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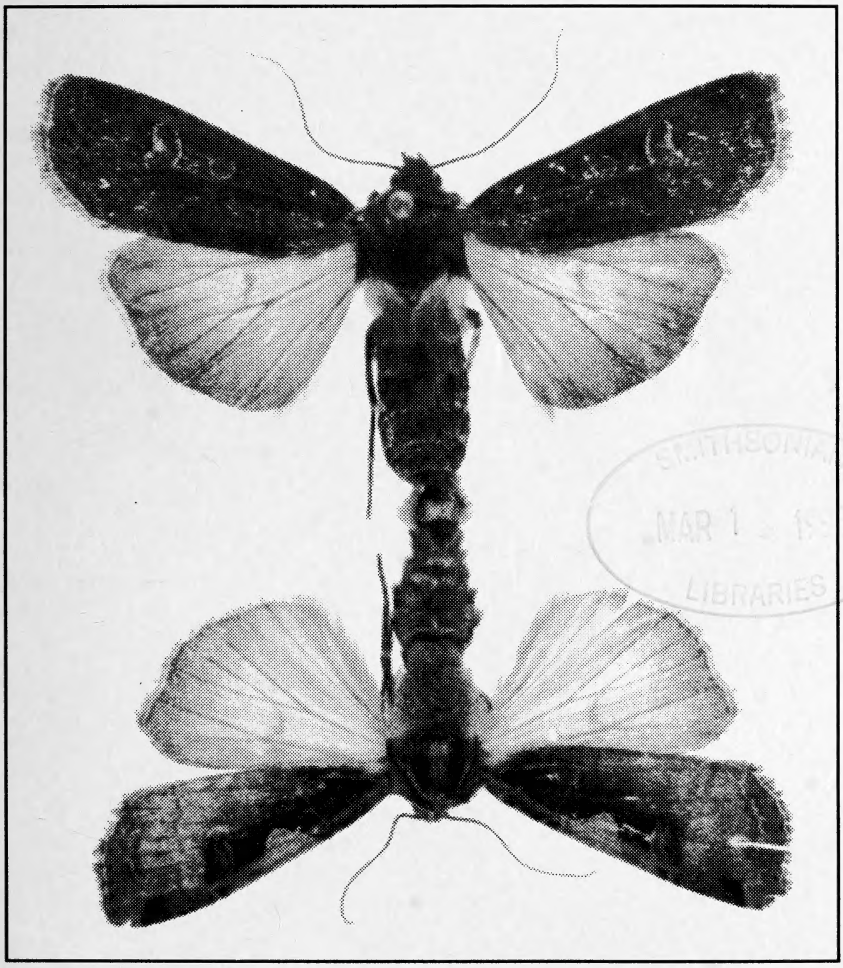

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COVER: This ill assorted pair of noctuid moths was caught in the act and photographed by Jim Troubridge of the Pacific Research Centre, Agriculture and Agri-Food Canada. The upper, darker moth is a female *Euxoa lidia* locked in copulation with a male *Xestia c-nigrum*. They were in a mercury vapour light-trap 16 km E of Invermere, B.C., in July 1994. The photograph was digitized on an Abaton page scanner at 300 dots per inch and, for the first time, sent electronically to the Graphic Designer by the Editor. He solicits good quality line drawings or photographs for future insects of the year.

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Reproduction and longevity of the predatory mite, *Phytoseiulus persimilis* (Acari: Phytoseiidae) and its prey, *Tetranychus urticae* (Acari: Tetranychidae) on different host plants[1]

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ABSTRACT

The biological control of twospotted spider mites by the predator *Phytoseiulus persimilis* is usually unsuccessful on greenhouse tomato crops in British Columbia. Experiments were conducted to determine the influence of host plant on the longevity and reproduction of the predator, and on the suitability of twospotted spider mites as prey. Lifespan and reproduction of *P. persimilis* were lower on tomato leaves than on bean leaves but feeding on spider mites that had been reared on tomato or bean leaves had no effect on the reproduction or lifespan of *P. persimilis*. A strain of twospotted spider mites that came from an outbreak on a greenhouse tomato crop lived for shorter periods and laid fewer eggs when confined on tomato leaves than on bean leaves. A strain of twospotted spider mites that had been maintained on bean leaves was unable to reproduce on tomato leaves. Exudates from glandular hairs were toxic to *P. persimilis*. Glandular hairs are important in pest management on tomato crops. Their removal through breeding might make plants more susceptible to herbivores. Therefore it would be preferable to develop other methods for biological control of twospotted spider mites on tomato.

INTRODUCTION

Biological control of twospotted spider mites, *Tetranychus urticae* Koch (Acari: Tetranychidae) by *Phytoseiulus persimilis* (Dosse and Bravenboer (Acari: Phytoseiidae) is successful on wide range of greenhouse crops throughout the world (van Lenteren and Woets 1988). However, the use of this predator for biological control of *T. urticae* on greenhouse tomato crops has been unsuccessful in British Columbia, and elsewhere (Ravensburg *et al.* 1982). This has been attributed to the entrapment of *P. persimilis* on the glandular hairs on the stems and leaf petioles of tomato plants (van Haren *et al.* 1987).

It is possible that other factors associated with hairiness may also be involved in the lack of efficacy of *P. persimilis* on greenhouse tomato crops. Many mechanisms of resistance to insects and mites have been identified in tomato (Farrar and Kennedy 1991b). Several toxic and repellant chemicals, for example 2-tridecanone, are present in the glandular hairs and on the leaves of tomato plants (Farrar and Kennedy 1991b). A predator such as *P. persimilis* would be exposed to these chemicals either directly, through contact with the leaf, or indirectly, through ingestion of prey.

Many of the mechanisms of resistance in tomato are effective against *T. urticae* (Farrar and Kennedy 1991b). The degree to which the tomato plant affects reproduction and population growth in spider mite populations might aid in determining strategies for dealing with this pest.

We present here results of experiments to determine the mortality and fecundity of the predatory mite, *P. persimilis* and its prey, *T. urticae*, on tomato leaves.

MATERIALS AND METHODS

General: The spider mite strains used in this study were maintained in continuous culture on their respective host plants. The strain adapted to feeding on bean (B-strain) originated from a commercial insectary (Applied Bio-nomics Ltd., Sidney, B.C.) where it had been reared continuously on snap bean (*Phaseolus vulgaris* L.) for several years. The strain adapted to feeding on tomato (*Lycopersicon esculentum* Mill.) (T-strain) originated from an outbreak on tomato plants in a greenhouse in Surrey, B.C. in 1992.

The B-strain mites were reared on pinto beans (*P. vulgaris*) in pots on a laboratory bench. The

plants were inoculated weekly from stock materials obtained from Applied Bio-nomics Ltd. The T-strain mites were reared on excised tomato leaflets (cv Dombito, DeRuiter Seeds, Ohio) on styrofoam trays floating in water filled trays. The petioles of the leaflets were inserted through holes in the styrofoam into the water below. Fresh leaves were added to the trays as required.

The *P. persimilis* used in these experiments were also obtained from Applied Bio-nomics. Eggs of *P. persimilis* were produced for experiments by isolating 2 to 5 females on detached bean leaves on water-saturated cotton batting and providing them with abundant spider mites. The predator eggs were removed every 24 h. Females of *P. persimilis* were produced for experiments by rearing single eggs to adults on detached bean leaves with an abundant supply of spider mites (B-strain). The predators were examined daily, and the females were used in experiments within 24 h of the final molt to adult. All experiments were conducted in growth chambers at 26°C under 16 h of light from cool white fluorescent tubes.

Twospotted spider mites: The effects of host plant species and spider mite strain on egg hatch, development, and survival to adult of *T. urticae* were determined on leaf discs on water-saturated cotton in petri dishes. Eight discs, 1 cm in diam., of each plant species were placed in rows of four on water-saturated cotton batting in each of ten, 9.2 cm square, plastic Petri plates.

A single spider mite egg (< 24 h old) was placed on each leaf disc. Four bean leaf discs in each plate received B-strain mite eggs, and four received T-strain mite eggs. Four tomato leaf discs received T-strain mite eggs and four received B-strain eggs. The spider mites were observed daily through their development. Molts were determined by the presence of cast skins. Spider mites were moved to fresh leaf discs as required.

The effects of the plant host on reproduction in the two strains of spider mite were determined in an identical experimental design to that above, except that adult females (<24 h old) were placed on leaf discs. These females were obtained by rearing spider mites individually on their respective host plants from the protonymph stage. Females at the quiescent deutonymph stage were confined with males. On molting to adult, both the female and the male were transferred to either bean or tomato leaf discs in the experiment. Eggs were counted and removed daily. The mites were transferred to fresh leaf discs as required. Results were analyzed as a factorial design by analysis of variance (Proc GLM, SAS Institute 1992).

Predator mites: To determine if plant species affected reproduction of *P. persimilis*, a single female (<24 h old) was placed with a male on either a bean leaf disc infested with B-strain spider mites or on a tomato leaf disc infested with T-strain spider mites. Predator eggs were counted daily. Predators were transferred to fresh leaf discs as required. The results were analyzed by T-test.

Development time of *P. persimilis* fed on the two different strains was determined on 2 cm diam. plastic discs floating on water-saturated cotton batting in a Petri dish. Four discs were placed in each Petri dish and a single egg of *P. persimilis* was placed on each disc. After the eggs hatched, two of the predators were fed eggs of spider mites reared on bean plants, and two were fed eggs of spider mites reared on tomato plants. Eggs were collected with a camel-hair brush from active spider mite colonies. An excess supply of eggs was placed on each disc. Molts were determined by the presence of cast skin. The results were analyzed by T-test.

To determine if the effects seen in the previous experiment were due to plant species or spider mite strain, adult female *P. persimilis* (<24 h old) were placed on styrofoam discs 2.5 cm in diam. Mixed age populations of spider mites were provided daily on fresh pieces of leaf. The prey were either B-strain spider mites on a bean leaf, B-strain mites on a tomato leaf, T-strain mites on a tomato leaf, or T-strain mites on a bean leaf. Predator eggs were counted and removed daily. Only records for those females that died of natural causes on the disc surface were used for analysis. Mites that abandoned the discs and drowned were not included in the analysis. Results were analyzed by a factorial design analysis of variance (Proc GLM, SAS Institute, 1992).

The toxicity of exudates from glandular hairs of tomato to *P. persimilis* females was determined by exposing them directly to glandular hairs, or to an aqueous solution of exudates, or to water. Twenty mites were exposed directly to glandular hairs. These were held on the tip of a moist camel-hair brush and lightly touched to 30 to 40 glandular hairs on a piece of tomato stem. They were then placed on a sheet of filter paper to recover, then held for examination. Twenty

mites, selected at random, were exposed to exudate solution. These were dipped for 4 sec in the solution, placed on filter paper to dry, and then held for examination. The solution was prepared by collecting exudate from the tips of glandular hairs, allowing this to dry overnight, then dissolving 0.28g of the dried exudate in 2 ml of distilled, de-ionized water. Twenty mites were similarly dipped in distilled, de-ionized water. After 24 h, the dead mites were counted. Results were analyzed by a χ^2 test for goodness of fit.

RESULTS

Twospotted spider mites: Neither host plant nor mite strain had a significant effect ($p>0.05$) on the proportion of eggs hatching (Table 1). There was a significant interaction ($F=18.11$, $p>0.001$) between host plant and mite strain with respect to survival of mites from hatch to adult. There was high mortality of B-strain spider mites on tomato leaf discs, but not on bean leaf discs, and low mortality of tomato strain spider mites on both tomato and bean. Due to high mortality of B-strain mites on tomato leaf discs data on development of this strain were not included in the analysis. Instead, host plant/mite-strain combinations were used as three treatments in a two-way analysis of variance with sex of the mite as the other main effect. There was no interaction between sex of mite and treatment ($p>0.05$). Neither sex of the egg nor host-plant/mite-strain combination had an effect on the time to egg hatch ($p>0.05$; Table 2). Female mites took longer to develop from larvae to adults than males ($F=4.71$, $p=0.0331$). Treatment

Table 1

Mean number of eggs hatched, and survival to adult in 10 cohorts of 4 mites of each strain on bean and tomato leaf discs.

Host plant	Mite strain	Number hatched of four (N=10)	Proportion surviving of four (N=10)
Bean	Bean	3.6	0.90
	Tomato	3.7	0.85
Tomato	Bean	3.4	0.03
	Tomato	3.5	0.88
Mean Square Error		0.3167	0.1721
Anova Results			
Host plant	*F (p)*	1.26 (0.2685)	15.42 (0.0004)
Mite strain	*F (p)*	0.32 (0.5776)	13.37 (0.0008)
Host x Strain	*F (p)*	0.00 (1.000)	18.11 (0.0001)

Table 2

Mean (N, Standard Error) number of days for tomato and bean strain spider mites to complete development on tomato and bean leaf discs.

Host plant	Mite strain	Male		Female	
		Egg	Total*	Egg	Total*
Tomato	Tomato	5.3a	10.0a	5.0a	11.2a
		(7, 0.18)	(7, 0.90)	(19, 0)	(19, 0.46)
Bean	Tomato	5.2a	5.2b	5.3a	5.7b
		(9, 0.15)	(9, 0.36)	(18, 0.11)	(18, 0.27)
Bean	Bean	5.1a	5.1b	5.2a	5.6b
		(19, 0.11)	(19, 0.19)	(10, 0.20)	(10, 0.16)

* Time from egg hatch to molt to adult

Means in a column followed by the same letter are not significantly different.

Table 3

Egg production and survival of bean strain and tomato strain adult female twospotted spider mites on bean and tomato leaf discs.

Host plant	Mite strain	N	Number of Eggs	Days Alive
Bean	Bean	9	49.7	13.2
	Tomato	15	38.7	16.6
Tomato	Bean	10	0.6	6.0
	Tomato	8	2.6	10.0
Mean Square Error			27.8203	7.4501
Anova Results				
Host plant	*F (p)*		22.75 (0.0001)	8.55 (0.0058)
Mite strain	*F (p)*		0.26 (0.6124)	2.43 (0.1270)
Host x strain	*F (p)*		0.55 (0.4637)	0.02 (0.8960)

Table 4

Mean development and reproduction parameters (± standard error) for *Phytoseiulus persimilis* feeding on spider mites on bean or tomato leaves (N = 10).

	Host plant: Bean	Tomato
Development Time	2.6±0.18	2.8±0.17
Total Eggs Laid	56.0±5.67	38.1±3.34*
Days of Oviposition	13.9±1.50	9.6±0.87*
Lifespan	20.7±2.71	11.3±0.60*
Eggs laid per day	3.0±0.46	3.4±0.28

*Significant effect of host plant (T-test, $p<0.05$)

(host-plant/mite-strain combination) had a significant effect on the time for development from egg to adult ($F=134.96$; $p<0.0001$). Both male and female T-strain mites required significantly longer to develop on tomato than either T-strain mites on bean or B-strain mites on bean.

Spider mites produced significantly fewer eggs on leaf discs of tomato than they did on leaf discs of bean (Table 3). Spider mite lifespan was also shorter on leaf discs of tomato than on leaf discs of bean. Strain had no effect on either egg production or longevity of spider mites.

Predator mites: There was no effect of spider mite (prey) strain on development time of *P. persimilis* on leaf discs (Table 4). Females on discs of tomato leaf laid fewer eggs over a shorter period and had shorter lives than females on discs of bean leaf (Table 4). There was no effect of host plant species on the rate of oviposition.

When *P. persimilis* were confined on styrofoam discs and supplied with prey on leaf pieces, there was no effect of host plant leaf pieces on the life span or fecundity of female *P. persimilis* (Table 5). Females that were fed B-strain mites lived for a significantly shorter time than females that were fed T-strain mites irrespective of the plant species on which the spider mites were presented.

Ten percent of females of *P. persimilis* died after exposure to water, 50% died after exposure to a solution a glandular hair exudates, and 85% died after direct contact with glandular hairs. These were significant differences ($\chi^2=22.6$, $p<0.05$).

DISCUSSION

The twospotted spider mite, *T. urticae*, is broadly polyphagous. However, some spider mite populations are selectively adapted to only some of the plants that are part of their host range (Fry 1989). It is probable that no spider mite population is able to feed and reproduce on all of

the known hosts. The T-strain of spider mites used in this study originated from an outbreak on a tomato crop in a commercial greenhouse. However, it was able to use bean, *P. vulgaris*, as a host, and survived and reproduced better on bean than on tomato (Table 3). There were no differences in reproduction or survival between the B- strain and the T-strain on bean. On tomato, the B-strain of *T. urticae* was virtually unable to reproduce. Very few immatures survived to reproduce, and females placed on tomato laid few eggs.

The reproductive abilities of the T-strain of *T.urticae* are so reduced on tomato that it appeared surprising that this strain was able to survive on tomato, let alone generate an outbreak. However, in laboratory culture this strain reproduced rapidly on excised leaves of tomato. The major difference between the laboratory culture and the experiments described here was that many spider mites were used to start a culture, whereas a single mite was used in experiments. The large number of mites used to inoculate the laboratory colony produced copious silk. Mites tend to walk on the silk and would therefore have been isolated from the leaf surface. Tomato plant glandular hairs contain many substances that are toxic to twospotted spider mites (Farrar and Kennedy 1991b). The silk would tend to protect the mites from the effects of the hairs and the larger number of mites on the leaf would tend to dilute exposure to glandular hair substances.

The strain of spider mite had no effect on the fecundity of the predator, *P. persimilis*. In an initial experiment (Table 4) fecundity was lower for females feeding on T-strain spider mites on tomato leaves than for those feeding on B-strain spider mites on bean leaves. On styrofoam discs, neither the strain of spider mites nor the plant species on which they were provided had any significant effect on reproduction in the predator. This is probably because the predators did not have to spend all of their time on the plant section provided, but could move about on the styrofoam disc, thus avoiding contact with the glandular hairs.

Predators that were fed on B-strain spider mites had shorter lives than predators fed on the T-strain mites (Table 5). In these results the interaction between host plant and spider mite strain was not significant. However, it is large enough to indicate that the significant effect of spider mite strain on lifespan could have resulted from the short lifespan (15.3 days) of *P. persimilis* that were fed B-strain spider mites on tomato leaf pieces. Lifespan of *P. persimilis* in all other treatments was greater than 18 days. Mortality among B-strain mites on tomato leaves could have reduced the number of prey available to *P. persimilis*. Plant resistance characters are known to affect the biology of natural enemies, even though Wheatley and Boethel (1992) showed that resistance to spider mites in soybeans (*Glycine max*) had no effect on *P. persimilis*. However, other natural enemy associations are affected by resistance characteristics in soybeans (Orr and Boethel 1986, Rogers and Sullivan 1986, Yanes and Boethel 1983). Resistance to *Manduca* spp. (Lepidoptera: Sphingidae) in tomato has toxic effects on the parasitoid *Telenomus sphingis* (Hymenoptera: Scelionidae) (Farrar and Kennedy 1991a).

Table 5

Numbers of eggs laid and lifespan for *Phytoseiulus persimilis* females held on styrofoam floating discs and fed spider mites reared on either bean or tomato leaves (N = 10).

Host plant	Mite strain	Total Eggs	Lifespan (days)	Eggs per day
Bean	Bean	53.1	18.1	3.2
	Tomato	54.9	18.9	3.1
Tomato	Bean	44.2	15.3	3.0
	Tomato	42.6	19.9	2.4
Mean Square Error		23.95	3.9	1.53
Anova Results				
Host Plant	*F (p)*	1.96 (0.1701)	0.51 (0.4801)	0.98 (0.3283)
Mite Strain	*F (p)*	0.00 (.9895)	4.58 (0.0392)	0.53 (0.4714)
Host x Strain	*F (p)*	0.05 (0.8236)	2.27 (0.1407)	0.37 (0.5475)

The host plant of the spider mite upon which *P. persimilis* fed did not greatly affect the biology of the predator. Females of *P. persimilis* confined on tomato leaflets have a shorter lifespan than females confined on bean leaves. As a consequence, the number of eggs laid is reduced, and population growth and predation would be reduced. This effect is due to contact with leaf, not the consumption of prey. Eating B-strain mites fed on tomato reduced the lifespan of *P. persimilis*. The cause of this was not clear.

Up to 75% of *P. persimilis* die moving from leaf to leaf on tomato plants (van Haren *et al.* 1987). If the reproduction of the remainder is reduced by up to 40% as a result of reduced lifespan on leaf blades, then it would appear that enormous numbers of predators would have to be introduced into tomato crops to offset these effects

Resistance in tomato plants to spider mites can be affected to some degree by environmental factors. Increased fertilization reduces resistance through lowering both glandular hair densities and 2-tridecanone levels (Barbour *et al.* 1991). Glandular hair density is conversely increased in long-day, high light level conditions (Kennedy *et al.* 1981). Glandular hair density and other resistance factors might be reduced through breeding. However, resistance to pests based on glandular hairs is important for preventing feeding by many species of herbivores (Farrar and Kennedy 1991b), and should not be discarded for the sake of single predator/prey association. It would be preferable to develop alternative strategies for releasing and managing *P. persimilis* in tomato crops, or to seek other predator species that are not affected by the resistance mechanisms of tomato.

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NOTE

1. Contribution number 516 from the Pacific Agriculture Research Centre, Agassiz, B.C.

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Phenology of the alfalfa weevil (Coleoptera: Curculionidae) in alfalfa grown for seed in southern Alberta

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ABSTRACT

An algorithm to forecast occurrence of four life-stage categories of the alfalfa weevil, *Hypera postica* (Gyllenhal), was derived from data collected in fields of seed alfalfa, *Medicago sativa* (L.) in southern Alberta. The algorithm assumes a linear developmental response to mean daily temperatures above a threshold of 10°C. Overwintering adults were active after the accumulation of 100 degree-days above 10°C (DD_{10}), and were scarce by 250-300 DD_{10}. Early larvae (instars 1 + 2) were found beginning at 120 DD_{10} and their numbers peaked at 200 DD_{10}. Late larvae (instars 3 + 4) were present beginning at 160 DD_{10} and their numbers peaked at 350 DD_{10}. New generation adults appeared after 500 DD_{10}. In southern Alberta, alfalfa seed production is frequently combined with honey production. This algorithm enables producers to forecast the occurrence of the most damaging stage of alfalfa weevils which may require control with insecticides; the advance notice enables optimal timing of treatment and also allows apiarists to minimize pesticide mortality by moving or confining their bees.

Key words: Thermal units, degree days, simulation, phenology

INTRODUCTION

Pest control measures are economically justifiable only if their benefits exceed their cost (Stern *et al.* 1959). Normally, cost is the sum of pesticide purchase plus its application, and benefit is measured by reduced yield loss. However, other factors may enter the cost:benefit equation; this occurs in alfalfa production in southern Alberta, where seed producers frequently obtain additional income by charging apiarists to place honeybees (*Apis mellifera* L. (Hymenoptera: Apidae)) in their fields. Thus, strategies to control pest insects in alfalfa seed fields must acknowledge the susceptibility of honeybees to many pesticides.

One approach to reconciling alfalfa pest management with apiculture is to give apiarists sufficient warning to cover the hives, or to move them, before pesticides are applied. This approach requires a method of forecasting the occurrence of the pest population. This paper presents a simple method of doing so, which is based on observed correlations between phenological events and degree-day accumulations.

In southern Alberta, the alfalfa weevil is a serious insect pest of alfalfa, feeding on shoots, flower buds and foliage during prebloom to early bloom (Hamlin *et al.* 1949). If not controlled it can severely reduce seed yield. Adult alfalfa weevils spend the winter in protected locations in alfalfa fields or in litter nearby. Overwintered adults become active about the time the first alfalfa shoots appear in the spring. They feed for a few days, mate, and begin ovipositing. Peak egg density usually occurs in late May or early June, but eggs can be found during most of the summer.

Rates of pre-imaginal development are temperature-dependent. Egg incubation takes 4 to 21 days. Larvae develop through the four instars in about 3 to 4 weeks. Instars 1 and 2 (early larvae) feed within the tightly-curled developing leaves and buds; instars 3 and 4 (late larvae) feed on expanded leaves.

Feeding damage is most obvious in mid- to late-June, concurrent with peak densities of late larvae. Defoliation is most severe toward the terminals. This type of feeding results in loss of foliage, flower buds, and nutrients, with consequent delays in plant growth and development. Quantity and quality of the seed yield may be reduced.

Late larvae inflict the greatest damage, so agricultural losses can be expected to start accumulating at the onset of this life stage (Dennis *et al.* 1986). Consequently, the timing of control tactics for the alfalfa weevil should be optimized, based on an understanding of physiological

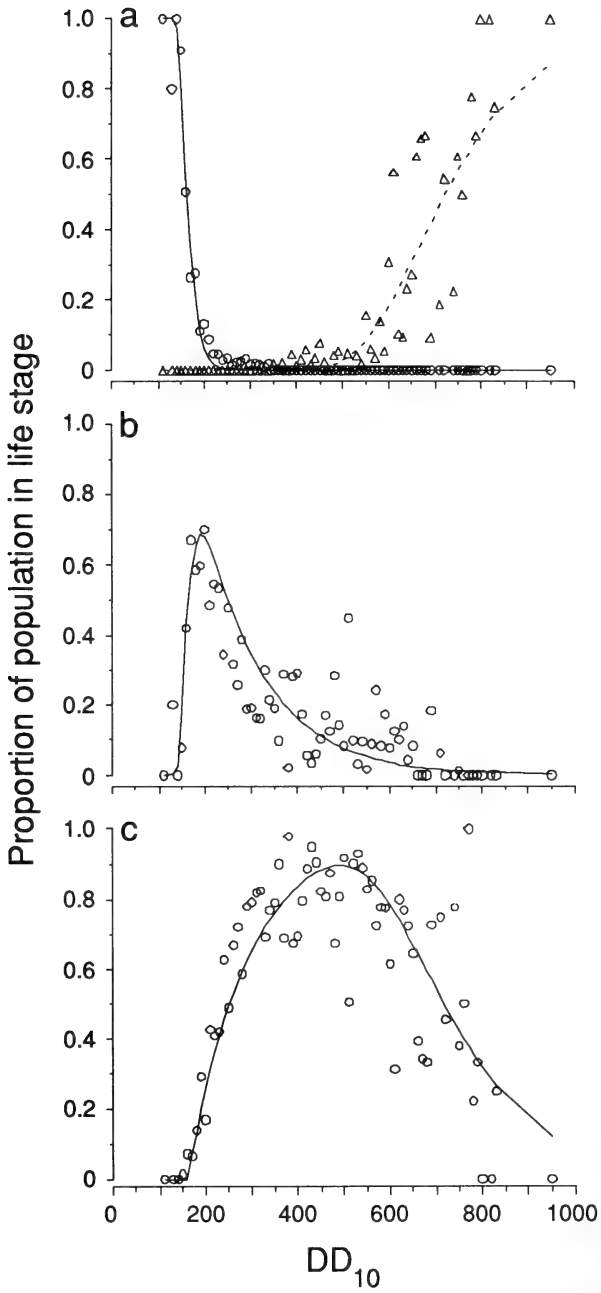

Figure 1. Observed and predicted proportion of alfalfa weevil in relation to DD_{10}. a) Overwintering adults (life stage = 1): o and solid line. New generation adults (life stage = 4) Δ and dotted line; b) first and second instars (early larvae; life stage = 2); c) third and fourth instars (late larvae; life stage = 3). Lines are predictions made using Equations 1-3 in text.

and behavioral processes (Harcourt 1981; Whitford and Quisenberry 1990), to target this life stage. This optimization requires information on the seasonal abundance and time of occurrence of the immature stages of the alfalfa weevil through a combination of population monitoring and phenological models (Schaber and Richards 1979).

In southern Alberta, chemical insecticides are the primary method of alfalfa weevil control. Efficient use of insecticides requires that applications should be timed to target the first late larvae, i.e. after they have moved to exposed positions on the leaves, but before they have caused much damage. This timing requirement establishes a potential conflict between pest control and honey production. A reliable method of forecasting the occurrence of late larvae could resolve this conflict.

This study was conducted to develop a technique that would predict the appearance of late instar alfalfa weevil larvae in seed alfalfa fields, using southern Alberta field data. This technique would enable better timing of insecticide applications in relation to insect development, and allow seed producers and apiarists more lead time to protect pollinators.

The temperature-dependence of insect development dictates that developmental models be based on thermal-unit accumulation. Simple methods for modelling phenology based on field data are available, and can be used to develop realistic models in the absence of detailed data on insect development processes (Hudes and Shoemaker 1988; Kemp and Onsager 1986; Kemp *et al.* 1986; Lysyk 1989). Degree-day accumulation has been used to predict peak hatch and subsequent activity of alfalfa weevil in forage alfalfa in southern Ontario (Harcourt 1981). However, Tauber *et al.* (1988) have suggested that the phenology of an insect species can vary among geographic regions due to adaptation of thermal biology to local climatic conditions, so another objective was to compare phenology of the alfalfa weevil populations in southern Ontario and southern Alberta.

METHODS

Algorithm development

The algorithm was developed using phenology data obtained from four research plots at the Agriculture and Agri-Food Canada Research Centre (AACRC) at Lethbridge, Alberta. Alfalfa weevil abundance was determined by taking five sweeps per plot with a 38-cm net (Johansen *et al.* 1979). Each plot was sampled every one to three days from 3 June to 12 August 1985; 12 May to 8 August 1987; 3 June to 20 July 1988; 3 June to 4 July 1989, and was sampled weekly from 4 June to 23 July 1990. Daily maximum and minimum temperatures (°C) were obtained from the AACRC meteorological station.

Alfalfa weevil phenology was modeled by correlating phenological events with degree-day accumulations using a developmental threshold of 10°C. This threshold was used because, although alfalfa weevil eggs hatch at 8°C, the resulting larvae do not survive even if subsequently exposed to a higher temperature (Guppy and Mukerji, 1974). Accumulated degree-days above 10°C (DD_{10}) from 1 January were calculated for each year by sine-wave integration (Allen 1976). Accumulated DD_{10} on each date was rounded to the nearest 10, and samples from the 4 plots were grouped according to these rounded values. The proportion of alfalfa weevils which were adults, early larvae and late larvae were calculated for all such grouped samples, and these proportions were related to the rounded DD_{10} accumulations by non-linear regression (Proc NLIN, SAS Institute 1989) as outlined below.

To provide a standardized estimate of when the weevils and larvae were most abundant, and to establish correlations between phenological events and DD_{10} accumulations, their relative abundance was calculated for each plot on each day in each growing season by summing the number of weevils collected and dividing by the greatest number collected in one day for that plot in that year. These relative abundances were grouped across plots and years by the rounded degree-day values. The correlations between relative abundance and DD_{10} accumulations were used to develop an algorithm to predict the appearance of the different life stages.

Alfalfa weevil phenology was divided into four stages (i): overwintered adults (i = 1), i.e.,

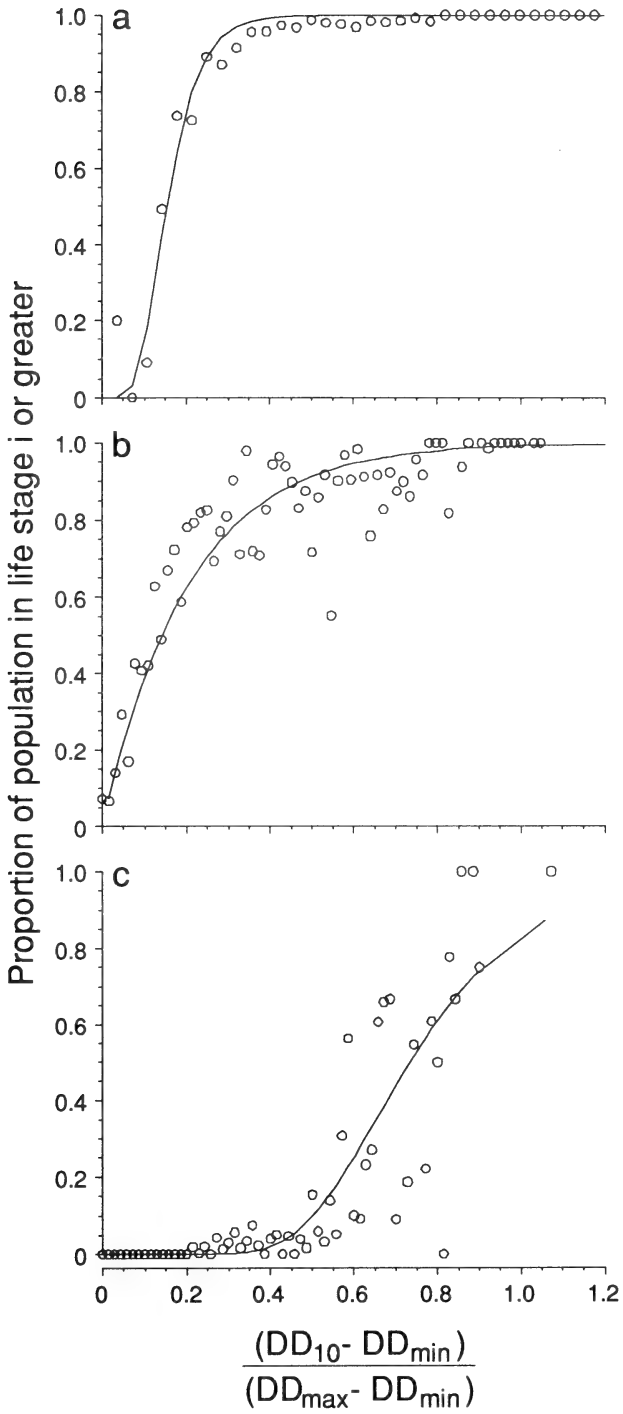

Figure 2. Proportion of alfalfa weevil in a) life stage 2 or greater, b) life stage 3 or greater, and c) life stage 4. Solid lines are model predictions using equation 2 and parameters estimates given in Table 1.

those present before the larval peak at 350 DD_{10}; early larvae (i = 2); late larvae (i = 3); and new generation adults (i = 4), i.e, those occurring after the larval peak at 350 DD_{10}.

The algorithm was developed as outlined below (Hudes and Shoemaker 1988). For each rounded DD_{10} value, the following calculations were made:

$$F_2 = (n_2 + n_3 + n_4) / \Sigma n$$
$$F_3 = (n_3 + n_4) / \Sigma n$$
$$F_4 = n_4 / \Sigma n$$

where n_i(i=2-4) is the number of weevils in life stage i, Σn is the total number of weevils, and F_i is the proportion of insects in life stage i or later. Note that because all insects are in a life stage equal or greater than the overwintered adult stage, $F_1 = 1$.

The time trends in each F_i were modelled using equation 1.

$$\hat{F}_i = [1 - e^{-a_i * t_i}]^{b_i} \quad (1)$$

Non-linear regression was used to obtain estimates of the parameters (a_i, b_i; i = 2 - 4). The variable t_i is a scaled estimate of thermal time calculated for each life stage as:

$$t_i = \frac{DD_{10} - DD_{\min(i)}}{DD_{\max(i)} - DD_{\min(i)}} \quad (2)$$

In equation 2, $DD_{min(i)}$ and $DD_{max(i)}$ represent the approximate value of DD_{10} for the beginning and end of life stage i, obtained by inspection of the data.

The functions describing time-change in $_i$ were then used to predict the proportion of insects in each life stage ($\hat{p}_i$):

$$\hat{p}_1 = 1 - F_2,$$
$$\hat{p}_2 = F_2 - F_3, \quad (3)$$
$$\hat{p}_3 = F_3 - F_4,$$
$$\hat{p}_4 = F_4.$$

Algorithm validation

Independently-obtained data were used to validate the algorithm. These were collected from plots in Brooks, Rosemary and Rolling Hills, Alberta (ca. 130 km N.E. of Lethbridge) by WestAg, Inc., a pest management scouting company. These plots were sampled weekly for up to 13 weeks in 1984-1988, starting the last week of May and continuing through August. Samples in a specific plot in each year were taken at approximately the same time of day to minimize any effects of insect diurnal cycle on sampling efficiency (Johansen *et al.* 1979). The data consisted of weekly mean numbers of adults and of early and late larvae. The numbers of fields sampled were 48, 40, 42, 48 and 42 for 1984 through 1988. Sample counts were tabulated weekly. Daily maximum and minimum temperatures were obtained for each year from the Alberta Special Crops and Horticultural Research Center in Brooks, Alberta, and the DD_{10} accumulation from January 1 were calculated by sine-wave integration (Allen 1976). The DD_{10} accumulation in the middle of each week was matched with the weekly insect data. The average proportion of weevils in the adult, early larval, and late larval stages was calculated for each week and compared graphically to the algorithm predictions.

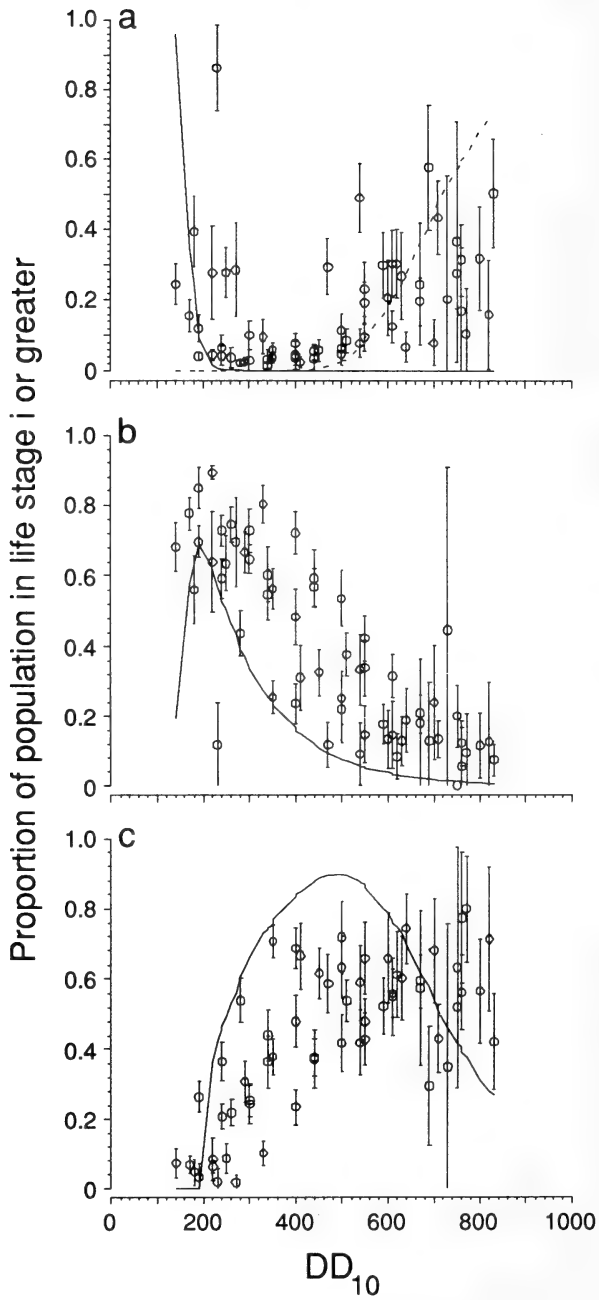

Figure 3. Proportion of alfalfa weevil in commercial seed alfalfa fields. Symbols are observed mean proportion ± 1 standard error, and lines are predictions made using Equations 1-3. a) adults, solid line is overwintered generation (life stage = 1) and dotted line is new generation (life stage = 4); b) first and second instars (early larvae; life stage = 2); c) third and fourth instars (late larvae; life stage = 3).

RESULTS

Seasonal phenology of alfalfa weevil

Adult weevils were first found at about 100 DD_{10} (Fig. 1a) and at that time were the only stage collected. The proportion of adult weevils declined from about 250 DD_{10} and they had become scarce by 350 DD_{10}. Early larvae appeared at about 120 DD_{10} (Fig. 1b), reached a maximum at about 200 DD_{10}, and then declined slowly. Late larvae appeared at ca. 160 DD_{10} (Fig. 1c), peaked near 450 DD_{10}, and then declined. New generation adult weevils began to appear after 400 DD_{10}, and increased steadily to nearly 100% of the population by 900 DD_{10}.

Algorithm output

Figure 1a-c illustrates the good agreeement between the algorithm output and the Lethbridge data. Estimates of the regression parameters are listed in Table 1. Coefficients of determination (r^2) were 0.97, 0.84, and 0.74 for life stages 2, 3 and 4 respectively. Model predictions of proportions of insects in life stage i or greater are overlaid with observations in Fig. 2a-c

Algorithm validation

Observed and predicted values of the proportion of weevils in each life stage for the test data are shown in Fig. 3 a-c. The predicted proportions of weevils in the adult life stages (1 and 4) seem reasonable (Fig. 3a). For early larvae, the algorithm predicted the timing of the peak population (Fig. 3b), and in general captured the seasonal population trends, but overall underestimated the proportion of weevils in this life stage. For late larvae (Fig. 3c) the algorithm predicted the start of the stage and captured the essence of the seasonal trends, but tended to overestimate the proportion of insects in this stage.

DISCUSSION

The phenology we observed differed from that recorded in Ontario (Harcourt 1981). In Ontario, most of the feeding damage occurred between 260 and 335 Degree-days base 9°C, whereas in this study, the damaging stage extended beyond 500 DD_{10}. These differences may reflect adaptation of the insect to a different cropping pattern, i.e. seed alfalfa *vs* forage alfalfa, or to a different climate. Harcourt's (1981) model does not seem to apply to the Alberta population of alfalfa weevil.

Table 1

Estimated parameters for component equations of the algorithm simulating alfalfa weevil population phenology.

	Equation (1)[a]			Equation (2)[b]	
Life Stage (i)	a	b	r^2	DDmin	DDmax
2	18.15	11.01	0.97	120	400
3	4.84	1.00	0.84	160	800
4	5.05	29.81	0.74	200	900

a Nonlinear regressions of the temporal change in proportions of observed insects in life stage (i), using

$$\hat{F}_i = [1 - e^{-a_i \cdot t_i}]^{b_i}$$

b Scaled estimates of thermal time for life stage (i), calculated as:

$$t_i = \frac{DD_{10(i)} - DD_{\min(i)}}{DD_{\max(i)} - DD_{\min(i)}}$$

Details are given in the text.

Although qualitatively similar, there is some discrepancy between the predictions and the validation data. Several factors can affect the accuracy and reliability of the algorithm. First, separating alfalfa weevil larvae into life stages is somewhat subjective, particularly when differentiating between second and third instars, and variation among observers can affect the accuracy of sampling for pest insect populations (Shufran and Raney 1989).

Another possible source of the discrepancies results from the differing ways in which samples were handled. The alfalfa weevils and larvae captured in the sweep net at Lethbridge were placed in paper bags and stored at −40°C until counted, whereas in the validation data they were counted in the field immediately after capture. These differences in method, coupled with the subjective assignment to stages, could affect the performance of algorithm.

Another possibility is that the use of degree-days may not be strictly applicable because it disregards both the nonlinearity of the developmental rate function (e.g. Lactin and Holliday 1993), and the ability of insects to control body temperature behaviourally (Huey and Kingsolver 1989), and can not account for the effects of transient unfavourable conditions (Lactin 1992).

Finally, insecticides were used in the commercial fields surveyed by WestAg, Inc., and differential mortality among the life stages may acount for the bias between algorithm predictions and field data. Early larvae feed mostly within the flower buds and are largely protected from contact insecticides, whereas late larvae feed on expanded foliage and are not (Johansen *et al.* 1979). These differences in exposure risk could bias the population structure of the validation fields, compared to that predicted by the algorithm, which was based on observations from insecticide-free fields.

CONCLUSION

This paper outlines the development of an algorithm to predict the occurrence of damaging stages of the alfalfa weevil. Although there is a consistent bias in the estimate of proportion of these stages in the population, the algorithm estimates the timing of stages quite well, and can provide sufficient advance warning to optimize the timing of insecticide application, and thus allow apiarists to remove or confine their bees.

