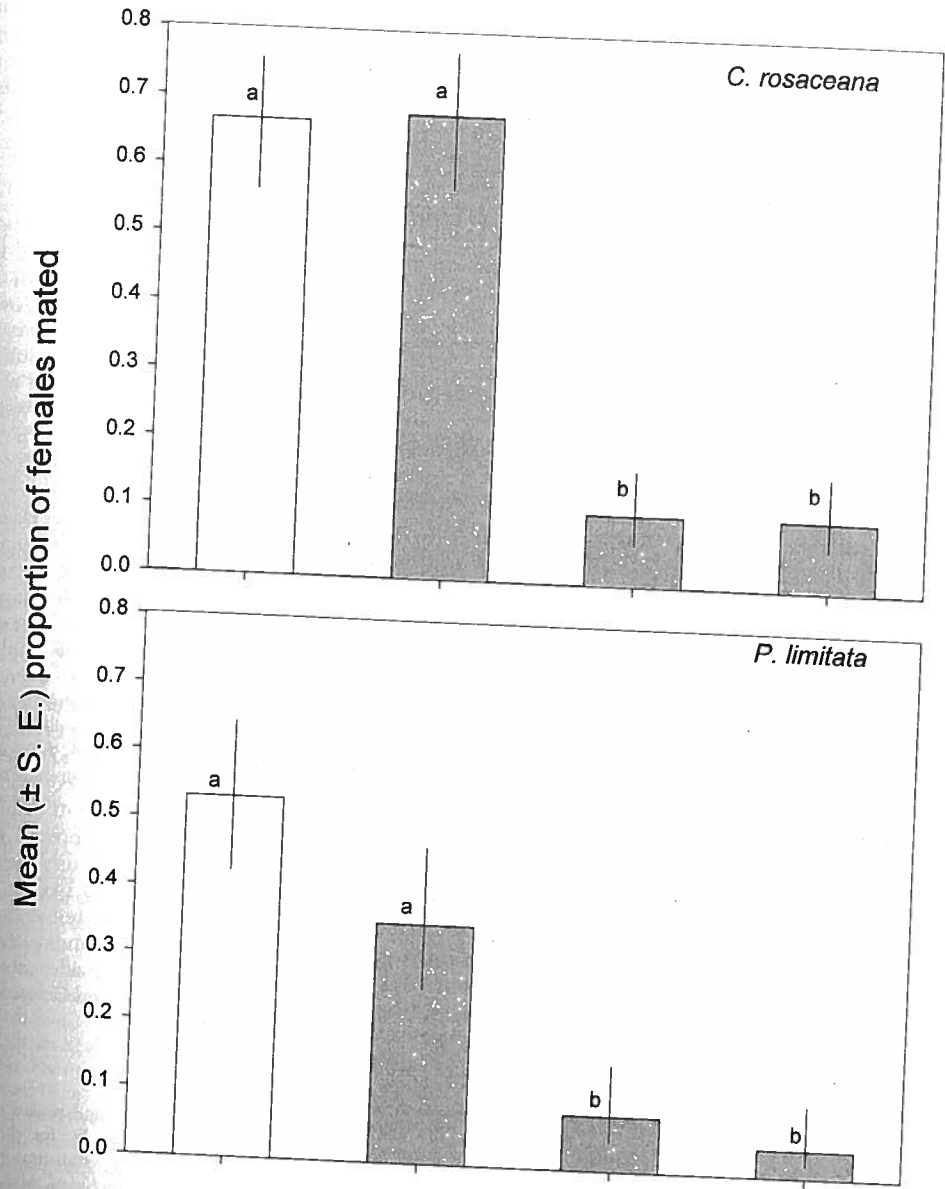
Fig. 5. Proportions of tethered female *C. rosaceana* and *P. limitata* mating in experiment 5 in nontreated plots or plots treated with the *P. limitata* pheromone (blend 4) or blend 3 in combination with Z9-14:OAc (blend 5) in a 1:1 ratio, 12 August–30 August 1996, Cawston, BC, $n = 4$. Within each species, bars with the same letter are not significantly different, Z-test, $P > 0.05$.