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Robber flies (Diptera: Asilidae) new to Canada, British Columbia, Yukon and the Northwest Territories with notes on distribution and habitat

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ABSTRACT

Twenty-one species of robber flies from British Columbia, not previously reported in Canada, are listed. Three genera are also new: *Callinicus, Coleomyia,* and *Megaphorus.* Two additional genera (*Stichopogon* and *Andrenosoma*) and 12 species already known from Canada are reported for the first time from British Columbia. Sixteen species new to the Yukon, and seven to the Northwest Territories are also recorded. These records update the list of Asilidae for this region last published by Stone and others in 1965.

Key words: Diptera, Asilidae, British Columbia, Yukon, Northwest Territories, distribution, status

INTRODUCTION

This paper makes some additions to the list of the robber flies (Diptera: Asilidae) of British Columbia, Yukon and western Northwest Territories and discusses the status of other species. Some of these new records represent recent collections, some are the result of the examination of unidentified or misidentified specimens in various collections, and some are records of material simply not previously published. The starting point for the list is the treatment of the Asilidae by Martin and Wilcox in the Catalogue of Diptera of America by Stone *et al.* (1965). Species not listed from the region in that Catalogue, and that have not appeared in subsequent publications, are considered new records. Three short lists (Foxlee 1941, 1944; Hine 1904), overlooked and not in the 1965 Catalogue, are also included here as new material. Twenty-five species whose occurrences in the region have been published since the Catalogue, are listed separately and their status is clarified. The purpose of these lists is to update Stone's Catalogue for the western Canadian region.

Few publications relevant to the asilid fauna of the region have appeared since the Catalogue was published. Adisoemarto (1967) summarized the distribution of the robber flies of Alberta, and included some data from surrounding regions. Adisoemarto and Wood (1975) published some British Columbia records in their revision of *Dioctria* and relatives, as did Martin (1975) in his work on the Asilini and Wilcox on *Efferia* (1966) and *Stenopogon* and *Scleropogon* (1971). Cannings (1989) added a number of species to the Canadian total in a study of the asilid fauna of a *Festuca* grassland in the Okanagan Valley of British Columbia.

The species lists here are annotated with brief comments on range, distribution in the area under consideration, and other information. Localities are given for those species represented by only one or two records. Museum collections containing the material examined are: the California Academy of Sciences, San Francisco [CAS]; Canadian National Collection, Ottawa [CNC]; Spencer Entomological Museum, University of B.C., Vancouver [UBC]; Royal British Columbia Museum, Victoria [RBCM]; Royal Ontario Museum, Toronto [ROM]; Pacific Forestry Centre, Victoria [PFC]; University of Guelph, Guelph [UG].

RESULTS

Twenty-one species and three genera previously unrecorded in Canada are documented (Table 1). The genera are *Callinicus, Coleomyia,* and *Megaphorus.* Twelve other species and two genera (*Andrenosoma* and *Stichopogon*) have not previously been reported from British Columbia. Sixteen species are new to the Yukon and seven to the Northwest Territories.

Table 1

Range extensions of Asilidae. Species are newly recorded for the jurisdiction indicated.
CAN = Canada; BC = British Columbia; YT = Yukon Territory; NWT = Northwest Territories.

SPECIES	CAN	BC	YT	NWT
Leptogaster arida	X	X		
Leptogaster fornicata	X	X		
[1]*Callinicus pollenius*	X	X		
[1]*Coleomyia hinei*	X	X		
Cyrtopogon ablautoides	X	X		
Cyrtopogon auratus		X		
Cyrtopogon bimacula			X	X
Cyrtopogon dasylloides	X	X		
Cyrtopogon dubius	X	X		
Cyrtopogon falto		X		
Cyrtopogon fumipennis			X	
Cyrtopogon glarealis			X	
Cyrtopogon lineotarsus		X		X
Cyrtopogon princeps	X	X		
Cyrtopogon sansoni		X		
Eucyrtopogon diversipilosus			X	
Eucyrtopogon nebulo			X	
Eucyrtopogon punctipennis	X	X		
Heteropogon senilis	X	X		
Lasiopogon actius	X	X		
Lasiopogon canus			X	X
Lasiopogon cinereus		X		
Lasiopogon hinei		X	X	
Lasiopogon prima		X	X	X
Lasiopogon willametti	X	X		
Nicocles dives	X	X		
Nicocles rufus	X	X		
[2]*Stichopogon fragilis*	X	X		
[2]*Andrenosoma fulvicaudum*		X		
Laphria astur	X	X		
Laphria gilva			X	
Laphria index		X		
Laphria insignis		X	X	X
Laphria janus			X	X
Laphria milvina			X	
Laphria partitor			X	
Laphria posticata		X	X	X
Laphria sackeni	X	X		
Laphria ventralis	X	X		
Laphria vivax			X	
Laphria vultur	X	X		
Efferia frewingi		X		
Machimus callidus			X	
Machimus vescus	X	X		
[1]*Megaphorus willistoni*	X	X		

1. Genus is new to Canada
2. Genus is new to British Columbia.

List of Robber Flies New to Canada, British Columbia, Yukon Territory, and Northwest Territories

Specific localities are listed when only a few collection sites are known, otherwise a general description of the distribution is given. The faunal element to which the species belongs is indicated by the following terms:

Beringian: restricted to the northern parts of the region, especially Alaska, the Yukon, and extreme northwestern Mackenzie.

Boreal: transcontinental in the Boreal Forest and south, to varying degrees, in the western mountains.

Cordilleran: mountain forests of western North America.

Holarctic: parts of both North America and Eurasia, usually Arctic-Alpine or Boreal Forest species.

Intermontane: plateaus and valleys of the western mountain ranges; predominantly grassland species. A few species in this category also spread into the grasslands of the western Great Plains.

Pacific Coast: west of the Coast Mountains; lowland forest or sea beach species.

Southern: from coast to coast south of the Boreal Forest, transcontinental at least in the United States; in Canada only in extreme southern areas.

Western: western mountains and associated lowlands, often extending into the adjacent areas of the Great Plains.

Subfamily Leptogastrinae

Leptogaster arida Cole. Western; dry forests and adjacent grasslands of the south coast and southern Interior of British Columbia [CNC, RBCM]. Ranges east to Alberta and south to California. New to Canada and British Columbia.

Leptogaster fornicata Martin. Intermontane; dry forests and adjacent grasslands of the southern Interior of British Columbia. Pavilion [UBC]; specimens from Osoyoos [RBCM,UBC] are close to this species. Also known from Idaho. New to Canada and British Columbia.

Subfamily Dasypogoninae

Callinicus pollenius (Cole). Cordilleran; dry forests of the southern Interior of British Columbia [CNC, RBCM, UBC, PFC]. South to Wyoming and California. Genus new to Canada and British Columbia.

Coleomyia hinei Wilcox and Martin. Cordilleran; dry forests of the southern Interior of British Columbia [CNC, RBCM, UBC]. South to Oregon and Idaho. Genus new to Canada and British Columbia.

Cyrtopogon ablautoides Melander. Cordilleran; dry forests of the southern Okanagan Valley (Oliver [CNC]). South to Washington. New to Canada and British Columbia.

Cyrtopogon auratus Cole. Cordilleran; subalpine forests of southern British Columbia north to the Cariboo region [CNC, RBCM]. East to Alberta and south to Utah and Wyoming. New to British Columbia.

Cyrtopogon bimacula Walker. Boreal; widespread in British Columbia, Yukon (north to Old Crow), and Northwest Territories [CNC, RBCM, UBC]. Trans-Canada south to New Hampshire and New Mexico. New to Yukon and Northwest Territories.

Cyrtopogon dasylloides Williston. Cordilleran; subalpine forests of southern British Columbia [CNC, RBCM, UBC]. South to California. New to Canada and British Columbia.

Cyrtopogon dubius Williston. Cordilleran; subalpine forests of southern Coast Mountains (Squamish, Diamond Head Trail [CNC]). South to Oregon. New to Canada and British Columbia.

Cyrtopogon falto Walker. Boreal; forests of central British Columbia (Skeena River Valley [CNC]). East to Nova Scotia, south along the Appalachians to Florida. New to British Columbia.

Cyrtopogon fumipennis Wilcox and Martin. Cordilleran; mountain forests north to the southern Yukon (Nahanni Range Rd., km 128; Carcross [UBC]). South to Washington and Idaho. New to Yukon.

Cyrtopogon glarealis Melander. Cordilleran; forests of the British Columbia Interior north to the central Yukon (Pelly Crossing [UBC]). East to Alberta, south to California and Wyoming. New to Yukon.

Cyrtopogon lineotarsus Curran. Cordilleran; forests of the British Columbia Interior (Robson [RBCM]), north to N.W.T. (Yellowknife [CNC]). According to Fisher and Wilcox (1987), *C. predator* Curran is a synonym of *C. lineotarsus*; *C. predator* is known from Fort Fraser and Fort St. James, B.C. [CNC]. East to Alberta, south to Washington and Montana. New to British Columbia and Northwest Territories.

Cyrtopogon princeps Osten Sacken. Cordilleran; subalpine forests of the Cascade Mtns. of southwestern British Columbia [RBCM]. South to California. New to Canada and British Columbia.

Cyrtopogon sansoni Curran. Cordilleran; Kootenay region of southeastern British Columbia (Robson [CNC]). East to Alberta. New to British Columbia.

Eucyrtopogon diversipilosus Curran. Cordilleran; forests of the British Columbia Interior north to the southern Yukon (Carcross [UBC]). East to Alberta. New to Yukon

Eucyrtopogon nebulo (Osten Sacken). Cordilleran; dry forests and adjacent grasslands; widespread in British Columbia (Cannings 1989) north to the northern Yukon (Old Crow, Mason Hill [RBCM, UBC]). South to California. New to Yukon. Yukon specimens may represent an undescribed species.

Eucyrtopogon punctipennis (Melander). Cordilleran; forests of southern British Columbia [CNC, RBCM, PFC]. South to Idaho and Washington. New to Canada and British Columbia.

Heteropogon senilis (Bigot). Cordilleran; forests of southern British Columbia [CNC, RBCM]. South to California. New to Canada and British Columbia.

Lasiopogon actius Melander. Pacific Coast; sand beaches of coastal British Columbia (Queen Charlotte Is. [RBCM]).South to California. New to Canada and British Columbia.

Lasiopogon canus Hine. Beringian; widespread in dry forests and streambanks of Yukon, including shrub tundra; east to Tuktoyaktuk Peninsula, Northwest Territories [CNC, RBCM, ROM, UBC]. Alaska south and east to northwestern Alberta. New to Yukon and Northwest Territories.

Lasiopogon cinereus Cole. Cordilleran; forests and streambanks of southern Interior of British Columbia [RBCM, UBC]. East to Alberta, south to Wyoming and California. New to British Columbia.

Lasiopogon hinei Cole and Wilcox. Beringian; dry forests and streambanks of Yukon [CAS, CNC, RBCM, ROM, UBC]. Alaska south and east to northwestern Alberta. New to British Columbia and Yukon.

Lasiopogon prima Adisoemarto. Beringian; dry forests and streambanks of northern British Columbia and Yukon [CAS, RBCM, ROM, UBC, UG] Northwest Territories (Cache Creek Springs [UBC]). Alaska south and east to northwestern Alberta. New to British Columbia, Yukon and Northwest Territories.

Lasiopogon willametti Cole and Wilcox. Pacific Coast; sand beaches of Vancouver Island and sandbanks and bars of lower Fraser River and delta, southwestern British Columbia [RBCM, UBC]. South to northern California. New to Canada and British Columbia.

Nicocles dives (Loew). Cordilleran; dry forests of the southern Interior of British Columbia [CNC, RBCM, UBC]. Listed in Foxlee (1944). South to California. New to Canada and British Columbia.

Nicocles rufus (Williston). Pacific Coast; Garry Oak/Arbutus/Douglas-fir woods of southern Vancouver Island and Gulf Islands of southwestern British Columbia [CNC, RBCM, UBC]. South to California. New to Canada and British Columbia.

Stichopogon fragilis Back. Intermontane; sandy grasslands of the southern Okanagan Valley (Osoyoos [CNC]). South to New Mexico and Arizona. Species new to Canada; genus new to British Columbia.

Subfamily Laphriinae

Andrenosoma fulvicaudum (Say). Southern; forests of southern Interior of British Columbia [RBCM, UBC]; noted in Foxlee (1941). Transcontinental in the United States; south to the tropics. Genus and species new to British Columbia.

Laphria astur Osten Sacken. Cordilleran; forests of southern British Columbia [CNC, RBCM, UBC]; listed in Foxlee (1941). South to California. New to Canada and British Columbia.

Laphria gilva (Linnaeus). Holarctic (Boreal in North America); widespread in forests of British Columbia, Yukon and Northwest Territories [CNC, RBCM, UBC]. Yukon (Dawson, Whitehorse [CNC]). East to the Atlantic, south to Massachusetts and Oregon. New to Yukon.

Laphria index McAtee. Boreal; forests of British Columbia Interior (Robson [RBCM, UBC]). Transcontinental in Canada; south to Virginia. New to British Columbia.

Laphria insignis (Banks). Boreal; forests of British Columbia Interior [CNC, RBCM, PFC, UBC], north to the southern Yukon and Northwest Territories. Yukon (Dawson, 14 mi [23 km] E [CNC]; Nahanni Range Rd., km 128 [UBC]). Northwest Territories (Norman Wells [CNC]). East to Labrador; in the West, south to California. New to British Columbia, Yukon and Northwest Territories.

Laphria janus McAtee. Boreal; forests of the British Columbia Interior north to Northwest Territories (South Nahanni Rd. [CNC]) and Yukon (Alaska Hwy. km 1403, Judas Creek [ROM]). Transcontinental in the Boreal Forest, south to New York and Michigan in the East, Utah and Colorado in the West. New to Northwest Territories and Yukon.

Laphria milvina Bromley. Cordilleran; forests of British Columbia Interior [CNC, RBCM, UBC] north to the southern Yukon (Rancheria-Swift River [CNC]). South to Oregon. New to Yukon.

Laphria partitor (Banks). Cordilleran; forests of southern Yukon (Slims River delta, Kluane [ROM]) south through British Columbia (CNC, RBCM, UBC) and Washington to Oregon. New to Yukon.

Laphria posticata Say. Boreal; forests of the British Columbia Interior [RBCM, UBC] north to the southern Yukon (Carmacks, Whitehorse [CNC]) and Northwest Territories (Fort Simpson, Fort Smith [CNC]). East to the Atlantic, south to New York in the East and British Columbia in the West. New to British Columbia, Yukon and Northwest Territories.

Laphria sackeni (Banks). Cordilleran; forests of the southern Interior of British Columbia [RBCM,UBC]. South to California. New to Canada and British Columbia.

Laphria ventralis Williston. Pacific Coast; dry forests of southern Vancouver Island and Gulf Islands of southwestern British Columbia [CNC, RBCM, PFC, UBC]. South to California. New to Canada and British Columbia.

Laphria vivax Williston. Cordilleran; forests of the British Columbia Interior north to the southern Yukon (Carcross [UBC]). South to New Mexico. New to Yukon.

Laphria vultur Osten Sacken. Cordilleran; forests of southern British Columbia south of 51 degrees N [RBCM, UBC]; listed in Foxlee (1941). South to California. New to Canada and British Columbia.

Subfamily Asilinae

Efferia frewingi Wilcox. Western; grasslands of upper (eastern) parts of Kootenay and Columbia river valleys in British Columbia [CNC, RBCM, UBC]. Described in Wilcox (1966) from Oregon. East to Saskatchewan, south to Utah and California. New to British Columbia.

Machimus callidus (Williston). Cordilleran; Widespread in the forests of British Columbia north to the southern Yukon (Whitehorse [CNC], Snafu Creek [UBC]). South to Oregon. New to Yukon.

Machimus vescus (Hine). Cordilleran; dry forests of southern Interior of British Columbia (Oliver [UBC]). South to California. New to Canada and British Columbia.

Megaphorus willistoni (Cole). Intermontane; grasslands of southern Okanagan and Similkameen valleys (Chopaka [RBCM]). South to California and Arizona. Genus new to Canada and British Columbia.

Two species recorded from British Columbia in the literature are separated here from the main list because their identification is doubtful and specimens could not be located for confirmation. If their identification were confirmed, these species would be new to Canada. *Cyrtopogon rejectus* Osten Sacken, cited under the name *C. positivus,* was reported from Port Renfrew by Hine (1904). A female in the Ohio State Collection identified as this species, apparently by Hine (Hope Mts., 27.vii.1906, R.V. Harvey), is closer to *C. fumipennis* Wilcox and Martin. *Negasilus platyceras* (Hine) was reported from Robson by Foxlee (1941). It was identified as *Asilus platyceras* by Bromley; the specimen cannot be located.

The following 25 species were not recorded in Stone et al. (1965) from the region examined herein, but have subsequently been recorded in the references indicated and, in most cases, through additional collections:

Subfamily Dasypogoninae

Cophura brevicornis (Williston). Western; Ponderosa Pine and Douglas-fir forests and less frequently in adjacent grasslands of southern Interior of British Columbia north to the Chilcotin region [CNC, RBCM, UBC]. South and east to Nebraska, Colorado and California. First recorded in Cannings (1989).

Dicolonus nigricentrum Adisoemarto and Wood. Intermontane; grasslands of southern Okanagan and Similkameen valleys. South to Washington and Idaho. First recorded in Adisoemarto and Wood (1975). Additional specimens from Osoyoos (Blades and Maier 1992) and Penticton (Cannings 1989) [RBCM].

Dicolonus simplex Loew. Pacific Coastal; Garry Oak parkland of southern Vancouver Island and Gulf Islands. South to California. First recorded in Adisoemarto and Wood (1975). Additional specimens [RBCM, UBC, CNC].

Dioctria henshawi Johnson. Intermontane; grasslands and dry forests of southern Okanagan and Similkameen valleys. South to California and Utah. First recorded in Adisoemarto and Wood (1975). Additional specimens from Osoyoos (Blades and Maier 1992) [RBCM].

Dioctria pusio Osten Sacken. Cordilleran; dry forests and adjacent grasslands of southern Interior of British Columbia. South to Colorado and California. First recorded in Adisoemarto and Wood (1975). Additional specimens from Penticton (Cannings 1989) [RBCM].

Lasiopogon aldrichii Melander. Cordilleran; widespread in mountains of southern Interior of British Columbia, especially in Engelmann Spruce/Subalpine Fir forests. South to Colorado and Utah. First recorded in Adisoemarto (1967). Additional specimens [RBCM, UBC].

Lestomyia sabulona (Osten Sacken). Intermontane; grasslands of southern Okanagan Valley, British Columbia [CNC, RBCM, UBC]. East to Alberta, south to Wyoming and California. First reported in Adisoemarto (1967). Additional specimens (Cannings 1989) [RBCM, UBC].

Myelaphus lobicornis (Osten Sacken). Intermontane; local in southern Interior grasslands of British Columbia, especially where *Chrysothamnus nauseosus* (Pall.) Britt. (Rabbit-brush) is present. South to Utah and California. First recorded in Adisoemarto and Wood (1975).

Additional specimens from Penticton [RBCM, UBC, CNC] and Dutch Creek, Columbia Lake [RBCM] (Cannings 1989).

Nicocles utahensis Banks. Intermontane; dry forests and grasslands of the southern Interior. East to Alberta, south to Utah and California. Cited in Foxlee (1941) as *N. punctipennis* Melander. Recorded by Adisoemarto (1967).

Ospriocerus abdominalis (Say). Western; rare in low elevation grasslands of Thompson, Okanagan, and Similkameen valleys of southern British Columbia. East to Manitoba, south to Pennsylvania, Nebraska and Texas. First recorded in Adisoemarto (1967); additional specimens [CNC, RBCM].

Scleropogon bradleyi (Bromley). Pacific Coastal (in the northern part of its range); Garry Oak parklands of southern Vancouver Island and Gulf Islands. South to California.The specimen of *S. helvolus* Loew listed in Hine (1904) should be referred to this species; it is in the Ohio State Collection and was examined during this study. Specimens recorded in Wilcox (1971) from Lytton in the southern Interior of British Columbia are apparently *S. neglectus*. Additional specimens [RBCM, UBC].

Scleropogon neglectus (Bromley). Western; widespread in dry, open forests and grasslands of southern British Columbia and prairie provinces. South to New Mexico and Arizona. First recorded in Wilcox (1971). Additional specimens [RBCM, UBC, CNC].

Stenopogon rufibarbis (Bromley). Intermontane; grasslands, especially mesic ones, in southern British Columbia. Also in grasslands of southern Alberta and Saskatchewan. South to Arizona and California. First recorded in British Columbia by Adisoemarto (1967). Recorded on the Great Plains as *S. obscuriventris* Loew by Adisoemarto (1967) (Wilcox 1971). Additional specimens [CNC, RBCM, UBC, PFC].

Subfamily Laphriinae

Laphria aimatus McAtee. Cordilleran; dry coniferous forests in the southern Interior of British Columbia and the Alberta mountains. First recorded by Adisoemarto (1967). Additional specimens [CNC, RBCM].

Laphria fernaldi (Back). Cordilleran; widespread in the forests of British Columbia and the mountains of western Alberta. First recorded by Adisoemarto (1967). Additional specimens [CNC, RBCM, UBC, PFC].

Pogonosoma ridingsi Cresson. Cordilleran; dry forests of southern British Columbia (including coastal and interior areas) and the southern Rocky Mountains of Alberta. *P. stricklandi* (Adisoemarto) named from Alberta by Adisoemarto (1967) is probably conspecific. Additional specimens [CNC, RBCM, PFC].

Subfamily Asilinae

Dicropaltum mesae (Tucker). Western; widespread in grasslands of southern Interior of British Columbia north to the Chilcotin region. Southern Alberta; cited in Adisoemarto (1967) as *Asilus mesae* (Tucker) and in Martin (1975) in *Negasilus,* this species is here placed in *Dicropaltum* to conform to the proposed treatment of Fisher and Wilcox (1987). Additional specimens [RBCM, UBC]

Efferia albibarbis (Macquart). Southern; xeric grasslands of extreme southern Okanagan Valley, especially where there is sand [CNC, RBCM, UBC]. Only other Canadian localities are on the beaches of Lake Erie, Ontario [RBCM, CNC, UG]. First recorded in Cannings (1989).

Efferia benedicti (Bromley). Intermontane; grasslands of the southern Interior of British Columbia, especially on silty soils. This is the species that Adisoemarto (1967), using the genus *Nerax,* incorrectly called *N. canus* (Hine). In British Columbia first recorded by Cannings (1989). Additional specimens [CNC, RBCM, UBC, PFC, UG]. There is no evidence that the species occurs in Alberta despite its inclusion in Adisoemarto (1967) and Strickland (1946).

Efferia coulei Wilcox. Intermontane; grasslands, especially mesic ones, of the southern Interior of British Columbia north to the Chilcotin region. Described in Wilcox (1966) from Washington. First recorded in Cannings (1989). Additional specimens [CNC, RBCM, UBC, UG].

Efferia staminea (Williston). Western; mesic grasslands in southern Interior of British Columbia. First reported in British Columbia by Cannings (1989). Additional records [CNC, RBCM, UBC].

Machimus erythrocnemius (Hine). Southern; forests of British Columbia Interior [CNC, RBCM]. First recorded in Adisoemarto (1967). Additional records [RBCM].

Proctacanthus milbertii Macquart. Southern; grasslands of southern Interior of British Columbia. First recorded in British Columbia in Cannings (1989). Additional specimens [CNC, RBCM, UBC, PFC].

Proctacanthus occidentalis Hine. Intermontane; grasslands of the southern Interior of British Columbia. First recorded by Cannings (1989). Additional specimens [CNC, RBCM, UBC, PFC].

Rhadiurgus variabilis (Zetterstedt). Holarctic; Boreal in Canada. Widespread in subalpine forests throughout southern British Columbia and the Rocky Mountains of Alberta. Widespread in the Boreal Forest across Canada from Yukon to Labrador. Treated as *Nigrasilus nitidifacies* Hine in Stone *et al.* (1965); the names were synonymized in Cannings (1993). First reported in British Columbia by Hine (1909) and by Cannings (1993) in Yukon and Northwest Territories.

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Insect pest and natural enemy populations in paired organic and conventional apple orchards in the Yakima Valley, Washington

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ABSTRACT

Insect pest and natural enemy populations were evaluated during the 1990 growing season in five paired certified organic and conventional apple orchards in the Yakima Valley, Washington. Each orchard-pair was managed by one grower and had similar conditions of location, extent, cultivars, and tree density. Organic orchards had not been treated with synthetic insecticides for 1-2 years before this study. Fruit injury from codling moth and population densities of phytophagous mites, sucking bugs, rosy apple and green aphids, leafminers, leafhoppers, and selected natural enemies were monitored throughout the season. Damage from codling moth was over 3% in three of the five organic orchards. Densities of phytophagous mites were high in one conventional orchard at the end of the season. Organic orchards had significantly higher populations of sucking bugs at bloom than did conventional orchards. There was no significant difference between orchard types in the densities of rosy apple aphid colonies per tree, but colonies in conventional orchards had significantly more aphids and significantly less parasitism than in organic orchards. The population density of green aphids was higher in conventional than organic orchards during the second half of the season. There was little difference in numbers of adult leafhoppers caught on sticky traps between orchard types, but captures of a leafhopper egg parasite were significantly higher in organic than in conventional orchards throughout the season. Immature leafminer populations were significantly higher and parasitism of leafminer was significantly lower in conventional than organic orchards after July. Parasitism of codling moth was not found in any orchard.

Key words: Codling moth, organic, apple, pest management, aphid, mite, leafhopper, leafminer, egg parasite

INTRODUCTION

Increased public awareness and changes in societal attitudes towards pesticides (Ott *et al.* 1991) and increased consumer support for IPM practices (Hollingsworth *et al.* 1993) are forcing a reconsideration of existing pest management programs in apple production (Prokopy & Croft 1994). The focus of this movement is to develop alternatives to broadspectrum neuroactive insecticides for the major pests in each region. In the western U.S., codling moth, *Cydia pomonella* (L.) is the key insect pest in apples and conventionally-managed orchards rely on a series of 'cover sprays' against this pest during the season (Washington State Cooperative Extension Service 1992). Organophosphate insecticides have been used almost exclusively to manage codling moth during the last 35 years, and resistance has recently been documented (Varela *et al.* 1993, Knight *et al.* 1994). The frequent use of organophosphate insecticides in apple also contributes to outbreaks of secondary pests (Prokopy & Croft 1994), such as mites, sucking bugs, aphids, leafhoppers, and leafminers. The mean number of insecticide sprays applied in Washington apple orchards is eight per season (Beers & Brunner 1991). Biological control plays a limited role in managing populations of pests in sprayed orchards, except for instances where natural enemies have developed insecticide resistance (e.g., predatory mites [Hoyt 1969]).

The level of biological control of insect pests which can be established in commercial apple orchards can probably best be viewed by examining populations in certified-organic orchards. Organic orchards cannot be treated with organophosphate, carbamate, pyrethroid, or other synthetic insecticides (Washington State Department of Agriculture 1992). Instead, growers must rely on a short list of materials which includes botanicals, microbials, minerals, natural oils, and

soaps. These materials are thought not to be as disruptive of natural enemies as synthetic insecticides. The organic certification program in Washington state began in 1988 with 11 growers having a total of 40 ha of pome fruits. This peaked in 1990 with 100 growers and 800 ha (M. McEvoy, personal communication). The size of the program has stabilized at ca. 0.5% of the total apple production in Washington (350 ha). Little information has been gathered on the success of organic apple pest management during this brief period. The objective of my study was to compare insect and mite pests and natural enemy population densities in paired organic and conventional apple orchards in the Yakima Valley of Washington.

MATERIALS AND METHODS

Study sites. In 1990, five apple growers with both organic and conventional orchards in the Yakima Valley were included in this study. Each organic orchard was paired with another orchard treated conventionally with synthetic insecticides. Orchard-pairs were matched for their similarity in area, cultivar, and planting density. The orchards were primarily 'Delicious' interplanted with 'Golden Delicious' at a density of 450-600 trees per ha and ranged in size from 4-16 ha.

Spray practices. Conventional orchards received an average of 3.7 sprays of azinphosmethyl (Guthion 50W, Miles Chem., Kansas City, MO) directed at codling moth. In contrast, organic orchards were treated with either ryania (Ryan 50, Dunhill Chem., Riverside, CA), granulosis virus (provided by Dr. L. Falcon, Univ. of California, Berkeley), *Bacillus thuringiensis* Berliner (Dipel 2X, Abbott Labs, N. Chicago, IL), or cryolite (Kryocide 96, Penwalt Chem., Bryan, TX) alone or in various combinations (a mean of 14 sprays of these materials was applied per orchard). Secondary pests in conventional orchards were treated with a mean of 2.5 sprays of carbamate and organophosphate insecticides at standard rates (Washington State University Cooperative Extension Service 1992). These included: phosphamidon (Swat 8E, Ciba Geigy, Greensboro, NC), carbaryl (Sevin XLR, Union Carbide, NY, NY), and oxamyl (Vydate 2L, E. I. Dupont de Nemours & Co., Wilmington, DE). Growers applied in organic orchards a mean of 2.0 sprays for secondary pests at standard rates; including soap, pyrethrum, and rotenone (Integrated Fertility Management 1990).

Pests and Natural Enemies. Population densities of various pest and beneficial arthropods were monitored in each orchard. These included: the phytophagous mites, *Tetranychus urticae* Koch and *Panonychus ulmi* (Koch) and the predatory mite, *Typhlodromus occidentalis* (Nesbitt); the sucking bug, *Campylomma verbasci* (Meyer); rosy apple aphid, *Dysaphis plantaginea* Passerini, a complex of green aphids, *Aphis pomi* DeGeer, *Rhopalosiphum fitchii* (Sanderson), and *Aphis spiraecola* Patch, aphid parasitism, and generalist aphid predators; white apple leafhopper, *Typhlocyba pomaria* McAtee and a mymarid egg parasitoid, *Anagrus* sp.; western tentiform leafminer, *Phyllonorycter mespilella* (Hubner) and levels of leafminer parasitism; and fruit injury by codling moth.

Sampling. Sampling was done on 11 and 24 May, 8 and 20 June, 6 and 31 July, 16 and 27 August, and 10 September. Fruit injury was determined 2-3 July and 27-28 August. Scouts walked transects within each orchard and arbitrarily chose the trees, shoots, and leaves to sample. Mites were sampled by collecting 16 leaves from each of ten trees at each orchard. Leaves were washed in 800 ml of a 50:50 solution of water (with 1 g detergent added) and 25% ETOH for 30 s. The liquid was poured through a fine sieve into a petri plate, and mites were counted under a dissecting microscope. *C. verbasci* nymphs were washed similarly from five blossom clusters collected from each of ten trees per orchard on 23 April. Rosy apple aphids were sampled by counting the number of infested shoots observed per 3 min from 10 trees in each orchard on 2-3 July. Ten colonies were collected and the number of living and parasitized aphids and the number of generalist predators within each colony were recorded. Green aphids were sampled by counting the number of aphids on the most infested leaf per shoot from five shoots on each of 10 trees in each orchard. The total number of generalist predators per shoot was also recorded. Adult white apple leafhopper and *Anagrus* sp. adults were sampled with sticky yellow cards (Trece Inc., Salinas, CA). Five traps were placed at 2.0 m in the tree canopy and were retrieved after 7 d. Data were expressed as the mean number of adults caught per day per trap for each or-

chard. The number of immature leafminers per 10 leaves was counted from 20 trees in each orchard by selecting the third leaf down the shoot from the leaf visually selected. Levels of parasitism were assessed for each generation by dissecting 50 mines from each orchard. Host feeding was included as a part of total parasitism (Barrett & Brunner 1990). Fruit injury was determined mid-season and at harvest by inspecting fruit along 40 transects, 20 apples from five consecutive trees (4,000 apples per orchard). Fruit injury for each orchard was weighted by the percentage of the total number of trees of each cultivar. Corrugated cardboard bands were placed around forty trees in each orchard on 10 June and 15 August to determine parasitism of codling moth larvae. Diapausing larvae were kept at 2°C for 120 d and then reared at 22°C until the completion of moth and parasitoid emergence. Differences in the mean population counts of pests and natural enemies between organic and conventional orchards were analyzed using a paired sample t-test for each date.

RESULTS

Pest and Natural Enemies. Phytophagous mite populations were low and populations of predatory mites were high in all orchards during the season (Fig. 1A and 1B). However, on the last sample date, phytophagous mite populations (*T. urticae*) increased in one conventional orchard to high levels, more than 20 mites per leaf (Fig. 1A).

Population densities of *C. verbasci* during bloom were significantly higher in organic than in conventional orchards (mean ± SE = 2.0 ± 0.5 and 0.1 ± 0.01 nymphs per five blossom clusters, respectively). Fruit injury at harvest from *C. verbasci* was detected only in one orchard (2.8% of fruit).

Densities of rosy apple aphid colonies per tree did not differ between organic and conventional orchards (Fig. 2A). However, the number of living aphids per colony in early July was significantly higher in conventional orchards. In addition, within individual colonies, significantly higher number of parasitized aphids were found in the organic orchards (Fig. 2B). Predator densities in aphid colonies did not differ between orchard types.

Densities of green aphids were low in organic orchards all season (Fig. 3). Densities were much higher in conventional than in organic orchards during July and August and on two dates these differences were significant. Few generalist predators (primarily immature coccinellids, syrphids, and chrysopids) were found on shoots infested with aphids (i.e., less than 0.1 predators per shoot in the organic orchards) but these data are not included here.

Few differences were seen in populations of white apple leafhopper between organic and conventional orchards during the season (Fig. 4A). In contrast, density of the egg parasitoid, *Anagrus* sp., was substantially higher in organic orchards in five of the seven samples (Fig. 4B).

Table 1

Summary of fruit injury by codling moth in mid-summer (2-3 July) and just before harvest (27-28 August) in organic and conventional apple orchards, 1990.

	Percentage fruit injury			
	Mid-summer		At Harvest	
Orchard	Organic	Conventional	Organic	Conventional
Y1	4.00	0.28	32.48	0.78
Y2	10.18	0.15	21.33	0.23
Y3	0.28	0.13	0.83	0.20
Y4	0.13	0.20	3.65	0.90
Y5	0.23	0.03	0.28	0.05
Mean	2.96	0.16	11.70	0.43
SE	1.95	0.04	6.50	0.17

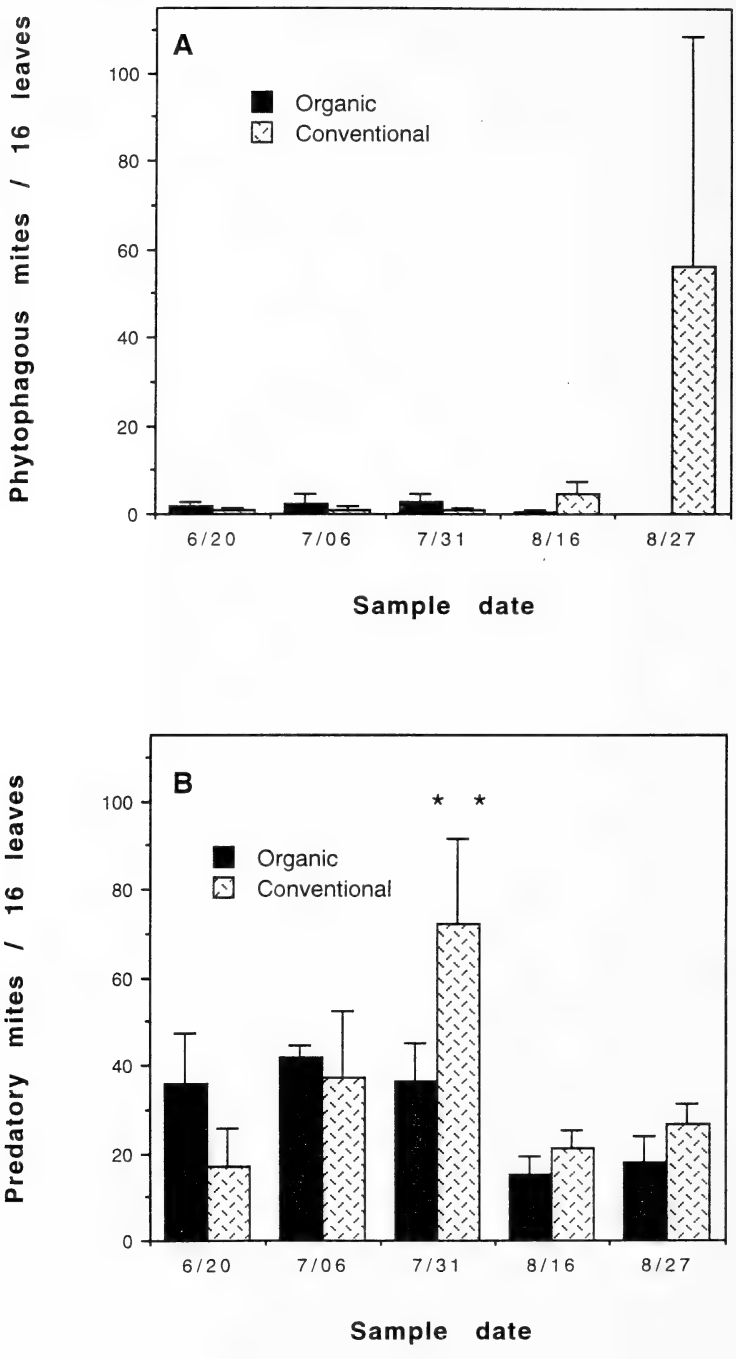
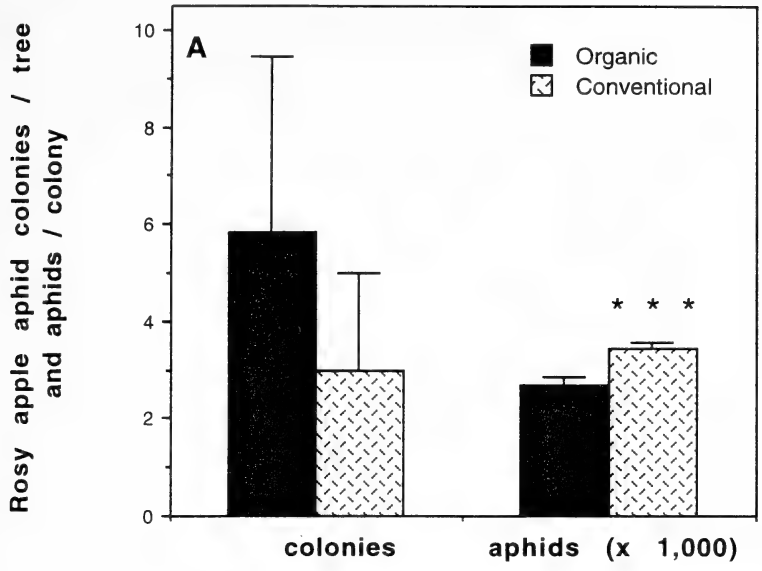


Figure 1. Seasonal population densities of (A) phytophagous mites and (B) predatory mites (B) per sample of sixteen leaves per tree from five paired organic and conventional orchards, 1990. '**' denotes a significant difference, $p < 0.05$.



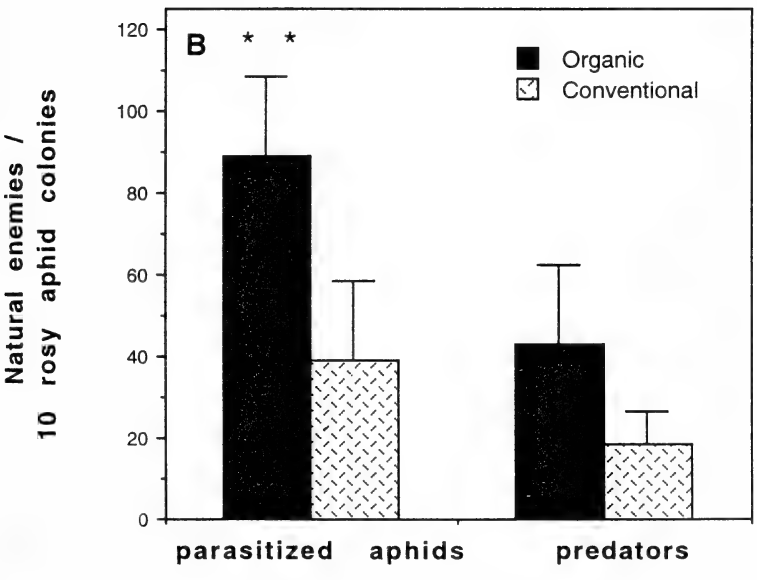


Figure 2. Number of rosy apple aphid colonies per tree and aphids per colony (A) and the number of parasitized aphids and generalist predators per colony (B) from five paired organic and conventional orchards, 2-3 July, 1990. '**' and '***' denotes a significant difference, $p < 0.05$ and < 0.01, respectively.

Densities of leafminers increased steadily during the season in all orchards but averaged less than 1.5 mines per leaf by the third generation (Fig. 5A). During August and September significantly more mines were found in the conventional than organic orchards. Percent parasitism of leafminer larvae was significantly higher in the organic than in the conventional orchards in both the second and third generations (Fig. 5B).

Large numbers of codling moth were recovered from the cardboard bands placed in organic orchards from the summer and overwintering generations (103 and 532 adults emerged, respectively), but no parasitoids were collected. Similarly, no parasitoids were collected from the sample of overwintering codling moth from conventional orchards (108 adults emerged).

Following the first flight of codling moth the organic orchards Y1 and Y2 had high levels of fruit injury (Table 1). Both of these orchards were adjacent to small unsprayed apple blocks treated unsuccessfully with an experimental sex pheromone membrane dispenser. At harvest, levels of fruit injury from codling moth exceeded 20% in orchards Y1 and Y2. In addition, the organic orchard Y4 suffered nearly 4% fruit injury at harvest. In contrast, both organic orchards Y3 and Y5 which were situated within 1 km of each other and were fairly isolated from other apple orchards, had less than 1% fruit injury at harvest. Fruit injury in all five conventional orchards was less than 1% before harvest (Table 1).

DISCUSSION

This study shows that densities of pests other than codling moth and *C. verbasci* are similar in organic and conventional orchards or are lower in organic than conventional orchards in the Yakima Valley. The elimination of broad-spectrum insecticides from organic orchards appeared to allow higher levels of natural enemies to develop than in conventional orchards. However, codling moth was not controlled biologically in either orchard type. In contrast, there were low levels of parasitism in abandoned apple orchards (3.4% of the overwintering larvae) and crabapple plantings (7.0% of summer generation and 8.7% of overwintering larvae) in Yakima. All the parasitoids collected were the braconid *Ascogaster quadridentatus* Wesmael or its hyperparasitoid *Perilampus* sp.

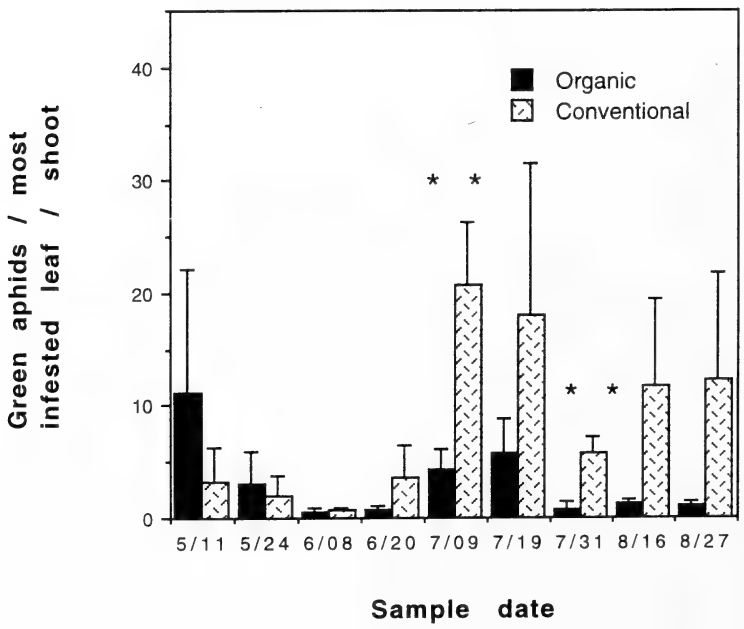


Figure 3. Seasonal population densities of green aphids per most infested shoot per tree from five paired organic and conventional orchards, 1990. '**' denotes a significant difference, $p < 0.05$.

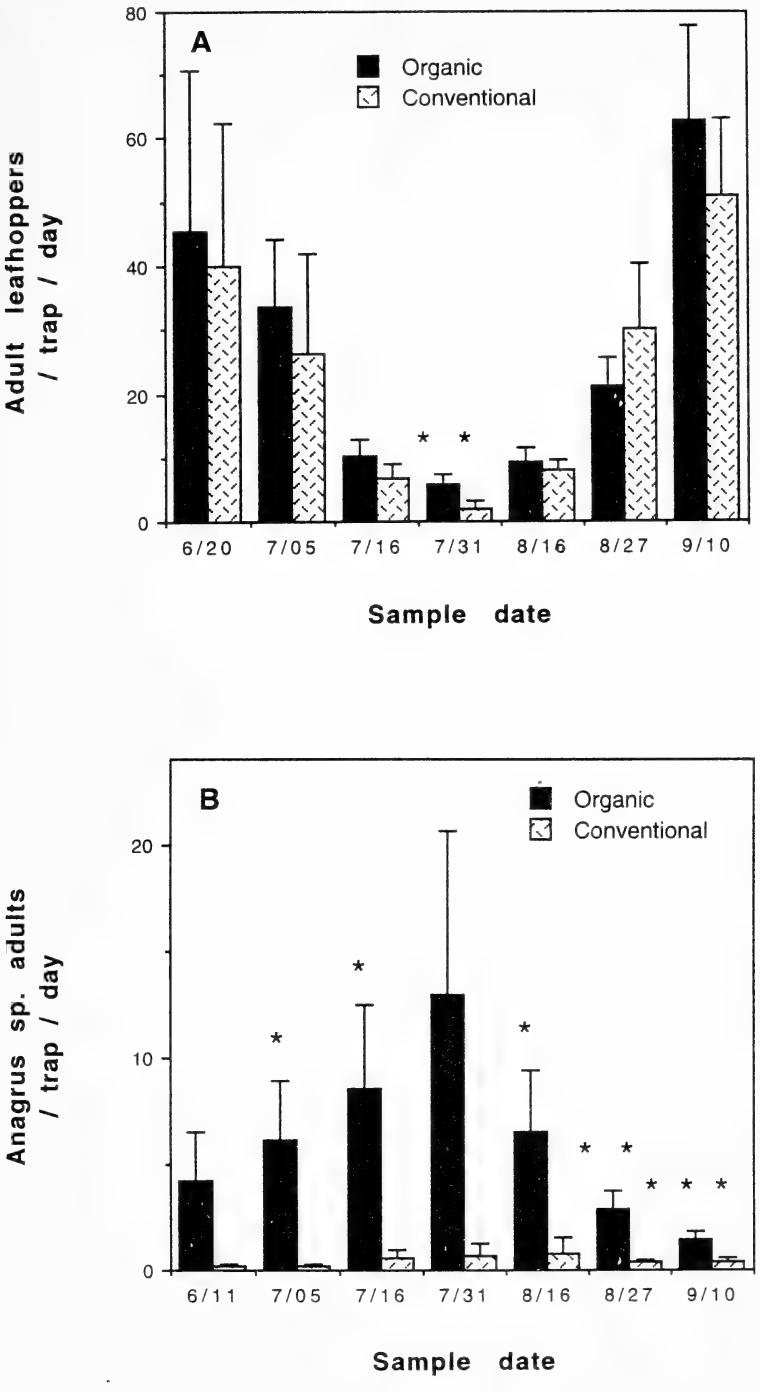


Figure 4. Seasonal population density of adult leafhoppers per trap per day (A), and adult *Anagrus* sp. per trap per day (B) from five paired organic and conventional orchards, 1990. '*', '**', and '***' denotes a significant difference of $p < 0.10$, < 0.05, and < 0.01, respectively.

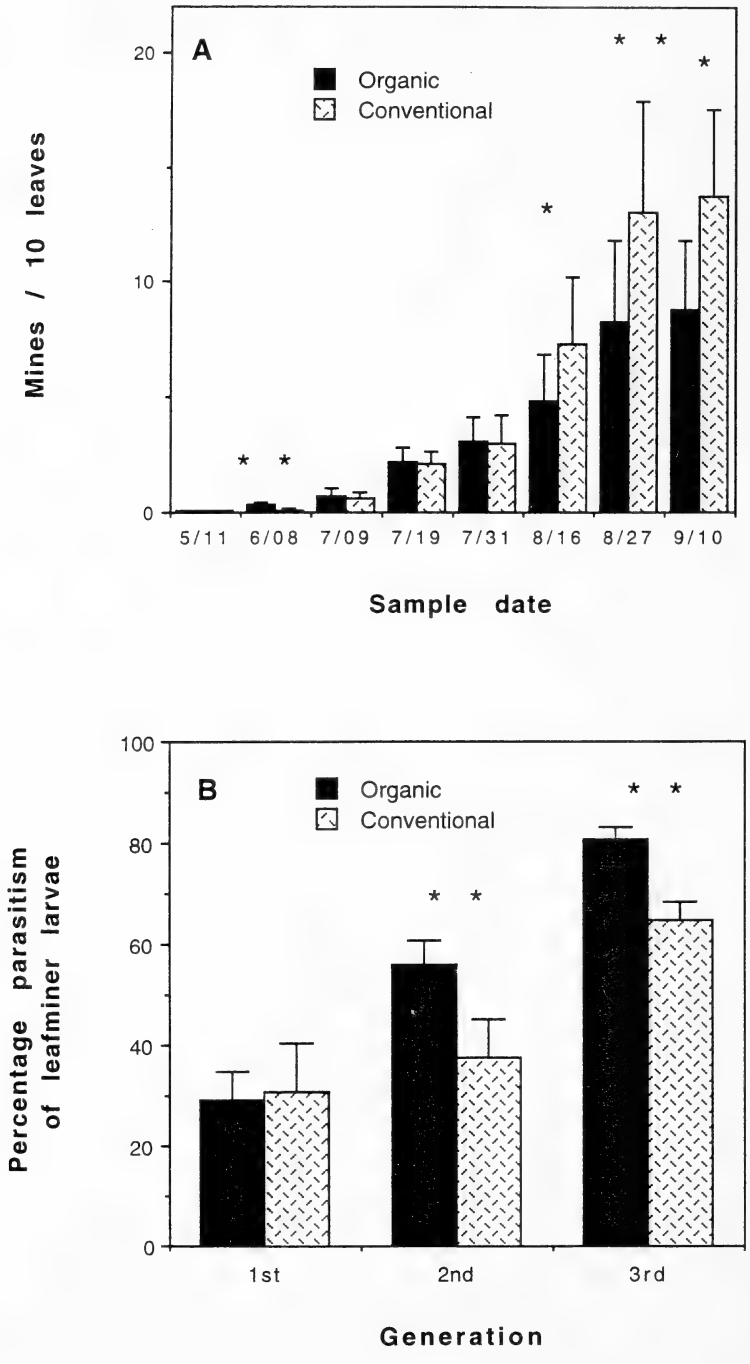


Figure 5. Seasonal population densities of western tentiform leafminer per 10 leaves per tree (A) and percent parasitism per generation (B) in organic and conventional orchards, 1990. '*' and '**' denotes $p < 0.10$ and < 0.05, respectively.

Factors regulating the population of *C. verbasci* in apple are poorly known (Thistlewood *et al.* 1990). Fewer *C. verbasci* nymphs were found during bloom in organic than in conventional apple orchards in British Columbia (McBrien *et al.*, in press). However, these orchards had been organic for 10-15 yrs and were not sprayed during the season with ryania.

To manage codling moth in 1990, organic apple growers had to choose between a number of relatively ineffective materials. Typically, organic growers in Washington used weekly sprays of ryania, Bt, and virus, often in combination. The cost of pest management for organic growers compared with a conventional program of azinphosmethyl was 5- to 10-fold higher (Knight, unpublished data), yet despite these costs, many growers suffered economic levels of fruit injury. In a spray trial conducted in 1991, fruit injury during the second generation of codling moth was reduced only 81, 47, and 16% with six weekly applications of ryania, virus, and Bt compared with an unsprayed check, respectively (Knight, unpublished data). Inspection of these injuries plus those collected from four commercial orchards treated with combinations of these materials, found that on 65-80% of these apples, codling moth larvae had created only shallow tunnels. The absence of feeding by codling moth larvae prior to entering the fruit makes stomach poisons such as Bt (Andermatti *et al.* 1988) and virus (Falcon *et al.* 1968) largely ineffective in producing clean fruit, although these materials can potentially be used to reduce populations in later generations (Wearing 1990). Ryania acts as both a contact and stomach poison and was used commonly in the 1950's in seasonal spray programs (Patterson & MacLellan 1954). However, orchards must be sprayed 6-12 times per season and repeated applications of ryania can cause severe phytotoxicity on some cultivars (Knight, unpublished data).

Because of their inability to control codling moth in 1990, two organic growers dropped out of the program. In 1991, a pheromone dispenser system (Isomate-C, Pacific Biocontrol, Davis, CA) was registered for mating disruption of codling moth and its adoption by organic growers during the past three years has been high (> 90% in 1993, M. McEvoy, personal communication). A survey of fifteen organic growers, who adopted mating disruption, found that their use of ryania, Bt, and virus declined by 80% from 1990 to 1993 (Knight, unpublished data). The benefit of using mating disruption for organic growers can be seen by comparing levels of fruit injury in the two organic orchards Y3 and Y5 in 1991. Orchard Y3 adopted mating disruption and had less than 0.4% fruit injury. In contrast, the organic orchard Y5 continued to use virus and Bt and suffered ca. 40% fruit injury from codling moth. Subsequentially, the grower dropped out of the program (Knight, unpublished data).

Mating disruption has worked well in apple orchards with low population densities of codling moth (Gut & Brunner 1991, Howell 1992). Yet, in a three year survey of seven paired conventional and pheromone-treated orchards in the Yakima Valley, the use of insecticides for secondary pests declined only 20% and levels of biological control of secondary pests did not increase with the adoption of mating disruption (Knight, in press). In particular, some apple growers suffered economic losses to leafrollers in orchards treated with mating disruption (Howell 1992, Brunner *et al.* 1992) and use of organophosphate insecticides for the summer generation of leafroller has become widespread. Interestingly, leafrollers were not observed in orchards in this study in 1990. In the following year, however, 12% fruit injury from the leafroller, *Pandemis pyrusana* Kearfott, occurred in one orchard. During the following two years, the grower used Bt for both the overwintering and summer generation and fruit injury was less than 0.3% (Knight, unpublished data).

Knight (in press) concluded that natural enemies cannot reduce pest populations in apple orchards sprayed with broad-spectrum insecticides nor can they respond quickly to pest outbreaks in small, isolated pheromone-treated orchards surrounded by sprayed orchards. Creating a sustained role for biological control in tree fruit pest management may require area-wide reduction in the use of broad-spectrum insecticides.

In the eastern U.S., Prokopy *et al.* (1990) suggested that apple orchardists adopt a transitional approach towards the use of fewer insecticides and enhanced biological control. In transitional second-stage IPM, orchards would not be treated with synthetic insecticides after petal-fall except along borders. Adoption of a similar approach in the western U.S. orchards might have to rely on mating disruption to manage codling moth, with Bt possibly mating disruption for

leafroller. Other pests would either be managed early in the season or later with selective insecticides and growers would rely more on biological control. Continued study of pest and natural enemy populations in organic orchards using mating disruption for codling moth may provide more evidence for the success of this approach.

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Limiting white pine weevil attacks by side and overstory shade in the Prince George Forest Region

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ABSTRACT

A study was initiated in 1985 to measure the effects of side and overstory shade on attack by white pine weevil and on annual growth in interior white spruce. The study was undertaken in the Prince George Forest Region where the weevil causes extensive damage to plantations of interior white spruce. Annual attack rates decreased significantly with increased brush cover. The treatment with side shade was achieved using narrow strip cuts running east and west. Side and overstory shade also reduced annual growth. Results indicate that up to 6% reductions in annual attack rates could be expected for at least 5 years following treatment but that differences in attack rates between treatments took at least three years to appear.

INTRODUCTION

Young trees of interior white spruce (*Picea glauca* (Moench) Voss *engelmannii* Parry ex Engelm.) are subject to severe damage by the white pine weevil (*Pissodes strobi* (Peck)) in the Prince George Forest Region (Taylor *et al.* 1991). This damage results in the formation of stem defects such as crooks and forks (Alfaro 1989), which reduce the merchantability of the tree. Growth loss also occurs since the leader is killed through girdling by the larvae of the weevil.

Effects of side or overstory shade on damage levels and weevil behaviour have been reported for interior white spruce, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and eastern white pine (*Pinus strobus* L.). Shade has direct or indirect negative effects on weevil feeding, oviposition activity and brood development (McMullen 1976, Sullivan 1959), on the weevil's visual response to the leader silhouettes of the host (VanderSar and Borden 1977), and on survival of overwintering adults (Harman and Kulman 1969, Droska 1982). Shading also reduces the diameter and length of the leader to less than the size preferred by the attacking weevils (Harman and Kulman 1969, Taylor *et al.* 1991) and improves recovery of damaged trees (Alfaro and Omule 1990).

The purpose of this study was to quantify the effects of side and overstory shade both on weevil attacks and the annual growth of the spruce.

METHODS

The study was conducted in the Prince George Forest Region in mesic plantations located in the willow variant of the wet cool sub-boreal spruce subzone (see Pojar *et al.* 1987 for details of this classification system). Three interior white spruce plantations, 50 kilometers east of Prince George, were selected (Fig. 1) to establish this trial after a random walk through them indicated an active weevil population. These plantations had been clearcut in 1969, site prepared with a broadcast burn in 1970 and planted in 1971 with 2+1 bareroot spruce seedlings (grown for two years in the nursery greenhouse and for one year in outside transplant beds).

Three treatment plots were established in each plantation (Fig. 1 and 2) as follows:

- the overstory shade were untreated controls with an intact deciduous overstory that was relatively continuous. The overstory shade trees that overtopped the spruce were: trembling aspen (*Populus tremuloides* Mich), paper birch (*Betula papyrifera* Marsh), willow species (*Salix* spp.) and alder (*Alnus crispa* spp. *sinuata* (Regal) Hult);
- the no shade treatment had all of the deciduous overstory removed at one time; and

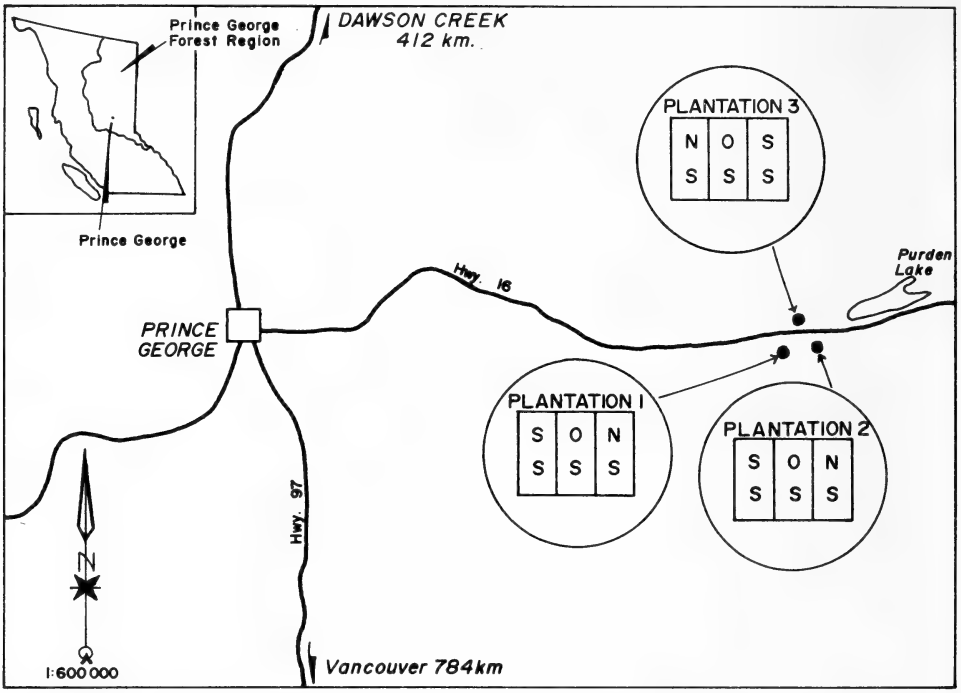

FIGURE 1. Location and design of the plots in the three study plantations. (Treatments for plots: SS = side shade, OS = overstory shade, and NS = no shade)

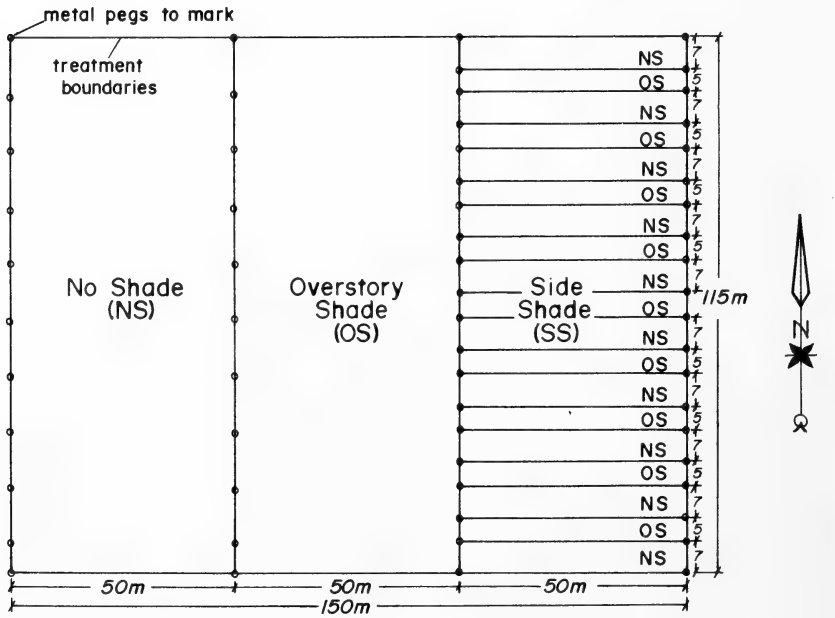

FIGURE 2. The plot design for the project, replicated on each of three plantations.

- the side shade treatment consisted of alternate strips with brush removed (no shade) and unbrushed strips (overstory shade), so that the crop trees in the debrushed strips were in partial or side shade from the unbrushed strips.

Strips in the side shade treatment were run in an east-west direction to provide shading to the exposed spruce trees when the sun angle was at its maximum. A maximum angle of 58.5° was calculated to occur at noon on the 21st of June at the study sites (Anon. 1965). The sun angle one hour before and after the noon maximum was determined to be 55°. This lower angle was used for the calculations of required strip width.

Plots were laid out and cleared mechanically of brush in November of 1985. A stem map of the plots were completed in April 1986 and all spruce trees were permanently identified with numbered metal tags. The past occurrence of weevil attacks was estimated to provide a history of weevil activity within the stand, and annual weevil attacks with leader and diameter growth were periodically recorded.

A randomized complete block design was used in this experiment with three blocks (plantations) and three silvicultural treatments (plots) within each block. The annual growth and weevil rate attack data were subjected to analysis of variance in order to assess potential treatment effects. Data analysis for the weevil attacks was conducted on the sample means for each plot, but data analysis for height increment was based on the individual observations within each plot.

Analysis of variance was conducted for annual height growth using the following linear model:

$$Yijk = u + Pi + Tj + PTij + Eijk$$

where
- u – grand mean
- Pi – ith plot effect
- Tj – jth treatment effect
- PTij – block by treatment interaction
- Eijk – residual error

The least square solution was used to compute the sum of squares and significance test by SAS GLM procedures (SAS 1985, Searle 1987).

Preliminary analysis showed that the weevil attack data were not distributed normally. Thus, analysis of variance was not appropriate. As these data were binomially distributed a loglinear model was used for analysis of variance (Bishop, Fienberg and Holland 1975). The SAS CATMOD Model (SAS 1985) was used to test the differences in weevil attack on the three treatments. Then the Chi-Square Test was used to test for differences between means of attack rates as this was discrete data and the Duncan Multiple Test was used on the height increments, a continuous variable.

RESULTS

The annual attack rates for 1993 averaged 21.3%, 14.8% and 15.1% for the no shade, side shade and overstory shade treatments respectively (Fig. 3). Significant treatment effects, at the 1% level (Table 1), appeared in 1989 and persisted for the 1990, 1991 and 1993 remeasurement periods. However, no significant differences were found before 1989. No measurements were taken in 1992. The multiple contrasts indicated that all comparisons between no shade versus overstory shade, and between no shade versus side shade were significant from 1989 to 1993 (Table 1).

It took three full growing seasons before differences in attack rates between treatments started to show. The maximum difference between the no shade and overstory shade plots was 6% in 1993. Table 1 also indicates that there were interactions at the block level possibly due to the site. These interactions vindicate the decision to use a randomized complete block design.

The density of the trees was 951, 1151 and 791 stems per hectare for plantations 1, 2 and 3 respectively. The mean height in 1991, in all plots, was 4.4 ± 1.4 m (S.D.) and mean DBH was 6.2 cm (± 2.6 cm).

Analysis of variance indicates that there were significant treatment effects at the 1% proba-

Table 1

Effect of three silvicultural treatments (Overstory Shade, Side Shade, and No Shade) on percentage of weevil attacks and results of analysis of variance by category model method.

Year	1987	1988	1989	1990	1991	1993
Treatment	*Average percentage of weevil attacks*[a]					
Overstory Shade	1.59a	1.22a	2.37a	2.70a	4.56a	15.10a
Side Shade	1.16a	1.21a	3.13a	2.96a	5.83a	14.75a
No Shade	2.20a	1.53a	5.39b	5.70b	9.16b	21.30b
Sources of variation	*Probability levels*[b]					
Treatment	0.829	0.789	0.002**	0.004**	0.001**	0.013**
($\chi^2_{2,4}$)	(0.37)	(0.45)	(12.51)	(11.13)	(17.85)	(8.69)
Block	0.001**	0.002**	0.001**	0.001**	0.001**	0.346
($\chi^2_{2,4}$)	(24.49)	(12.51)	(35.25)	(38.79)	(27.47)	(0.89)

a Means within columns, followed by the same letter are not significantly different (p=0.05) according to χ^2 pairwise contrasts of categorical model.

b ($\chi^2_{2,4}$) is a Chi-square value under null hypothesis.

**Significant difference at 1% level.

Table 2

Effect of three silvicultural treatments (Overstory Shade, Side Shade and No Shade) on annual height increment (mean ± standard error) and results of analysis of variance.

Year	1986	1987	1990	1991
Treatment	*Average annual height increment*[a] *(cm)*			
Overstory Shade	22.4±0.5a	27.9±0.6a	36.1±0.4a	42.8±0.4a
Side Shade	21.9±0.4a	25.9±0.5b	38.0±0.4b	44.4±0.5b
No Shade	18.5±0.3b	22.0±0.4c	37.6±0.5b	45.3±0.4b

a Means within columns, followed by the same letter are not significantly different at (p=0.05) level according to Duncan multiple comparison.

bility level on all height increments (Table 2). The tests for multiple comparisons accentuate these differences as the order of the significant relationship between the no shade and overstory shade regimes in 1986 are reversed for the 1991 measurements (Table 2). It is interesting to note that height increment also took about three growing seasons before differences started to appear. There are significant differences between plots, but no significant interaction effect between plot and treatment.

DISCUSSION

The reduction in weevil damage and spruce growth rates reported in this study are similar to those reported in Stiell and Berry (1985) for white pine, McLean (1989) for Sitka spruce and Taylor *et al.* (unpublished observations) for interior white spruce. The fact that differences in attack rates between treatments varied only between 1 to 6% indicates that measures to modify broadcast herbicide treatments, as suggested in Taylor *et al.* (unpublished observations), will not be worthwhile until current attack rates exceed at least 15% to 20%. If the attack rates had been at this level when the experiment started, larger differences between treatments may have been noticed. Nonetheless, a side shade regime should significantly reduce the levels of weevil attacks in areas of high weevil hazard.

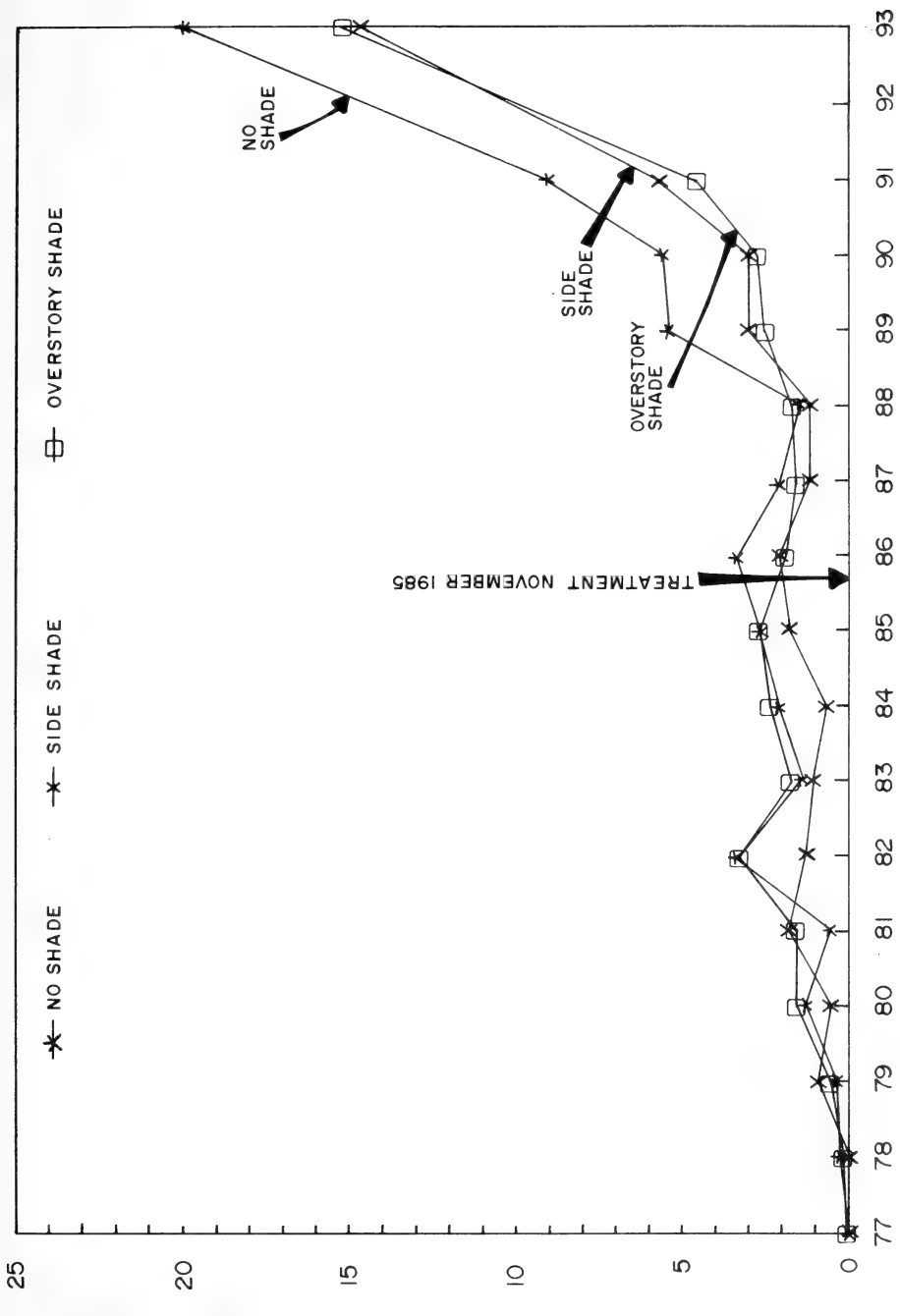

FIGURE 3. A comparison of current attack rates between the three treatment regimes.

The weevil seems to need at least three full growing seasons to manifest its response with increased attack rates at a stand level. A partial explanation for this may be either that initial attack rates were relatively low when the project started or that the stand level differences in shade levels between treatments were minor. A similar delayed response has been noticed on permanent weevil plots in the Southern part of the Region.

Increased height increment with decreased shade levels is a well documented phenomenon and helps to support the contention found in Taylor *et al.* (unpublished observations) that a trade-off exists between reduced weevil attack and decreased spruce growth rates. The exact nature of this trade-off must be left for future study.

The close relationship observed here between weevil attack rate and annual growth has been commonly accepted for white pine and Sitka spruce for a long time (Wood and McMullen 1983; Kline and Mitchell 1979; and VanderSar and Borden 1977).

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Effects of male to female ratio and number of females per nesting tunnel on sex ratio and number of progeny of the alfalfa leafcutter bee *Megachile rotundata* (Hymenoptera:Megachilidae)

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ABSTRACT

This paper reports the results of two 3-year studies on the effects of: 1) the ratio of males to females in the parental generation on percent female progeny; and 2) the ratio of females to nesting tunnels on percent female progeny. In study 1): there were no significant differences between treatments in percent females in the progeny or total number of nesting cells produced each year. The average percentages of females were 22% in 1990, 27% in 1991, and 28% in 1992. In study 2): there were significantly fewer female progeny with 2 females per tunnel in 1991, and in all years, significantly fewer progeny when the females were crowded. The total number of cells produced was inversely related to crowding with ratios of females per tunnel of 1:2, 1:1 and 2:1.

Key words: alfalfa leafcutter bee, *Megachile rotundata*, alfalfa seed

INTRODUCTION

The alfalfa leafcutter bee, *Megachile rotundata* (F.), is the primary pollinator of commercial alfalfa seed in the Pacific Northwest of the United States and southwestern Canada (Richards 1984; Mayer *et al.* 1990). Alfalfa seed growers in the U.S. often purchase leafcutter bees by the gallon from producers in Canada. A gallon of bees contains about 10,000 cells, although the percent females in a gallon may vary considerably. Consumers (alfalfa seed growers) prefer the highest possible percent females because females, not males, pollinate the seed crop.

Variable sex ratios have been reported for *M. rotundata* (Osgood 1964, Stephen and Osgood 1965, Waters 1969, Maki and Moffett 1986). Basal cells in the nesting tunnel tend to contain female bees, whereas apical cells contain males (Rothschild 1979).

Some studies show that tunnel diameter affects sex ratios (Stephen and Osgood 1965). In wider tunnels the percentage of females produced is greater than in narrower tunnels of the same depth. Klostermeyer *et al.* (1973) showed that the percent of females increased progressively in 4, 4.8 and 6.2 mm diameter holes. However, Rothschild (1979) found no differences in percent females using 6.35 and 7.14 mm diameter holes.

Gerber and Klostermeyer (1970) showed sex determination to be a voluntary act for *M. rotundata* concluding that the stimulus which induces the bee to lay fertilized, or female eggs is associated with tunnel depth. Later Gerber and Klostermeyer (1972) showed that altering the depth at which cells were completed changed the probability that a cell would receive a fertilized egg. Depths of 4, 8 and 16 cm showed a significant association with sex ratios although there was none with a 12 cm tunnel. Rothschild (1979) also found no association between sex and tunnel with an 11.7 cm tunnel. Stephen and Osgood (1965) found no correlation between sex ratio and tunnel depths of 5.0, 7.5 and 15.0 cm. Jay and Mohr (1987) found sex ratios (male to females) from 1.6:1 to 3:1 despite the use of tunnels of standard length and diameter. They also concluded that there were no significant increases in females produced in replacement nests. Tepedino *et al.* (1994) in a one-year study showed that intertunnel distance had a significant effect on the percentage of female progeny.

Tepedino and Parker (1988) found that the sex ratio of emergent second-generation bees was strongly biased toward females and the sex ratio of diapausing bees was strongly biased toward males: only 35.5% of second generation bees were males compared with 61.7% of those that

entered diapause. Parker and Tepedino had reported limited evidence of alternation of sex ratio in 1982.

Gosek *et al.* (1988) reported percentages of females in different breeding lines from 0 to 87%, with a mean of 48%; in wild populations it was 45%. An over-abundance of males led to a small number of females in the next generation (one-quarter to one-fifth of normal). The highest proportion of females (50% above normal) was obtained when the parental generation had only a low number of males. They concluded that the optimal number of males in isolated mating cages is about 15% of the population.

Gerber and Klostermeyer (1972) and Rothschild (1979) concluded that females act as though they know beforehand the number of cells they will provision per tunnel. They could 'know' the number of eggs they will fertilize.

I report here results of 2 studies: 1) the effect of the ratio of males to females in the parental generation on percent female progeny; and 2) the effect of the ratio of females to nesting tunnels on percent female progeny.

MATERIALS AND METHODS

Each year, new nest blocks were prepared by taping laminate wood pieces (1cm x 13cm x 12cm) together with strapping tape to form small blocks with 104 nesting tunnels, and covering the back of each block with aluminum foil. Tunnels were 5mm in diameter and 12cm deep. One nest block was placed in each cage.

Each year, loose bee cells were obtained from Mr Pollination Services in Canada during the winter and stored at 3° C for about 36 weeks. In the spring, the cells were removed from storage and incubated at 28-29° C. Adults that emerged after about 19-21 days were allowed to fly

Table 1

Effect of the ratio of male to female leafcutter bees on percent female progeny and total cells produced. Prosser, WA.

	1990		1991		1992	
Males:Females	% Females	Total	% Females	Total	% Females	Total
6:1	24a	684a	28a	576a	32a	589a
3:1	19a	683a	24a	664a	30a	661a
2:1	26a	726a	31a	660a	29a	694a
1:5	18a	606a	29a	867a	21a	588a

Means within a column followed by the same letter are not significantly different at the p=0.05 level, Newman-Keuls studentized range test.

Table 2

Effect of the ratio of female leafcutter bees to tunnels on percent female progeny and total cells produced. Prosser, WA.

	1990		1991		1992	
Females:Tunnels	% Females	Total	% Females	Total	% Females	Total
1:2	18a	566a	33a	421a	30a	505a
1:1	23a	496a	30a	303b	34a	483a
2:1	22a	181b	19b	300b	28a	286b

Means within a column followed by the same letter are not significantly different at the p=0.05 level, Newman-Keuls studentized range test.

in the laboratory and males and females were counted and collected into separate vials off the windows. The adults were then released into the cages containing blooming alfalfa and the nest blocks.

For the male-to-female ratio studies, 16 cages (6 x 6 x 1.8 m) and for the females-per-tunnel studies, 12 similar cages were erected over different plots of blooming alfalfa each year at Prosser, WA. For male-to-female ratio studies, 80 females were put in each cage and then males added to obtain a 6:1 ratio in 4 cages, 3:1 in 4 cages, 2:1 in 4 cages, and 1:5 in 4 cages. For female-per-tunnel studies, 52 females were put in 4 cages (1 female:2 tunnels), 104 females were put in 4 cages (1 female:1 tunnel) and 208 females in 4 cages (2 females:1 tunnel). Males were put in the cages at the same time and in equal number to females (1:1). In 1990, bees were put in the cages on 30 July; in 1991 on 5 July; and in 1992 15 July.

The bees foraged and constructed cells in the nest blocks during each season. At the end of the nesting season (August) the bee cells were extracted from the laminate boards, counted and put into cold storage at 3° C. After a chilling period of about 36 weeks, the cells were incubated at 28-29° C, the adults reared out and sexed to determine sex ratios.

The data were analyzed as a randomized complete block design by analysis of variance, with Newman-Keuls studentized range test for mean separations (Lund 1989).

RESULTS AND DISCUSSION

Male to Female Ratio

There were no significant differences between treatments in the percent females in the progeny in any year (Table 1), and no significant differences between treatments in the total number of cells produced each year. There were no significant differences in the mean percent females in different years (22% in 1990, 27% in 1991, and 28% in 1992).

In contrast to Gosek *et al.* (1988), I found that the ratio of males to females had no effect on percent females in the progeny. This difference could conceivably be attributed to different test conditions, methods, or even differences between races of the alfalfa leafcutter bee.

Females per Tunnel

In 1991, there was a significantly lower percentage of female progeny produced with 2 females per tunnel (Table 2). In all 3 years, there were significantly fewer progeny produced when the bees were crowded (2:1 ratio) than when uncrowded (1:2 ratio). The total number of cells produced was inversely related to crowding with ratios of females per tunnel of 1:2, 1:1 and 2:1. Large-scale research is needed to confirm these effects in the field.

CONCLUSION

The percentage of female progeny in any population of alfalfa leafcutter bees appears to depend on several, interrelated, factors. It was not affected by different ratios of male to female parents or the number of females released into large cages with a fixed number of wooden tunnels. Larger numbers of females made significantly fewer cells. The results were consistent over three years except that in one year the percentage of females was reduced in the most crowded condition.

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The role of two eulophid parasitoids in populations of the leafminer, *Phyllonorycter mespilella* (Lepidoptera:Gracillariidae) in British Columbia

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ABSTRACT

In 1991, orchards in the Naramata region of the Okanagan valley in British Columbia had significantly larger populations of the leafminer, *Phyllonorycter mespilella*, than those of the Osoyoos/Oliver region, 50 km south, where parasitism had been shown to keep the miner below treatment levels. We questioned if different roles of the parasitoid species caused the discrepancy. Leaves were collected and leafminers and parasitoids assessed from overwintering populations and also weekly from May through October (1992) in apple orchards representative of the areas. *Pnigalio flavipes* and *Sympiesis marylandensis* were the major parasitoid species overwintering in 52.3 and 46.7% respectively of the *P. mespilella* mines. The percentages of the two species did not differ significantly between the orchards screened in both areas and did not account for the differences in the numbers of overwintering or summer generation mines. *P. flavipes* was the dominant parasitoid species in both regions through the three summer generations. *S. marylandensis* was only found at low levels in three of the eight orchards until the second and third generations. Parasitoid-induced-mortality in 1992 did not have a consistent significant impact on intraseasonal leafminer increase. Five of the orchards studied had leafminer populations above treatment thresholds.

Key words: Treefruit, biological control, Hymenoptera, leafminer

INTRODUCTION

Phyllonorycter mespilella (=elmaella) (Hubner) (Lepidopera: Gracillariidae), is a tentiform leafminer that feeds within the leaves of several economically important fruit trees in the Pacific Northwest (Hoyt 1983). Four parasitoid species were associated with this leafminer when it was first established in the orchards of the Okanagan and Similkameen valleys of British Columbia in 1988 (Cossentine and Jensen 1992). *Pnigalio flavipes* (Ashmead) (Hymenoptera: Eulophidae) was identified as the major parasitoid of the leafminer in British Columbian and Washington State orchards (Barrett 1988, Cossentine and Jensen 1992). Parasitism by this species could reduce the host's intraseasonal population increase and keep its density below treatment levels (Barrett and Brunner 1990). The value of the other three leafminer parasitoids, species of *Sympiesis, Eulophus* and *Cirrospilus* (Hymenoptera: Eulophidae), in control of *P. mespilella* in the interior of British Columbia have not been studied.

In the 1991 apple growing season, orchards in the Naramata area of the Okanagan valley had very high populations of the leafminer. This was in contrast to the well controlled populations of *P. mespilella* in the Osoyoos and Oliver orchards, about 50 km further south where *P. flavipes* was first established, and its effective role in regulating the leafminer populations during the summer became evident (Cossentine and Jensen 1992). In the 1992 growing season we sought to determine if the parasitoids and their roles differed between the two areas, and if these differences could explain the variation in the leafminer populations.

MATERIALS AND METHODS

In 1992 we selected five orchards in the Naramata area that had high populations of *P. mespilella* in 1991 and three in the Oliver/Osoyoos area which had low populations that had been well controlled by parasitism in the past. More orchards and leaves were screened in Nara-

mata, because judging from high leafminer counts in previous years, we expected fewer parasitoids would be found.

We collected leaves in January 1992 (Naramata 200, Oliver/Osoyoos 100) from the orchard floor at each site before winter diapause of the leafminer or parasitoid pupae was broken. Leaves from each orchard were placed in a ventilated 2-l plastic container and held at room temperature (20-22°C). The containers were checked daily for parasitoid emergence and the adult parasitoids were frozen until identified and sexed. Representative specimens were identified by systematists at the Centre for Land and Biological Resources Research, Ottawa. Comparisons of emerging parasitoids were based on the assumption that each species would have an equal chance of successfully developing under the described conditions. The leaves from three orchards in Naramata were so severely torn that mines per leaf could not be assessed. An estimated appropriate mass of torn leaves was therefore collected from each of these orchards so that emerging parasitoid adults could be collected and identified.

One hundred leaves were collected randomly from the canopy of each orchard weekly from May 7 until October 5, and on October 24. The infestation level was determined by counting the mines per leaf and assessing the mine contents of these leaves. This count included the numbers of living and dead sap-feeders (instars 1-3) and tissue-feeders (instars 4-5), pupae, emerged pupae, parasitoid eggs, larvae and pupae, mines with a round parasitoid exit hole, as well as empty mines. Leaves containing parasitoids in any stage of development were placed in ventilated 2-l plastic containers and the emerging parasitoid adults were aspirated, frozen and later identified and sexed.

Pnigalio and *Sympiesis spp.* cause leafminer mortality both as larvae which feed externally on host larvae as well as adults 'host-feeding' on leafminer larvae and occasionally on pupae (Barrett 1988, Van Driesche and Taub 1983). In the first generation total parasitoid-induced-mortality (PIM) was assessed as the number of mines containing dead leafminers and/or parasitoids divided by the total number of mines minus the number of empty mines. The fate of the *P. mespilella* from empty mines could not be determined. In the second and third generations the PIM and total number of mines per leaf were assessed as above; however, mines with emerged pupae, empty mines and parasitoid exit holes were removed from the calculations because they may have occurred in the first generation. The number of parasitoids emerging per mine was de-

Table 1

Phyllonorycter mespilella mines per overwintered apple leaf and for each summer generation, assessed on 100 leaves at peak sap- and tissue-feeding stages.

		Mines per apple leaf					
	Overwintering	First Generation		Second Generation		Third Generation	
	(n)	sap	tissue	sap	tissue	sap	tissue
Naramata Orchards							
1.	11.00 (200)	0.07	0.06	1.07	1.84	4.82	7.48
2.	5.57 (200)	0.36	0.03	1.88	3.55	5.32	5.78
3.	[a]	0.03	0.02	0.41	1.79	6.82	7.53
4.	[a]	0.00	0.00	0.08	1.03	2.46	6.54[b]
5.	[a]	0.19	0.15	2.02	4.18	9.33	13.94
Osoyoos/Oliver Orchards							
1.	2.76 (100)	0.10	0.06	2.71	4.25	14.64	15.64
2.	0.44 (100)	0.02	0.02	0.24	0.58	2.90	2.82
3.	1.22 (100)	0.02	0.01	0.75	1.76	7.63	8.10

[a] leaves were torn and mines per leaf could not be determined.

[b] count from previous week, orchard cut down.

Table 2

Pnigalio flavipes (Pf) and *Sympiesis marylandenis* (Sm) parasitoids per *Phyllonorycter mespilella* mine (n=total mines).

	Parasitoids per mine per parasitoid generation														
	Overwintering			First			Second			Third			Fourth		
	Pf	Sm	n	Pf	Sm	n	Pf	Sm	n	Pf	Sm	n	Pf	Sm	n
Naramata Orchards															
1	0.12	0.08	2222	0.19	0.00	57	0.08	0.03	73	b	b	50	0.10	0.00	136
2	0.10	0.09	1114	0.12	0.02	73	0.36	0.10	125	b	b	50	0.05	0.00	215
3	a	a		0.07	0.00	61	0.17	0.00	123	0.06	0.02	354	0.03	0.03	254
4	a	a		0.00	0.00	50	0.07	0.07	101	b	b	50	0.06	0.06	156[c]
5	a	a		0.49	0.00	114	0.07	0.00	109	0.03	0.00	371	b	b	50
Osoyoos/Oliver Orchards															
1	0.11	0.13	276	0.18	0.00	61	0.37	0.07	159	0.14	0.00	442	0.03	0.03	375
2	0.00	0.12	44	0.24	0.03	50	0.46	0.00	89	0.26	0.00	92	0.18	0.00	58
3	0.28	0.05	122	0.17	0.02	53	0.29	0.06	121	0.26	0.00	171	0.10	0.00	219

[a] leaves were torn and mines could not be determined.