| | control |
|------------|---------|
| Z11-14:OAc | 0 |
| E11-14:OAc | 0 |
| Z11-14:OH | 0 |
| Z11-14:Ald | 0 |
| Z9-14:OAc | 0 |
| E9-14:OAc | 0 |

Approximate release

Fig. 6. Proportions of tethered female *C. rosaceana* and *P. limitata* mating in experiment 5 in nontreated plots or plots treated with Z9-14:OAc alone, blend 3 in combination with Z9-14:OAc (blend 5) in a 1:1 ratio, 12 July 1997, Cawston, BC, $n = 4$. Within each species, bars with the same letter are not significantly different, Z-test, $P > 0.05$.



| | control | blend 5 | blend 3 | blend 3 + blend 5 |
|------------|---------|---------|---------|-------------------|
| Z11-14:OAc | 0 | 0 | 9.8 | 9.8 |
| E11-14:OAc | 0 | 0 | 0.2 | 0.2 |
| Z11-14:OH | 0 | 0 | 0 | 0 |
| Z11-14:Ald | 0 | 0 | 0 | 0 |
| Z9-14:OAc | 0 | 9.8 | 0 | 9.8 |
| E9-14:OAc | 0 | 0.2 | 0 | 0.2 |

Approximate release rates (mg/ha per h) of semiochemical components

Fig. 6. Proportions of tethered female *C. rosaceana* and *P. limitata* mating in experiment 6 in nontreated plots or plots treated with Z9-14:OAc alone, blend 3 alone, or blend 3 in combination with Z9-14:OAc (blend 5) in a 1:1 ratio, 14 June-19 July 1997, Cawston, BC, n = 4. Within each species, bars with the same letter are not significantly different, Z-test, P > 0.05.

semiochemical components

ing in experiment 5 in nontreated plots or plots treated with Z9-14:OAc (blend 5) in a 1:1 ratio. Bars with the same letter are not significantly different.

The significant reduction in the proportion of female *P. limitata* that mated over a wide range of release rates of blend 1 in experiments 2 and 3, except at the lowest release rate of 0.1 mg/ha per hour (Fig. 3), is in contrast to observations that release rate of pheromone is important in preventing mating and providing crop protection in several mating-disruption systems (Schwalbe and Mastro 1988, Webb et al. 1990, Suckling and Shaw 1992). Blend 1 also reduced mating by tethered *C. rosaceana* females at pheromone release rates >1.3 mg/ha per hour (Evenden et al. 1999b).

Atmospheric treatments composed of components from both species' blends disrupted mating in both species to varying degrees. In experiments 4 and 5, blends incorporating Z9-14:OAc disrupted mating of *P. limitata* but were less effective against *C. rosaceana* (Figs. 4 and 5). Mechanisms that may be acting to prevent *P. limitata* from mating in these experiments include camouflage of female-produced plumes, adaptation, and habituation. In experiment 5, the tested blends contained the same components in different ratios. Blend 4, an ≈91:6 ratio of Z11-14:OAc to Z9-14:OAc is an attractive blend to *P. limitata*, and could therefore have invoked false-trail following. The other treatment, blends 3 + 5, represents an off-ratio blend for *P. limitata* with an approximate 1:1 ratio of these components. Experiment 5 (Fig. 5) shows that at the tested release rate, the attractive blend 4 was no more effective as a mating disruptant of *P. limitata* than the off-ratio blend. Because of the presence of the antagonist Z9-14:OAc, the reduction in mating of *C. rosaceana* in these same plots, could only be the result of neurophysiological effects or emigration from treated areas. In support of this finding, Evenden et al. (1999b) demonstrated that partial pheromone blends (blends 2 and 3) were equally effective as mating disruptants of *C. rosaceana* as the more attractive blend 1.

Blends containing antagonists and pheromone components have been used as mating disruptants for several species. Large-scale mating disruption of the light brown apple moth, *Epiphyas postvittana* (Walker), was achieved using a formulation that contained a behavioral antagonist, produced as a by-product of pheromone synthesis, which rendered the formulation unattractive (Suckling and Shaw 1995). Suckling and Burnip (1996) found no difference in disruption of mate location of *Planotortrix octo* (Dugdale) (Lepidoptera: Tortricidae) when an attractive pheromone disruptant treatment and an unattractive partial pheromone containing an antagonist were compared. Bengtsson et al. (1994) demonstrated that male pea moths emigrated from treated areas when isomerization of a pheromone component resulted in the production of an inhibitory isomer in the disruptant formulation.