[b] no parasitoid adults emerged to identify.

[c] counts from previous week, orchard cut down.

Table 3
Mortality attributed to parasitoids (PIM) per 100 apple leaves at peak tissue-feeding *Phyllonorycter mespilella* stages within each of three summer generations.

	Mortality[a]		
	First Generation	Second Generation	Third Generation
Naramata Orchards			
1.	38.6[b]	87.9	96.8
2.	32.9	72.7	100.0
3.	8.2	47.0	99.2
4.	50.0	34.4	79.5
5.	75.8	86.7	99.5
Osoyoos/Oliver Orchards			
1.	19.7	95.3	87.0
2.	42.0	84.2	94.6
3.	30.2	80.5	99.3

[a]Mortality was considered to include: parasitoid eggs, larvae, pupae, parasitoid exit holes (first generation only) and dead host larvae and pupae divided by total mines (excluding mines containing emply pupae, parasitoid exit holes or empty mines in the second and third generations).
[b]each value in the table represents the assessment per 100 mines.

termined as the total of adult parasitoids divided by the number of mines per leaf assessed as above.

Parasitoid and leafminer counts were not averaged over weeks within generations because each sample could not be considered a replicate of an extended stabilized point in the host-parasitoid life histories (Van Driesche 1983). Rather, the leafminer populations were compared at five individual weeks during maximum sap-feeding and tissue-feeding stages within each generation. PIM was assessed at the peak tissue-feeding stage when conditions were most opportune for parasitism and host-feeding.

P. mespilella mines per leaf, parasitoids per mine and PIM were compared between the two regions using an ANOVA (SAS Institute 1985). Percent parasitism, the sex of each parasitoid, mines per leaf and PIM within the overwintering population were compared between the two regions using a correlation procedure (SAS Institute 1985).

RESULTS AND DISCUSSION

Overwintering population. Leaves collected in January from orchards in the Naramata area contained significantly (p=0.04) higher numbers of mines per leaf than did leaves collected from Oliver and Osoyoos orchards (Table 1). This illustrates the contrasting infestation levels between the two orcharding regions observed in 1991. Emerging total number of overwintering parasitoids per mine did not differ significantly (p>0.05) between the two regions (Table 2).

P. flavipes and *Sympiesis marylandensis* Girault (Hymenoptera:Eulophidae) (identified by J. Huber, Centre for Land and Biological Resources Research, Ottawa) were the parasitoid species most commonly reared from overwintering *P. mespilella* mines. *S. marylandensis* is probably the same species of *Sympiesis* previously recorded as a minor parasitoid of the leafminer in the Okanagan valley (Cossentine and Jensen 1992), although it is not one of the three species of *Sympiesis* previously cited as parasitizing *Phyllonorycter elmaella* in the Fraser valley (Doganlar and Bierne 1980).

P. flavipes represented 52.3% and *S. marylandensis* 46.7% of the overwintering parasitoid populations in the eight orchards (n=358). This was unexpected as *P. flavipes* was the dominant parasitoid species in the summer studies of 1988-1990 (Cossentine and Jensen 1992) and was therefore expected to infest a higher proportion of the overwintering mines. Percentage of the

total population varied from 0 to 85.7% and from 14.3 to 100% for *P. flavipes* and *S. marylandensis*, respectively. The percentages of *P. flavipes* and *S. marylandensis* in the overwintering mines did not differ significantly ($p>0.05$) between the two regions. Barrett and Jorgensen (1986) reported that *S. marylandensis* was the dominant parasitoid species of the first and third *P. elmaella* generations in Utah and that *P. flavipes* was dominant in the second and fourth generations. The percentages of male and female adults of each of the two parasitoid species did not differ significantly ($p>0.05$) between the two regions (*Pnigalio* male:78.5%, 61.9%; female: 21.5%, 38.2%; *Sympiesis* male: 78.7%, 90.5%; female: 21.3%, 9.5%, in the Naramata and Osoyoos/Oliver regions, respectively).

Zagrammosoma multilineatum (Ashmead) (Hymenoptera:Eulophidae), a species not previously recorded from *P. mespilella* in British Columbia (Cossentine and Jensen 1992, Doganlar and Bierne 1980) represented 6.06% of the parasitoid population emerging from one Naramata

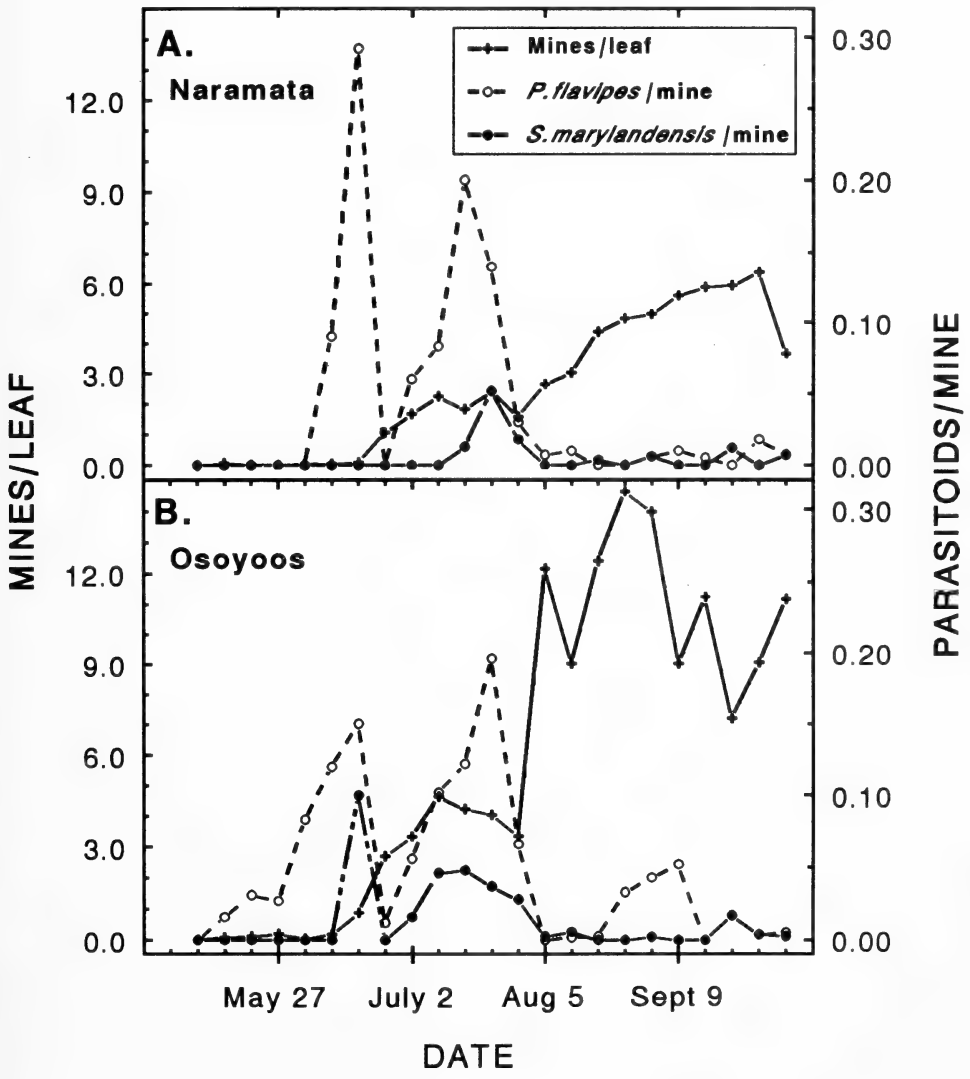

Figure 1. *Phyllonorycter* mines per leaf and parasitism by *Pnigalio* and *Sympiesis* per mine from May to October 1992. A=orchard 1, Naramata; B = orchard 1, Osoyoos/Oliver.

orchard. Over all orchards this represented only 0.76% (n=385) of the overwintering parasitoids.

Summer populations. The number of sapfeeding mines per leaf did not differ significantly ($p>0.05$) between the two regions in the first generation (Naramata: $\bar{x}=0.13$ mines/leaf, Oliver/Osoyoos: $\bar{x}=0.05$ mines/leaf) (Table 1). We then questioned if the percent parasitism by each species independently, or the sex ratio of *P. flavipes* or *S. marylandensis* within the overwintering population, affected the number of *P. mespilella* mines per leaf or percent of PIM in the first generation. None of these factors in the overwintering population consistently or significantly ($p>0.05$) influenced mines per leaf or PIM in the first generation when counts were analyzed as separate regions and as a whole (Tables 1 and 3). The number of overwintering mines was not significantly correlated with the number of sap-feeding ($r=0.2$, $p=0.63$)) or tissue-feeding ($r=0.65$, $p=0.23$) mines in the first generation. This contradicts Barrett and Brunner's (1990) conclusion that the survival of overwintering leafminers, rather than the seasonal levels of parasitism, determine the leafminers' year-to-year population dynamics.

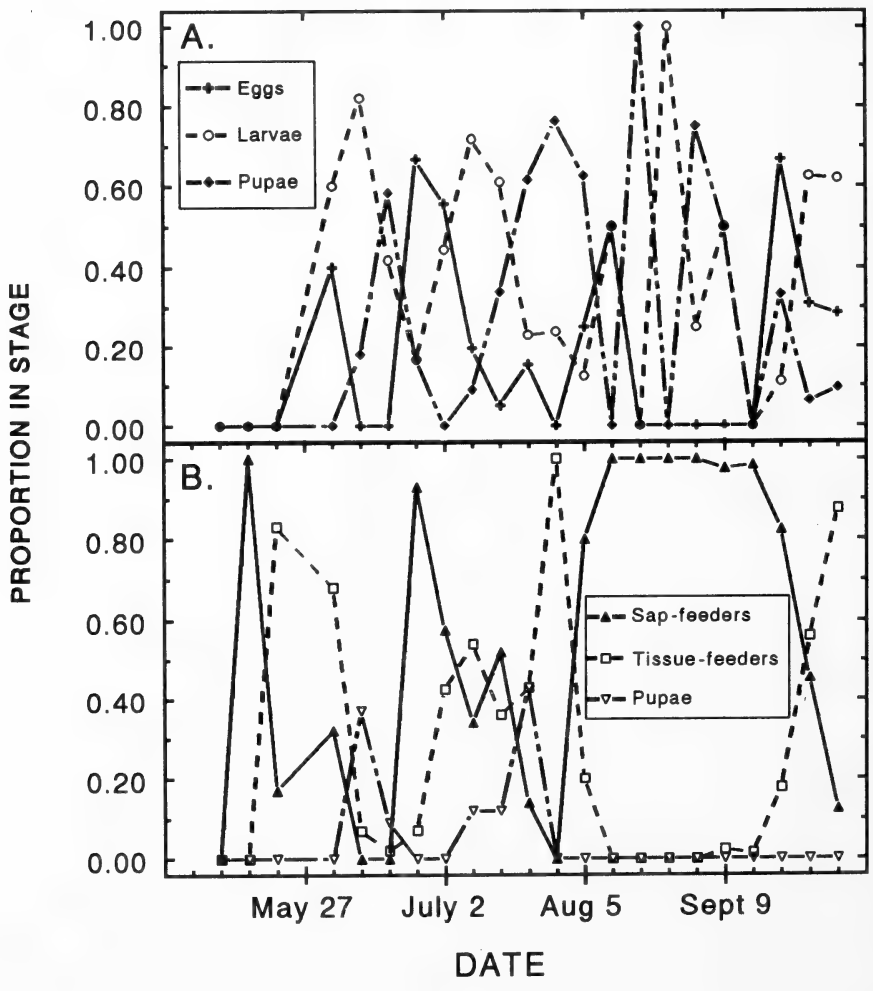

Figure 2. Proportion in each developmental stage: A = parasitoids *Pnigalio* and *Sympiesis*; B = leafminer *Phyllonorycter* determined from weekly samples May to October 1992 from orchard 1, Naramata.

Throughout both regions, *P. flavipes* remained the dominant parasitoid species over the three generations. Significantly ($p<0.05$) more *P. flavipes* emerged per 100 mines than did any other parasitoid species in all three generations. Despite its major role in the overwintering populations, *S. marylandensis* represented a small percent of the parasitoids in the first summer generation (Table 2, Fig. 1), increasing in its role as a parasitoid in the second generation.

The mean number of mines per leaf did not differ significantly ($p>0.05$) between the two regions in the second generation (Table 1). Mortality caused by host-piercing and oviposition of *P. flavipes* and *S. marylandensis* in the first generation was expected to be negatively correlated with the number of mines per leaf found in the second and third generations (Barrett and Brunner 1990, Cossentine and Jensen 1992, Van Driesche and Taub 1983). This was true only for the Osoyoos/Oliver region where the PIM in the tissue-feeding stage of the first generation was significantly negatively correlated (r=0.90-0.96, $p<0.05$) with the mines per leaf in the second generation over a two-week period.

The economic treatment threshold for leafminers in apple has been estimated at one sap-feeder per leaf for the first generation, two sap-feeders per leaf for the second generation provided that PIM is <30% in the first generation, and five sap-feeding mines per leaf in the third generation (Hoyt 1987). The only orchard sampled in this study that exceeded this treatment threshold in the second generation was in the Oliver/Osoyoos region. Leafminer counts in this orchard did not exceed thresholds in 1991. Despite finding six of the eight orchards with PIM above 30% in the first generation (Table 3), five of the eight orchards had exceeded the treatment threshold by the third generation (Table 1).

To explain the high 1992 *P. mespilella* populations, the warm weather early in the season in 1992 may have allowed the leafminers to establish large populations before *P. flavipes* could have a significant controlling effect. Unfortunately, neither emergence of adult *P. mespilella* nor the parasitoid species was assessed in the spring to judge if their emergences were synchronized. In Connecticut, adult *S. marylandensis* emerged two to four weeks before its host, *Phyllonorycter blancardella*, in the spring (Maier 1984). *S. marylandensis*, which made up about 50% of the overwintering parasitoid population, did not appear to influence *P. mespilella* control until the second and third generations by which time the leafminer populations were already above economic thresholds in some orchards. The developmental stages of the parasitoids appear to be in synchrony with those of the leafminer host in the first two summer generations (Fig. 2), with the parasitoids pupating just at the end of the *P. mespilella*'s first generation and the parasitoid eggs being laid at the beginning of generations two and three. The parasitoids appear to have two generations during the leafminers third (Fig. 2).

Parasitoid-induced-mortality increased with generation (Table 3), contrary to what was observed by Barrett and Brunner (1990) but they excluded mines judged to be from an earlier generation in their counts. We excluded mines but that were empty or contained an emerged pupa or a parasitoid hole. We do not believe that the dead larvae could be assigned to a particular generation consistently. The high PIM in the second and third generations in our study may be partially due to the accumulation of dead larvae from previous generations. However the PIM in the second and third generations was also high when compared to studies done in a similar fashion in the Okanagan valley from 1988 to 1990 (Cossentine and Jensen 1992). These high percentages indicate that a low number of live leafminers would be found in the 1992-93 overwintering mines. This must, at least in part, account for the low populations of *P. mespilella* observed in the summer of 1993.

We conclude that the percentage of *P. flavipes* and *S. marylandensis* in the overwintering leafminer population of 1991-92 did not differ between the orchards screened in Naramata and Oliver/Osoyoos, and could not explain the differences in the number of first generation mines in any of the eight orchards. We found *P. flavipes* to be the dominant parasitoid in the three summer generations. *S. marylandensis* did not start to participate within the complex, except at low levels in three orchards, until the second generation. Neither the *Eulophus* or *Cirrospilus* species previously found parasitizing the leafminer in the south Okanagan valley of British Columbia were found in the orchards studied.

The leafminer parasitoid complex is usually an efficient and effective biological control of the

host populations. In 1992 leafminers exceeded economic thresholds in orchards in the Okanagan valley. Neither *P. flavipes* or *S. marylandensis* had a significant influence on intraseasonal leafminer increase. However, increasing season-long PIM had a dramatic impact on the number of leafminers entering overwintering diapause in the fall of 1992.

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Notes on the biology and rearing of the carrion fly *Prochyliza brevicornis* (Melander) (Diptera: Piophilidae)

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ABSTRACT

I describe the first successful rearing of *Prochyliza brevicornis* (Melander) in the laboratory on a variety of media. The average developmental period from egg to adult for non-diapausing individuals was 42-47 days with a range of 32-74 days. Best survival of those that emerged as adults (16-32 %) was on ox-tail bones and ground beef. The majority of the larvae in each generation remained quiescent or did not pupate for up to six months which probably indicates an obligatory overwintering diapause in this species.

Key words: Diptera, Piophilidae, British Columbia, forensic entomology, carrion

INTRODUCTION

Piophilids, also known as carrion flies, are commonest in northern temperate areas (Danks 1980; McAlpine 1977, 1987). They grow and develop on proteinaceous substances such as animal carrion, bone and bone marrow, cheese, fish and cured meat (Simmons 1927), corpses (Oldroyd 1964, Nourteva 1977; Smith 1986), hoofs and horns (Bishop 1917), human excreta (Howard 1900) and in household garbage (McAlpine 1977).

Melander (1924) reviewed the family Piophilidae and described *Prochyliza brevicornis* (Melander) as a new species. It occurred usually in the months of July-August in some localities in Yellowstone Park, Montana and in Chicago, Illinois in the U.S.A. and in British Columbia, Canada. The revised classification of Piophilidae by McAlpine (1977) lists eight species under the genus *Prochyliza*.

Very little information is available on the biology and rearing of the members of this family except for a few species such as *Piophila casei* (L). Herein I report on some aspects of the rearing and biology of *Prochyliza brevicornis*. Adults of *P. brevicornis* emerging from a forensic sample of insects brought to Simon Fraser University from Sprott lake , B.C. were used to start a colony for rearing and observations. Their identification was confirmed by Dr. J. L. McAlpine at the Biosystematics Research Centre, Agriculture Canada, Ottawa.

MATERIALS AND METHODS

I reared *P. brevicornis* for three successive generations at 26 ±1°C, 50% ±5% RH, with a 12L:12D photoperiod. Seventeen newly emerged adults serving as a starter colony were placed in 10x10x10 cm wooden cages with a clear acrylic plastic front and a Saran screen at the rear. For second and third generation rearing 40 and 8 adults were caged respectively. Sugar cubes and skim milk powder in a 5.0 cm diam petri dish were provided as food, and water was supplied in conical flask with dental cotton wicks. Ovipositional substrates such as uncooked ox-tail bones, ground beef, chicken wings were provided in a 5.0 cm diam. petri dish and placed inside the adult cage. For larval rearing the above three substrates as well as beef salami and processed cheddar cheese slices were used.

Larvae were reared in 4 l jars.The medium was on a layer of paper towels and was covered with facial tissue to provide dry surfaces for pupation.

RESULTS AND DISCUSSION

Adults mated after emergence as soon as they were released inside the cage. Mating lasted from 15 sec to 15 min. Males mounted the females during copulation and made vigorous jerks from side to side. In some cases two males were *in copula* at the same time with one female.

Table 1

Development (in days) on ox-tail and ground beef of *P.brevicornis* for three generations at 26 ± 1°C, 50±5%R and 12L:12D.

Developmental stage	Generation 1			Generation 2			Generation 3		
	N	Duration Mean±SE	Range	N	Duration Mean±SE	Range	N	Duration Mean±SE	Range
eggs	150	1.5±0.3	1.0-2.0	200	1.5±0.3	1.0-2.0	150	1.5±0.3	1.0-2.0
larvae	36	36±6.2	23-65	79	33±4.4	28-40	129	38±2.8	33-43
pupae	24	8.3±0.9	7-13	48	7.7±1.2	4-12	49	7.5±0.6	6-8
total	24	41.9±5.9	32-74	48	42.4±1.4	37-47	49	47.5±2.4	43-51

During the course of rearing four females and eight males were found dead after such dual copulation. Under the dissecting microscope, the detached genitalia of one male were observed to be fused externally with the female genitalia. The other males died attached to females. This is evidence that dual mating with one female might be common in this species. Simmons (1927) reported a similar phenomenon for *Piophila casei* (L.) in which adults of advanced age can copulate but not separate in the laboratory and die *in copula.*

Eggs were laid singly or in clusters. Most oviposition occurred during 3-5 days after mating. Several ovipositional substrates, such as uncooked chicken wings, ground beef, cheese slices and ox-tail, were offered to mated females. Ox-tail appeared to be the preferred substrate for egg laying. Ox-tail bone dries rapidly when left at room temperature for 1-2 days and is much drier than chicken wings or ground beef. It is quite likely that the putrifying fat around the meat and bones stimulates egg laying. Eggs hatched in 24-48 h at 26°C.

Newly hatched larvae were 1.5-2.0 mm long, and were very soft and fragile. Second instar larvae were 2-3 mm long, and could be distinguished by their prominent slender mouth hooks. The final instars were 5-6 mm long, and could be readily recognized by the presence of strong mouth hooks and their skipping behavior. The larva skips by bending its body in the shape of a ring and hooks its oral claws over the sharp angle formed by the ventral edge of the posterior beveled truncation. It then pulls hard and the hold is suddenly released resulting in snap throwing of the insect in the air (Simmons 1927). Larvae grew well on ground beef or ox-tail bones. Some trials were made by placing second and third instar larvae on beef salami, chicken wings and cheese in Petri dishes. No development occurred on beef salami and all larvae either died or were overtaken by mould or bacterial growth. Similarly development on chicken wings or cheese slices resulted in only a few pupae.

The larvae reared on ox-tail bones grew well up to the third instar and slowly started disappearing. There was no sign of escape from jars but a close examination of the ox-tail pieces revealed that larvae had entered the bones and hard ligaments. No attempt was made to extract them. Larvae on ground beef were given fresh portions of ground beef every two weeks. A froth would appear the next day on the fresh meat where larvae congregate. This could be a result of bacterial activity. Most of the larvae growing either on ground beef or ox-tail bones did not pupate and remained quiescent for up to six months, after which the cultures were either discarded or observations terminated. Simmons (1927) reported that retarded growth of piophilid larvae was caused by low temperature or starvation as a result of desiccation of food. Because none of these two factors could have occurred in my cultures, the quiescent larvae had probably entered an obligatory diapause. The total larval period lasted from 23-65 days for those larvae which pupated (Table 1). Third instar larvae in their skipping stage wandered around apparently in search of dry places for pupation. The pupal period lasted 4-13 days.

The total developmental period from egg to adult of 121 insects that developed successfully was 32-74 days. The yield of the insects reared to adulthood was 16-32 % (Table 1).

In the field, Piophilids infest vertebrate cadavers at the decompositional stage when fatty acids are formed (Johnston and Villeneuve 1897, Nourteva 1977). Thus oxtail bones may be a more suitable substrate for development than fresh ground beef or chicken wings.

Piophilids have been used as forensic indicators to establish the season and year of their infestation of human remains (Skinner *et al.* 1988; Smith 1986). In view of its prolonged and asynchronous larval development in the laboratory, and its apparent obligatory diapause, this insect would be a poor indicator of the elapsed time since death, especially if it were the only insect found on the remains.

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Biological control of the two-spotted spider mite in raspberries with the predator mite, *Phytoseiulus persimilis*

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ABSTRACT

Phytoseiulus persimilis was released to control the two-spotted spider mite, *Tetranychus urticae*, in field raspberries at Agassiz, B.C. The mite predators became established and responded numerically to the prey in the treatment plots. For a period of 8 weeks after release, the numbers of *T. urticae* were consistently lower in the treatment plots than in the controls. Differences in numbers of *T. urticae* between the treatments and the controls were significant on two dates.

Key words: *Tetranychus urticae, Phytoseiulus persimilis, Rubus idaeus*, biological control, Fraser Valley

INTRODUCTION

The two-spotted spider mite, *Tetranychus urticae* (Acari: Phytoseiidae) Koch is a common pest of raspberries in British Columbia. A severe infestation can result in almost complete defoliation by August. Photosynthetic reserves necessary for cold hardiness are lost if premature defoliation occurs (Jennings *et al.* 1964). An infestation in the autumn can result in reduced bud survival during the following winter (Doughty *et al.* 1972). Weak plants leaf out earlier in the spring, and are thus more susceptible to late frosts than healthy plants (W.Peters, District Horticulturist, Abbotsford, B.C., personal communication).

Phytoseiids are widely used for the biological control of spider mites on various greenhouse crops (Costello and Elliott 1981; Mori *et al.* 1989; Tanigoshi 1982). Because of its high voracity, short developmental time, high fecundity (Laing and Huffaker 1969) and good dispersal ability (McMurtry 1982), *Phytoseiulus persimilis* Athias-Henriot is an important predator of *T. urticae* in greenhouses. In addition, *P. persimilis* has also been successfully used for mite control in field strawberries in England, California and New Zealand (Easterbrook 1988; Oatman *et al.* 1968; Waite 1988).

We describe the results of an experiment to determine the efficacy of *P. persimilis* as a biological control agent of *T. urticae* on raspberry crops in the Lower Fraser Valley.

MATERIALS AND METHODS

The experiment was done in a plot of nine rows of red raspberries, *Rubus idaeus* L., at the Agriculture Canada Research Station in Agassiz. Each row consisted of four eight meter sections separated by two meters of bare ground. Three treatments and a control were assigned at random within a row. This was replicated five times on alternate rows, leaving a buffer row between treatments. We released *T. urticae*, obtained from Applied Bionomics (Box 2637, Sidney, B.C. V8L 4C1), on 11 May, 1989 by placing three pieces of mite-infested bush bean leaf (*Phaseolus vulgaris* cv Provider) per stool (a group of five raspberry canes derived from the same root) onto the raspberry foliage in each plot. The procedure was repeated on 9 and 27 July because the mites did not become established owing to wet, cold weather. The predator *P. persimilis* was introduced on 2 August when a sample of 30 leaflets per treatment indicated density of 0.70 *T. urticae* per leaflet. The bean leaves on which the predators were supplied were stapled onto the raspberry foliage in the middle of the canopy in numbers according to the following ratios of adult females to predators: 1:50 (High); 1:100 (Medium); and 1:200 (Low); and a control.

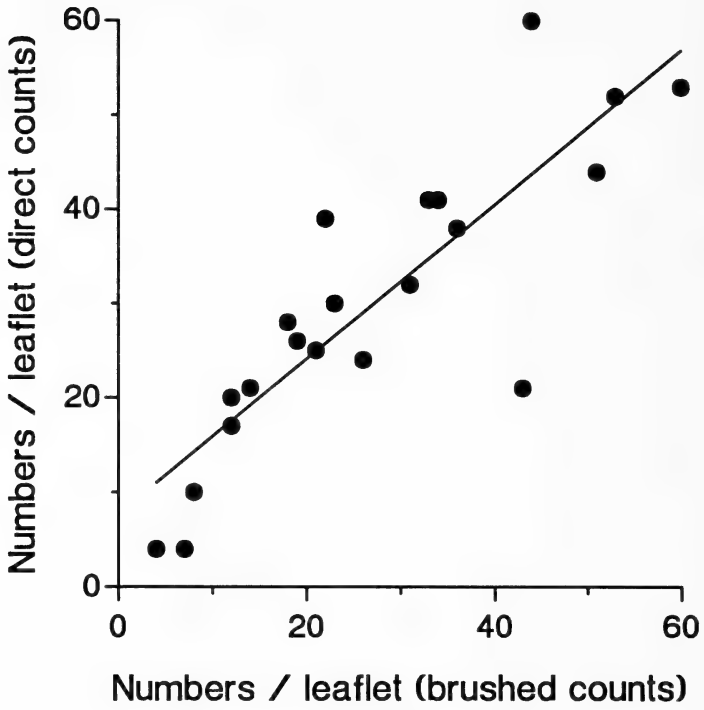

Figure 1. The relationship between estimated numbers of *Tetranychus urticae* on raspberry leaflets by direct counts and counts after removal with a mite-brushing machine.

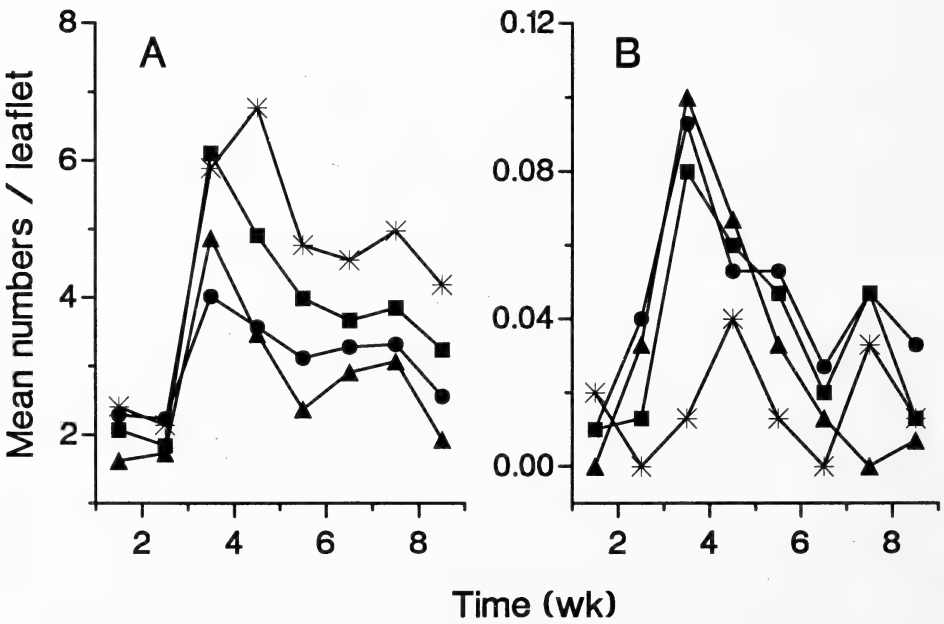

Figure 2. Population trends of *Tetranychus urticae* (A) and *Phytoseiulus persimilis* (B) in raspberry plots at Agassiz, B.C., 1989. Each point is the average of five replicates for the predator/prey treatments: 1:50,(●); 1:100 (▲) ; 1:200 (■); and control,(∗). One average standard error of a given mean density was 1.491 (A) and 0.03(B) mites per leaflet. Time zero was 2 August when *P. persimilis* was introduced.

Mites were sampled on 13 August and at weekly intervals thereafter until 1 October. Samples consisted of 30 leaflets per replicate, 10 leaflets picked equally from the top, middle, and bottom of the plant. The mites were removed from the leaves with a mite-brushing machine (J.G.H. Edwards, Llanfair Orchards, RR1, Okanagan Falls, B.C.), and all stages other than eggs were counted at 10X magnification under a dissecting microscope.

Brushed-mite counts were compared to direct counts of mites on leaves. Twenty-one leaflets were picked at random from raspberry plants that were infested with *T. urticae*. The mites were counted under a dissecting microscope. Each leaflet was then passed through the mite-brushing machine (Henderson and McBurnie 1943), and the *T. urticae* were counted again.

The data were analyzed using SAS® REG and GLM Anova procedure with repeated measures (SAS Institute Inc. 1985). The GLM analyses were performed on log- and square-root-transformed, and untransformed data with similar results. The results reported are from analyses of untransformed data.

RESULTS AND DISCUSSION

The regression of direct counts (y) on brushed-mite counts (x) (Fig. 1; $r^2 = 0.732$; $p < 0.01$; $y = 7.74 + 0.82\ x$) was linear since the addition of x^2 to the equation was not significant ($p > 0.05$). The x-intercept was not significantly different from zero ($p > 0.05$). The data obtained using the mite brushing machine were therefore analyzed without calibration.

The population trends for *T. urticae* in the three treatments and the controls followed a similar pattern during the first 2.5 weeks after release, then the numbers diverged (Fig. 2A). Overall differences between treatments were not significant ($p > 0.05$), but contrast analysis using Bonferroni's method showed significant differences between the High treatment and the controls at 4.5 weeks ($p < 0.05$), and between the Medium treatment and the control at 4.5 and 5.5 weeks ($p < 0.05$). Two-spotted spider mite population levels in the High and Medium treatments maintained the same position relative to the controls through the rest of the experiment but were not significantly different from the controls ($p > 0.05$).

Phytoseiulus persimilis became established in the treatment plots at low levels and followed a pattern of population fluctuations similar to that of *T. urticae* (Fig. 2B). Average *P. persimilis* numbers increased almost ten-fold within 3.5 weeks. The numerical response was analyzed by regressing average numbers of *P. persimilis* on average numbers of *T. urticae* for each treatment (High, $r^2 = 0.604$, $p = 0.023$; Medium, $r^2 = 0.608$, $p = 0.023$; Low, $r^2 = 0.857$, $p = 0.001$; and controls, $r^2 = 0.309$, $p = 0.153$). The data indicate that *P. persimilis* was able to find its prey and reproduce when prey were abundant.

The experiment shows that *P. persimilis*, which is not native to B.C., can establish and survive in a raspberry field during the summer, for at least 8.5 weeks, at a prey density of 0.7-6.0 *T. urticae* per leaflet. Significant treatment effects on two dates indicate that *P. persimilis* may reduce *T. urticae* numbers at both a 1:50 and 1:100 predator/prey ratio. The results are in agreement with other research showing that, in general, agents should be released at a predator:prey ratio of no less than 1:100 (Hoy *et al.* 1982; and Mori *et al.* 1989).

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Evaluation of monitoring methods for western flower thrips, *Frankliniella occidentalis* (Thysanoptera: Thripidae), during the blossom period of 'Granny Smith' apples

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ABSTRACT

Commercial sticky board traps (150 x 100 mm) of three different colors (blue, white or yellow) were treated with one of two chemical attractants (p-anisaldehyde and ethyl nicotinate) and with the solvent ethanol. Blue and white traps caught four and three times more thrips respectively than yellow traps. Attractants improved catches by only about 20% and were not considered economical. If traps are used, a plain blue trap is recommended. Trapping, beating tray and flower cluster flicking monitoring methods were compared. Trapping gave a time-averaged indication of thrips numbers, but numbers are probably affected by location of the trap and flowering stage of the apple. The beating tray method was the most versatile. It could be used regardless of flower condition and produced instant results. The currently recommended flower cluster flicking method produced few thrips and is affected by condition and age of the flowers, as well as time of day. We conclude that it is an ineffective method. Monitoring thrips numbers after blossom using a beating tray may give more practical economic thresholds for treatment.

Key words: thrips, apples, *Frankliniella occidentalis*

INTRODUCTION

Western flower thrips (*Frankliniella occidentalis* (Pergande)) are small (1-2 mm) slender insects that feed on the flowers of many plants. They can cause damage on stone fruit by rasping the surface of the fruit as they feed. The main damage on apples is from females ovipositing in the young fruitlets, just after petal fall. The resulting puncture causes 'pansy spot', a whitish area around the oviposition site. This damage shows up mainly in light skinned varieties such as Granny Smith, but can also be a problem in Rome Beauty and McIntosh (Flint 1991).

Chemical control of thrips may not be required every year. If other plants are in flower at the same time, they may dilute the thrips population below damaging levels (Beers *et al.* 1993). Although the relationship between thrips population and fruit damage is unclear, the relationship can only be found by monitoring the thrips during critical periods. Once the relationship is found, monitoring will show if control is required. Many monitoring methods require field samples to be taken and analyzed in the laboratory (Madsen *et al.* 1975). For most consultants this is not convenient, because growers need the results immediately. Most instant monitoring methods involve either sampling individual flowers (DeGrandi-Hoffman *et al.* 1988, Terry & DeGrandi-Hoffman 1988, Beers *et al.* 1993), or the use of a beating tray as used for sampling pear psylla (N. Simone personal communication).

The objectives of this study were to compare different sampling methods and times and to evaluate colored sticky board traps. We also assessed thrips damage in the fruit.

MATERIALS AND METHODS

The 'Granny Smith' apple orchards used had either a previous history of thrips pests, or blocks where thrips had been found during flowering. They were at Moxee, Zillah, Prosser, Pasco (Sagemoor) and Mattawa, WA. All orchards used conventional insecticide pest control programs, except for the Mattawa orchard which used organic controls.

Three monitoring methods were examined. The first involved sampling individual flower clusters (Beers *et al.* 1993). Five clusters from five trees were picked and individually given three vigorous shakes (or 'flicks') into a white plastic cup and the total number of thrips recorded.

Table 1

The effect of color and attractant on mean (n = 72) daily number of total thrips caught. Means with the same letter are not significantly different at $p < 0.05$ (log (x+1) transformation).

Factor		Daily trap catch
Colour	blue	41.3a
	white	34.9b
	yellow	10.6c
Attractant	p-anisaldehyde	33.4a
	nicotinate	27.9ab
	none	25.4b

In the second method thrips were sampled by jarring them from a limb onto a white cloth tray and counting them. A 46 cm (18") square cloth beating tray was held under a nearly horizontal section of limb ¾ to 1¼ inch in diameter with an average complement of flower clusters. The limb was tapped firmly three times with a 1-foot length of rubber hose. Twenty-five randomly selected sites on 25 trees were sampled throughout the block and the total number of thrips recorded.

The third method used blue, white and yellow colored sticky traps. Also, Teulon *et al.* (1993) mentioned trap catch enhancement with the use of chemical attractants. We looked at both color and attractants as a sub-study within this evaluation. The traps were 10 x 15 cm Chroma line card traps produced by Phero Tech Inc., 7572 Progress Way. Ladner, B.C. Three colors were examined: non U.V. white (No. 201); bright blue (No. 411); and bright yellow (No. 611). A chemical attractant, either p-anisaldehyde or nicotinic acid ethyl ester (Sigma Chemicals, POB 14508, St. Louis, MO) were each sprayed on 112 different cards.

Each attractant was mixed as a 40% solution in 95% ethanol as described in Teulon *et al.* (1993). The control was 95% ethanol. Attractants were applied to both sides of card traps using one 'squirt' (emitting 0.8 ml) per side from a plastic spray bottle, held about 10 cm away.

Traps were hung within foliage at about two-thirds of the height of the tree (between 1.0 and 1.8 m) . At each sub block three blue traps, three blue traps treated with p-anisaldehyde, three blue traps treated with nicotinic, three white traps, three white traps treated with p-anisaldehyde, three white traps treated with nicotinic, three yellow traps, three yellow traps treated with p-anisaldehyde and three yellow traps treated with nicotinic were hung on trees. Trees were selected randomly and traps placed randomly. After a period of 3-5 days the numbers of all visible thrips (all life stages and both sexes) were recorded and new traps randomly placed.

Damage was assessed on 6 July at Sagemoor, Mattawa and Moxee and 12 July at Zillah. One hundred fruit were examined on five trees in each sub-block, and the number with one or more pansy spots was recorded.

Data from the effect of color and chemical attractants on trap catch study, were transformed using log (x+1) and analyzed using General Linear Model in SAS. Site and time were included as factors.

RESULTS AND DISCUSSION

During the 1994 blossom season, relatively few thrips were found in south central Washington. In some orchards that previously had a thrips problem, none could be found during blossom. The orchard in Prosser and one in Zillah were dropped from the study due to a lack of thrips. In two of the orchards (Sagemoor and Mattawa), thrips were found relatively late in the flowering period.

At Sagemoor the traps were not replaced after counting on 18 April. The number of thrips caught during the 18-20 April period in Table 3 was obtained by subtracting the number caught in the 13-18 April period from the 20 April total. These data were not used in the analysis of variance in Table 1.

Blue caught more thrips than white and white more than yellow and the effect of color was significant at the $p < 0.001$ level (Table 1). The attractant p-anisaldehyde caught significantly ($p < 0.05$) more thrips than the check (Table 1). There was no significant differences between blue (the most attractive color) and attractants (Table 2).

Table 3 shows the relative numbers found using the three methods. Traps collected the most thrips but the beating tray method gave immediate results.

The Sagemoor Road orchard was monitored for the longest period and showed a rapid increase in thrips population (the beating tray method yielded 11 thrips on the first visit which rose to an average of 91 only one week later). The population later declined as expected (DeGrandi-Hoffman *et al.* 1988). Traps caught steadily increasing numbers of thrips over the whole period. The flower flick method at Sagemoor produced numbers that correlated with the beating tray method, but after petal fall is no longer a viable method since there are no flowers.

At Moxee, more thrips were collected using the flower flick method compared to other methods than at Sagemoor. This may be because trees at Sagemoor had more flowers per unit of limb than those at Moxee. The blue traps caught proportionately fewer thrips at Moxee than the other orchards, possibly because of the low flower and limb density, or the increased competition from a greater number of open flowers. As at Sagemoor, the late stage of flowering at Mattawa caused the traps to catch proportionately more thrips than the beating method.

Table 4 shows little difference in damaged fruit between the orchard blocks. The orchard at Zillah, while having no thrips present during flowering , had similar damage to the other blocks.

The best color for catching western flower thrips is still controversial. Even studies by one group of researchers can produce conflicting results. For example, Yudin *et al.* (1987) suggested white was the best color, yet one of their experiments showed blue catching the most. Our results support Moffit (1964), that white was far superior to yellow, but he did not test blue. We showed that white is superior to yellow, contrary to the statements of the manufacturers (Phero Tech, personal communication). Blue caught more thrips than white and it was easier to see the thrips and to locate the traps in an orchard full of white blossom where white traps were particularly difficult to find. These conflicting results may be due to subtle differences in the spectral qualities of the colors used and possibly to differences in the thrips population. Thrips in different areas or at different times of the year may move to flowers of different colors.

We did not see the 2-6 fold increase through the use of attractants that Teulon *et al.* (1993) found after applying anisaldehyde to sticky traps. This may be due to several factors. They used yellow traps, which are seldom the most attractive color. Our method of applying attractant differed from theirs, although we applied more attractant than them. Our study was conducted in the windy conditions of the field, while they conducted theirs in greenhouses, where it may be easier for thrips to fly towards an odor gradient. Wind would release more volatile attractants from the surface, while at the same time diluting its atmospheric concentration (Van der Kraan & Ebbers 1990). Anisaldehyde also formed yellow clusters of crystals on the surface of the sticky board, a possible reaction with the solvents used, and this may have reduced the 'stickiness' of the trap as well as diluting the effect of the attractant.

Attractants produced little benefit considering the effort required to apply them. Both attractants were skin irritants and the spray drift reddened arms and hands when they were applied. There was also more than one anisaldehyde spill, making travel an unpleasant olfactory experience.

Yudin *et al.* (1987) discussed attractive traps and found good correlation between numbers caught in contrasting colored traps and the thrips population in lettuce crops. We had no absolute method of determining population, but we considered that the beating tray most consistently indicated population levels. This method sampled a unit of branch area, and while this varied from orchard to orchard as tree management varied, it did not change in a single orchard over the sampling period. Variation between orchards, might make economic thresholds difficult to determine.

Compared with the results of the beating tray, the traps became more attractive near the end of flowering. This is probably when more thrips were leaving the apple trees. Traps give a time-averaged population estimate, since they 'smooth' variations of activity during and between

Table 2

The effect of attractants on daily total number of thrips caught in different colored traps. Means with the same letter for the same color trap are not significantly different at $p < 0.05$ (log (x+1) transformation).

Treatment	Blue	White	Yellow
Treated with p-anisaldehyde	41.8a	45.4a	13.6a
Treated with nicotinate	41.9a	34.4b	7.3b
Untreated	40.1a	13.6c	10.8ab

Table 3

Comparison of thrips monitoring methods for 'Granny Smith' apple blocks, at three Washington orchards.

Block	Date	Blossom[1]	Flower Flick[2]	Beating Tray[3]	Blue Traps[4]
Sagemoor – Both	13 Apr	35% PF	1	11	–
Sagemoor – E	18 Apr	60% PF	3	33	–
Sagemoor – W	18 Apr	55% PF	4	38	–
Sagemoor – E	20 Apr	70% PF	24	82	73
Sagemoor – W	20 Apr	60% PF	10	111	108
Sagemoor – E	25 Apr	99% PF	NF	31	129
Sagemoor – W	25 Apr	95% PF	NF	51	87
Moxee – Both	22 Apr	Full Bloom	9	30	–
Moxee – NW	26 Apr	20% PF	5	85	41
Moxee – SE	26 Apr	20% PF	11	69	31
Mattawa – NE	22 Apr	99% PF	NF	30	164
Mattawa – SW	22 Apr	99% PF	NF	49	129

1 PF = Petal Fall, NF = No Flowers

2 Flower flick method, total number of thrips found after flicking 25 flower clusters into a white paper cup.

3 Limb tapping method, total number of thrips found after 25 beating tray observations following three limb hits.

4 Blue trap method, daily average of total thrips caught in all nine blue traps.

– no collection

Table 4

Incidence of Pansy spot in samples of 500 fruit from 'Granny Smith' orchard blocks

Block	Pansy Spot
Sagemoor – E	2.4%
Sagemoor – W	2.2%
Moxee – NW	2.6%
Moxee – SE	2.0%
Mattawa – NE	4.0%
Mattawa – SW	1.6%
Zillah	2.0%

days. The catch may also be affected by density of flowers around each trap. Position may also affect the catch, and we noticed that traps in sunny positions caught more than those in the shade. These factors also make comparisons between different orchards difficult.

Madsen & Jack (1966) suggested that post petal-fall is the best time to spray for thrips, so monitoring at that time may give the best prediction of damage. The number of thrips caught may be related to number of flowers (or fruitlets) on a limb, which may make determining economic thresholds difficult. Beers *et al.* (1993) suggested that flower flicking should only be done in the late morning since thrips may only be on the flowers then. The beating tray method is not affected by this movement as the thrips probably only move on to neighboring leaves and branches. The beating tray method seemed to be the easiest and quickest and because it was probably not affected by time of day consultants could visit several orchards in a day.

The flower flick method yielded few thrips, and is affected by time of day (Beers *et al.* 1993). Consultants would therefore be at orchards only between 10 am and noon. The method can not be used once flowering is finished, even though it does give an actual number of thrips per flower, which may give a good estimate of potential damage. Late in the flowering period, flower flicks could yield abnormally high numbers because all thrips might be on the last remaining flowers. Hence flower flicks may not truly reflect relative risk of apple damage from the next generation of thrips. Madsen *et al.* (1975) used 20 thrips per 100 clusters (using a glass cylinder thrips extractor) as a treatment threshold, but found it did not keep damage below an acceptable level. Terry & DeGrandi-Hoffman (1988) found flower flicking less efficient than laboratory extraction methods, especially late in the blossom period. Numbers given by this method depend greatly on flower stage.

Damage to the apples was similar in all orchards. Terry (1991) found that oviposition (during flowering) did not increase significantly with the number of thrips, hence monitoring by any method may not be particularly useful. Terry's study ceased soon after petal fall. This is not the time of fruit damage but later in the season (as suggested by Madsen & Jack 1966).

Further work is needed to determine if the beating tray method gives consistent results at any time of day as we suspect it should. Monitoring populations during the flowering season and after flowering to see when thrips are in the trees would be useful to see if their presence later in the season can be related to damage. Populations of thrips were low in 1994. Other years might have high thrips numbers during flowering which could require preventative control at that time. Monitoring populations in more orchards during peak blossom and a few days after-petal fall, followed by an assessment of damage should indicate any correlation between numbers and damage.

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An occurrence of two exotic ant (Formicidae) species in British Columbia

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ABSTRACT

Specimens of two exotic ant species, *Wasmannia auropunctata* Roger and *Parathrechina longicornis* Emery were found in an indoor tropical rainforest exhibit in Vancouver. Both species have spread far from their historical ranges to become established in tropical and subtropical areas around the world, and are occassionally found in greenhouses and other protected areas in temperate regions.

Key words: ants, exotic, habitat, indoor, British Columbia

DISCUSSION

Several species of tropical ants, because of the small size of the workers, polyphagous eating habits, and their ability to nest in a variety of situations, have become associated with human activities in regions far beyond their original ranges. Their ability to nest and feed within buildings allows them to live in much colder climates than would ordinarily be expected, and often causes them to be pests. They are sometimes called tramp species because of their tendency to hitch rides to new locations and to feed on spilled or unprotected human food. In January, 1994, specimens of two such ant species, *Wasmannia auropunctata* Roger (Myrmicinae) and *Paratrechina longicornis* Emery (Formicinae), were collected from within the tropical rainforest exhibit at the Vancouver Aquarium.

W. auropunctata, commonly called the little fire ant, is an aggressive, neotropical species. It is sensitive to cold temperatures and has become established in Mexico, south Florida (Spencer 1941) and California (Smith 1979), as well as other sub–tropical and tropical areas around the world. It is not a close relative of the imported red fire ant, *Solenopsis invicta* Buren, another neotropical species which has become a pest through much of the southern United States.

W. auropunctata workers are small, 1.5–2 mm long, and yellow. Members of the genus can be identified by 11–segmented antennae (terminating in a 3–segmented club), 2 obvious spines protruding from the propodeum (posterior end of the alitrunk), and frontal carinae (raised ridges on the frons) that extend posteriorly past the eyes so as to form the lateral boundaries of grooves (scrobes) into which the first segments of the antennae can be folded. There are five mandibular teeth, and the large head is much broader than the thorax (Hölldobler and Wilson 1990; Ulloa–Chacon and Cherix 1990).

Little fire ants do not construct their own nests but use sheltered locations including rotten wood, covered soil, and plant cavities. The nests are diffuse and inconspicuous and often aggregate to form large, polygyne nests. Workers are polyphagous and opportunistic feeders that prefer to collect honeydew from aphids, hunt a wide variety of prey, or collect plant material. They are attracted to fatty and oily household foods, and dirty and sweaty clothing, but not sweets. Workers have a sometimes–painful sting but generally sting only when trapped between the body and clothing or some object. They have been a pest in citrus orchards, where they sting pickers, and have been reported to drive out less aggressive ant species and to cause an imbalance in phytophagous insect communities in a number of crops by defending honeydew–producing insects from predators and parasites (Thompson 1990; Ulloa–Chacon and Cherix 1990).

At the Vancouver Aquarium, large numbers of little fire ants were found throughout the Graham Amazon exhibit, where they formed numerous foraging trails along the edges of walls and floors, along the undersides of walkways, and up the trunks of plants. In the larger foraging trails, I observed up to 60 individuals passing a given point in both directions, each minute. The ants were found tending scale insects, and were most apparent on those plants (e.g., Amazon lily, *Eucharis*) that hosted scales. Up to several hundred of the tiny ants could be found, together with the scales, on the undersides of individual lily leaves. Nests were apparently contained within cracks in large

cement "rocks" contained within the display, and in walls separating the display from various fish tanks. The nests were not examined.

W. auropunctata is occasionally found in greenhouses far from its endemic and naturalized ranges. As early as 1907, it was well established at Kew Gardens in London (Ulloa–Chacon and Cherix 1990), and Ayre (1977) reported it from Assiniboine Park, Winnipeg, MB, where it was the most numerous of several ant species in the greenhouse area of the tropical house. It is likely that it was introduced to the display at the Aquarium in plant material, associated soil, or both. The hot and humid conditions within the tropical display have recreated the ideal habitat for this species, but it is unlikely that it could become locally established elsewhere, except in such greenhouse environments. Although little fire ants do occasionally sting Aquarium staff, they are not a problem for visitors, and probably go unnoticed because of their small size.

Paratrechina longicornis workers are monomorphic, brown–black with bluish reflections, and approximately 2.5 mm long. There is a single reduced segment (petiole) between the alitrunk and the gaster, and it is somewhat rounded, rather than scale–shaped as in all the native British Columbia species of the subfamily Formicinae. The antennae and legs are unusually long, and there are long, spiny hairs on the gaster and running in 2 rows down the alitrunk. Workers have no sting and do not bite. They are rapid runners, and sometimes show jerky, erratic movements (Thompson 1990).

These ants may have originated in the Orient, although in North America they are now abundant in Florida and the Gulf States (Trager 1984). In more temperate areas they seek refuge indoors to survive cold winters (Smith 1965); they are commonly found indoors in New York city (Creighton 1950). Nests of another member of this genus, *P. fulva* Mayr, have been found in the tropical house at Assiniboine Park, Winnipeg, MB (Ayre 1977). *P. longicornis* will nest in trash, plant cavities, rotten wood, soil, or small crevices, and seek food throughout a building. They tend honeydew producers, and will also eat other insects, seeds, meats, greases, and sweets (Smith 1965). Colonies may contain up to 2,000 workers and 40 queens.

Only two *P. longicornis* foragers were found within the tropical display at the aquarium. The relative lack of abundance is not surprising in the face of the aggressive nature and large numbers of *W. auropunctata* in that area. It is possible that *P. longicornis* nests were located elsewhere in the aquarium complex, and only a small number of workers were foraging in the tropical display. The presence of this species represents little or no problem at the aquarium because of its lack of sting or bite, and small numbers.

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An unusually large aggregation of the western conifer seed bug, *Leptoglossus occidentalis* (Hemiptera: Coreidae), in a man-made structure

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ABSTRACT

An overwintering aggregation of more than 2000 *Leptoglossus occidentalis* is reported in a manufacturing plant in the southern interior of British Columbia. Such aggregations may be mediated by pheromones. Range extension may have occurred through inadvertent transport of aggregations of overwintering adults.

DISCUSSION

The western conifer seed bug, *Leptoglossus occidentalis* Heidemann, is a serious pest of conifer seed production (Koerber 1963), particularly on *Pinus* spp. (Connelly and Schowalter 1991). During the fall adults, like other coreids, seek sheltered overwintering sites. When human habitation interfaces with forests, these sites can include garages, birds' nests (Hussey 1953) and houses (T.W. Koerber, Entomological Services Inc., Berkeley, California, personal communication). *L. occidentalis* has recently extended the eastern limits of its range and has become a common household pest in Michigan (Gall 1992), Ontario (Marshall 1991; McPherson *et al.* 1990), Wisconsin and Minnesota (Katovich and Kulman 1987). Numbers of insects found in or on the homes varied from less than a dozen to roughly a hundred individuals.

In October 1993, Richard Prebble, Manager of the Imperial Chemical Industries (ICI) Explosives Plant in Tappen, BC, 78 km east of Kamloops, reported an infestation of *L. occidentalis* in and around the manufacturing plant. On inspecting the site, I found large numbers of *L. occidentalis* congregated around door jambs, windows and in cracks within the concrete walls. Hundreds of bugs were aggregated around heating exhaust ports. I collected 1065 live bugs (608 males and 457 females) and estimated that there were at least 1000 more dead on the floors, window sills and in the door jambs; a result of chemical control by the plant staff. Several workers indicated that the infestation was 'manageable' compared with what it had been just two weeks before. For the past three years, similar infestations have been observed at this plant; they reportedly last for roughly three weeks and then 'disappear'. An aerial photograph obtained from the BC Ministry of Forests showed that *L. occidentalis* must have flown a considerable distance to reach the aggregation site. The plant is located in a meadow, at least 300 m from forest edges to the north and west, 900 m from a patch of conifers to the east and 750 m from a small patch of conifers to the south.

Small aggregations of *Leptoglossus corculus* (Say) have been observed in the southern USA (J.C. Nord, USDA Forest Service, Athens, Georgia, personal communication) and overwintering aggregations of other Hemiptera also occur. Schowalter (1986) documented an aggregation of ca. 8,000 boxelder bugs, *Boisea rubrolineata* (Barber), in western Oregon. The aggregation was found 500-1,000 m away from feeding hosts. Aggregations of > 6,000 swallow bugs, *Oeciacus vicarius* Horvath, have been reported in Washington (Zack 1990). Chinch bugs, *Blissus leucopterus leucopterus* (Say), also aggregate to overwinter in groups of typically < 200 individuals (Negron and Riley 1991). In all instances, pheromonal attraction was suggested as a causal factor of aggregations. It has been hypothesized that extension in the range of *L. occidentalis* has occurred through the inadvertent transport by mankind of aggregations of bugs overwintering on or in transported goods (L.M. Humble, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC, personal communication).

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Parasitoids of blackheaded fireworm (*Rhopobota naevana* Hbn.) larvae on cranberries, and larval escape behaviour

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ABSTRACT

The parasitoids *Hemisturmia tortricis* (Coq.) (Tachinidae), *Sympiesis bimaculatipennis* (Girault) (Eulophidae) and one male of the genus *Microplitis* (Braconidae) were reared from blackheaded fireworm larvae collected on a cranberry farm in the Fraser Valley, B.C. Fireworm larvae escape ovipositing parasitoid females by dropping from an "escape hatch" hole cut in the bottom of the feeding shelter.

Key words: *Vaccinium macrocarpon, Hemisturmia tortricis, Sympiesis bimaculatipennis, Microplitis,* Tortricidae, biological control, behaviour

DISCUSSION

The blackheaded fireworm of cranberry, *Rhopobota naevana* Hbn. (Lepidoptera: Tortricidae) is an economically important pest for which biological and other non-chemical control measures are currently being sought. Two indigenous parasitoids, *Trichogramma minutum* Riley and *T.* sp. nr. *sibericum* Sorokina, are known to parasitize blackheaded fireworm eggs (Li *et al.*, 1993), and a granulosis virus is associated with larval mortality in the field (Fitzpatrick and Theilmann, unpublished data). Spiders of the genus *Pardosa, Xysticus* and *Tibellus* have been found preying upon fireworm moths in field cages (Fitzpatrick and Troubridge, 1993) and ladybird beetles, *Coccinella californica* Mann., have been observed feeding on fireworm larvae in the field (Plank, 1922). However, except for Plank's (1922) report that "numerous very small wasplike insects ... can be seen flying over the tops of the vines on badly infested bogs", there are no records of parasitoids attacking larvae.

In 1991, we collected ca. 200 blackheaded fireworm larvae from a cranberry farm in Pitt Meadows, B.C. that was seldom treated with insecticide. From these larvae, six parasitoids belonging to three species emerged. Two were *Hemisturmia tortricis* (Coq.), a tachinid fly known to parasitize nine other leafroller species as well as larvae in the moth families Glyphipterygidae, Nymphalidae, Oleuthreutidae, Pterophoridae and Pyralidae (Arnand, 1978). Three parasitoids were *Sympiesis bimaculatipennis* (Girault), an eulophid wasp that attacks leafrollers but is reported to prefer blotchmining or skeletonizing lepidopterans (Krombein, 1979). The sixth parasitoid was a male of the genus *Microplitis* (Hymenoptera:Braconidae) that could not be keyed further because males of this genus cannot be identified to species (M. Sharkey, C.L.B.R.R., Ottawa, personal communication).

Blackheaded fireworm larvae feed at the tips of cranberry runners or upright shoots, although newly hatched first instars may mine into the underside of the leaf on which they hatch if no new growth is available (Plank, 1922). A larva webs three to five of the top leaves together and, protected within this "tent", feeds on new leaves and leaf primordia. We have observed female *S. bimaculatipennis* walking over the tents, tapping with their antennae and probing between leaf edges with their ovipositor. Although we have not observed the host-seeking behaviour of *H. tortricis,* other members of its tribe (Winthemiini) lay eggs directly on the host, so it too must somehow locate larvae within tents (D.M. Wood, personal communication). We have seen ladybird beetle larvae attempting to pry tents open using their legs and mandibles.

However, entry into a tent does not guarantee success for a parasitoid or predator, because the larva often drops on a silken thread through an "escape hatch" hole previously cut in the bottom of the tent. Larvae also use the holes to leave tents depleted of food. Holes range in size from

approx. 0.5 mm by 0.7 mm (made by early instars) to 4.6 mm by 1 mm (made by late instars). Larvae have been seen returning to tents from which they have previously escaped.

The tiny, leaf-mining first instars may also be subject to parasitism by *S. bimaculatipennis*, although this remains to be demonstrated or observed.

ACKNOWLEDGEMENTS

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COVER : The symbol of the 1995 Annual General Meeting of the Entomological Societies of Canada and British Columbia is reproduced on this year's cover. It is from a limited edition print, *Frozen Mosquito* by BC native artist, Michael Blackstock. He was born in 1961 and is a status native with the Gitanmax Band in Hazelton, as well as a professional forester. He was inspired by the Tsimshian legend of the origin of the mosquito - in ancient times, blood sucking animals in human form used to invite travellers to their village and then drain their victims' blood by stabbing their long crystal noses into the necks of the unsuspecting travellers while they slept. One young man awoke in time to save himself. He fled from the village with the chief in hot pursuit. The chief tracked the young man to a lake where he had hidden in a tree on the shore. The chief exhausted and soaked himself trying to attack the man's reflection in the water and then, while recovering on the shore, froze solid. The young man and his people took the frozen chief and burned him to ashes. When the fire had burned out, a wind came up and blew the ashes into the air where they turned into clouds of mosquitoes. The photograph superimposed on the drawing was taken and scanned by the editor from a frozen female *Culiseta incidens* (Thomson) reared by David Onyabe. One of the Province's commonest and largest species; it is magnified 7.5 times.

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Ovipositional preferences of the walnut husk fly, *Rhagoletis completa* (Diptera: Tephritidae) on various fruits, vegetables and varieties of walnuts

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ABSTRACT

The ovipositional preferences of the walnut husk fly, *Rhagoletis completa,* were studied using different fruits, vegetables, and walnut cultivars. Among the fruits and vegetables tested, pear was the substrate most often chosen for egg deposition, followed by nectarine, apple, green pepper, potato, and tomato. The eggs hatched equally well in all the substrates, but the larvae completed their growth and development only in nectarine. Among the varieties of walnuts tested, the most egg punctures per nut were in CVs 'Spurgeon' and 'Manregian' and the most eggs per nut were deposited in 'Manregian'. The females made the fewest egg punctures deposited the fewest eggs per nut in 'Hartley'.

Key words: Oviposition, development, walnut, walnut husk fly, *Rhagoletis completa.*

INTRODUCTION

Tephritid fruit flies have been cultured throughout the world for different research purposes, and have been reared from different hosts. Multivoltine tropical fruit flies are relatively easy to rear (Steiner and Mitchell 1966), whereas the univoltine temperate flies including the walnut husk fly (WHF), *Rhagoletis completa* Cresson (Diptera: Tephritidae) are difficult to culture in the laboratory. Different techniques such as wax domes, gelatin balls, paraffin foam balls, and agar balls have been tried for oviposition, with varying degrees of success (Hagen *et al.* 1963, Prokopy 1966, Haisch and Boller 1971). Foam rubber spheres of about 5 cm diam, wrapped in parafilm, were developed by Hagen as oviposition devices for the WHF (Cirio 1972). We have tested different artificial diets for rearing WHF larvae without much success; consequently, this insect has never been satisfactorily reared in the laboratory on artificial diets. Larval diet seems to be the major difficulty to continuous rearing.

The WHF is a major pest of walnut, but has also been recorded from peaches and nectarines. We have found breeding populations of WHF from a peach orchard in Washington state, although such occurrences are rare. Differential susceptibility of walnut varieties to WHF was shown by Boyce (1934) in California. Reported here are the results of an ovipositional preference study dealing with different fruits, vegetables and selected varieties of walnuts. The larval development and survival in the different substrates is also reported.

MATERIALS AND METHODS

Different fruits and vegetables were tested including the 'D'Anjou' pear (*Pyrus communis*), 'Golden Delicious' apple (*Malus domestica*), 'Supreme' nectarine (*Prunus*

persica), 'Pontiac' red potato (*Solanum tuberosum*), 'Jupiter Premarilla' green bell pepper (*Capsicum annum)*, and ripe 'Roma' tomato (*Lycopersicon esculentum*) using a randomized complete block design to test for ovipositional preference. Adult WHF were maintained at 24±1° C, 80±10% RH and 16:8 L:D photoperiod. A diet consisting of a mixture of yeast hydrolysate, fructose (Nutritional Biochemicals Co., Cleveland, Ohio) and distilled water at a ratio 4:7:10 by weight, respectively, as described by Tsiropoulos (1978), was provided for adults. This diet and distilled water were offered to the flies continuously on sterile absorbent cotton. Twelve mated pairs of mature flies (18-20 days old) were confined in each of four wooden-frame cages (35x25x40 cm) containing one each of the six substrates described above. The flies were given 48 hr to oviposit. The experiments were repeated 4 times, and the substrates were examined for numbers of punctures, and eggs in each puncture. The data were analyzed using ANOVA and means were separated by Duncan's multiple range test (significant at $p \leq 0.05$).

Substrates provided to the flies for egg laying were dissected to obtain eggs. One hundred eggs (<24 hr old) were removed randomly from each substrate and placed separately on moist filter paper in petri dishes, for each substrate. The petri dishes were placed in cardboard cartons and then transferred to a growth chamber at 24±1°C, and 80±10% RH. The eggs were examined daily until the 8th day after first hatch, then discarded.

To determine the development of larvae in different substrates, oviposited substrates (four of each kind) with 1-2 oviposition punctures were placed in plastic containers (18.5x13x11 cm) (Tri-State Plastics, Dixon, NY) with sifted vermiculite in the bottom so that mature larvae could pupate. These containers were placed in a rearing room maintained at 24±1°C, 80±10% RH, and 16:8 L:D photoperiod, for larval development. Pupae collected from nectarines, were stored at 3°C for four months and then moved to a rearing room for adults to emerge.

Eggs laid in apples in the laboratory were removed and surface sterilized in 0.01% sodium hypochlorite solution for 3 min, rinsed in 70% ethyl alcohol and then washed in distilled water (Neilson 1969, AliNiazee and Brown 1977). These eggs were then placed on wet filter paper in petri dishes and transferred to a growth chamber maintained at 24±1°C, and 80±10% RH for hatching. Newly hatched larvae were transferred with a fine camel hair brush to two different artificial diets developed for the closely-related larvae of the western cherry fruit fly, *Rhagoletis indifferens* (AliNiazee and Brown 1977) and the apple maggot, *Rhagoletis pomonella* (Neilson 1969) in 5 cm diam petri dishes and larval development was checked.

To determine the oviposition of WHF on five walnut varieties, a randomized complete block design was used for the treatments, replicated four times. The experiment was set up in a rearing room maintained at 24±1°C, 80±10% RH, with a photoperiod 16:8 L:D. Nuts of varieties 'Franquette', 'Spurgeon', 'Mayette', 'Manregian', and 'Hartley' were obtained from unsprayed orchards near Junction City, Oregon. They were thoroughly checked for oviposition punctures, and clean nuts with 5 cm twigs were placed in 35 mL plastic cups with water. One nut of each variety was hung in its cup in each of four wooden cages (35x25x40 cm). Five mated pairs of mature flies (18-20 days old) were released in each cage. Food and water were provided to flies as described. After 48 hr the nuts were examined for oviposition punctures, and eggs in the punctures. The data were analyzed using ANOVA and means were separated by Duncan's multiple range test ($p \leq 0.05$).

RESULTS AND DISCUSSION

The data (Table 1) show a significant ($p \leq 0.001$) difference in ovipositional response of WHF to different fruits and vegetables provided for oviposition. The highest numbers of egg punctures per substrate were in pear (8.7±0.5, mean±SD), followed by nectarine (5.5±0.9), apple (3.0±0.4), green bell pepper (1.7±0.5), potato (1.2±0.2), and tomato (0.5± 0.3). The number of eggs laid was also significantly different. The highest total number of eggs per substrate was laid in pear (227.5±10.4, mean±SD) followed by nectarine (69.7±16.6), apple (37.7±8.6), pepper (17.0±3.7), potato (10.0±2.2), and tomato (5.5±3.28). The substrate with the highest number of punctures also had the most eggs and the substrate with the lowest number of punctures had the fewest eggs.

Table 1

Ovipositional preferences of female *Rhagoletis completa* for various substrates in the laboratory.

OVIPOSITIONAL SUBSTRATE	PUNCTURES/ SUBSTRATE MEAN ± SD	EGGS/ SUBSTRATE MEAN ± SD	EGGS HATCHED (%)
Pear	8.7 ± 0.5 a	227.5 ±10.4 a	92
Nectarine	5.5 ± 0.9 b	69.7 ±16.6 b	92
Apple	3.0 ± 0.4 c	37.7 ± 8.9 c	90
Pepper	1.7 ± 0.5 cd	17.0 ± 3.7 cd	84
Potato	1.2 ± 0.2 de	10.0 ± 2.2 cd	86
Tomato	0.5 ± 0.3 e	5.5 ± 3.3 e	88

Means in a column followed by different letters are significantly different (Duncan's multiple range test), $p<0.05$.

Cirio (1972) reported that the female WHF probably selects an ovipositional substrate based on visual stimuli, such as color, shape, size, and other surface characteristics and to a certain extent on the internal humidity. It appears that pear must closely resemble walnuts in physical qualities to elicit such a high ovipositional response from WHF (Table 1). Although no walnuts were included in this trial for direct comparison, indirect comparison of data shown in Table 2, taken under the same conditions, suggests that more eggs were laid in pears than in walnuts.

Eggs obtained from various substrates hatched on moist filter paper (Table1), and there were few apparent differences. For example, about 92% of the eggs obtained from pears and nectarines hatched followed by 90% from apples, and 84% from green bell peppers. However, larval survival was not uniform. In potatoes, tomatoes and green peppers the larvae died soon after hatching, whereas in pear and apple, some larvae reached the second and even third instars but died before pupation. In nectarine the larvae pupated successfully. In an earlier study, Boyce (1934) had found peach to be a suitable host for this insect, while other fruits tested including naval orange, tangarine, grapefruit, apple, pear, grape, potato, egg plant, bell pepper and tomato were unsuitable.

The WHF larvae did not develop on the artificial diets suitable for cherry fruit fly and apple maggot larvae, although some larvae moulted to the second and even third instars

but all died before pupation. These media might support larval development with some additional ingredients and changes. Unusual growth of mold on artificial diets may also have interfered with larval growth.

Rhagoletis flies are well known for developing races specific to particular hosts (Bush 1969, Boller and Bush 1974). Bush (1969) speculated that the apple maggot developed different sympatric races as a result of shifts to unexploited hosts. The shift of apple maggot from its native host hawthorn (*Crataegus* spp.) to domestic apple (*Malus domestica*) in eastern North America over one hundred years ago, has now resulted in partial reproductive isolation for these two populations (Feder *et al.* 1988). McPherson *et al.* (1988a,b) found significant differences in allele frequencies between apple maggot fly populations raised on apple and hawthorn, and these siblings have been cited as example of sympatric speciation through divergence in host plant association (Bush 1969). Seasonal asynchrony caused by different fruit developing at different times is perhaps sufficient to initiate and maintain a restricted gene flow among different fly populations from different hosts thus leading to new host races (Smith 1988). Although no host race formation has been reported in *R. completa,* some genetic changes in different WHF populations collected from walnuts have already been reported by Berlocher (1984) as a result of the introduction of this species to different areas of the western United States.

The data on varietal preference presented in Table 2 show that female flies made significantly ($p \leq 0.05$) more punctures per nut in cultivars 'Spurgeon' and 'Manregian' and deposited the highest numbers of eggs in these two varieties. Significantly fewer eggs were deposited per nut in 'Mayette' and 'Franquette'. The fewest punctures and eggs were found in 'Hartley', which appeared to be highly resistant to oviposition. In a field study, Shelton and Anderson (1990) showed that 'Hartley' was much less susceptible to WHF attack than other varieties tested, including CVs 'Ashley', 'Payne', or 'Serr', over a 6-year study period in California.

Table 2

Ovipositional preferences of female *Rhagoletis completa* for walnut varieties.

VARIETY	PUNCTURES/NUT MEAN ± SD	EGGS/NUT MEAN ± SD	EGGS/PUNCTURE MEAN ± SD
Hartley	0.5 ± 0.3 a	4.7 ± 2.7 a	9.5 ± 0.5 a
Mayette	1.0 ± 0.0 a	14.2 ± 1.1 bc	14.2 ± 1.1 bc
Franquette	1.0 ± 0.0 a	26.7 ± 5.3 cd	28.0 ± 4.8 d
Spurgeon	3.2 ± 0.2 c	43.7 ± 7.0 de	13.2 ± 1.1 bc
Manregian	2.2 ± 0.2 b	51.0 ± 8.7 e	20.2 ± 2.0 cd

Means in a column followed by different letters are significantly different (Duncan's multiple range test), $p<0.05$.

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Reduction in feeding by diapausing and postdiapause pear psylla (Homoptera: Psyllidae) caused by extract from buffalo gourd (Cucurbitaceae)

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ABSTRACT

Rates of honeydew production were lower in diapausing winterform pear psylla, *Cacopsylla pyricola* (Foerster), than in psylla brought out of diapause by exposure either to long-day conditions or to an insect growth regulator (fenoxycarb). An extract obtained from a nonhost species, buffalo gourd (*Cucurbita foetidissima* HBK.), caused reduced honeydew production when misted onto pear shoots. Reductions in feeding were as pronounced in diapausing insects as in psylla that were in a postdiapause condition. Ovarian development scores were positively correlated with honeydew production, indicating that feeding deterrents may be useful for delaying the onset of egglaying in the field.

Key words: Insecta, *Cacopsylla pyricola*, diapause, honeydew production, feeding deterrent.

INTRODUCTION

Pear psylla, *Cacopsylla pyricola* (Foerster), is an important pest of commercial pears in both North America and Europe. The species is seasonally dimorphic, producing a large, dark overwintering form (winterform) in fall. This morphotype overwinters in a photoperiod-induced reproductive diapause, characterized by immature ovaries and a reduction or absence of mating (Krysan and Higbee 1990). Large numbers leave the pear orchard in fall to overwinter on nonhost species. Reentry into the orchard and egglaying begin in late winter.

The winterform morphotype has been the focus of a great deal of research, both because control of this stage prevents problems later in the season (Westigard and Zwick 1972), and because aspects of its life history (especially diapause) may make it vulnerable to new control technologies (e.g., Krysan 1990). There is a complex relationship between diapause status of psylla and its host plants. Overwintering psylla require access to a moisture source (Kaloostian 1970, Hodgson and Mustafa 1984). A number of species, including pear, appear to satisfy this requirement (Horton *et al.* 1994). The fact that many winterform psylla survive the winter outside of the pear orchard indicates that diapausing insects must be somewhat generalized feeders. Conversely, late postdiapause and reproductive insects are uncommon outside of the pear orchard. Thus, nonpear species may become less acceptable or unacceptable to pyslla coinciding with the end of diapause.

We tested three hypotheses dealing with pear psylla diapause, feeding, and their interaction. We first tested whether feeding by winterform psylla is reduced in the presence of an extract obtained from a nonhost plant species. Secondly, we tested whether feeding rates are higher in postdiapause psylla than in diapausing psylla. One

common characteristic of diapause in other insects is a reduction in feeding (Tauber *et al.* 1986). Thirdly, we compared feeding rates of diapausing and postdiapause psylla in the presence and absence of a putative feeding deterrent, and hypothesized that the deterrent would have less effect on diapausing insects, due to their generalist feeding habits, than on postdiapause insects.

MATERIALS AND METHODS

Female winterform pear psylla were collected from commercial pear orchards near Yakima, WA on three dates: 14 Dec. 1993, 28 Dec. 1993, and 23 Nov. 1994. Psylla were exposed to one of three conditioning treatments designed either to maintain diapause or to end it: (a) control (short-day [10:14 L:D]); (b) long-day (16:8 L:D); (c) short-day; shoots misted with an insect growth regulator (fenoxycarb; obtained from Maag Agrochemicals, Vero Beach, FL). The insects were kept in three screened plastic cages (1 cage per conditioning treatment) containing dormant pear shoots from an unsprayed orchard; shoots had their cut ends placed in jars of water. Control (short-day) conditions maintain diapause, whereas both long-day conditions and contact with fenoxycarb break diapause (Krysan 1990). For the fenoxycarb treatment, the pear shoots were sprayed to runoff with fenoxycarb at the rate of 0.1 g [AI] per liter of tap water. Shoots were allowed to dry, and psylla were added to the cage. Psylla were conditioned for 1 week at 20°C in three separate environmental chambers (1 chamber per conditioning treatment).

After seven days of conditioning, the feeding portion of the experiment was conducted. Conditioned psylla were moved to 135 ml screened feeding arenas, each arena containing a single cut shoot of dormant pear from an unsprayed orchard. The cut end of the shoot was kept in tap water. Four females from the same conditioning treatment were placed in each arena. There were 46-48 arenas per conditioning treatment (summed over the three collection dates). The insects were kept at room temperature (22°C) for the duration of the feeding trial.

Half of the pear shoots for each conditioning treatment (N = 23-24) were misted to runoff with an extract known to cause reduced egglaying by psylla (Weissling unpublished data). The extract was made from the tap roots of buffalo gourd, *Cucurbita foetidissima* HBK., obtained in the summer of 1988 from plants growing near Parks, Nebraska. The plant material was air-dried and ground to a fine powder (60-80 mesh), and then stored at room temperature in a sealed jar until use. One part root powder was mixed with 10 parts water and allowed to sit for 5 min. The mixture was then poured through a coarse filter to remove root particles. The supernatant was put in an atomizer and misted on pear shoots before introducing the psylla to the feeding arena.

Feeding was allowed for 6 days. On days 1, 3, and 6 of the trial, the number of insects on each shoot (vs on the arena wall) was determined. After 6 days of feeding, the psylla were removed from the arenas and frozen for later dissection and determination of ovarian development. Adult winterform psylla produce honeydew in solid, generally oval-shaped pellets, and the number of pellets was determined in each feeding arena. A preliminary experiment in which ninhydrin was used to stain honeydew (Paguia *et al.* 1980) verified that our counting methods were accurate (correlation between counts of honeydew before and after staining was 0.98 [N = 48]).

We also compared the size of pellets among treatments (third collection date only). After the November, 1994 feeding trial, five feeding arenas from each treatment combination were randomly selected and the honeydew was brushed onto petri dishes. Between 5-20 pellets in each petri dish were randomly chosen, and maximum length and

width measured using a dissecting microscope equipped with an ocular micrometer.

The feeding experiment was analyzed as a two-factor (conditioning x shoot treatment) randomized block design, with collection date included as a blocking factor. The response variable was the number of honeydew pellets per arena. Interactions involving collection date were not significant ($p > 0.25$); thus, sums of squares associated with these interactions were combined with residual sums of squares, and the new residual term was used as the error for all tests (Bancroft 1964). Numbers of insects in contact with the pear shoot on days 1, 3, and 6 were compared among treatments with a two factor (conditioning x shoot treatment) repeated measures ANOVA. Size (length; width) of honeydew pellets was compared among treatments with a two factor (conditioning x shoot treatment) multivariate analysis of variance (MANOVA).

All insects were dissected after the feeding trials to determine ovarian development. Development was scored using stages described in Krysan and Higbee (1990), in which 1 is most immature and 7 is mature (>50% of ovarioles with mature eggs). Stage 4 is considered to be the first clear indication of postdiapause development (Krysan and Higbee 1990). Stage 5 is the category at which the first mature egg is present. Scores were averaged for the four insects in a feeding arena, and mean scores compared among treatments with ANOVA.

Spearman's rank correlation was used to determine whether ovarian development and honeydew production were associated. Ovarian development varied among the three collection dates (see below). We therefore removed the effects of collection date from the ovarian scores with ANOVA before estimating correlation. A one-way ANOVA was calculated using mean ovarian score as the dependent variable and collection date (with 3 levels) as the independent variable. Residuals obtained from the ANOVA were then used in the rank correlation analyses.

RESULTS

Conditioning significantly affected ovarian development (Fig. 1). Averaged over the three collection dates, development was most advanced in fenoxycarb-treated insects (mean ovarian score = 5.2; N = 48), intermediate in long-day insects (mean = 4.4; N = 48), and least advanced in control (short-day) insects (mean = 3.2; N = 46). Comparisons among pairs of means were all significant ($p < 0.001$; by single df contrasts). Effects were not constant across collection dates (significant collection date x conditioning interaction [$p < 0.001$]). Although the dates in Fig. 1 refer to two different years, the medians suggest that fenoxycarb had more effect on younger insects (those collected in November) than those presumably more deeply in diapause (December insects). By the late December collection, long-day conditions and fenoxycarb produced almost identical median scores (Fig. 1).

The effects of the cucurbit extract on honeydew production were the same in all three conditioning treatments (Fig. 2; nonsignificant shoot treatment x conditioning effect [$p = 0.45$]). This result indicates that diapausing and postdiapause psylla were affected similarly by the extract. The extract significantly reduced honeydew production in all of the insects. Averaged over conditioning treatments, mean [±SE] honeydew production was 8.9 [2.1] pellets (N = 71) on treated shoots and 14.9 [2.1] pellets (N = 71) on untreated shoots ($p = 0.04$).

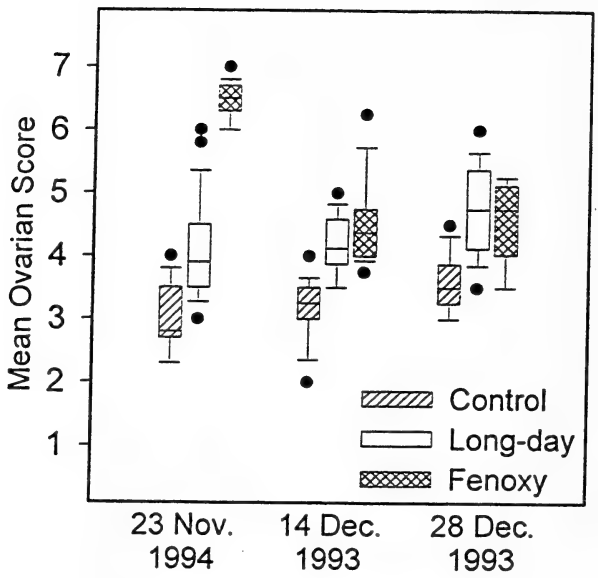

Figure 1. Box plots of effects of conditioning and collection date on ovarian scores; shoot treatments had no effect on mean score ($p = 0.42$). Upper and lower boundaries of boxes 75th and 25th percentiles, respectively. Line in box shows median. Error bars 10th and 90th percentiles. Solid circles are outlying points.

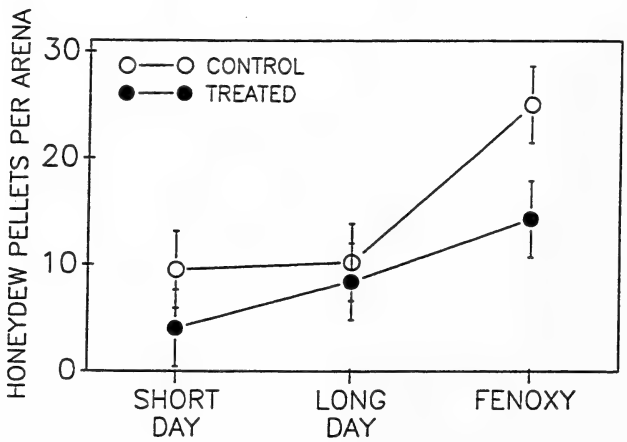

Figure 2. Mean (±SE) honeydew production as a function of shoot treatment and conditioning. Open circles, untreated; filled circles, treated with extract.

Conditioning also significantly affected honeydew production (Fig. 2; $p = 0.001$). Averaged over shoot treatment, mean [±SE] honeydew production was 6.8 [2.6] pellets for the control (N = 46), 9.3 [2.6] pellets for long-day insects (N = 48), and 19.7 [2.6] pellets for fenoxycarb-treated insects (N = 48). Single df contrasts indicated that the

control differed significantly from the fenoxycarb treatment ($p < 0.001$) but was similar to the long-day treatment ($p = 0.48$).

Pellet size also differed significantly ($p < 0.001$) among conditioning treatments (shoot treatment effects were nonsignificant). Single df contrasts indicated that pellets were significantly larger in long-day and fenoxycarb-treated insects than in control insects ($p < 0.001$ for both contrasts). Pellets were similar in size between long-day and fenoxycarb-treated insects ($p = 0.19$).

Numbers of psylla in contact with the pear shoot on days 1, 3, and 6 were not affected by shoot treatment ($p = 0.95$) or conditioning ($p = 0.80$). This result suggests that the differences in honeydew production among treatments were not due to differences in the amount of time the psylla were in contact with the pear shoot.

Rank correlation analysis showed that ovarian scores and honeydew production were positively associated (Table 1). That is, insects that produced larger amounts of honeydew tended also to have more advanced ovaries, even within a conditioning treatment.

Table 1.

Correlation (Spearman's rank) between ovarian scores and honeydew production. Effects of collection date removed from scores before estimating correlation.

	Control	Long-day	Fenoxycarb
Untreated shoots	0.46 ($p = 0.026$) (N = 23)	0.22 ($p = 0.29$) (N = 24)	0.52 ($p = 0.010$) (N = 24)
Treated shoots	0.22 ($p = 0.31$) (N = 23)	0.49 ($p = 0.016$) (N = 24)	0.44 ($p = 0.033$) (N = 24)
Combined	0.29 ($p = 0.047$) (N = 46)	0.35 ($p = 0.016$) (N = 48)	0.54 ($p < 0.001$) (N = 48)

DISCUSSION

The winter form of pear psylla is an important target for management, because control of this morph often prevents problems later in the year (Westigard and Zwick 1972). Current difficulties in controlling this stage with broad-spectrum insecticides have forced growers to consider other methods, including techniques that reduce feeding and oviposition (e.g., by applying oil in spring [Zwick and Westigard 1978] or, potentially, by using unpalatable pear varieties [Stuart *et al.* 1989, Bell and Stuart 1990, Puterka *et al.* 1993]).

The specific plant cues that cause probing and continuous feeding in psylla are unknown but, as in other Homoptera (Walker 1987, Walker and Gordh 1989), may include cues received at the plant surface (Ullman and McLean 1988, Horton and Krysan 1990). Quantification of honeydew production is commonly used in studies of Homoptera to screen plant varieties (Padgham and Woodhead 1988) or otherwise determine host suitability (Blua and Toscano 1994). We used this method to show that an extract from buffalo gourd, a nonhost species, caused reductions in feeding. Extracts from buffalo

gourd have been shown to cause reduced feeding in other insect species (Weissling *et al.* 1991), perhaps because of the presence of cucurbitacins (Metcalf *et al.* 1982). Weissling (unpublished data) showed that the extract also caused about a 50% reduction in oviposition by pear psylla in choice tests.

A number of physiological and behavioral characteristics are associated with diapause, including delayed ovarian development and reduced feeding (Tauber *et al.* 1986). We tested two specific hypotheses related to diapause in pear psylla. First, we tested whether feeding rates were higher in postdiapause psylla than in diapausing insects. Second, we tested whether feeding by diapausing insects was affected less by a nonhost extract than feeding by postdiapause insects. Numbers and size of honeydew pellets were both larger in fenoxycarb-treated insects than in short-day, diapausing insects. Long-day and short-day insects produced similar numbers of pellets, but pellets were larger for the long-day insects. These results support our first hypothesis.

Our second hypothesis was prompted by the observation that diapausing psylla are numerous outside of the pear orchard, whereas late postdiapause psylla or reproductive psylla are rarely encountered outside of the orchard. Thus, psylla evidently is a more generalized feeder in diapause than when out of diapause. Support for our second hypothesis would have been provided by a significant shoot treatment x conditioning effect in the analysis of variance. No such effect was noted; rather, the extract caused significantly reduced feeding in all insects, independent of diapause status.

Finally, there was evidence that feeding rates and ovarian development were associated (Table 1). Compounds that strongly deter feeding might therefore be used to cause a delay in oviposition. Horton *et al.* (1994) showed that postdiapause development of winterform psylla that overwintered on nonhost species was slower than that of insects that overwintered on pear, results that appear to be consistent with observations in this study. Growers regularly use a spring oil application to delay egglaying by winterform psylla. Our results show that compounds other than oil might also prove to be useful as feeding deterrents or for delaying oviposition.

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Monitoring and dynamics of a Douglas-fir beetle outbreak in Jasper National Park, Alberta

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ABSTRACT

A Douglas-fir beetle outbreak in Jasper National Park was discovered at 10 sites in 1991, and has since expanded to 30 sites in 1992, and 55 sites in 1993. Individual sites surveyed in 1993 contained from 3 to more than 200 attacked trees covering areas of 10 m^2 to 1 km^2 respectively. Sites containing pheromone population monitoring funnel traps contained significantly more attacked live trees than those sites without pheromone traps, suggesting that the traps attract larger beetle populations to the site. Diameter measurements indicated that in the initial years (~1990) of the infestation, larger diameter trees were attacked more commonly. In 1993, freshly attacked green trees were of a smaller diameter.