In experiment 6, unlike in experiments 4 and 5, mating in both species was reduced significantly when the atmosphere was treated with blend 3 alone and blends 3 + 5 in a 1:1 ratio (Fig. 6). Blends 3 + 5 reduced mating of *C. rosaceana* females by 85% in experiment 6, which is greater than the 73 and 65% reductions in experiments 4 and 5, respectively. The latter 2 experiments were conducted the year before

experiment 6 in different orchards with differing canopy structures, and with greater population pressure as measured by monitoring traps adjacent to experimental plots. The relatively low proportion of females that mated in the control plots in experiments 4 and 5 may thus reflect a high level of competition from female females.

Treatment with Z9-14:OAc (blend 5) alone had no effect on the proportion of females of either species that mated. For *C. rosaceana* this was expected because Z9-14:OAc is a known pheromone antagonist (Cardé and Baker 1984, Evenden et al. 1999a), and treatment with pheromone antagonists alone has not provided effective mating disruption in other studies (Kaae et al. 1974, Rothschild 1974, Daterman et al. 1975). Pheromone antagonists are not perceived as antagonists unless they are present in the same plume as the pheromone components (Liu and Haynes 1993b, Rumbo et al. 1993). Furthermore, there are antennal receptors (ie. Den Otter and van der Haagen 1989) and glomeruli in the macroglomerular complex in the antennal lobe of some insects that process response to pheromone antagonists alone (Mustaparta 1996), and over stimulation of this pathway does not appear to alter pheromone blend integration and upwind flight to females. For *P. limitata*, however, Z9-14:OAc is a minor pheromone component (Roelofs et al. 1976). There was a slight, nonsignificant reduction in mating of *P. limitata* in plots treated with Z9-14:OAc alone (Fig. 6). In other species, minor components alone may be effective as mating disruptants (Yashima et al. 1975, Miyashita et al. 1976, Kanno et al. 1978, Stadlbacher et al. 1983). We previously demonstrated (Evenden et al. 1999a) that Z9-14:OAc does not alter capture of male *P. limitata* in female-baited traps. It appears that the major pheromone component, Z11-14:OAc, is required to provide adequate mating disruption of both *P. limitata* and *C. rosaceana*.

Acknowledgments

We thank H. L. McBrien for advice and review of the manuscript; R. Gries and H. D. Pierce, Jr., for chemical analyses; C.A. Levesque and J. Hall for statistical advice; M.G.T. Gardiner and L.J. Chong for technical advice and assistance; and N. C. Delury, N. L. Weremy, G. Zilahi-Balogh, and L. E. Delury for field assistance; and R. Schneider, A. Turner, and T. Wills for welcoming research in their orchards. We thank Ecogen, Incorporated, for preparation of pheromone dispensers. This research was supported by the Science Council of British Columbia, the Similkameen Okanagan Organic Producers' Association, the British Columbia Fruit Growers' Association, Phero Tech Incorporated, and the Natural Sciences and Engineering Research Council of Canada.