INTRODUCTION

Jasper National Park's montane forest is unique because it contains the most northerly stands of natural Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in Alberta. Within Jasper Park's 10,920 km^2, a computer analysis of the Jasper Biophysical Vegetation Map (Holland and Coen 1982) shows only 0.02% (167 km^2) with Douglas-fir as a dominant tree and 0.01% (145 km^2) with Douglas-fir as a subdominant tree. The stands infested by Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopk.) are pure or mixed structures with individual trees as old as 575 years. The stand composition for sites with and without pheromone traps are similar, and both site types are near infested hosts.

In Jasper Park, there have been minor Douglas-fir beetle (DFB) infestations consisting of 60 trees in 1980 and three trees in 1986. The onset of the current infestations was first observed near Annette and Patricia lakes in 1987 (Cerezke and Edmond 1989). In 1988, additional sites were found between Jasper townsite and the west gate (Edmond and Cerezke 1989). It was not until 1990/91 that the DFB infestations became well established in several stands of mature Douglas-fir in Jasper and were present in low numbers in Kootenay, and Yoho National Parks (Cerezke *et al.* 1991). At the time of this study (1993), the Jasper Park infestation was the only one known in Alberta. DFB infestations have occurred previously in southern Alberta and caused an estimated loss of 538,000 and 238,000 m^3 (19 and 8.5 million ft^3) of timber in the Interior and Coastal regions of British Columbia between 1956 and 1970 (McMullen 1977).

Since the discovery of 10 DFB sites in Jasper Park in 1991, the number has increased to 30 in 1992, and 55 sites in 1993, each with 3 to over 200 attacked trees (Figure 1). The current outbreak of DFB in Jasper appears to parallel that in British Columbia; where tree mortality from DFB covered 115 ha in 1989, 800 ha in 1990, 1,500 ha in 1991, and 3,425 ha in 1992 (Humphrey and Ferris 1992). Almost half the damage in 1993, 1,400 ha, was in the Mount Robson Forest District, bordering Jasper National Park to the west.

Douglas-fir beetles are an important component of Douglas-fir montane forests, normally attacking weakened or dying Douglas-fir trees. Stand-age, lack of tree vigour, and disturbances (i.e. windstorms, root rot, drought, insect defoliation, and fire) are key factors that may increase DFB populations and allow them to attack standing Douglas-fir trees (Furniss *et al.* 1981). This may result in an aggregate pattern of attacked healthy trees leading to a "fine-scale gap dynamics that favour establishment and (or) the release of the next generation of its host, suggesting a co-evolutionary relationship", as Peterman (1978) suggested for mountain pine beetle in lodgepole pine forests. The reasons for the current infestation in Jasper are speculative. In 1989 before the height of the DFB outbreak, severe winter windstorms added to the dead Douglas-fir material available for DFB. In 1989, Parks Canada lit a prescribed fire in the sub-alpine forest region, east of Highway 16 and north of Jasper townsite, near some of the largest current DFB infestations. Some Douglas-fir trees may have been weakened or killed by spot fires associated with the main fire block allowing Douglas-fir beetles to multiply and move to nearby Douglas-fir stands that were not affected by the fire. Finally, the drought conditions of the early 1990's may have stressed Douglas-fir trees making them more susceptible to DFB attacks.

Jasper National Park's main purpose is to promote public understanding, appreciation, and respect for Canada's natural and cultural heritage. Its mandate states that the Park exists for its intrinsic value as an important component of the larger regional ecosystem. Park managers recognize the DFB as an important agent disturbing the natural Montane ecosystem. In 1992, Parks Canada initiated detailed monitoring of DFB, consisting of aerial surveys and two sites baited with pheromone funnel traps for population monitoring. This was continued in 1993 and the number of pheromone-baited sites was expanded to six. The purpose of my 1993 study was three-fold: 1) to continue aerial monitoring of the number and size of infestation sites; 2) to determine if the DFB initially favours larger diameter trees; and 3) to determine whether the presence of pheromone-baited traps increased the numbers of green attacked trees in baited sites.

METHODS

Stands where Douglas-fir is the dominant or sub-dominant tree species were identified using Jasper Park's biophysical vegetation maps (Holland and Coen 1982). Aerial surveys were conducted to map DFB outbreaks in these stands, as indicated by more than 2 or 3 clumped red or recently dead trees. Subsequent ground surveys were made for as many of the sites identified by air during the summer of 1993 as time would allow. Twenty-nine of the 55 sites identified by aerial surveys were checked. Ground surveys consisted of counting the number of beetle attacked trees that were dead and had no-foliage (bare), red foliage, yellow foliage, or green foliage, taking the diameter at breast height (DBH) of each of these trees, and verifying the location of each site. Because the surveyed infestations were only a few years old, I assumed that dead, red, and yellow trees were attacked three to five, two, and one year(s) ago respectively. I assumed that green attacked trees were attacked during the first or second beetle flight of 1993.

On one site where attacked green trees continued up-slope for some distance, trees were counted on a line randomly placed across the slope. A second site contained pheromone traps and trees within three 50 m^2 plots were sampled because this site had an obvious spotted infestation pattern over 500 m^2. Since the sampling method for these two sites was inconsistent with that used for all other sites, the second attack site was excluded from calculations related to the effect of pheromone traps, but both sites were

used to determine the mean diameters of each infestation category (no-foliage, red, yellow, and green) for sites with and without pheromone traps.

Multiple funnel traps (Lindgren 1983) containing ethanol, frontalin (1, 5-dimethyl-6, 8-dioxabicyclo [3.2.1]octane), and MCOL (1-methycyclohex-2-enol) were used to monitor annual beetle population fluctuations. Lindgren (1992) found frontalin to be an effective aggregation pheromone for the DFB. Traps were placed in six sites (the two sites used in 1992 and four additional sites in 1993) under the direction of Dr. H. Cerezke of Forestry Canada (Figure 1).

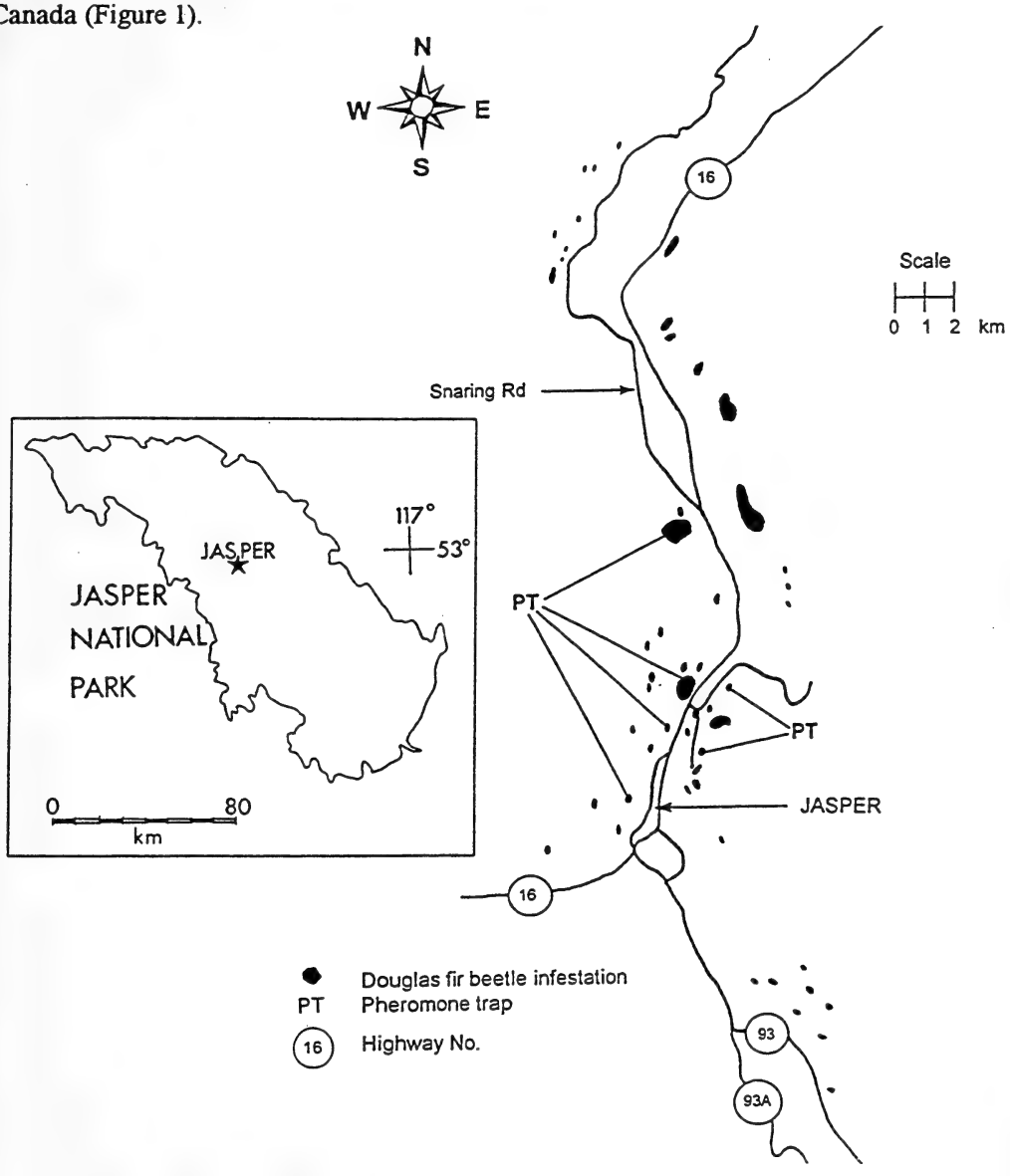

Figure 1. Douglas-fir beetle infestations in Jasper Park (inset). Sites with pheromone traps are marked.

The sites were chosen because they had active beetle populations and were accessible. Site size or possible tree stressing factors were not a factor in site selection. Each trap site contained three funnel traps, spaced 40 meters apart, in a triangle. Each trap was hung 2 meters above the ground on non-host trees. The traps were checked weekly to ensure they were intact and functional, and to collect captured beetles.

Data Analysis

The mean logarithms of tree diameter for each infestation category (no-foliage, red, and green) were compared using a two-sample, one-tailed t-test at the 99.5% confidence level. The yellow foliage category was not analyzed since very few trees had turned yellow, perhaps as a result of a cool and wet summer. The diameters were transformed to logarithms to give normal distributions. A total of 1,611 trees from all 29 infested sites was used in the diameter comparison. The logarithms of diameters were compared between sites with and without pheromones to determine if the pheromone had an effect on the diameter of any infestation category. All sites were used because there was no significant difference between the mean diameters of infestation categories in sites (excluding sampled sites) with and without pheromone traps.

To assess the effect of the pheromone traps on the infestations, first, the numbers of green attacked trees in sites with and without pheromone traps were compared using a two-sample, one-tailed t-test at the 99.5% confidence level. Secondly, to determine if the extent of the current infestation is related to its initial size, a correlation analysis of the number of bare (no-foliage) trees to the current number of green attacked trees was performed. These analyses assume that since the infestation in the Park is fairly new, the bare trees were attacked 3-5 years ago and the green trees with fresh boring dust were attacked in 1993.

RESULTS

From a total of 1,611 trees, the geometric mean diameter (DBH) for attacked bare (no-foliage) and red trees was 43 cm and 48 cm respectively. These were significantly different from each other (Table 1). Both bare and red trees had a mean diameter significantly larger than attacked green trees, mean DBH = 39 cm ($t = 3.59$ and 10.44 respectively, $p \geq 0.005$).

Table 1

Mean diameters (DBH) of four classes of attacked Douglas-fir trees in 29 sampled sites

Parameter	Green trees	Yellow trees	Red trees	Trees with no foliage
No. of trees	685	78	450	398
Mean (cm)	39	42	48	43
Log mean	1.596	1.623	1.684	1.631
Std. dev.	0.1	0.2	0.1	0.2

The five sites with multiple funnel traps (one trap site was excluded) had a significantly greater proportion of attacked green trees than sites without pheromone traps (Figure 2) ($t = 3.32$, $DF = 20$, $p \geq 0.005$). There was no linear relationship between the initial infestation size (number of attacked trees without foliage) and the current size (number of attacked green trees), since the x-coefficient ($r = 0.26$) was not significantly different from zero. Figure 2 shows that sites with pheromone traps were among those with the most attacked green trees.

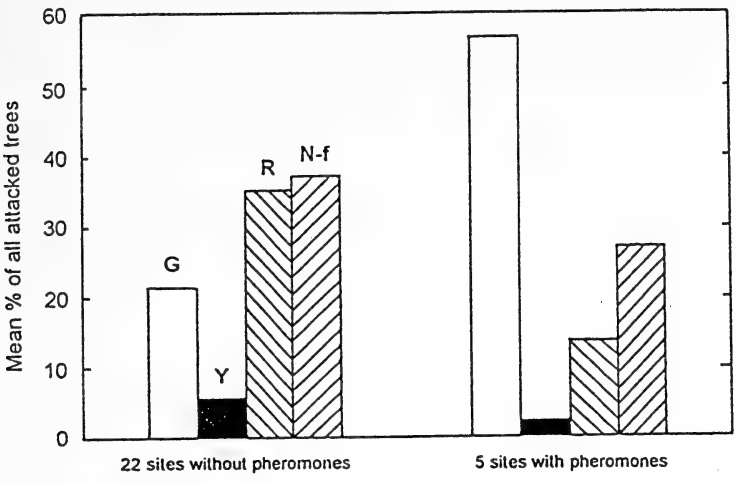

Figure 2. Comparison of the mean percent attacked green,(G) yellow,(Y) red,(R) and trees without foliage (N-f), for sites with and without pheromones. Two sampled sites, one with pheromones and one site without, are excluded from the analysis. Of 1611 Douglas-fir trees surveyed, 547 were in sites with, and 1064 in sites without pheromones.

DISCUSSION

The mean DBH of the no-foliage and red trees in all surveyed sites was 4 to 8 cm larger than that of the attacked green trees. In Idaho, Furniss *et al.* (1981) found that attacks tended to be more dense and more successful on larger size diameter trees since they produce more resin than the smaller diameter trees. Initially a high resin production may increase tree resistance, but the resin may also contain kairomones or pheromone precursors that attract more beetles, increasing the probability of a successful attack. The beetle population in Jasper Park may now be large enough to overwhelm the smaller diameter trees.

The mean diameter comparison, for each infestation category, used all infestation sites since there was no apparent difference between the mean logarithmic diameters of each category in sites with and without pheromones. This could be because the study design was not detailed enough to pick-up variances in attacked diameters with increased distance from the pheromone traps. Knopf and Pitman (1972) found that within a 10 m radius of the baits, 58% of 10 cm and larger diameter trees were attacked and larger diameters were progressively favoured as the distance increased from 4.3 -10.0 m.

There was a significant positive correlation between pheromone baited sites and the number of green attacked trees. Surprisingly, a large initial infestation (number of attacked trees with no-foliage) did not correspond to a large number of attacked green trees. Therefore, the current number of green attacked trees may be related to the recent practice of pheromone baiting. Figure 2 shows that sites containing pheromone traps were among those with the highest number of green attacked trees. Baker and Trostle (1973) also found that frontalin and camphene pheromones attracted more beetles into an area when 58.5% of the trees within 33 feet of the baits were attacked and only 3.6% were attacked in the control sites.

Although the pheromone sites had more green attacked trees, some of them may survive. In Montana, out of 739 attacked 188-year-old trees, 29% were unsuccessfully attacked (no reproductive galleries were established) and 22% of the trees survived the attack (Furniss *et al.* 1981). To minimize stress on the attacked Douglas-fir trees in the Park, I did not remove the bark to investigate the galleries. It is likely that a similar proportion of our green attacked trees may survive.

The DFB pheromone baits may have shifted and concentrated the attack centres to trees with funnel traps. The pheromone baits can result in spill-over onto neighbouring green host trees (Thier and Weatherby 1991), resulting in an increased concentration of natural pheromones, and thus significantly increasing the attractiveness of neighbouring trees. Stock *et al.* (1994) found a similar concentrating effect with aggregating pheromones of western balsam bark beetle *Dryocoetes confusus*.

Placing pheromone traps in Douglas-fir stands for population monitoring over several years may give misleading results. During the first few years of trapping it may appear that the beetle populations are increasing or have stabilized at a high level. Due to the continual pheromone emission from the traps combined with the natural tree and beetle pheromones many beetles may be attracted to the trapping site, causing an overestimate of population levels in the stand. Once most of the susceptible green trees are attacked in that locality, the populations may disperse, resulting in fewer beetles in the pheromone traps. This may give the false notion that the population has declined.

Some researchers now suggest that the pheromone lures be placed at least 100 m from the nearest Douglas-fir tree. This may reduce the risk of establishing and intensifying infestations in surrounding stands. However, if the baits are placed in the same place year after year, the results may still vary as the beetle infestation centres move through the forest over time. This would make it extremely difficult to determine population trends.

Pheromone traps have great potential in managed forests for attempting to contain certain insect outbreaks and for determining if a particular insect is present or absent. However, the results obtained over successive years from monitoring DFB population trends with pheromone traps may be difficult to interpret. In National Parks designated as wilderness or preserves with natural ecological processes, monitoring beetle populations with pheromone traps may be inappropriate. Pheromone traps are likely to alter beetle populations and the forest stand structure by modifying the number of trees attacked and killed, the infestation centres, and the diameter of trees attacked.

Jasper Park will continue to monitor the Douglas-fir beetle infestations aerially, but will no longer use pheromones. No plans have been made to control the infestations. Instead, park personnel conduct and encourage non-intrusive monitoring of the dynamics of the Douglas-fir beetle infestations and their effects upon its montane forest ecosystem.

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Larch sawfly, *Pristiphora erichsonii* (Hymenoptera: Tenthredinidae) and its parasitoids from Alaska

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ABSTRACT

The larch sawfly and four parasitoids were reared in the laboratory from cocoons collected in Alaska for two consecutive years. Emergence of adult sawflies exceeded thirty percent each year. The number of parasitoids emerging was four times greater from the 1993 collection than from the subsequent year. Twelve *Tritneptis klugii* (Ratzeburg) emerged from one cocoon of the 1993 collection. The emergence of *Delomerista laevis* (Gravehorst) from the same collection established a new host record. *Mesoleius tenthredinis* Morley was the most common parasitoid that emerged from cocoons collected in 1993, and the only one that emerged from cocoons collected in 1994.

Key words: Rearing, sawfly, Tachinidae, Ichneumonidae, Pteromalidae

INTRODUCTION

The larch sawfly, *Pristiphora erichsonii* (Hartig), is a Holartic destructive insect on *Larix* spp. (Drooz 1960). Insects feeding on the leaves of hosts stunt tree growth and may kill the tree.

Schmiege (1966) first reported the larch sawfly in Alaska. He collected specimens near Fairbanks in 1965 and found evidence that the sawfly had been in the area since at least 1960. He did not note the presence of its parasites. Our rearing of adult sawflies and parasitiods from cocoons provides the first information on emergence in the laboratory of both specimens from Alaska.

MATERIALS AND METHODS

Cocoons of the larch sawfly were collected from leaf litter 32 km east of Fairbanks, AK in September 1993 and 1994. Approximately 400 cocoons were shipped to Cary, NC in September each year in a ventilated box that contained damp sphagnum. Cocoons collected in 1993 were stored at 4°C until 1 April 1994 when 170 fungus-free cocoons were placed individually into plastic boxes that were incubated at 18±2°C. Cocoons collected in 1994 were stored at 4°C until 15 March 1995 when adult sawflies began to emerge. On 17 March 1995, 200 fungus-free cocoons were incubated. Moisture in the plastic boxes was maintained by wetting blotter paper beneath the boxes. This technique provides a suitable microenvironment, and precludes the escape of *Tritneptis klugii* (Ratzeburg) (Hymenoptera: Pteromalidae) and additional parasitization of cocoons during rearing (Drooz and Thompson 1986). It also aids in culling fungus-infected cocoons.

Data on the emergence of sawflies and parasitoids were recorded. Parasitiods were identified and voucher specimens deposited at the USDA Systematic Entomology Laboratory, Beltsville, MD.

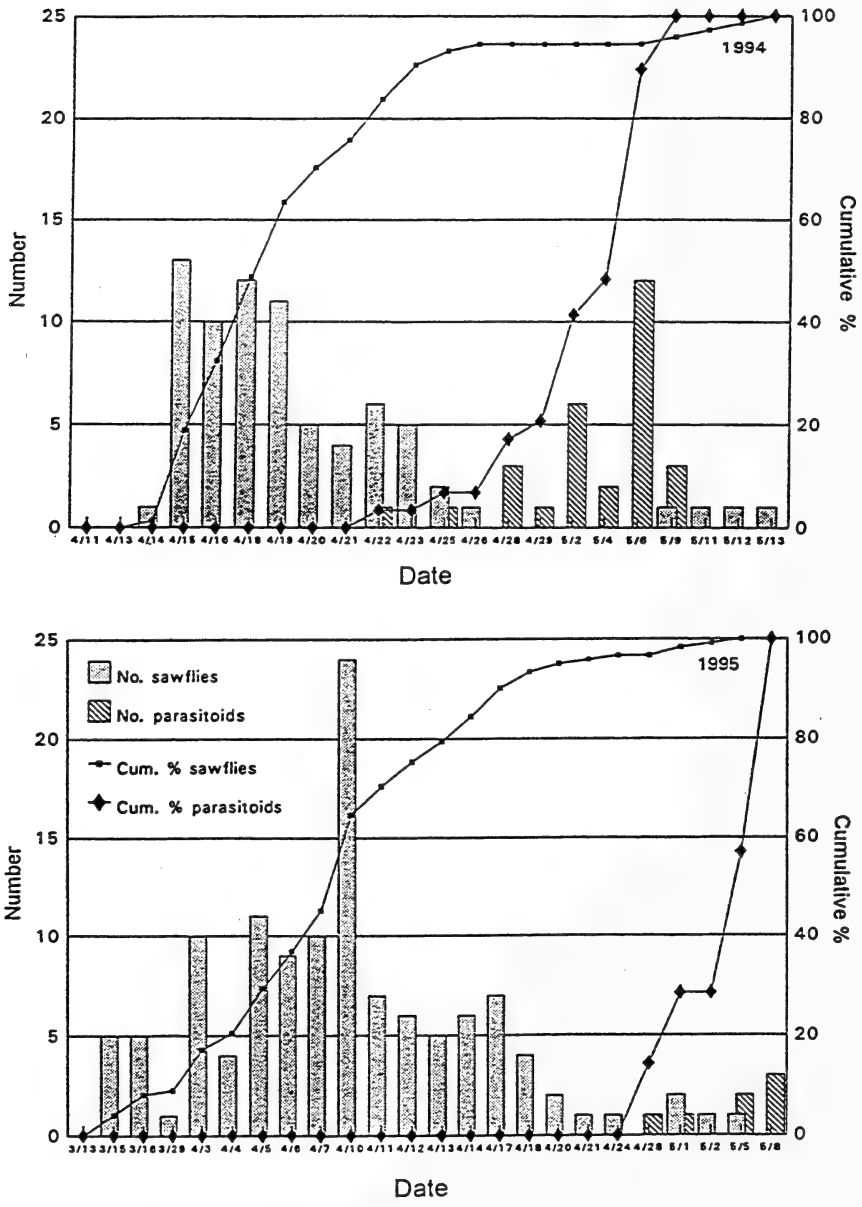

Figure 1. Number and cumulative percent of larch sawflies, *Pristiphora erichsonii* and parasitoids reared in 1994 and 1995 in the laboratory from cocoons collected in September 1993 and 1994 in Alaska.

RESULTS AND DISCUSSION

During laboratory rearing 74 adult sawflies and 30 adult parasitoids emerged from the 1993 collection, and 122 sawflies and 7 parasitiods emerged from the 1994 collection (Fig 1).

For the 1994 rearing, larch sawflies began emerging 14 days after incubation began and continued for about 1 month. Most sawflies emerged between the second and third week, at which time parasitoids also started to emerge. The start of parasitoid emergence is similar to that seen when rearing *Olesicampe benefactor* Hinz (Hymenoptera: Ichneumonidae), a common parasite of the larch sawfly (Drooz and Thompson 1986).

Of the 30 parasitoids that emerged from the 1994 rearing, 2 were *Bessa harveyi* (Townsend) (Diptera: Tachinidae); 14 were *Mesoleius tenthredinis* Morley (Hymenoptera: Ichneumonidae); 2 were *Delomerista laevis* (Gravenhorst) (Hymenoptera: Ichneumonidae); and 12 were *T. klugii* that emerged from one cocoon on 6 May. Almost all *B. harveyi*, *T. klugii*, and *M. tenthredinis* emerged after the peak of host emergence. *D. laevis*, a new host record, emerged on 9 May, after most of the hosts.

For the 1995 rearing, 10 adult sawflies emerged at 4°C on March 15 and 16 before cocoons were incubated (Fig. 1). After 200 cocoons were incubated on March 17, an additional 112 sawflies and 7 parasitoids also emerged. All of the parasitioids were *M. tenthredinis*. Peak emergence of sawflies occurred between April 3 and 10, earlier than peak emergence for the 1994 rearing.

The larch sawfly in Alaska is host to parasites native to Alaska and to one previously found only in other areas of North America. *B. harveyi*, *D. laevis*, and *T. klugii* are native parasites that attack across families of sawflies. In contrast, *M. tenthredinis*, a host specific parasitoid, was introduced into Canada from England in 1910 (Hewitt 1912). Subsequent releases were made in eastern and central Canada (Criddle 1928), and it was released in southeastern British Columbia in 1934 (Hopping *et al.* 1943). It was never released in Alaska, and we suggest it arrived there with the northwestern migration of its only known host, the larch sawfly.

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The impact of codling moth (Lepidoptera: Tortricidae) mating disruption on apple pest management in Yakima Valley, Washington

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ABSTRACT

From 1991 to 1993, pheromone-based mating disruption for control of codling moth, *Cydia pomonella* (L.)was evaluated in seven apple orchards. Each pheromone-treated orchard was paired with a similar orchard without pheromone. Populations of codling moth, secondary pests, and selected natural controls were monitored. The cost of using pheromone dropped nearly $100 per ha from 1991-1993 because of reductions in the price of dispensers and improved application. Growers saved $87-147 in insecticides per ha in pheromone-treated orchards, because of an 83% reduction in sprays for codling moth, but savings from reduced labor and machinery costs in treated orchards were minimal. Damage from codling moth was high in one treated orchard in 1991 (7.4%), and increased to 20.8% in 1992. The population density of codling moth was low in the other orchards (fruit injury < 0.4%) in all three years. Insecticide applications after petal-fall for secondary pests were reduced by 18% in treated orchards. Populations of secondary pests were similar between orchard pairs. Among natural controls only parasitism of leafminers differed significantly between treated and untreated orchards. In 1991, leafrollers caused > 3% fruit injury in three of seven treated orchards, but were not a problem thereafter. Substituting mating disruption for insecticides to manage codling moth in apple orchards may therefore be successful, but for the first three years, may not substantially improve biological control of secondary pests.

Key words: *Cydia pomonella*, apple, mating disruption

INTRODUCTION

Apples are identified by the public in the United States as a wholesome food (Washington State Apple Commission 1993), yet they are one of the crops most heavily sprayed with pesticides (Pimental *et al.* 1992). Increased public awareness and changes in social attitudes towards exposure to pesticides (Ott *et al.* 1991) are forcing a reconsideration of existing pest management programs in tree fruits (Prokopy & Croft 1994). In the western U.S., codling moth, *Cydia pomonella* (L.) is the key pest of apples. Conventionally-managed orchards rely on a series of 'cover sprays' during the season (Washington State University Cooperative Extension Service 1992). Organophosphate insecticides have been used almost exclusively for codling moth during the last 35 years, but resistance has recently been documented (Varela *et al.* 1993, Knight *et al.* 1994a).

Much of the effort to transform apple pest management in the western United States from broadspectrum pesticides to more biointensive methods has focused on using sex pheromones to disrupt mating of codling moth. Since the registration of a multicomponent polyethylene tube pheromone dispenser in 1991, successful field trials have been reported by Barnes *et al.* (1992) and Pfeiffer *et al.* (1993). Researchers continue to evaluate mating disruption of codling moth and to optimize its efficacy and

cost (Knight 1992). Yet the effect of adopting this technology on the complex of secondary pests and natural enemies in apple orchards is unclear. A three year study was conducted from 1991 to 1993 to evaluate the use of polyethylene tube dispensers in commercial apple orchards in the Yakima Valley. The objectives of this study were to evaluate the effect of mating disruption on: 1) the control of codling moth; 2) growers' spray schedules and cost of pest management; and 3) the population densities of some other pests and their natural enemies compared with similar orchards not treated with pheromone.

MATERIALS AND METHODS

Study Sites. Seven apple growers near Yakima treated a portion of their orchards in 1991 with 1,000 translucent polyethylene tube dispensers (Isomate-C^R, Pacific Biocontrol, Davis, CA) per ha for codling moth. The dispensers were loaded with an average of 171 mg active ingredient of (E,E)-8,10-dodecadien-1-ol, 1-dodecanol, and 1-tetradecanol (63:31:6 blend); plus 13% inert ingredients (UV inhibitors and antioxidants). Each year, a single application of dispensers was applied in orchards before the moths emerged (third week of April to early May).

Each grower's pheromone-treated orchard was paired with another without pheromone (designated as untreated). Paired orchards were matched for similar area, cultivar, tree size, and planting density and represented typical horticultural practices, including the use of insecticides, for this region (Table 1). Borders of paired orchards were usually separated by 100 to 200 m. Pest management advice was provided by farm managers and fieldmen from a local chemical supply company.

Table 1

Apple orchards treated with pheromone dispensers for codling moth from 1991 to 1993. Each was paired with a similar untreated orchard

Orchard	Area treated (ha) 1991-1993[a]	Cultivars	Trees / ha	Mean tree height (m)
Y1	7.3-2.0	Rome & Granny Smith	598	3.5
Y2	7.0-7.0	Red Delicious & Golden Delicious	633	4.1
Y3	2.5-2.5	" " " "	527	3.6
Y4	6.5-6.5	" " " "	269	4.4
Y5	4.0-2.0	" " " "	664	3.8
Y6[b]	8.0	" " " "	332	2.9
Y7[c]	7.3	" " " "	427	3.9

[a] Area treated with pheromone in 1991 and 1993.
[b] Orchard Y6 was in the study from 1991-1992.
[c] Orchard Y7 was in the study only in 1991.

Evaluation of Costs. Costs associated with the pheromone dispensers were assessed by interviewing growers. Besides the growers in this study, 10 others using mating disruption were interviewed. The costs included the dispensers and labor ($6 per hr). Costs of insecticides were obtained from a local chemical supply company. Sprays applied only to orchard borders were counted as 0.2 and alternate-row middle sprays (every other row was sprayed) were treated as 0.5 of a full application.

Sampling Pests and Natural Enemies. Population densities of various pest and beneficial insects were monitored in each orchard. These included: adult codling moth; a

complex of green aphids, viz. *Aphis pomi* DeGeer, *Rhopalosiphum fitchii* (Sanderson), and *Aphis spiraecola* Patch; white apple leafhopper, *Typhlocyba pomaria* McAtee and its mymarid parasitoid, the *Anagrus* wasp; western tentiform leafminer, *Phyllonorycter mespilella* (Hübner), and associated parasitoids; and larval populations of the leafroller moth, *Pandemis pyrusana* Kearfott. Sampling dates were chosen to coincide with periods of peak population densities of each pest. Fruit injured by codling moth and *P. pyrusana* was sampled at mid-season and just before harvest.

Sampling protocols varied between years. All orchards were divided into four sections in 1991 and five sections (four edges and the middle of the orchard) in 1992-93. Edges were designated as the outer 20 m of the orchard. Trees, shoots, and leaves were sampled randomly along transects within each section.

Green Aphids. Green aphids were sampled by counting the number of aphids on the most infested leaf per shoot (Hull & Grimm 1983). In 1991 they were counted on five shoots from 10 trees within each section from 14-22 August. During the next two years, they were sampled by counting the number of aphids on the most infested leaf per shoot from five shoots on 12 trees per section. Sample dates were 28-29 July, 1992 and 1-3 July, 1993, respectively. Five density classes were established: **1** = 0 aphids; **2** = 1-25; **3** = 26-100; **4** = 101-250; and **5** = > 250 aphids. The total number of generalist predators per shoot was also recorded.

Leafhoppers. Adult white apple leafhopper and *Anagrus* sp. adults were sampled with sticky yellow cards (22.7 x 27.7 cm) (Trece Inc., Salinas, CA). The traps were placed at 2.0 m height in the tree canopy and were retrieved after 6-10 d. Five traps were placed in each section from 1-8 July, 1991. Five traps were again placed in each orchard during both adult flights 3-5 June and 4 September, 1992 and 17 June and 25-27 August, 1993. Results were recorded as the mean number of adult leafhoppers and parasites caught per day per trap.

Leafminers. The density of immature leafminers was sampled in each orchard in 1991 on 15-19 July and 14-21 August by counting the number of mines on the third leaf down the shoot from the leaf visually selected. In each section, five leaves were sampled per tree from 10 trees. Levels of parasitism were assessed for each generation by dissecting 20 mines per section. Parasitism of first generation mines was assessed on 11-12 June. In 1992, leafminers were sampled on 2-7 July and 23-29 September, by counting the number of recent mines per leaf on 10 leaves per tree on 20 trees. Levels of parasitism were assessed on 21-29 May, 8-9 July and 3 September by dissecting 100 mines per orchard. The number of first generation mines in 1993 was too low to assess percent parasitism. The protocol from 1992 was used to assess leafminer density and parasitism on 3-4 August and 25-26 August, 1993. In all three years, host feeding was included as a part of total parasitism (Barrett & Brunner 1990).

Leafrollers. Larval populations densities were estimated by counting the number of rolled leaves per 1 minute of searching 20 trees per section from 12-14 June and 28-30 July, 1991. Sampling during 1992 and 1993 consisted of examining 40 terminal shoot tips (20 from the top and 20 from the bottom of the canopy) from 20 trees on 12-15 May and 9-14 July, 1992 and 20 May, 1993, respectively.

Codling Moth. Two pheromone-baited traps (Scentry Inc., Buckeye, AZ) were placed in each section (separated by > 50 m) to monitor adult codling moth in 1991. One was baited with a red rubber septum loaded with 1 mg and the other with a septum loaded with 10 mg codlemone (Trece Inc., Salinas, CA). The septa were replaced every 4 weeks and type of septum was alternated between traps in each section. Traps at a density of one per 1.0-2.0 ha were placed in each orchard during 1992 and 1993. All traps in

pheromone-treated orchards were baited with septa loaded with 10 mg of codlemone; traps in untreated orchards had 1 mg septa. Septa were replaced every 3 weeks. Trap liners were replaced as needed.

Fruit Injury. Percent fruit injured by codling moth in 1991 was assessed on 2-3 July and for both *P. pyrusana* and codling moth prior to harvest (3-10 d) of each major cultivar ('Golden Delicious' from 10-20 September and 'Red Delicious', 'Rome' and 'Granny Smith' from 2-9 October). Fruit injury was sampled in mid-season and at harvest along ten transects (examining 20 fruits from five consecutive trees) per section (or 4,000 fruits per orchard).

Mid-season fruit injury in 1992 was assessed on 19-30 June and injury prior to harvest from 3-17 September. Mid-season injury was sampled by visually inspecting from the ground 30 fruits high and 30 fruits low in the canopy of 100 trees (estimated to be equivalent to 6,000 half-fruits). Injury at harvest was measured by manually examining 15 fruits per height from 10 trees per section (1,500 fruits per orchard).

Injury was sampled in 1993 mid-season from 18-23 June and prior to harvest on 11 September for 'Golden Delicious' and 23 September for late cultivars. On all three sampling dates, 15 fruits were manually examined at both heights from 10 trees per section (1,500 fruits per orchard). Fruit injury was weighted by the percentage of each cultivar in the orchard.

Statistical Analysis. Aphid density classes in pheromone-treated and untreated orchards were compared on each date with Wilcoxon Signed Rank test (Hintze 1987). Means from all other counts were compared between treatments on each date using a paired t-test.

RESULTS

Cost of Using Pheromone. Costs varied among the seventeen growers interviewed depending on the way the dispenser was attached to the tree. The lowest cost (mean $\pm$ SE) was for dispensers applied by hand from the ground (n=5, \$27 $\pm$ 7 / ha). However, in 1991 most growers (n=9) used ladders to apply dispensers in the upper third of the canopy. This method was the most expensive (\$69 $\pm$ 10 / ha) and was disliked by many growers because of the risk to workers. Workers of other growers applied dispensers from trailers pulled through the orchard by a tractor (n=3, \$35 $\pm$ 5 / ha). With each method, costs were highest in orchards where growers trained their workers carefully and monitored their work. Beginning in 1992, many growers tied the dispensers onto plastic clips (Series W, No. 6, Kwik Lock Corp., Yakima, WA) and used a telescoping pole to attach dispensers at the recommended height in the canopy. The average cost of this method (\$38 $\pm$ 4 / ha) was similar to the use of trailers, but allowed growers greater flexibility in placing dispensers. The cost of the dispensers declined during this study from \$326 / ha in 1991 to \$272 / ha in 1993.

Insecticide Usage. The number of sprays applied for codling moth in orchards treated with pheromone during this three-year study was 83% lower than in the untreated orchards (Table 2). The use of insecticides for codling moth in the pheromone-treated orchards was highest in 1992 as more growers either sprayed borders or supplemented their use of pheromone. In 1993, three growers applied a single insecticide spray to the border of their pheromone-treated orchards.

Table 2

Spray records and cost of insecticides in paired orchards treated with and without codling moth sex pheromone, 1991-1993, Yakima Valley, WA

	Mean number of sprays applied per orchard					
	1991		1992		1993	
Pest	Pheromone	None	Pheromone	None	Pheromone	None
Codling moth	0.5	3.0	0.9	2.8	0.1	3.8
Leafrollers[a]	0.9 (0.4)	1.1 (0)	0.4 (0.3)	0.8 (0)	0.6 (1.0)	0.6 (0.7)
Leafminers	0.0	0.1	1.0	1.3	0.0	0.0
Aphids and leafhoppers	1.5	2.4	2.2	2.5	2.6	2.6
Mites	0.1	0.1	0.2	0.3	0.2	0.2
General	1.0	1.0	1.0	1.0	1.0	1.0
Mean cost ($)[b]	194.64	282.30	243.54	345.06	202.79	349.75

Materials used (/ ha) included: Guthion 50W (1.7-2.2 kg) and Imidan 50W (5.6-6.6 kg) for codling moth; Lorsban 50W (3.4 kg) and Penncap-M 2F (7.0-9.3 liter)for leafrollers; Vydate 2L (0.6-2.3 liter) for leafminer; Phosphamidon 8E (0.6-0.9 liter), Sevin XLR (1.2-1.8 liter) Thiodan 50WP (2.2-4.4 kg), Meta-Systox R 2E (3.5 liter), Phosdrin 4E (0.6 liter), Pyrellin (2.3 liter), Lannate 1.8L (0.6 liter), and Methoxychlor 50W (4.7 liter) for aphids and leafhoppers; Omite 30W (6.7-8.4 kg) for mites; and Lorsban 4E (4.7 liter) for general pests. Sprays applied to borders counted as 0.2; sprays applied to alternate row middles counted as 0.5.

[a] Mean number of sprays of Dipel 2X (1.1 kg) / ha for leafrollers in parentheses.

[b] Mean cost is the total retail cost of all insecticides used during the season.

Insecticides were applied for other pests in orchards both with and without pheromone (Table 2). Nearly all orchards in 1991 were sprayed during the summer for leafrollers. During the second year, growers switched from chlorpyrifos to encapsulated methyl-parathion to control leafrollers and fewer orchards were treated (Table 2). Following widespread bee poisoning from summer use of insecticides for leafrollers in 1992 (M. Willett, personal communication) the use of products containing *Bacillus thuringiensis* Berliner increased in 1993. All orchards were treated with 1 or 2 applications of insecticide for leafminer in 1992. Insecticides were widely used to control green aphids and leafhoppers during all three years of this study. Only 2 or 3 orchards were sprayed for mites each year (Table 2).

The mean cost of insecticide materials per ha was higher in the untreated than in the pheromone-treated orchards each year, i.e. $87 more in 1991, $101 in 1992, and $147 in 1993 (Table 2). However, there were minimal savings from reduced operating costs in pheromone-treated versus untreated orchards because of the application of materials other than insecticides during the season (growers commonly mixed several insecticides, mineral supplements, herbicides, or fungicides together). No change was observed in the rates of chemicals used between orchard-pairs.

Aphids. The population density of green aphids varied from year to year and no significant difference was found between orchards with and without pheromone on the selected dates (Table 3). Few generalist predators were found in samples during 1991 and 1992 (< 1.0% of shoots had $\geq$ 1 predator), and no difference in their population density was found between orchard pairs (Table 4). However, in 1993, 4.3% of the shoots

in the pheromone-treated orchards had ≥ 1 predator compared with 0.7% in the untreated orchards ($p = 0.10$). The most abundant predators were immature chrysopids, immature and adult coccinelids, immature syrphids, and adult hemipterans.

Table 3

Mean (± SE) population densities of some secondary pests in pheromone-treated and untreated apple orchards

		1991		1992		1993	
Pest sample	Generation	Pheromone	None	Pheromone	None	Pheromone	None
Mean density class: green aphids / most infested shoot[a]	-	1.22(0.07)	1.23(0.06)	2.45(0.38)	2.50(0.28)	1.93(0.34)	1.76(0.29)
No. leafhopper adults	1st	38.7(11.8)	31.8(7.0)	47.6(7.9)	88.0(30.1)	46.7(18.3)	64.5(40.9)
per sticky trap	2nd	-	-	86.8(33.4)	121.8(42.5)	14.2(17.7)	6.5(8.7)
No. leafminer larvae	2nd	0.19(0.06)	0.19(0.05)	5.44(1.64)	4.74(1.33)	0.22(0.10)	0.21(0.08)
per leaf	3rd	0.48(0.19)	0.33(0.11)	3.23(1.38)	2.50(0.80)	0.57(0.30)	0.96(0.49)
No. leafroller larvae	1st	0.02(0.00)	0.06(0.4)	0.00	0.00	0.00	0.00
per shoot sample	2nd	0.11(0.04)	0.07(0.02)	0.00	0.00	0.00	0.00
% leafroller injury	-	3.00(1.63)	0.8(0.35)	0.14(0.06)	0.09(0.05)	0.08(0.08)	0.04(0.04)

Differences in aphid density ranks ($p > 0.05$, Wilcoxon Signed Ranks test) and other samples ($p > 0.05$, paired t-tests) not significant in any year between orchard types.

[a] Aphid density classes: 0 aphids = 1; 1-25 = 2; 26-100 = 3; 100-250 = 4; and > 250 aphids = 5.

Table 4.

Mean (± SE) population densities of some natural enemies in pheromone-treated and untreated apple orchards

		1991		1992		1993	
Natural enemy sample	Generation	Pheromone	None	Pheromone	None	Pheromone	None
% shoots with aphid predators	-	0.71(0.62)	0.85(0.42)	1.73(0.61)	2.21(0.70)	4.34(1.83)	0.67(0.40)
No. adult *Anagrus*	1st	0.07(0.01)	0.10(0.07)	0.65(0.49)	0.34(0.28)	0.46(0.19)	0.44(0.24)
/ sticky trap	2nd	-	-	0.000.00	1.26(1.04)	0.26(0.21)	
% parasitism of	1st	30.9(3.9)a	17.6(3.9)b	6.2(2.9)	2.8(0.8)	-	-
leafminer larvae	2nd	27.1(10.3)	21.2(9.0)	5.8(3.2)	0.7(0.5)	19.5(6.8)	11.2(3.7)
	3rd	42.9(9.3)	33.8(10.1)	15.0(8.4)	13.8(5.8)	27.5(8.8)a	12.2(5.5)b

Means within year for each generation followed by different letters are significantly different, $p < 0.05$, paired t-test.

Leafhoppers. Population densities of white apple leafhoppers were not significantly different between pheromone-treated and untreated orchards (Table 3). However, there was weak evidence ($p = 0.09$) of a reduced population density of second generation adults in 1992 in the pheromone-treated orchards. In general, there were fewer leafhoppers in pheromone-treated than untreated orchards during 1992 and 1993 (Table 3).

Few *Anagrus* sp. were caught on sticky traps and numbers varied among orchards (Table 4). On two dates (first generation in 1992 and second generation in 1993) the density of this parasitoid was 1.8-4.1 times higher in the pheromone-treated than in untreated orchards, but these differences were not significant (Table 4). The ratio of adult parasites to leafhopper adults on traps on these two dates was also higher (4.2-6.7 times) in the treated than in the untreated orchards, but these differences were not significant ($0.20 < p < 0.30$). During the second generation in 1992, no adult parasites were found on sticky traps (Table 4).

Leafminers. The mean number of mines per leaf was low in all orchards in 1991 and their density only exceeded 1 mine per leaf in two pheromone-treated orchards during the third generation (Table 4). In contrast, populations were high (> 3 mines per leaf during second generation) in all but one pair of orchards 1992, and orchards were sprayed at least once with insecticide (Table 2). Leafminer populations were low in all orchards during 1993.

Levels of parasitism of leafminers were higher in treated than untreated orchards, but the difference was only significant on two dates, first generation in 1991 and the third generation in 1993 (Table 4). Levels of parasitism were low in all orchards during 1992.

Table 5

Catches of codling moths and fruit injury at harvest in-pheromone-treated and untreated orchards

		Mean moths / trap / season			% fruit injury		
Orchard	Treatment[a]	1991	1992	1993	1991	1992	1993
Y1	pheromone	1.0	4.0	0.0	0.00	0.16	0.00
	none	16.0	6.5	0.0	0.25	0.08	0.10
Y2	pheromone	0.0	0.0	0.0	0.10	0.00	0.00
	none	0.0	1.0	0.0	0.15	0.00	0.00
Y3	pheromone	3.0	5.5	0.0	0.25	0.17	0.05
	none	20.3	76.0	17.5	0.20	0.00	0.00
Y4	pheromone	1.0	0.5	0.0	0.0	0.00	0.00
	none	1.0	2.0	0.0	0.0	0.00	0.00
Y5	pheromone	0.3	1.0	1.0	0.40	0.00	0.33
	none	1.8	6.0	7.5	0.15	0.00	0.00
Y6	pheromone	0.9	68.5	-	7.43	20.82	-
	none	14.5	150.0	-	0.42	0.17	-
Y7	pheromone	0.3	-	-	0.00	-	-
	none	5.0	-	-	0.00	-	-

[a] Traps in pheromone-treated and untreated orchards were baited with 10 mg and 1 mg lures, respectively.

Leafrollers. Leafroller larvae were found overwintering in nearly all orchards in 1991 after the application of the delayed-dormant insecticide (Table 3). Fruit injury at harvest was greater than 3% in three orchards. No larvae were found in shoot terminal samples in 1992 and 1993, and fruit injury at harvest was low and restricted to two orchards during these two years (Table 3).

Codling Moth. Traps baited with 10 mg codlemone in 1991 caught 2.1 times more moths than those baited with 1 mg in treated orchards. In contrast, traps baited with 1 mg in the untreated orchards caught 1.4 times more moths than traps baited with the 10 mg lure. Cumulative trap counts were low in all orchards in 1991, but increased in the untreated Y3 and both Y6 orchards in the second year (Table 5). Catches were low in all orchards in 1993.

Levels of codling moth injury to fruit after the first generation in 1991 were low (<0.1%) in all orchards except in the pheromone-treated Y6 orchard. At harvest, injury in Y6 increased to 7.4% (Table 5). Cumulative moth catches per trap did not reflect this high level of injury (Table 5). Levels of injury were ≤0.4% at harvest in all other

pheromone-treated and untreated orchards. Injury increased nearly three-fold in the pheromone-treated Y6 orchard in 1992. Damage in this orchard, as in 1991, was primarily restricted to one edge of the orchard reaching about 65%. In 1992 and 1993, injury was low in all other orchards, <0.35% at harvest (Table 5).

DISCUSSION

Use of pheromones to disrupt mating of codling moth was effective in six of the seven apple orchards monitored from 1991 to 1993. In these orchards, the densities of codling moth remained low and use of insecticides for this pest was significantly reduced. The poor control of codling moth in orchard Y6 can be explained. This orchard had a previous history of codling moth injury and the density of the overwintering population in 1991 was unknown. In 1991, the pheromone was applied at a half rate (500 dispensers per ha) along the northeastern edge of the orchard by mistake. A number of physical characteristics found in this area of the orchard also reduced the effectiveness of mating disruption: a large number of missing trees (no pheromone was applied in areas with missing trees), an uneven canopy with tree heights ranging from 2.5 - 5.0 m, and a 6% slope.

The adoption of mating disruption of codling moth by growers is currently limited by its high material cost relative to the use of insecticides (Williamson *et al.* 1994). Further adoption will be enhanced by factors that can lower the cost of application, the cost of the dispensers, and/or the cost of supplementary insecticides applied for codling moth and other secondary pests. Dispenser application costs are likely to be high for any tie-on technique, and the need for applying dispensers in the upper canopy (Weissling & Knight, in press) will add to this cost. However, use of the telescoping pole and plastic clip has lowered the cost of application and improved placement. Nevertheless, alternative methods for using pheromones in tree fruits should be investigated. Broadcast application of dispensers has been tested previously for codling moth (Moffitt & Westigard 1984), and is used commercially for pink bollworm, *Pectinophora gossypiella* (Saunders) where labor costs are high (Brooks *et al.* 1979). Expectations of growers (Alway 1991) and researchers (Barnes *et al.* 1992) that the adoption of mating disruption for codling moth will reduce insecticide use for other pests and enhance the role of biological control in tree fruits, were not met in this study. Less use of insecticides for secondary pests would add to the benefits of adopting mating disruption. For example, elimination of a single spray in a 'Delicious' orchard would save on average $71 per ha (Hinman *et al.* 1992). Results from this study, however, showed that growers in the Yakima Valley continued to spray for secondary pests in pheromone-treated orchards, especially for aphids and leafrollers. Moreover, the potential saving from fewer spray applications for codling moth was reduced by the continued need to apply other farm chemicals on the same dates.

Conversely, the balance between pests and natural enemies expected in apple orchards not sprayed with insecticides for codling moth was not found in this study. The outbreak of leafminers in all orchards in 1992 demonstrated the cyclic failure of biological control for this pest and forced the growers to spray an insecticide disrupting the natural enemies of leafminers and leafhoppers (Table 4). Severe injury to fruit by leafrollers in 1991 caused growers to treat orchards with summer applications of organophosphates in subsequent years, even when pest populations were low. It is unlikely that natural enemies can control pest populations in orchards sprayed with broadspectrum insecticides nor can they respond quickly to pest outbreaks in small, isolated pheromone-treated

orchards surrounded by sprayed orchards. Sustained biological control in tree fruit pest management evidently depends on the registration of non-disruptive tools for these sporadic and secondary pests.

The level of biological control possible in apple orchards in the Yakima Valley can probably be seen best in certified organic orchards. Organic orchards cannot be treated with organophosphate, carbamate, pyrethroid, or other synthetic insecticides (Washington State Department of Agriculture 1992). During 1990, pest and natural enemy populations were surveyed in five paired organic and conventional orchards (Knight 1994). Organic orchards had significantly lower populations of aphids and leafminers than conventional orchards, and significantly higher populations of natural enemies of green aphids, leafminers, and leafhoppers. In 1990, leafrollers were not a problem in any of these orchards. However, fruit injury from codling moth was much higher at harvest in organic (0.3-32.0%) than in conventional orchards (0.1-0.9%). Mating disruption was not available in 1990 and organic growers used a seasonal average of 14 botanical and microbial insecticide sprays for codling moth (Knight 1994).

Empirical analysis of these data from 1990-1993 from organic and conventional apple orchards indicates that a combination of these programs could be adopted to reduce the use of broad-spectrum insecticides and enhance the role of biological control. Mating disruption could be used to manage codling moth, and other pests could be managed either early in the season or growers could use biological control and a limited number of selective insecticides. Development, demonstration, and validation of this approach are needed in representative orchards in the Yakima Valley, as well as in each of the other major fruit producing regions in the western United States.

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A sequential sampling system for the white pine weevil, *Pissodes strobi* (Coleoptera:Curculionidae)

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ABSTRACT

A sequential sampling system is described for determining degree of infestation by the white pine weevil, *Pissodes strobi*, in stands of spruce, *Picea* spp. The method requires that a maximum of 60 trees be randomly selected in sequence and that the cumulative number of infested trees be plotted against the total number of trees sampled. Sampling is stopped as soon as decision lines calculated for < 10% infestation or ≥20% infestation are crossed.

Key words: spruce, *Picea* spp., monitoring, pest management

INTRODUCTION

The white pine weevil, *Pissodes strobi* Peck, is a serious pest of reforestation and natural regeneration, causing severe damage to Sitka spruce, *Picea sitchensis* (Bong) Carr., Engelmann spruce, *Picea engelmannii* Parry, white spruce, *Picea glauca* (Moench) Voss, and their hybrids, in British Columbia. This weevil is widely distributed in North America, being found in most provinces of Canada and in many states of the Union. The hosts attacked in eastern North America include eastern White pine, *Pinus strobus* L., Jack pine, *Pinus banksiana* Lamb., and Norway spruce, *Picea abies* (L.) Karst.

P. strobi adults overwinter in the duff (Silver 1968), usually near the tree from which they emerged in the previous fall. Early in the spring (late March, April), adults fly or crawl to the terminal leader of host trees and commence feeding and mating. Oviposition begins soon after. Eggs are laid near the tip of the leader, just under the apical bud, in feeding punctures which are then covered with a fecal plug. After hatching, the larvae orient downwards and begin consuming the phloem. As their galleries merge, the larvae form the characteristic "feeding ring", in which larvae move downwards in synchrony, consuming all phloem around the circumference of the leader. This causes the girdling and destruction of the leader. Pupation takes place in chambers excavated in the xylem and covered with wood fibers. New adults emerge from late July to September. After emergence, these fall adults feed for a while, disperse, and when temperatures drop and photoperiod shortens, they go into hibernation in the duff.

Effective pest management programs for the white pine weevil (Alfaro *et al.* 1995) require regular monitoring in order to determine if existing insect populations and damage levels are at or near levels requiring treatment. Post-treatment assessments are also required to determine the efficiency of control measures.

The theory of sequential sampling was developed during World War II for use in quality control and in the 1950's it began to be applied to forest pest control decisions (Waters 1955). Regular sampling methods usually require a fixed number of samples that

will estimate a level of infestation to a desired level of precision. However, for the same precision, the specified number of samples will invariably be inadequate at low and excessive at high pest densities. Sequential sampling is a system designed to simply choose between two alternatives: is the density of the pest or the level of damage higher or lower than a given critical level? Sampling continues only until results indicate that one alternative is more likely than the other at some constant, acceptable level of probability. When infestations are very high or very low, the most likely alternative becomes apparent very quickly. Hence savings of up to 50% in time and cost of sampling can be achieved (Onsager 1976).

The objective of this paper was to report a sequential sampling system developed for the rapid assessment of white pine weevil infestations.

MATERIALS AND METHODS

The sampling system reported here was developed following the formulae indicated by Waters (1955). Infestations by the white pine weevil will be classified as light if the proportion of trees with current weevil damage is less than 10% (H_1) and severe if 20% (H_2) or more of the trees are attacked. Damage levels between 10 and 19% are termed moderate. These thresholds were based on practical considerations: estimates of merchantable volume at rotation, assuming infestations lasting 20 years, at the above thresholds, indicate losses of 13 and 21%, respectively (Alfaro 1994). Infestations below 5% of the trees/year are thought to represent endemic levels. The sampling plan developed here calls for examining sufficient trees until cumulative results indicate that either hypothesis H_1 or H_2 is more likely to be correct at some pre-established degree of reliability.

As in regular sampling, the specified degree of reliability will determine, to a large extent, the feasibility of the survey in terms of logistics and costs. For the sampling method reported here, both probability of Type I error (probability of accepting H_2 when H_1 is true) as well as for Type II error (probability of accepting H_1 when H_2 is true), were set to 10% (i.e. $\alpha = \beta = 0.10$). We use the operations for the binomial distribution reported by Waters (1955) to find the slope and intercepts of the parallel decision lines.

Intercepts:

$$a_1 = \frac{\log\left(\frac{1-\alpha}{\beta}\right)}{\log\frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)} \qquad a_2 = \frac{\log\left(\frac{1-\beta}{\alpha}\right)}{\log\frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)}$$

Slope

$$b = \frac{\log\left(\frac{1-p_1}{1-p_2}\right)}{\log\frac{p_2}{p_1}\left(\frac{1-p_1}{1-p_2}\right)}$$

Where α and β are the established probabilities for Type I and II errors and p_1 and p_2 are the classification thresholds of 10 and 20% infestation.

RESULTS AND DISCUSSION

The following equations were calculated for the upper and lower decision lines (Fig. 1):

$$d_1 = 0.145n + 2.71 \qquad d_2 = 0.145n - 2.71$$

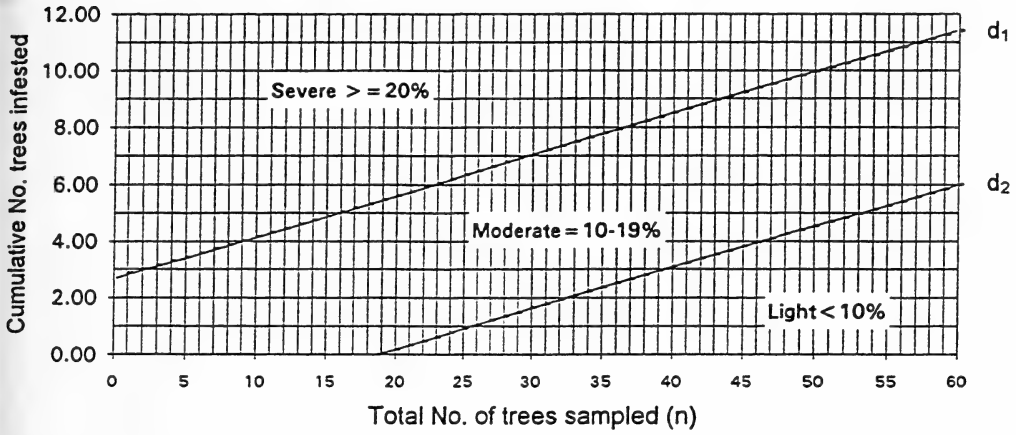

Figure 1. Parallel decision lines for a sequential sampling system for the white pine weevil, *Pissodes strobi*

Stands are classified as severely infested (>=20% of the trees attacked) if a plot of the cumulative number of attacked trees versus the total number of trees sampled crosses the upper line. Stands are classified as light (<10%) if the lower line is crossed. If after sampling 60 trees (see below) neither of the lines is intercepted, the stand is labeled as moderately infested (10-19% attack),

The reliability of this sampling system can be evaluated by examining the Operating Characteristic (O.C.) curve (Waters 1955) which indicates, for any infestation level, the probability of correctly classifying an infestation as light (Fig. 2). The probability of labeling a stand as light drops sharply when stands have higher than 10% infested trees.

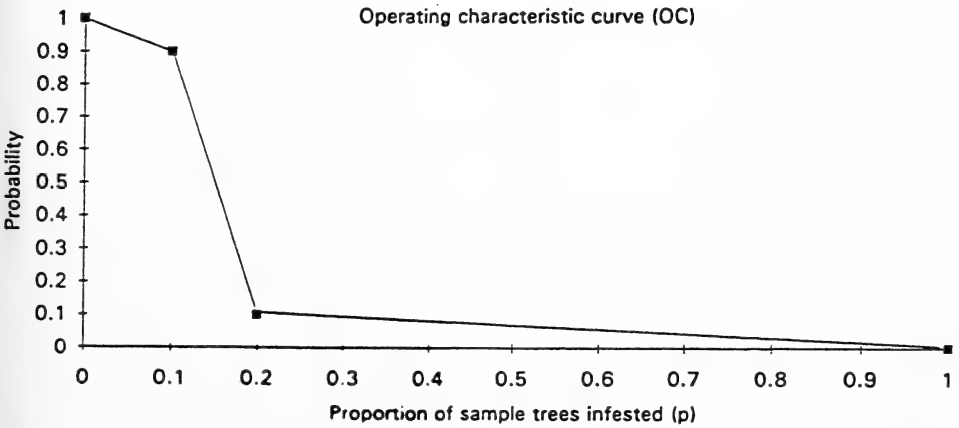

Figure 2. Probability (p) of classifying a stand as light for different degrees of infestation

The number of samples required to reach a decision can be evaluated by calculating the Average Sample Number (A.S.N.) curve (Waters 1955), which gives the number of samples that will, on the average, result in acceptance of either H_1 or H_2 for any level of infestation (Fig. 3). The A.S.N. allows us to realize the efficiency of this sequential sampling system. An uninfested stand will be identified after 19 sequential random samples without weevil attack (the X intercept in Fig. 1). A 100% infested stand (an unlikely situation) could be identified by finding only three infested trees in sequence (the Y intercept in Fig. 1). The largest number of samples (60) required to reach a decision occurs when the infested stand has between 10 and 19% infestation. If no decision has been reached after examination of 60 trees, the stand must be declared "Moderately infested".

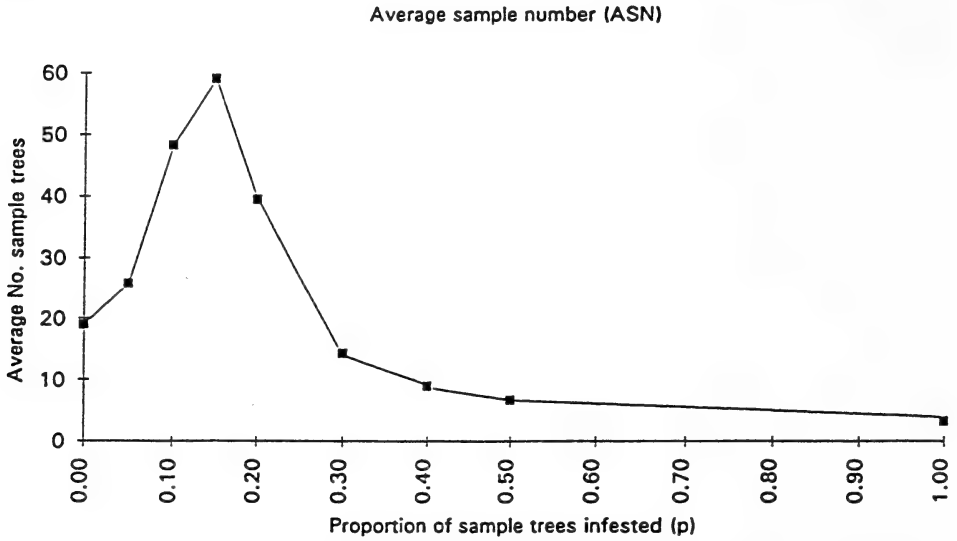

Figure 3. Average number of sample trees examined to reach a decision in stands with different degrees of infestation (p).

FIELD APPLICATION. One of the major drawbacks of sequential sampling in forestry is the requirement that trees are sampled at random and in the sequential order in which they were selected. This would result in an inefficient criss-crossing of the stand in order to maintain the sequence. I suggest that, in the office, the area of the stand be divided into a grid of X,Y coordinates (e.g. a 5m × 5m grid). Then, using a random number table or a packaged software program, select 60 random X,Y coordinates in the stand, keeping track of the sequential order of selection, i.e. 1 to 60. Divide the list into two groups: coordinate points numbered 1-30 and 31-60. Sample all trees in the first group as you move through the stand in the most efficient manner, i.e., without regard to the sequence, using a compass and measuring tape to locate the tree nearest to the selected X, Y coordinate. After sampling the first group, plot the cumulative number of attacked trees in Fig. 1, maintaining the order in which the coordinates were selected. If either of the decision lines have been crossed, stop sampling and record the stand as lightly or severely infested. If after 30 samples the cumulative attack line is still in the intermediate zone, sample the entire second 30-tree group, in the most efficient manner. At the end of this second pass through the stand, add to the cumulative plot drawn for the first group, keeping the sequential order of selection. This sequential plot will have either crossed one of the decision lines, or remained in the intermediate zone, causing the stand to be

classified as light, moderately or severely infested. It is anticipated that lightly or severely infested stands will be identified in the first pass. Moderately infested stands will require two passes, i.e. the sampling of the entire 60-tree sample. It is expected that this method will result in significant time saving when classifying stands for treatment.

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Range of gypsy moth in British Columbia: a study of climatic suitability

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ABSTRACT

The potential range of gypsy moth in British Columbia is predicted from climatic comparisons to its native range in Eurasia and by using temperature-dependent phenological models of the life stages. The cool and wet coastal areas, northern B.C., and high elevations are predicted to be unsuitable for gypsy moth. Southeastern Vancouver Island, parts of the lower mainland, and southern interior valleys appear to have suitable climates. However, the availability of preferred hosts may limit establishment in some of these areas. Habitats with Garry oak are of particular concern, since it is the most suitable native tree species and is already threatened by urban development.

Keywords: *Lymantria dispar*, Lymantriidae, discriminant function analysis, life stage, biogeoclimatic zones, development modelling

INTRODUCTION

The gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), a native of Eurasia, was introduced to North America in 1869 from France (Montgomery and Wallner 1988). Despite the inability of females of the European strain to fly, it has since expanded its range from the initial foothold in Massachusetts to the entire eastern forest region from southern Quebec and Ontario to Georgia, and to Wisconsin in the west. Individuals have been caught in western North America since the late 1970s, when pheromone traps were first developed and used. Moths have been trapped in Oregon, Washington, Utah, California, and British Columbia. An outbreak in Oregon in 1984, and local populations in Oregon, Washington and Utah, were all controlled with *Bacillus thuringiensis*. In B.C., all introductions so far have died out naturally or been controlled by spraying.

Its potential to become established in B.C. is a controversial but pressing question. The major mode of introduction is as egg masses, for example on recreational vehicles and trailers from infested areas in eastern North America. With increasing immigration and tourism from the east to B.C. and the abandonment of control efforts in Quebec and Ontario, introductions may continue at high levels in the future. The range of gypsy moth depends on adequate climate for the annual cycle of development and synchronization

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with hosts, and on the availability of suitable hosts. The gypsy moth is remarkably polyphagous, but its best development is on oaks and some poplars or aspen. The suitability of many of the woody plants of B.C. for gypsy moth has not been assessed. However, Garry oak, quaking aspen, and red alder are all favourable (Lechowicz and Mauffette 1986, Miller *et al.* 1991a). Larvae develop successfully on Douglas-fir, lodgepole pine and ponderosa pine in the laboratory, although development is slow, and larval survival is highly dependent on temperature and foliage age (Miller and Hanson 1989, Miller *et al.* 1991b). First instar larvae were unable to establish on Douglas-fir in another laboratory study (Jobin 1981).

The objective of this paper is to predict the potential range of gypsy moth in B.C., and identify areas of high susceptibility. We have used several approaches to accomplish this, but we have limited the analysis mostly to climatic factors. Hosts are considered only briefly.

The life cycle of the gypsy moth

The gypsy moth is univoltine, with an obligate winter diapause (Montgomery and Wallner 1988). The moths emerge in mid-summer (July in eastern North America and Europe). Females from Europe are flightless and emit a pheromone to attract males. Eggs are laid near the site of pupation which is usually on tree trunks or the undersides of branches, but also on rocks or man-made structures. All eggs are laid in a single mass covered with short hairs from the female's body. The embryos develop for about two weeks (depending on temperature), and the larvae overwinter within the eggs. In spring, around the time of budburst of the favoured oak hosts, the larvae hatch. Newly-hatched larvae climb upwards to locate food; if they are unsuccessful they will spin silk strands to be wind-blown (ballooning) to another tree. Early instar larvae feed during the day but the later instars feed at night, seeking sheltered spots to hide during the day. They may move between trees, especially if their original host tree is defoliated. Typically, larval development takes from six to eight weeks, with five instars in males, and six in females. Mature larvae seek protected spots for pupation, usually in crevices near the tree base, in the litter, or on rocks or structures, and emerge as adults about two weeks later.

Range of gypsy moth in Eurasia and eastern North America

The gypsy moth is native to most of Europe, northern Asia, Japan and China (Giese and Schneider 1979). In Europe, it occurs from the west coast to the Urals; extending north to a line from about central Sweden, east to Moscow, roughly corresponding to the northern limit of the range of oaks, its favoured hosts (Giese and Schneider 1979). In altitude it is found also as high as oaks will grow (Grijpma, 1989). The southern limit is in northern Africa and the islands of Corsica and Sardinia. Grijpma (1989) noted that gypsy moth is most abundant in the broadleaved forests of southern and southeastern Europe.

MATERIALS AND METHODS

We used several methods to predict the suitability of the regions of B.C. for establishment of gypsy moth, focusing on climatic parameters. First, we studied the climates in regions of Europe and Japan where the gypsy moth occurs, and those of neighbouring areas where it is absent, and compared them to the climates of British Columbia. We analysed the climatic limits in Eurasia with two-dimensional plots, and also used multivariate analyses. As well, we ran temperature-dependent models of gypsy moth development on climatic data from selected sites in B.C., to see whether gypsy moth can complete all its life stages in these climates.

Plotting of climatic limits

The gypsy moth ranges in Europe and Japan were extracted from the maps of Giese and Schneider (1979). Distribution records in Asia other than those of Japan were not considered to be reliable, so data for Asia were not included in the analysis. Climatic normals (30 year means) were obtained from Muller (1982) for stations in Europe, Japan, and North America, and from Environment Canada, Atmospheric Environment Service, for B.C. The normals for stations where gypsy moth occurs and those bordering on the range were plotted. Temperature and precipitation data for weather stations, in areas with and without gypsy moth, were plotted for comparison with B. C. weather stations.

Mapping of biogeoclimatic sub-zones

The biogeoclimatic classification system in British Columbia combines vegetation, soil, and climatic data to characterize forest and range ecosystems (Pojar *et al.* 1991). Climatic summaries (mean temperatures for warmest and coldest months, mean annual temperature, and mean annual precipitation) for biogeoclimatic sub-zones were matched with climatic limits for the gypsy moth as determined by Giese and Schneider (1979). Biogeoclimatic subzones with climatic characteristics where the gypsy moth might become established (precipitation >100 mm/year; mean Jan. temperature -18 to +12 °C; and mean July temperature +15 to +27 °C), and where the potential for outbreaks may exist (precipitation 250 - 1000 mm/year; mean Jan. temperature -18 to + 5 °C; mean July temperature +15 to + 23 °C), were plotted to outline potential climatic boundaries in B.C.

Discriminant functions

The above method can consider only two variables at a time, but climate is composed of many variables. We used discriminant functions to get a better idea of the multivariate influence of climate on the range of the gypsy moth. The discriminant function technique finds the best linear combination of variables for discriminating between two or more classifications, in this case the presence vs. absence of gypsy moth. The function can then be used to classify new observations, in this case sites in B.C. Variables used were Jan. and July mean monthly temperatures, average annual precipitation and temperature, July minus Jan. temperature (an index of continentality), and precipitation divided by July temperature (an index of dryness). The DISCRIM procedure of SAS was used (SAS Institute, 1985). The discriminant functions based on 139 European, Japanese and eastern North American stations in and around the current range of gypsy moth distribution were used to classify 55 sites in B.C. and the Pacific Northwest as to their climatic suitability for gypsy moth.

Life stage development modelling

The rate of growth of an insect depends on various factors, including food quality, population density, pathogen infection, and humidity (e.g. Lance *et al.* 1986, 1987), but temperature is the major determinant. As a minimum requirement for establishment, temperatures must be warm for long enough for the insect to complete all life stages from egg to adult. In B.C., climatic conditions vary considerably from the wet and cool coastal climate, to the hot and dry summers and cold winters of the interior. These temperature variations may define the potential range of the gypsy moth in B.C.

The timing of spring emergence is crucial because it is the starting point for the other stages. We predicted spring emergence using the biophysical model of Hunter (1993), which gave the most accurate prediction of hatch phenology in 3 out of 4 years of data from Quebec, out of three models tried (Hunter 1993). The program of Sheehan (1992) was used to simulate gypsy moth larval and pupal development.

We ran these models for Victoria, Vancouver, Castlegar, Williams Lake, Prince Rupert, Smithers, Prince George and Fort St. John. These sites had relatively complete

30-year weather records and are representative of east-west and north-south gradients in the province. The model was run for five years, chosen as follows: 1) The years with the lowest and highest average temperatures in the months Jan. to May were determined. Out of these, the years having the earliest and latest hatch were chosen based on the egg hatch model of Hunter (1993). 2) In addition, the years having the warmest and coldest average May temperatures were chosen, and 3) the year 1992, which was frequently among the warmest years, was chosen to give a standard across sites that was near to a best case for the gypsy moth. These years represented the best and worst years for gypsy moth development. Since the rate of development varies with host species, the model has several host plant options. We ran the model with all larvae feeding on red oak, a common Vancouver street tree. The rate of development on this host is slightly less rapid than on white oak, but more rapid than on most other hosts (Casagrande *et al.* 1987).

To validate the model, we compared predicted adult emergence times with available data on the timing of adult male moth catches in traps in the Vancouver area in 1991-1993, and in the east Fraser Valley in 1994. We used records of live moths found in detection traps by Agriculture Canada, with the assumption that moths would not survive for more than a few days once captured in a trap.

RESULTS

Plotting climatic limits

Plots of climate data showed that mean annual temperatures of 3 °C (Fig. 1) and Jan. temperatures of -15 °C (not shown) appear to limit the gypsy moth in the north. Only two stations with gypsy moth "present" had a mean July temperature below 15 °C (Brocken, Germany, and Botrange, Belgium; Fig. 2). The resolution of the maps of Giese and Schneider (1979) is not fine enough to determine whether or not these cold pockets (which are surrounded by warmer areas) actually have gypsy moth.

There are some areas where gypsy moth does not occur although it occurs at sites with similar climates (mean annual temperatures of 3 - 10 °C, Fig. 1; mean July temperatures of 15 - 18 °C, Figure 2). These sites are in the United Kingdom, Norway, Sweden and Finland, beyond the range of oaks, but within the ranges of aspen and alder which are potential hosts. The European distribution of gypsy moth closely matches the range limits of oaks. Most B.C. sites fall into this climatic range, in which the presence of oaks seems as important as climate. All of the sites in eastern North America with gypsy moth are within the same range of temperature and precipitation as the areas in Eurasia where gypsy moth occurs (Fig. 1 and 2). However, B.C. stations with low temperatures, and extremely high or low rainfall, are outside this range.

Few places receive as much precipitation as coastal B.C. (>1000 mm per year). Similar amounts occur on the Atlantic coast of Europe (Ireland and Norway), in some coastal areas of former Yugoslavia, and in Japan. The gypsy moth has not been recorded from Ireland or Norway. Outbreaks have occurred in Yugoslavia, but the resolution of Giese and Schneider's (1979) map is not high enough to determine whether these have occurred in the wet areas or in the dry Mediterranean climates of the coast. The gradient of precipitation is very steep in this area. Japan receives at least as much precipitation as coastal B.C. (Fig. 2), and the gypsy moth is present in the south of Japan, with outbreaks in the northwest and on Hokkaido. However, compared with coastal B.C. the climate in Japan is much warmer in the summer (Fig. 2), and oaks occur as important forest elements throughout the Japanese archipelago. Another difference is that this is the Asian strain of the gypsy moth, which has slightly different development rates and hosts.

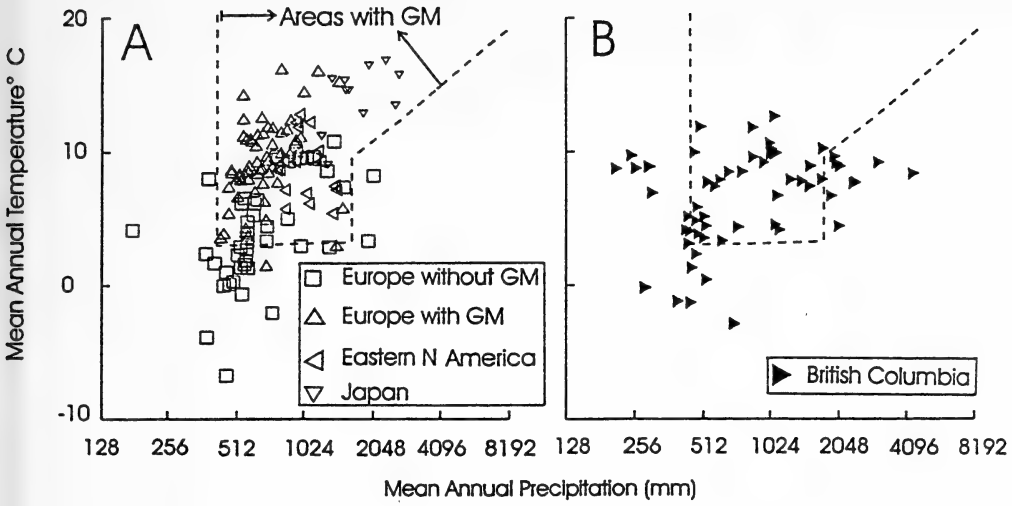

Figure 1. Annual mean temperature versus total precipitation for sites: A) with gypsy moth in Europe, Japan and North America, and without gypsy moth in Europe; and B) at 51 sites in British Columbia and 4 sites in the Pacific Northwest United States. The dashed line in A) encloses sites with gypsy moth in Europe, Japan, and North America (two cold outliers in Europe excepted, see text). The same lines have been superimposed on the data in B) for reference.

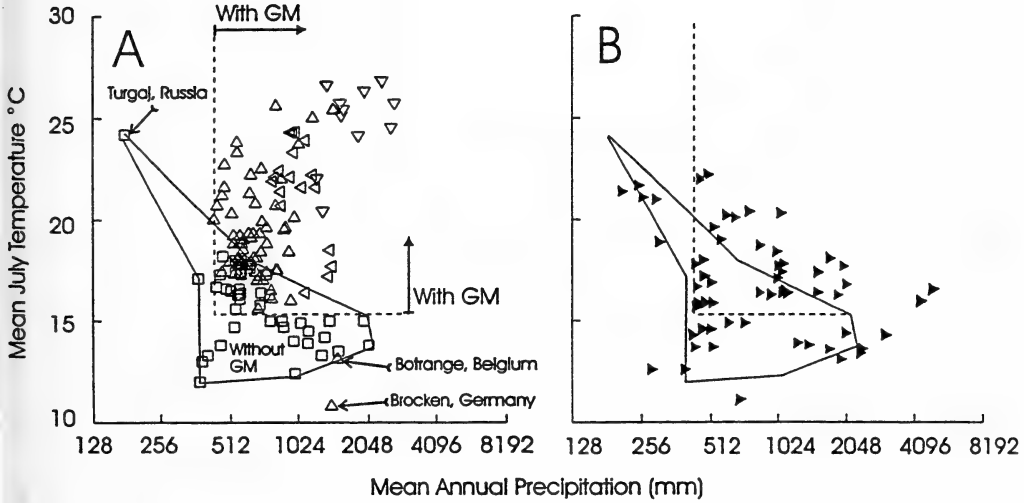

Figure 2. July mean temperature *vs* total precipitation for sites: A) with gypsy moth in Europe, Japan, and North America, and without gypsy moth in Europe; and B) at 51 sites in British Columbia and 4 sites in the Pacific Northwest United States. The solid line in A) encloses sites without gypsy moth in Europe. Areas with gypsy moth in Europe, Japan, and North America (two cold outliers in Europe excepted) are above and to the right of the dashed line. The same lines have been superimposed on the data in B) for reference.

Biogeoclimatic sub-zone

Figure 3 shows the results of mapping biogeoclimatic sub-zones with suitable climate based on Giese and Schneider's (1979) climatic limits for gypsy moth. This analysis shows that gypsy moth can establish in most of the southern part of British Columbia, with the exception of higher elevations and the wet coastal areas. Climatic conditions conducive to outbreaks exist in the Lower Mainland and the dry coastal areas immediately to the north of Vancouver, B.C. (the Sunshine Coast), the dry areas (east coast) of southern Vancouver Island, and the dry and warm valleys of the southern interior (Okanagan Valley and the Kootenay areas).

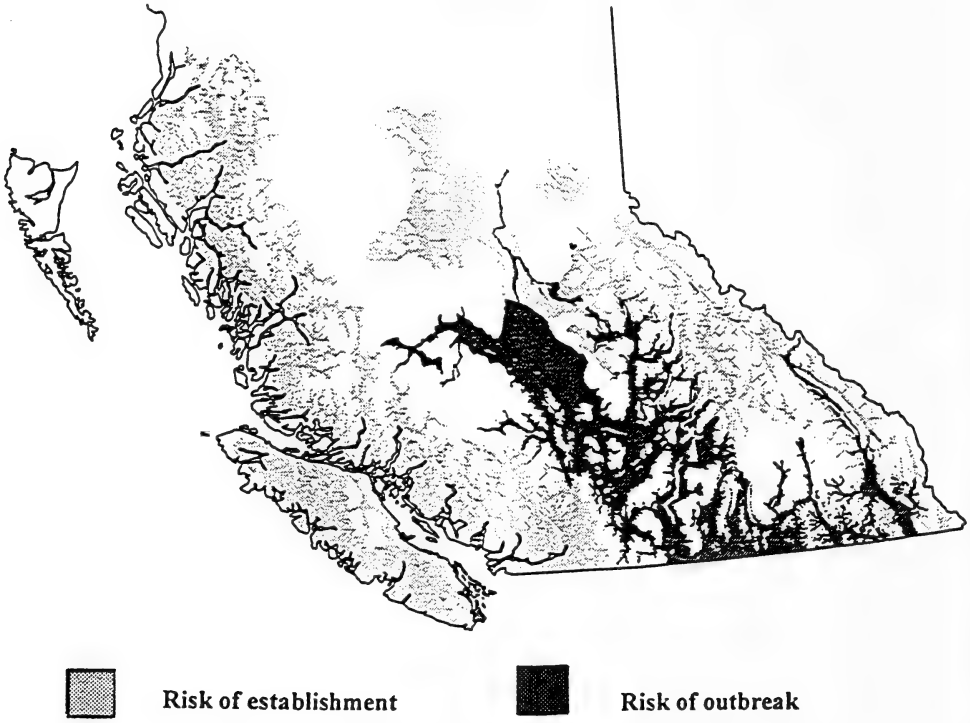

Figure 3. Areas at risk for establishment, or outbreak, respectively, of gypsy moth in B.C., based on plotting of biogeoclimatic subzones of B.C. and climatic range limits for the gypsy moth reported in the literature (Giese and Schneider 1979). Map courtesy of Forest Insect and Disease Survey, Pacific Forestry Centre, Canadian Forest Service, Victoria, B.C.

Discriminant function analysis

Discriminant function analysis showed that many areas of southern and central B.C. have climates very similar to those of Europe and Japan where gypsy moth is present (Fig. 3). Figure 4 shows a graphical representation of the results of this analysis, so that each weather station is represented as a dot, the size of which represents the discriminant function prediction of its climate's relative suitability for gypsy moth. In addition, Fig. 4 shows geographic locations where gypsy moth has been detected using pheromone trapping (triangles). Northern sites in B.C., and cool, wet sites of central and western B.C. are similar to sites in Europe that lack gypsy moth.

The functions misclassified 26 (17%) of the original 156 sites, including Brocken, Germany; Botrange, Belgium; and Turgaj, north of the Aral Sea in the former USSR

(Fig. 2). Thus, we can expect a similar error rate in B.C. Three of the four sites classified in the Pacific Northwest United States had a climate very suitable to gypsy moth. These were Medford, OR (similarity index of 0.99), Portland OR (0.96), and Seattle, WA (0.93). The fourth site (Tatoosh Island, at the extreme northwest tip of the Olympic Peninsula, WA) was classified as unsuitable (0.37).

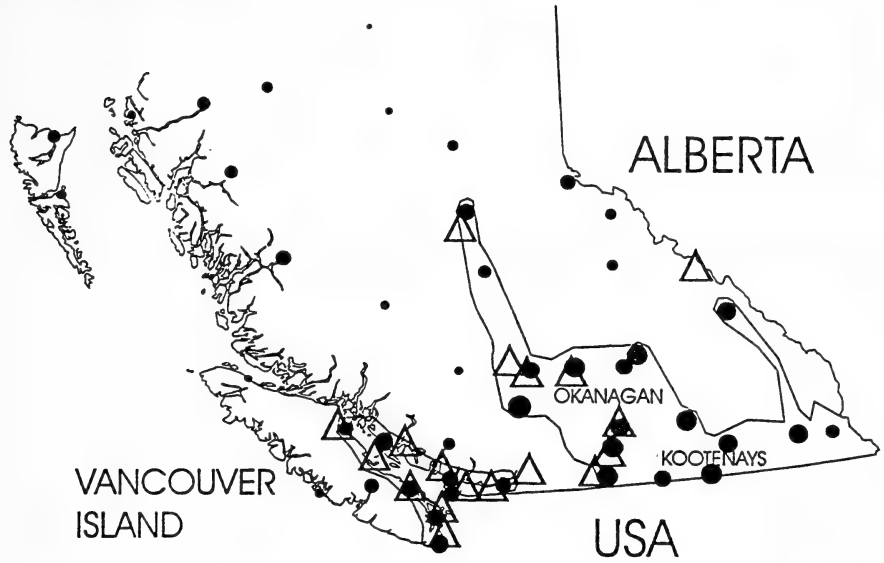

Figure 4. Graphical representation of the discriminant function analysis. Each weather station is represented by a dot, the size of which represents the discriminant function prediction of its climate's suitability for gypsy moth. The solid line encloses the subset of weather stations with climates very suitable for gypsy moth at lower elevations (cf. Figure 3, biogeoclimatic subzones with climate suitable for outbreaks). The triangles show locations where gypsy moth life stages have been found in B.C.

Life stage development modelling

Validation of Lower Mainland trap catch data. The models predict when adults emerge from pupae, and adults can be expected to live for several days. Thus, the actual catches can be expected to lag a couple of days or so behind the predicted emergence period. The model gave a remarkably good correspondence between predicted and observed phenologies, given that the flight time varies by up to a month among years, and considering the very small numbers of live moth catches (Table 1).

Ability to complete development. The temperature-dependent models predict that gypsy moth will be able to reach the adult stage in all years at the more southern locations, but not in every year in the northern ones. In northern B.C. few individuals complete development even in the warmest years (Table 2).

These models do not provide for the requirement that there must be sufficient warmth between the time that eggs are laid and winter begins for the embryos to develop into larvae. This is an additional constraint, so even if adults could emerge and mate in the fall, there may well be insufficient warmth for this embryonic development.

Table 1

Comparison of timing of catches of male gypsy moths found alive in traps on the Southern Mainland of British Columbia to predicted time of emergence of adults using 2 models (Sheehan 1992, Hunter 1993). Adults live for a few days after emergence.

		Period of gypsy moth flight	
Location	Year	Observed from trap catches	Predicted emergence
Vancouver	1991	7 Aug. - 4 Sept. (N=20)	5 Aug. - 31 Aug.
Vancouver	1992	9 July - 10 Aug. (N=26)*	17 July - 10 Aug.
Vancouver	1993	3 Aug. - 25 Aug. (N=13)	29 July - 24 Aug.
Chilliwack	1994	27 July, 5 Aug., 10 Aug. (N=3)	19 July - 12 Aug.
Hope	1994	3 Aug., 5 Aug. (N=2)	21 July - 14 Aug.

*One additional live moth was caught on 25 Aug.