References Cited

- Bartell, R. J. 1982. Mechanisms of communication disruption by pheromone in the control of Lepidoptera: a review. *Physiol. Entomol.* 7: 353-364.
- Bengtsson, M., G. Karg, P. A. Kirsch, J. Löfqvist, A. Sauer, and P. Witzgall. 1994. Mating disruption of pea moth *Cydia nigricana* F. (Lepidoptera: Tortricidae) with a blend of sex pheromone and attractant. *J. Chem. Ecol.* 20: 871-887.
- Cardé, R. T. 1990. Principles of mating disruption. In R. L. Ridgway, R. M. Silverstein, & [eds.], *Behavior-modifying chemicals for pest management: applications of pheromone and pheromone antagonists*. Marcel Dekker, New York.
- Cardé, R. T., and T. C. Baker. 1984. Sex pheromone with pheromones, pp. 355-376. In W. Cardé [eds.], *Chemical ecology of insect pests*. Marcel Dekker, MA.
- Cardé, R. T., and A. M. Minks. 1995. Chemical ecology of insect mating disruption: successes and constraints. *Entomol.* 40: 559-585.
- Collett, D. 1989. Modelling binary data. Chapman and Hall, New York.
- Daterman, G. E., G. Doyle Daves, Jr., and G. G. G. Comparison of sex pheromone versus pheromone communication in *buoliana*. *Environ. Entomol.* 4: 944-949.
- Deland, J.-P., G.J.R. Judd, and B. D. Roitman. 1989. Pheromone communication in the leafroller (Lepidoptera: Tortricidae) *Choristoneura rosaceana*. *Environ. Entomol.* 18: 235-242.
- Den Otter, C. J., and M. M. van der Haagen. 1989. Pheromone attractants and inhibitory pheromone components of the armyworm, *Mamestra brassicae* L. *Electrophysiological discrimination*. *J. Chem. Ecol.* 15: 235-242.
- Dyck, V. A., S. H. Graham, and K. A. B. Sterile insect release for eradication of the codling moth, *Cydia pomonella* (Lepidoptera: Olethreutidae), in British Columbia. *Proceedings of International Conference on Management of Insect Pests: New Molecular and Genetic Techniques*. IAEA Energy Agency, Vienna, Austria. 1A1.
- Evenden, M. L., G.J.R. Judd, and J. H. Judd. 1999a. Simultaneous disruption of pheromone-mediated mating of *Choristoneura rosaceana* (Harris) and *P. limitata* (Lepidoptera: Tortricidae) with pheromone and pheromone antagonist. *J. Chem. Ecol.* (in press).
- Evenden, M. L., G.J.R. Judd, and J. H. Judd. 1999b. Pheromone-mediated mating disruption of *Choristoneura rosaceana*: is the most attractive blend the most effective? *Entomol. Exp. Appl.* 100: 1-10.
- Flint, H. M., and J. R. Merkle. 1984. Mating disruption of the codling moth (*Cydia pomonella*) (Lepidoptera: Gelechiidae): alteration of gossypolure by release of its component. *Econ. Entomol.* 77: 1099-1104.
- GLIM. 1985. The statistical system for interactive modelling, 3.77. Numerical Algorithms Group, Oxford Science Publications, Oxford.
- Judd, G.J.R., and H. L. McBrien. 1999. Mating disruption of pome fruit pest by a multiple-species approach. In *Proceedings of the National Conference on Pesticide Research, Development and Control*. National conference of the Entomological Society of Canada, 19 October 1994, Winnipeg, Manitoba. Agriculture and Agri-Food Canada, Natural Resources Canada.
- Judd, G.J.R., H. L. McBrien, and J. H. Judd. 1999. Mating disruption of responses by *Campoplex* (Hymenoptera: Braconidae) to pheromone lures permeated with synthetic sex pheromone components. *J. Chem. Ecol.* 21: 19

different orchards with differing cand with greater population pressure monitoring traps adjacent to exper- relatively low proportion of females control plots in experiments 4 and 5 high level of competition from feral

Z9-14:OAc (blend 5) alone had no portion of females of either species *C. rosaceana* this was expected because a known pheromone antagonist (1984, Evenden et al. 1999a), and pheromone antagonists alone has not the mating disruption in other studies (Rothschild 1974, Daterman et al. Pheromone antagonists are not perceived as they are present in the same plume ne components (Liu and Haynes et al. 1993). Furthermore, there are (ie. Den Otter and van der Haagen) in the macroglomerular complex of some insects that process re- none antagonists alone (Mustaparta) stimulation of this pathway does not pheromone blend integration and up- males. For *P. limitata*, however, Z9- r pheromone component (Roelofs et was a slight, nonsignificant reduction *vitata* in plots treated with Z9-14:OAc n other species, minor components ctive as mating disruptants (Yashima shita et al. 1976, Kanno et al. 1978, al. 1983). We previously demon- n et al. 1999a) that Z9-14:OAc does of male *P. limitata* in female-baited that the major pheromone compo- c, is required to provide adequate n of both *P. limitata* and *C. rosaceana*.

Acknowledgments

We thank M. C. McBrien for advice and review of the manuscript and H. D. Pierce, Jr., for chemical analysis; D. Levesque and J. Hall for statistical advice; and L.J. Chong for technical advice and C. Delury, N. L. Weremy, G. Zilahi-Balogh, and J. Schneider for field assistance; and R. Schneider, M. Wills for welcoming research in their laboratory. Thanks to Ecogen, Incorporated, for preparation of the manuscript. This research was supported by the University of British Columbia, the Similkameen Okanagan Producers' Association, the British Columbia Fruit Growers' Association, the British Columbia Fruit Producers' Association, Phero Tech Incorporated, and the British Columbia Forestry and Engineering Research Council of Canada.

References Cited

2. Mechanisms of communication disruption in the control of Lepidoptera: a review. *Entomol.* 7: 353-364.
- Karg, P. A., Kirsch, J., Löfqvist, A., Sauer, and others. 1994. Mating disruption of pea moth *C. nigricana* F. (Lepidoptera: Tortricidae) by a repellent blend of sex pheromone and attraction inhibitors. *J. Chem. Ecol.* 20: 871-887.
- Cardé, R. T. 1990. Principles of mating disruption, pp. 47-71. In R. L. Ridgway, R. M. Silverstein, and M. N. Inscoe [eds.], *Behavior-modifying chemicals for insect management: applications of pheromone and other attractants*. Marcel Dekker, New York.
- Cardé, R. T., and T. C. Baker. 1984. Sexual communication with pheromones, pp. 355-376. In W. J. Bell and R. T. Cardé [eds.], *Chemical ecology of insects*. Sinauer, Sunderland, MA.
- Cardé, R. T., and A. M. Minks. 1995. Control of moths by mating disruption: successes and constraints. *Annu. Rev. Entomol.* 40: 559-585.
- Collett, D. 1989. *Modelling binary data*. Chapman & Hall, New York.
- Daterman, G. E., G. Doyle Daves, Jr., and G. Smith. 1975. Comparison of sex pheromone versus an inhibitor for disruption of pheromone communication in *Rhyacionia buoliana*. *Environ. Entomol.* 4: 944-946.
- 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. *Environ. Entomol.* 23: 1084-1090.
- Den Otter, C. J., and M. M. van der Haagen. 1989. Sex pheromone attractants and inhibitors in the cabbage armyworm, *Mamestra brassicae* L. (Lep.: Noctuidae): electrophysiological discrimination. *Insect Sci. Appl.* 10: 235-242.
- Dyck, V. A., S. H. Graham, and K. A. Bloem. 1993. Implementation of the sterile insect release programme to eradicate the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Olethreutidae), in British Columbia, Canada, pp. 285-297. In *Proceedings of International Symposium on Management of Insect Pests: Nuclear and Related Molecular and Genetic Techniques*. International Atomic Energy Agency, Vienna, Austria. IAEA, Vienna.
- Evenden, M. L., G.J.R. Judd, and J. H. Borden. 1999a. Simultaneous disruption of pheromone communication in *Choristoneura rosaceana* (Harris) and *Pandemis limitata* (Robinson) with pheromone and antagonist blends. *J. Chem. Ecol.* (in press).
- 1999b. Pheromone-mediated mating disruption of *Choristoneura rosaceana*: is the most attractive blend really the most effective? *Entomol. Exp. Appl.* (in press).
- Filnt, H. M., and J. R. Merkle. 1984. The pink bollworm (Lepidoptera: Gelechiidae): alteration of male response to gossypure by release of its component Z, Z-isomer. *J. Econ. Entomol.* 77: 1099-1104.
- GLIM. 1985. The statistical system for generalized linear interactive modelling, 3.77. Numerical Algorithms Group, Oxford Science Publications, Oxford, England.
- Judd, G.J.R., and H. L. McBrien. 1994. Pheromone-based mating disruption of pome fruit pests in British Columbia: a multiple-species approach. In *Proceedings, Workshop: Research, Development and Commercialization of Semiochemicals in Insect Pest Management in Canada*. National conference of the Entomological Society of Canada, 19 October 1994, Winnipeg, Manitoba. Pest Management Alternatives Office, Natural Resources, Ottawa, Canada.
- Judd, G.J.R., H. L. McBrien, and J. H. Borden. 1995. Modification of responses by *Campylomma verbasci* (Heteroptera: Miridae) to pheromone blends in atmospheres permeated with synthetic sex pheromone or individual components. *J. Chem. Ecol.* 21: 1991-2002.
- Kaae, R. S., H. H. Shorey, L. K. Gaston and H. H. Hummel. 1974. Sex pheromones of lepidoptera: disruption of pheromone communication in *Trichoplusia ni* and *Pectinophora gossypiella* by permeation of the air with nonpheromone chemicals. *Environ. Entomol.* 3: 87-89.
- Kanno, H., S. Tatsuki, K. Uchiumi, M. Kurihara, and J.-I. Fukami. 1978. Disruption of sex attraction in the rice stem borer moth, *Chilo suppressalis* Walker, with components of the sex pheromone and related chemicals. *Appl. Entomol. Zool.* 13: 321-323.
- Levesque, C. A. 1990. The nature and significance of fungal colonizers in the herbicidal effect of glyphosate. Ph.D. dissertation, Simon Fraser University, Burnaby, BC, Canada.
- Linn, C. E., Jr., and W. L. Roelofs. 1981. Modification of sex pheromone blend discrimination in male Oriental fruit moths by pre-exposure to (E)-8-dodecenyl acetate. *Physiol. Entomol.* 6: 421-429.
- Liu, Y.-B., and K. F. Haynes. 1993a. Pheromone-mediated responses of male cabbage looper moths, *Trichoplusia ni*, following various exposures to sex pheromone or (Z)-7-dodecenol. *J. Chem. Ecol.* 19: 503-515.
- 1993b. Impact of (Z)-7-dodecenol and turbulence on pheromone-mediated flight manoeuvres of male *Trichoplusia ni*. *Physiol. Entomol.* 18: 363-371.
- Minks, A. K., and R. T. Cardé. 1988. Disruption of pheromone communication in moths: is the natural blend really most efficacious? *Entomol. Exp. Appl.* 49: 25-36.
- Miyashita, K., K. Kawasaki, Y. Uesumi, and T. Sugiura. 1976. Mating suppression of *Spodoptera litura* F. (Lepidoptera: Noctuidae) in green-houses by a component of its sex pheromone. *Appl. Entomol. Zool.* 11: 364-367.
- Mustaparta, H. 1996. Central mechanisms of pheromone information processing. *Chem. Senses* 21: 269-275.
- 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. *Entomol. Exp. Appl.* 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, New York.
- Roelofs, W. L., and M. A. Novak. 1981. Small-plot disorientation tests for screening potential mating disruptants, pp. 229-242. In E. R. Mitchell [ed.], *Management of insect pests with semiochemicals*. Plenum, New York.
- Roelofs, W. L., A. Cardé, A. Hill, and R. T. Cardé. 1976. Sex pheromone of the threelined leafroller, *Pandemis limitata*. *Environ. Entomol.* 5: 649-652.
- Rothschild, G.H.L. 1974. Problems defining synergists and inhibitors of the oriental fruit moth pheromone by field experimentation. *Entomol. Exp. Appl.* 294-302.
- Rumbo, E. R., S. M. Deacon, and L. P. Regan. 1993. Spatial discrimination between sources of pheromone and an inhibitor by the light-brown apple moth *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae). *J. Chem. Ecol.* 19: 953-962.
- Schwalbe, C. P., and V. C. Mastro. 1988. Gypsy moth mating disruption: Dosage effects. *J. Chem. Ecol.* 14: 581-588.
- Shorey, H. H., and R. L. Hale. 1965. Mass rearing of the larvae of nine noctuid species on a simple artificial medium. *J. Econ. Entomol.* 58: 522-524.
- Stadlbacher, E. A., M. W. Barry, A. K. Raina, and J. R. Plimmer. 1983. Fatal interspecific mating of two *Heliothis* species induced by synthetic sex pheromone. *Experientia* 39: 1174-1176.

- Suckling, D. M., and P. W. Shaw. 1992. Conditions that favor mating disruption of *Epiphyas postvittana* (Lepidoptera: Tortricidae). *Environ. Entomol.* 21: 949-956.
1995. Large-scale trials of mating disruption of lightbrown apple moth in Nelson, New Zealand. *N.Z. J. Crop Hortic. Sci.* 23: 127-137.
- Suckling, D. M., and Burnip, G. M. 1996. Orientation disruption of *Planotortrix octo* using pheromone or inhibitor blends. *Entomol. Exp. Appl.* 78: 149-158.
- Thomson, D. R., N.P.D. Angerilli, C. Vincent, and A. P. Gauce. 1991. Evidence for regional differences in the response of obliquebanded leafroller (Lepidoptera: Tortricidae) to sex pheromone blends. *Environ. Entomol.* 20: 935-938.
- Vakenti, J. M., A. P. Gauce, K. N. Slessor, G.C.S. King, S. A. Allan, H. F. Madsen, and J. H. Borden. 1988. Sex pheromone components of the obliquebanded leafroller, *Choristoneura rosaceana* in the Okanagan Valley of British Columbia. *J. Chem. Ecol.* 14: 605-621.
- Van Deventer, P., and L.H.M. Blommers. 1992. Mating disruption of several leaf feeding orchard leaf-roller species with a single sex pheromone component. *Acta Phytopathol. Entomol. Hung.* 27: 615-620.
- Weatherston, I., D. Miller, and J. Lavoie-Dornik. 1985. Commercial hollow-fiber pheromone formulations: the degrading effect of sunlight on celcon fibers causing increased release rates of the active ingredient. *J. Chem. Ecol.* 11: 1631-1644.
- Webb, R. E., B. A. Leonhardt, J. R. Plimmer, K. M. Tatman, V. K. Boyd, D. L. Cohen, C. P. Schwalbe, and L. W. Douglass. 1990. Effect of racemic disparlure released from grids of plastic ropes on mating success of grape moth (Lepidoptera: Lymantriidae) as influenced by density and population density. *J. Econ. Entomol.* 83: 910-916.
- Witzgall, P., A. C. Backman, M. Svensson, M. Bengtsson, C. M. Unelius, J. Vrkoc, P. A. Kirsch, C. Loriatti, and J. Löfqvist. 1996. Potential of a blend of E8, E10-12OH and E8, E10-12Ac for mating disruption of codling moth, *Carpocapsa pomonella* (L.) (Lep., Tortricidae). *J. Appl. Entomol.* 120: 611-614.
- Yashima, T., Y. Tamaki, S. Kamano, and M. Oyama. 1978. Suppression of mating of the armyworm moth, *Spodoptera litura*, by a component of its sex pheromone. *Appl. Entomol. Zool.* 10: 237-239.
- Zar, J. H. 1984. *Biostatistical analysis*, 2nd ed. Prentice-Hall, Englewood Cliffs, NJ.

Received for publication 10 July 1998; accepted 11 January 1999.

Estimating Ec

a

OCTAVIO

Centro Agronómico Tropical de I

ABSTRACT An alternative developed and illustrated. A relations involved in determi a more manageable model o sends a simpler but conceptu and pest control costs are a f thresholds can result in lower but could also be less costly economic threshold that resu functions.

KEY WORDS economic th

THE USE OF injury levels and thres improved the practice of pest manag last half of the 20th century. Stern e duced to the entomological literatu economic injury level (EIL) and ec revolutionizing pest control decisio et al. 1983, Mumford and Norton 19 the EIL as the lowest population cause enough economic damage to artificial control measures. They als nomic threshold as the density at w sures should be determined to pre pest population from reaching the 1959).

To eliminate ambiguity and to m more rigorous economically, Hea Southwood and Norton (1973) rec the density at which the cost of equals the economic loss prevente the control tactic. Based on the forr defined the economic threshold as sity that represents a future popula which will prevent economic loss e implementing the control tactic. general formulas based upon the e of the EIL and the economic thres tions developed by Southwood a which, unlike in Chiang (1982) (1986), are not restricted to syst relationships between insect den

¹Department of Agricultural and Applied University, Box 42132, Lubbock, TX 79409-4213. This journal is a co-sponsor of this research.