Table 2

Predicted ability of gypsy moth to complete development at selected sites in B.C. in years with extreme climatic conditions and in 1992, which was among the warmest years at all sites. The table lists the most advanced stages attainable (A = Adult, P = Pupa), and the date when moths begin to emerge from pupae. All individuals did not necessarily achieve the most advanced stage before the onset of winter.

	Development Stage Reached and Date of First Flight in Year (with)				
Location	Coldest May	Warmest May	Earliest hatch	Latest hatch	1992
Victoria	A - Aug 28	A - Jul 20	A - Jul 22	A - Aug 27	A - Jul 22
Vancouver	A - Aug 28	A - Jul 10	A - Jul 29	A - Aug 28	A - Jul 17
Castlegar	A - Aug 3	A - Jul 22	A - Jul 14	A - Aug 2	A - Jul 14
Williams Lake	A - Oct 2	A - Sep 12	A - Aug 14	A - Sep 16	A - Aug 14
Smithers	P	A - Aug 12	A - Aug 30	A - Sep 25	A - Aug 31
Prince Rupert	P	A - Oct 8	A - Oct 8	P	P
Prince George	P	A - Aug 13	A - Aug 13	P	A - Aug 13
Fort St. John	P	A - Aug 21	P	P	A - Aug 21

In summary, Castlegar, Victoria, and Vancouver are suitable for complete development; Williams Lake, Smithers, and perhaps Prince George, are marginal; while Prince Rupert and Fort St. John would probably not permit complete gypsy moth development.

DISCUSSION

The results of the climatic analysis, the multivariate comparisons of the weather in European and Japanese sites, and the gypsy moth development models gave similar predictions: southern and central B.C. have climates suitable for the gypsy moth; northern areas, high elevations, and the cool, wet coastal areas are unsuitable. However, climate is not the only factor affecting the establishment of gypsy moth in B.C. Hosts are important, and the largely coniferous forests of B.C. may be quite resistant. Our analyses indicate that gypsy moth may not become established where there are no oaks, even if the climate is suitable, as seems to be the case in north-western Europe. The only native oak in B.C., Garry oak or western white oak (*Quercus garrayana*), is limited to the Gulf Islands and southeastern coastal Vancouver Island from the southern tip to Comox, plus

two small patches in the lower mainland (Lyons 1991). Ornamental oaks are common in urban and suburban areas, where introductions are most likely to occur.

Areas in the southern mainland, eastern Vancouver Island and Gulf Islands with preferred hosts and suitable climate and large numbers of people moving through them are probably at the greatest risk for gypsy moth establishment. Most catches of gypsy moth have been made in these areas (Figure 4). This pattern is also evident in Oregon and Washington: most catches are made in suburban areas or places with a large component of oak (Dreistadt and Dahlsten 1989).

We have included areas in Japan in the climatic analysis, although the Asian strain of the gypsy moth probably has different thermal requirements. We included these areas because it is more conservative to do so than to exclude them; including them gives the gypsy moth a larger potential range. However, the models of development are based on the European strain only.

Some other influences not examined here are: synchrony with plant phenology; negative effects of rain after hatch; and freezing after the breaking of winter dormancy. Gypsy moth larvae emerge from winter dormancy around the time of leaf emergence of oaks (Hunter and Lechowicz 1992; Hunter 1993). New foliage is preferred, since it is higher in nitrogen and water, and less tough (Hunter and Lechowicz 1992). Emergence at the correct time is important because there is a brief window between budburst and the time when foliage becomes unacceptable. Gypsy moth host-seeking activities (crawling up tree trunks, ballooning) are inhibited by cool and wet weather (Leonard 1971). Phenological models for tree budburst have not been developed for hardwoods of the Pacific Northwest, and there are few data on budburst for B.C., so we could not test whether gypsy moth would be well synchronized with leaf emergence in this region. Preliminary analyses using tree phenology models from eastern North America which we applied to climatic data from B.C. indicated good synchrony (Hunter, unpublished). However winter dormancy is the least well understood life stage of the gypsy moth and of the host trees. New models are being developed that encompass the entire diapause period and should yield better predictions of gypsy moth emergence times (Gray *et al.* 1991). However, using a "pre-release" version of this new model altered hatching dates by only one or two days, if at all, and did not have a dramatic impact on the predictions here (Hunter, unpublished).

Some further research may be worthwhile on host suitability for the most common B.C. forest and urban trees. Development rates are often slower on hosts other than oak, so the interaction between climate and host needs to be considered, particularly in marginal areas where the time available for development is limited. Also, although gypsy moth can survive on many species in the lab, they may avoid feeding or do much more poorly on these hosts in the field. This may be due to factors such as: unacceptably low quality of foliage during the host-seeking stage (Hunter and Lechowicz 1992); differential susceptibility to disease (Keating and Yendol 1987); mortality from predators on hosts where growth is slow, and lack of suitable day-time resting sites (Liebhold *et al.* 1986).

This is not the first effort to predict where gypsy moth will be able to establish. Giese and Schneider (1979) developed climatic limits in Europe and Asia using a cartographic comparison between isotherms and isohyets with the range of gypsy moth. Allen *et al.* (1993) developed predictions for Florida and for the entire world. Their world predictions, based on climate matching, seemed to indicate the potential for establishment of gypsy moth in southwestern B.C., but not northern Vancouver Island or Prince Rupert, and thus matched our more detailed projections for B.C. Sullivan and Wallace (1972)

examined the cold tolerance of overwintering gypsy moth eggs. They found that eggs can withstand several weeks exposure to -18 °C, and a few days below -24 °C with no reduction in survival. Snow cover provides effective insulation for egg masses laid close to the ground, so they can survive much lower air temperatures. Sullivan and Wallace (1972) predicted that the distribution of host plants would be more significant in determining northern range limits than would low winter temperatures. The range of the gypsy moth in eastern North America is apparently still expanding northward in Ontario (but not in Quebec, as far as is known) and it remains to be seen whether they will persist beyond the range of oaks.

In B.C. the most vulnerable area will be the range of Garry oak. Since this area is already threatened by urbanization, and Garry oak populations are declining, the potential impact of gypsy moth, should it establish itself there, is of great concern. Monitoring and education of landowners should be greatest in this area.

Two additional areas are of less certain susceptibility to gypsy moth. The southern mainland has suitable climates, particularly in the drier parts, and a variety of ornamental hardwoods that may provide suitable hosts. However, gypsy moth populations may not be able to persist in urban settings with little input from surrounding continuous hardwood forests. For persistence, Allen *et al.* (1993) estimated that a gypsy moth population requires a minimum patch size of 1.06 km diameter of continuous, suitable forest. Diffusion from smaller patches would be greater than reproduction within the patch, so populations would decline. In any case, in urban and suburban areas, gypsy moth would mostly be a "picnic problem" and is unlikely to threaten forestry or conservation. The other suitable areas, the dry interior valleys, should be monitored carefully, although lack of favoured hosts and spraying in orchards are likely to limit the impact of the gypsy moth.

We hope that these predictions will provide a useful guideline for determining areas where monitoring and protection efforts should be concentrated.

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Regional diversity of insects in the Pacific Northwest

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ABSTRACT

Provincial and state records for a sample of insect groups from British Columbia, Idaho, Oregon, and Washington show that this region, here termed "the Pacific Northwest", contains about 29% of North American insect diversity, a level that can be extrapolated to suggest that about 26,000 reported species occur in the region. Nearly half of these species are widely distributed in North America. Many species are more-or-less broadly western; 13% of all species essentially are confined to the Pacific Northwest, although some of them occur otherwise only in California, which contains many Pacific Northwestern species, especially in the north. Most of the fauna of British Columbia occurs also in the United States part of the region, and one-third of the species confined in Canada to British Columbia occur also in Idaho, Oregon or Washington. Despite these overall trends, there are wide differences among families and among genera, reflecting the diverse ranges, origins and ecological relationships of the different groups. Detailed studies that would more fully explain the differences are limited, even for groups of North American insects that are taxonomically better known. Nevertheless, the simple but feasible analysis of state and provincial records presented here provides useful indexes of regional occurrence, and indicates groups in the region that are of particular interest.

INTRODUCTION

This paper considers the diversity of the insects of the Pacific Northwest by comparing state and provincial records for selected groups within and beyond the region in North America. The nature of the data requires that entire states or provinces be included in such an analysis, and therefore the Pacific Northwest is defined here as the whole of British Columbia, Idaho, Oregon and Washington, a choice explained further below. An analysis of the insects of this region suggests patterns in the occurrence and restriction of the species there.

METHODS

A sample of relatively well known insect groups for which detailed state-by-state and province-by-province records or maps are available for the whole of North America was chosen for analysis. These groups, chiefly families, were selected as far as possible to represent the whole fauna (see Danks 1994b), including various taxonomic and ecological types, families from different orders, and groups represented most strongly in different parts of North America. The groups essentially are the same as those analyzed for North America by Danks (1994b), but excluding Pompilidae, for which distributional data could not effectively be analyzed for Idaho, Oregon and Washington separately. The sample thus comprises 3322 species, or nearly 4% of the fauna of North America, estimated to be about 90,250 reported species (Danks in press).

The range of each individual species was recorded by marking its occurrence in a

given region, and in the individual province or states of British Columbia, California, Idaho, Oregon and Washington, on to a standardized table of regions. Regional statistics were derived by summing the marked occurrences. Templates or transparent overlays were used to facilitate data extraction from particular combinations of columns in deriving the more complex statistics.

THE PACIFIC NORTHWEST

The Pacific Northwest is a convenient term for the far northwestern regions of North America, typified by relatively high rainfall and evergreen forests containing characteristic western coastal species such as Sitka spruce. Many other characteristic trees such as Ponderosa pine and Douglas fir are more widely distributed in the west. However, the wet coastal strip has some locally dry areas and it grades inland into a series of more or less complex cordilleran ranges with intervening or intermingling valleys and plateaus. Therefore, the habitats of the region are very diverse, with a considerable range in elevation and water supply, and include deserts, meadows, and aquatic, subalpine, alpine and other habitats in addition to moist coniferous forests.

The Pacific Northwest has been defined in various ways. For example, a typical encyclopaedia (Encyclopaedia Britannica 1983) limits it to Oregon, Washington and part of Idaho. The entomologist Melville Hatch, in a series of fascicles on "The beetles of the Pacific Northwest" (1953–1971) included British Columbia, Idaho, Oregon and Washington. Hitchcock *et al.* (1955–1969), in a treatment of the "Vascular plants of the Pacific Northwest", published in the same series of the University of Washington as Hatch's work, used detailed information for plants to circumscribe the area of Washington, Oregon, Northern Idaho, part of Montana, and southern British Columbia. Kavanaugh (1988) used the term for regions inland only to the western slopes of the Coast Ranges, Cascades and Sierra Nevada south to just south of San Francisco, and north to the Aleutian Islands, thereby including parts of Alaska, British Columbia, Washington, Oregon and California.

Most insect distributions are not known in great detail and for most species only state-by-state or province-by-province records, and not more detailed distributions or habitat information, are readily available in published form. Therefore, the area treated here includes British Columbia (BC), Idaho (ID), Oregon (OR), and Washington (WA), although the diversity of British Columbia as well as of California (CA) also is analyzed separately in relation to the fauna of the region. These and other regions considered in this paper are shown in Figure 1, the caption for which gives the approximate land areas of the regions.

INSECT DIVERSITY IN THE PACIFIC NORTHWEST

North American Comparisons

The occurrence of species of the selected groups in the Pacific Northwest (PNW) as a percentage of the North American fauna is shown in Table 1. Overall, some 29% of North American species have been recorded in the region, while the percentage in each state or province ranges from 16% (ID) to 20% (OR and BC). Nevertheless, there are considerable differences among groups. For example, the characteristic northwestern group Blephariceridae (48% of blephariceridae species occur in the PNW) is much better represented in OR and WA than elsewhere. The predominantly southwestern United States group Bethylidae (only 15% of species in PNW) is poorly represented throughout.

The group Culicidae (38% of species in PNW) is generally widely distributed in North America, and species are evenly distributed across the subregions. Northern syrphids are best represented in BC.

Similar differences are visible among genera in the selected groups. Table 2 lists genera that contain more than 50 species. The fact that overall patterns for these 12 large genera —

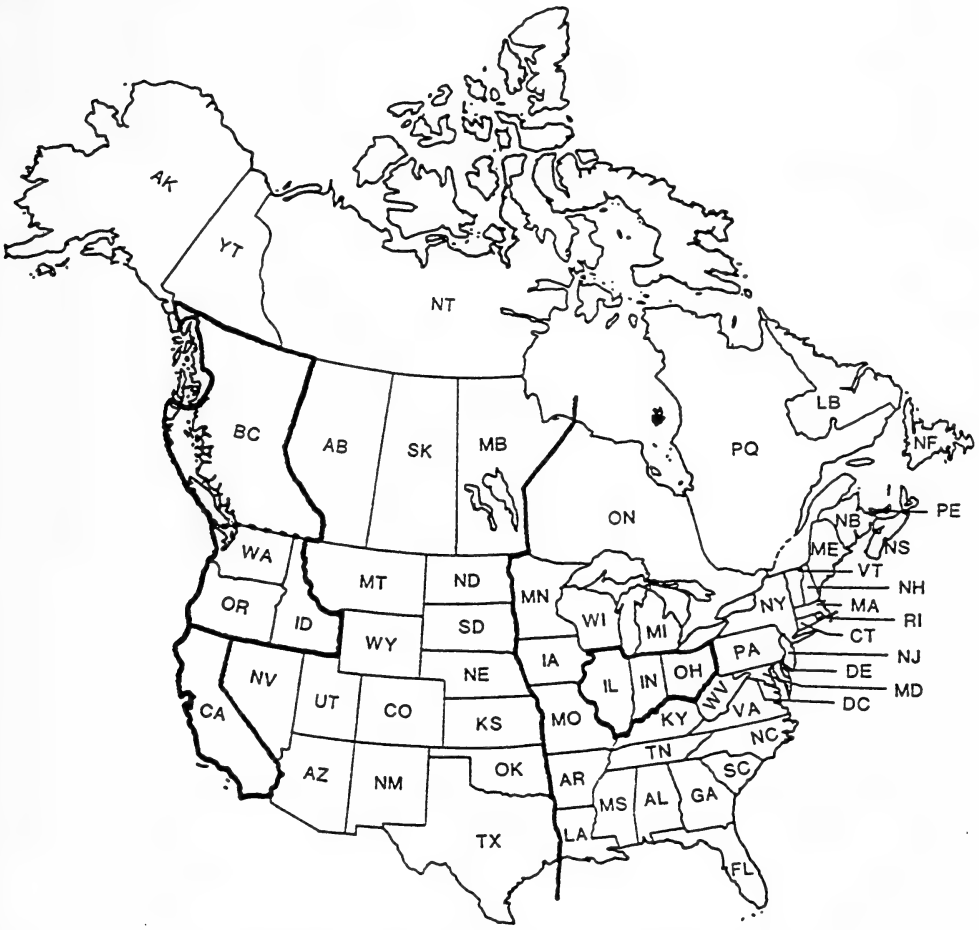

Figure 1. Regions of North America discussed in the text. The Pacific Northwest as considered here (approx. 1,583,000 km^2) comprises British Columbia (949,000), Idaho (213,000), Oregon (249,000), and Washington (172,000). The United States Pacific Northwest (ID–OR–WA, 635,000) is also compared with British Columbia, with California (405,000), with Illinois–Indiana–Ohio (343,000), which contains a similar number of reported species in the east, and with eastern North America.

just over a quarter of the species— are virtually identical to those for the full dataset (compare the two bottom lines of Table 2) suggests that the patterns shown by these samples are representative.

Subregions

The number of species from the Pacific Northwest, and their occurrence in the different subregions, is shown in Table 3. Many species are shared among the subregions

(56–69%) but a substantial proportion of species have not been found in the whole of the region. About 13% of species have been found only in the region, with or without CA as explained below. Two small but distinctive fractions of species restricted to the area would be added if Alaska (for northern species such as some carabids, culicids and syrphids) and Nevada (for some southern elements such as some carabids, chrysidids and butterflies) were to be included in the "Pacific Northwest".

Clues to the different patterns of occurrence are suggested by the differences among families. The presence of groups of more southern or Californian affinity decreases from OR to BC, as in Curculionidae, whereas groups of more northern or Alaskan affinity increase, as in Corixidae, and in Syrphidae, a family within which two better known but chiefly northern genera were analyzed.

British Columbia

British Columbia occupies a large area with a range of habitats including wet coastal forests in the south, dry interior grasslands, and relatively cold alpine and subalpine forests, especially in the north. Its fauna might therefore be expected to diverge from that of the United States Pacific Northwest, but in fact, partly because the northern fauna is relatively depauperate, nearly 80% of the species found there occur in ID, OR or WA too (Table 4). Seven percent of BC's species have been found only in the PNW.

From a Canadian perspective, many species occur in BC, and a significant fraction of all species (13% overall for the groups analyzed here) are confined to that province (Table 5), although there are considerable group-to-group differences. Additional reliable data are available for species distributions in Canada alone (Danks 1993, p. 60), and for these data 19% of 1583 species in 9 families (the whole of the Carabidae and 8 other different groups) have been reported only from BC; the percentage is increased especially because a full third of species of the characteristically western groups Scolytidae and Quediinae (Staphylinidae) are confined to the province (Danks 1993). One third of the species confined to BC (Table 5) nonetheless occur in the U.S. in ID, OR, or WA. Evidently many of these restricted Canadian species are part of the Pacific Northwestern fauna.

California

Habitats in northern California resemble those elsewhere in the PNW, although many different distinctive Californian and southwestern North American habitats occur in southern California. California as a whole therefore cannot be regarded as part of the Pacific Northwest, even though 7% of CA species otherwise occur only in the PNW (Table 6). Nevertheless, because some species centred in the PNW extend to CA, and because many more "southern" species characteristic of CA extend at least into OR, 56% of CA species occur also in the region considered here (Table 6).

Species in common

Within the region, many species are shared (Table 7). For example, 85% of Washington species have been collected also in Oregon; 75% of Oregon species are shared with Washington. About 65% of the United States Pacific Northwestern species occur also in CA, and 63% of them also in BC. However, only 30% of the same species occur in an area with a similar number of species farther east (see Fig. 1).

Once again there are considerable differences from group to group (Table 7). For example, the number of species shared between WA and OR is especially high in groups such as the Lycaenidae. Although relatively few species of characteristically western groups (e.g. Blepharicerids) occur in eastern N. America, the relatively consistent

occurrence in the east of PNW species in most groups is more striking. Indeed, nearly half of all the Pacific Northwest species are found to the east of a line from Manitoba to Texas (see Fig. 1; Table 7): many North American species are widely distributed and occur in different regions.

Range types

Several consistent types of ranges of species that occur in the Pacific Northwest can be detected. A detailed analysis is beyond the scope of this paper, but Kavanaugh (1988) recognized restricted coastal, coast centred, Great Basin, Rocky Mountain and transAmerican species (in addition to mainly northern range types), suggesting that since deglaciation species have entered the PNW by several common routes. In addition, prairie species enter the eastern part of the region not included by Kavanaugh.

Widespread and even transcontinental species are very well represented (Table 7, final column). Many others are more-or-less broadly western. Some species, as already noted, are restricted to the Pacific Northwest. Those that are confined to the PNW and surrounding areas show a variety of patterns, among which characteristic types are northern (e.g. PNW to southeastern Alaska and the Yukon Territory) and southern coastal (e.g. PNW to CA); for sample patterns see Scott (1986), Kavanaugh (1988) and papers cited there, and also compare plant ranges, e.g. Preston (1961). The variety of the individual ranges suggests that current distributions have developed in many different and complex ways. Kavanaugh (1988) emphasized barriers to the dispersal of insect species in the region, noting that centres of endemism include central Idaho, the northern Cascades, and southern and northern coastal centres.

CONCLUSIONS

In the absence of full and detailed data on the ranges and habitats of large numbers of species, analysis of state and provincial records is helpful for characterizing regional diversity (Danks 1993, 1994a, b).

This analysis for the Pacific Northwest — BC, ID, OR, WA — suggests that 29% of the species in North America, some 26,000 reported species, occur in the region (Table 2). Additional species revealed by further collecting, especially in old-growth forest canopies and in some montane habitats, would be expected to augment this number.

Nearly half of the species from the Pacific Northwest are widely distributed in North America; indeed, 30% of them occur in Illinois, Indiana and Ohio alone (Table 7). On the other hand, 13% of all species (or a quarter of the western species) are confined to the Pacific Northwest, with or without occurrence in California, northern parts of which have habitats characteristic of the main part of the zone. Within the region, Oregon and the larger British Columbia have the most species, estimated to be about 18,000 each (Table 2). Almost half of the rich California fauna does not occur in the Pacific Northwest; however, the smaller fauna of BC is dominated by the nearly 80% of species that occur also in WA, OR, or ID.

Despite these generalizations for the fauna as a whole, there are many differences among different groups (e.g. Tables 1, 2). Such differences suggest, for example, that groups with more species in and especially confined to the region, including Blephariceridae and some Carabidae and Curculionidae, would be especially useful for investigation of why these species contribute to the fauna to an unusual degree. The differences confirm too that current distributions depend on a wide variety of ecological and historical factors, reflecting the evolution and dispersal of species and the

modification and development of habitats, which have taken place in diverse ways over time. The variety of range types among the species that contribute to the fauna of the Pacific Northwest, and the combinations and intergradations of these range types, attest to the complexity of these processes.

Therefore, analysis of state and provincial records provides useful indexes of regional diversity, but fuller explanations about the nature and origin of the fauna require further systematic and ecological work. Kavanaugh (1979a, b, 1980, 1981, 1988) has been able to develop some explanations from prolonged and detailed studies of carabids of the genus *Nebria*, which contains many restricted northwestern species. Similar studies still are very limited for most of the groups treated here, even though they are among the best known taxonomically in North America.

ACKNOWLEDGEMENTS

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Table 1
Occurrence of North American species in selected groups in the Pacific Northwest

Order/Family	No. of N. American spp.	% of these spp. recorded in BC	ID	OR	WA	BC, ID, OR, WA
Dictyoptera	69	6	6	9	7	9
Hemiptera:						
Corixidae	125	26	9	16	21	36
Pentatomidae	221	18	13	13	10	23
Tingidae	153	14	7	12	9	23
Coleoptera:						
Carabidae (part)	757	19	12	16	16	26
Curculionidae(part)	483	7	9	15	11	18
Diptera:						
Blephariceridae	25	16	20	44	36	48
Culicidae	162	27	29	29	27	38
Dolichopodidae (part)	49	35	24	29	27	47
Syrphidae (part)	83	67	36	45	43	73
Lepidoptera:						
Papilionidae/ Pieridae	78	38	32	36	32	44
Nymphalidae	165	39	27	28	29	47
Lycaenidae	124	29	35	35	34	43
Hesperiidae	221	11	13	14	12	18
Hymenoptera:						
Pamphiliidae	71	27	7	17	13	30
Chrysididae	230	20	34	42	25	44
Bethylidae	197	7	10	12	9	15
Dryinidae	109	15	6	6	5	17
TOTAL	3322	20	16	20	17	29

Data for this and subsequent tables derived from Atkinson *et al.* 1991 (Dictyoptera *s.s.* [cockroaches]), Polhemus *et al.*, 1988, Henry and Froeschner 1992 (Corixidae), Froeschner 1988a (Pentatomidae), Froeschner 1988b (Tingidae), Bousquet and Larochelle 1993 (Carabidae), O'Brien and Wibner 1982 (Curculionidae), Darsie and Ward 1981 (Culicidae), Hogue 1987 (Blephariceridae), Hurley 1985 (Dolichopodidae), Vockeroth 1990, Knutson 1973 (Syrphidae), Scott 1986 (Papilionidae, Pieridae, Nymphalidae, Lycaenidae, Hesperiidae), Middlekauf 1958, 1964, Shinohara and Smith 1983, Eidt 1964 (Pamphiliidae), Bohart and Kimsey 1982 (Chrysididae), Evans 1978 (Bethylidae), Olmi 1984, 1989 (Dryinidae)

Table 2

Occurrence of North American species in selected larger genera in the Pacific Northwest

Family / Genus	No. of N. American spp.	% of these spp. recorded in BC	ID	OR	WA	BC, ID, OR, WA
Carabidae:						
Agonum	71	44	15	18	30	45
Cicindela	90	8	8	11	8	16
Chlaenius	51	12	4	8	12	12
Nebria	54	26	15	24	30	48
Curculionidae:						
Apion	154	5	8	12	12	14
Listronotus	76	13	16	20	11	22
Anthonomus	102	12	11	25	16	29
Conotrachelus	60	2	0	0	2	2
Sphenophorus	64	8	14	16	16	20
Culicidae:						
Aedes	76	41	39	38	37	51
Syrphidae:						
Platycheirus	70	63	33	37	39	69
Chrysididae:						
Chrysis	79	27	47	48	35	58
TOTAL (These genera)	947	20	17	21	20	31
TOTAL (All genera)	3322	20	16	20	17	29

Table 3

Occurrence of Pacific Northwest species in selected groups from British Columbia, Idaho, Oregon and Washington

		% of these spp. recorded in				
	No. of spp. in BC, ID, OR, WA	BC	ID	OR	WA	% recorded only from BC, ID, OR, WA, with or without CA
Dictyoptera	6	67	67	100	83	0
Hemiptera:						
Corixidae	45	73	24	44	58	18
Pentatomidae	51	76	57	55	45	6
Tingidae	35	63	29	51	40	11
Coleoptera:						
Carabidae (part)	198	74	44	60	63	27
Curculionidae (part)	86	42	51	83	64	27
Diptera:						
Blephariceridae	12	33	42	92	75	42
Culicidae	62	71	76	76	69	5
Dolichopodidae (part)	23	74	52	61	57	17
Syrphidae (part)	61	92	49	61	59	8
Lepidoptera:						
Papilionidae/ Pieridae	34	88	74	82	74	6
Nymphalidae	78	83	58	60	62	4
Lycaenidae	53	68	83	83	79	2
Hesperiidae	39	64	72	77	67	10
Hymenoptera:						
Pamphiliidae	21	90	24	57	43	5
Chrysididae	101	47	78	95	57	2
Bethylidae	30	47	67	77	60	0
Dryinidae	19	84	37	37	26	11
TOTAL	954	68	56	69	61	13

Table 4

Occurrence of species from British Columbia in selected groups in relation to occurrence in Idaho, Oregon and Washington

Order/Family	No. of spp. recorded from BC	% of BC spp. recorded also in ID, OR, WA	% of BC spp. otherwise only in ID, OR, WA, with or without CA
Dictyoptera	4	100	0
Hemiptera:			
Corixidae	33	58	9
Pentatomidae	39	82	5
Tingidae	22	50	5
Coleoptera:			
Carabidae (part)	147	77	16
Curculionidae (part)	36	92	11
Diptera:			
Blephariceridae	4	100	0
Culicidae	44	89	2
Dolichopodidae (part)	17	76	12
Syrphidae (part)	56	75	36
Lepidoptera:			
Papilionidae/ Pieridae	30	83	33
Nymphalidae	65	69	2
Lycaenidae	36	94	3
Hesperiidae	25	96	0
Hymenoptera:			
Pamphiliidae	19	53	0
Chrysididae	47	96	0
Bethylidae	14	79	7
Dryinidae	16	56	0
TOTAL	654	78	7

Table 5

Occurrence of species, confined in Canada to British Columbia, in Idaho, Oregon and Washington

Order/Family	No. of Canadian spp.	% of N.Am. spp. in Canada	% of Canadian spp. confined to BC	% of spp. confined in Canada to BC that occur in ID, OR, WA
Dictyoptera	7	10	0	--
Hemiptera:				
Corixidae	69	55	10	43
Pentatomidae	63	29	17	18
Tingidae	35	23	34	7
Coleoptera:				
Carabidae (part)	286	38	14	67
Curculionidae (part)	105	22	15	25
Diptera:				
Blephariceridae	7	28	0	--
Culicidae	74	46	7	40
Dolichopodidae (part)	39	80	15	33
Syrphidae (part)	73	88	15	36
Lepidoptera:				
Papilionidae/ Pieridae	46	59	13	17
Nymphalidae	89	54	9	25
Lycaenidae	55	44	13	14
Hesperiidae	55	25	9	0
Hymenoptera:				
Pamphiliidae	45	63	18	0
Chrysididae	61	27	23	0
Bethylidae	25	13	4	100
Dryinidae	38	35	3	100
TOTAL	1172	35	13	33

Table 6

Occurrence of species from California in selected groups in relation to occurrence in Idaho, Oregon, and Washington

Order/Family	No. of spp. recorded from CA	% of CA spp. recorded also in ID, OR, WA	% of CA spp. otherwise only in ID, OR, WA, with or without BC
Dictyoptera	14	29	0
Hemiptera:			
Corixidae	24	67	17
Pentatomidae	68	51	4
Tingidae	32	40	3
Coleoptera:			
Carabidae (part)	185	44	13
Curculionidae (part)	94	63	14
Diptera:			
Blephariceridae	16	75	31
Culicidae	48	77	2
Dolichopodidae (part)	12	83	25
Syrphidae (part)	27	85	7
Lepidoptera:			
Papilionidae/ Pieridae	36	69	6
Nymphalidae	59	73	4
Lycaenidae	64	75	2
Hesperiidae	60	52	7
Hymenoptera:			
Pamphiliidae	18	72	6
Chrysididae	164	57	1
Bethylidae	79	33	0
Dryinidae	23	35	0
TOTAL	1023	56	7

Table 7

Occurrence of species in selected groups from the Pacific Northwest in adjacent and in distant regions

Order/Family	% spp. from WA also in OR	% spp. from OR also in WA	% spp from ID-OR-WA also in CA	% spp. from ID-OR-WA also in BC	% spp. from ID-OR-WA also in IL-IN-OH	% spp. from ID-OR-WA also east of MB to TX
Dictyoptera	100	83	67	67	83	83
Hemiptera:						
Corixidae	62	80	52	61	26	52
Pentatomidae	70	57	80	73	41	50
Tingidae	71	56	54	46	33	42
Coleoptera:						
Carabidae (part)	77	80	50	69	28	37
Curculionidae (part)	87	68	73	41	33	44
Diptera:						
Blephariceridae	89	73	100	33	0	0
Culicidae	91	83	65	68	44	65
Dolichopodidae (part)	100	93	53	68	11	42
Syrphidae (part)	86	84	49	89	26	62
Lepidoptera:						
Papilionidae/ Pieridae	96	86	86	86	28	59
Nymphalidae	88	89	75	79	32	47
Lycaenidae	95	91	94	67	31	45
Hesperiidae	85	73	82	63	37	45
Hymenoptera:						
Pamphiliidae	100	75	100	77	0	31
Chrysididae	95	57	95	46	26	41
Bethylidae	89	70	93	39	43	64
Dryinidae	40	29	67	75	25	92
TOTAL	85	75	65	63	30	47

Table 8

Summary of the diversity of species in the regions discussed

Region	% of spp. reported in selected groups	Estimated total no. of spp. reported
North America	(100)	90,250
Canada	35	31,590
Pacific Northwest (BC, ID, OR, WA)	29	26,170
U.S. Pacific Northwest (ID, OR, WA)	24	21,660
British Columbia (BC)	20	18,050
Oregon (OR)	20	18,050
Washington (WA)	17	15,340
Idaho (ID)	16	14,440
California (CA)	31	27,980
Middle states (IL, IN, OH)	26	23,460

Feeding and performance of Colorado potato beetle, *Leptinotarsa decemlineata* (Coleoptera: Chrysomelidae), reared on nightshade and potato

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ABSTRACT

Larval feeding rates, growth rates of immatures, and adult fecundities were measured for Colorado potato beetle fed hairy nightshade (*Solanum sarrachoides*) or potato (*Solanum tuberosum*). Hairy nightshade is an important economic weed in local agriculture. The larvae consumed more dry weight of potato foliage than nightshade. Developmental rate was higher for larvae fed potato than for those fed nightshade. Mortality was similar on the two hosts. Pupae and adults obtained from larvae reared on nightshade were significantly heavier than those from larvae reared on potato. There were no significant effects of the rearing host on adult female longevity. Fecundity, however, was higher for beetles fed on nightshade than those fed on potatoes. We conclude that hairy nightshade is an important alternative and acceptable host plant for the Colorado potato beetle.

Key words: Hairy nightshade, potato, development, foliage consumption, survival, adult longevity, fecundity

INTRODUCTION

Colorado potato beetle, *Leptinotarsa decemlineata* (Say) has adapted to different local host plants, depending upon geographic location (Harrison 1987, Hsiao 1985). Hairy nightshade, *Solanum sarrachoides* Sendt., for example, serves as an alternative host of the pest in Colorado (Horton & Capinera 1990), Utah (Hsiao, personal communication) and Washington (Brown *et al.* 1980). This weed species, a native of South America, is locally abundant in potato (*Solanum tuberosum* L.) growing regions in the Pacific Northwest (Callihan *et al.* 1990). In late season, large numbers of beetles were seen feeding and ovipositing on nightshade plants, to the extent that beetle densities were much higher on nightshade than on potato (Xu & Long, unpublished data). Feeding and performance of the beetle has not been well documented with the beetle population in Washington. This study had two objectives: first, to measure foliage consumption and survival of larval stages, and longevity and fecundity of the adult beetle fed either nightshade or potato foliage; second, to determine whether the beetle was preferably adapted to the source host (host species from which the egg mass was collected) (Horton & Capinera 1990).

MATERIALS AND METHODS

Egg masses from first generation beetles were collected from nightshade and potato plants on 9 July, 1993 at the USDA Field Station, 8 miles east of Moxee, Washington. Eggs were brought to the laboratory and kept in an incubator until they had hatched (27 ± 1 °C, 16L:8D photoperiod)

Potatoes, (var. Russet Burbank) were planted in 3-litre plastic flower pots using standard potting soil (Sun Gro Horticulture Inc., Puyallup, WA). Hairy nightshade, *S. sarrachoides*, was germinated from seed and transplanted into pots as seedlings, using the same brand of potting soil. Plants were grown in the laboratory under a pressurized sodium vapor grow light. Both host species were regularly watered and were fertilized weekly with "Schultz-Instant" Liquid Plant Food (Schultz Co.).

Five newly-hatched larvae were randomly selected from each egg mass. Larvae were individually transferred to a small plastic petri dishes (5.5 cm × 1.5 cm), with one larva per dish. Each dish contained one to four leaf disks (2 cm diameter) from the same host species from which the egg mass had been obtained. The number of leaf disks that were provided depended upon larva size. A piece of wet cotton roll was placed in each dish to maintain humidity. Dishes and larvae were placed in an incubator at a constant temperature of 27±1°C and photoperiod of 16L:8D. Observations of the larval development and survival were at 24 hr intervals. Larval instars were determined by the presence of exuvium. A total of 105 larvae from each host plant were used.

Foliage consumption by each instar was estimated using a leaf disk technique we developed. Disks were cut from leaves using a cork-borer of 2 cm diameter. One to four disks per dish were provided, and replaced daily. For measuring the leaf area consumed, several circles of the same diameter as the disks were drawn on grid paper (2.5 mm). Disks which had been fed on by larvae were placed on the circles, and the consumed areas were estimated by counting exposed square units. The number of square units were then converted to square centimeters. We found the leaf disk technique to be reliable. No significant differences in development or weight of pupae and adults were found between disk and whole plant studies, as long as enough leaf disks were provided for the beetles (Xu & Long, unpublished data).

Since potato leaves are visually thicker than nightshade leaves, there might be differences in foliage weight between the two hosts with the same leaf areas. The difference was determined by measuring the dry weights of randomly selected leaf disks of both hosts. The disks were dried in an oven at 55 °C for 48 hours before dry weights were recorded. Different quantities of foliage were also clipped from both hosts. Leaf area of the foliage was measured. Dry weight was also determined as noted above. The relationship between leaf area and dry weight was estimated using linear regression, in which dry weight (mg) was the dependent variable and leaf area (cm^2) was the independent variable. Foliage consumption was then expressed in terms of both leaf area and dry weight.

When the mature larvae stopped feeding (prepupae) they were transferred to individual rearing cups (38 ml) containing soil collected from a potato field. The cups were kept in the same incubators as those used for larval development, and were monitored daily for pupation of beetles. The pupae were checked daily until the emergence of adults. Newly emerged adults were sexed. Three to five beetles of each sex from the two host species were then randomly selected and transferred to a cage ($30\times30\times60$ cm^3) to monitor adult longevity and fecundity. A pot of nightshade or potato with young shoots was provided. Five cages were used for each host. A total of 25 females was used for the nightshade test, and 19 females for the potato test. The cages were kept at room temperature (21±1°C)with a photoperiod of 16:8 (L:D). Foliage was replaced every other day. Egg masses on plants were counted and removed daily; and the number of eggs per egg mass was also recorded. The production of eggs was calculated daily using total number of eggs on a plant divided by the number of females in that cage. Survival of adults was recorded every day until the beetles died.

As described above, all beetles in earlier studies were fed only the source host, that is, the host species from which the egg mass was obtained. But we also determined whether beetles were most adapted to their source host, using cross-host plant tests (Horton & Capinera 1990). Forty larvae newly hatched from eggs obtained on nightshade plants were randomly selected. Twenty of the forty larvae were provided with leaf disks of nightshade, and the other 20 with leaf disks of potato. Another 40 larvae hatched from eggs collected on potato plants were also used, with half of them fed nightshade and the other half fed potato. The larvae were maintained in the manner as described above. Development and survival were monitored daily until adult emergence. Pupae were sexed using the characters described by Pelletier (1993), and the weight of each pupa was recorded. Newly emerged adults were also sexed and weighed.

Data for larval feeding, adult longevity and fecundity were compared between host species using *t* - tests. Data for larval and pupal survival on the two hosts were analyzed using chi - square test. A two - way factorial (source host x feeding host) analysis of variance (ANOVA with completely randomized design) was done for data obtained from the cross - host experiments, testing for effects of source host (host from which eggs were obtained), feeding host (host for larval feeding) and their interaction. Student-Newman-Keuls tests were conducted where appropriate. (SAS Institute 1988, 1990).

RESULTS

Larval Feeding. Most foliage consumption took place in the late larval stages (Table 1). For both hosts, about 70% of the leaf area was consumed by the fourth instars, about 20% by the third instars and less than 10% by the first and second instars. A *t* - test indicated a significant difference between the two hosts in foliage consumption (cm^2) for the entire larval period, ($p = 0.0017$). Larvae consumed more potato than nightshade foliage for completion of their development. However, the *t* - test failed to show significant differences between the two hosts in larval feeding for the first, second and fourth instars. The difference was significant for the third instar, which may have contributed to the significant difference in total larval feeding (Table 1).

Table 1.
Average foliage consumption (per stage) by larval Colorado potato beetles[1]

	Leaf area [cm^2(SE)]		Dry weight [mg(SE)]	
Larval stage	Nightshade	Potato	Nightshade	Potato
1st instar	0.48(0.02)a	0.51(0.02)a	0.79(0.03)a	1.66(0.08)b
2nd instar	1.49(0.09)a	1.69(0.11)a	2.43(0.15)a	5.51(0.36)b
3rd instar	5.17(0.22)a	6.39(0.25)b	8.42(0.36)a	20.82(0.83)b
4th instar	19.05(0.38)a	19.30(0.41)a	31.07(0.63)a	62.95(1.33)b
Entire larval stage	26.19(0.35)a	27.88(0.40)b	42.71(0.56)a	90.94(1.30)b

[1] 85 individuals developed on nightshade foliage and 90 on potato foliage. Means followed by different letters within the same row are significantly different, *t* - test ($p < 0.05$).

Leaf disks of potato were thicker than those of hairy nightshade, and consequently, dry weight differed between the two hosts. On average, dried potato leaf disks weighed 10.22 mg (SE = 0.18, n = 20); dried nightshade leaf disks weighed 5.23 (SE = 0.12, n = 20). A linear regression model was fitted to the relationship of dry weight (Y) to leaf area (X):

For nightshade foliage: $Y = 1.089 + 1.602 * X$ ($R^2 = 0.997$, n = 22);

For potato foliage: $Y = - 0.321 + 3.277 * X$ ($R^2 = 0.999$, n = 20).

Leaf area consumption was then transformed to dry weight using these models. As indicated by *t* - test, on a dry weight basis, beetles consumed significantly more potato than nightshade foliage (Table 1).

Survival. Larval survival of the beetle was similar on the two hosts ($p > 0.05$). Little difference in pupal survival was found between the two hosts ($p > 0.05$, Table 2). Sixty-nine adults emerged from 105 individuals fed on potato foliage, and sixty-five from same number of individuals fed on nightshade foliage.

Table 2.

Survival (%±SE) of total larval and pupal Colorado potato beetles

Developmental stage	Nightshade	Potato	*p* - value
1st instar	93.33±2.44	99.05±0.95	0.9739
2nd instar	93.88±2.42	98.05±1.36	0.9810
3rd instar	95.65±2.12	95.10±2.14	0.9975
4th instar	86.36±3.66	83.51±3.77	0.9862
pupa	85.53±4.04	85.19±3.95	0.9984

Adult longevity. Adult beetles survived for about two months, although there was a large variation among individuals. On nightshade foliage, the range of longevity varied from 9 to 65 days for females, and 24 to 61 days for males. On potato foliage, the range was 13 - 57 days for females, and 12 - 57 days for males. As shown in Table 3, the average longevity of females was similar for the two hosts ($p = 0.8198$); the average longevity of males was significantly different between the two hosts ($p = 0.0138$).

Table 3.

Adult longevity in days[1]

	Nightshade		Potato	
	N	Mean±SE	N	Mean±SE
Female	25	37.76±2.80a	19	38.82±3.84a
Male	23	41.35±2.20a	17	31.94±3.02b

[1] Means followed by different letters in the same row are significantly different, *t* -test ($p < 0.05$).

Fecundity. Egg mass per female ranged from 4 - 43 on nightshade foliage, and 7 - 32 on potato foliage. Females that developed on nightshade showed higher fecundity than those on potatoes; those fed on nightshade foliage laid about 6 more egg masses per female than those fed on potato foliage ($p = 0.0401$). The number of eggs per female was thus higher for beetles on nightshade than those on potato ($p = 0.0221$). A t - test failed to show a significant difference in number of eggs per egg mass between females fed on the different host plants ($p = 0.3041$) (Table 4).

Table 4.

Fecundity of Colorado Potato Beetles[1]

	Nightshade		Potato	
	N	Mean±SE	N	Mean±SE
Egg masses/female	25	25.44±2.67a	19	18.15±3.06b
Eggs/female	25	495.36±53.60a	19	395.42±61.69b
Eggs/egg mass	636	19.39±0.72a	345	20.51±0.70a

[1] Means followed by different letters in the same row are significantly different, t -test ($p < 0.05$).

Cross - host test. Larval development time (days) was not affected by source host ($p = 0.1652$), whereas the effect of feeding host was highly significant ($p = 0.0001$). The interaction between source host and feeding host was not significant ($p = 0.0805$), indicating that the effect of feeding host on larval development was independent of source host. Larvae that fed on potato foliage developed faster than those fed on nightshade foliage (Table 5).

Table 5.

Effects of source host and feeding host on larval development time (days±SE), pupal weight and adult weight (mg±SE) of Colorado potato beetles[1]

Source Host	Nightshade		Potato	
Feeding Host	Nightshade	Potato	Nightshade	Potato
Development time (58)[2]	15.49±0.19a	14.26±0.26b	15.94±1.67a	13.87±0.22b
Female pupa (33)	176.28±2.95a	121.65±3.98b	162.76±2.60a	126.20±3.66b
Male pupa (31)	143.90±3.75a	104.75±1.75b	142.88±4.44a	118.66±2.88b
Female adult (29)	138.06±3.41a	93.57±8.84b	138.15±4.13a	107.13±3.96b
Male adult (28)	121.30±1.73a	85.66±3.09b	117.48±3.77a	101.04±3.17ab

[1] Means followed by different letters within the same row are significantly different, Student-Newman-Keuls test ($p < 0.01$).
[2] Degree of freedom from ANOVA.

The effects of feeding host on pupal and adult weight were also highly significant ($p = 0.0001$ for pupal female and male, $p = 0.0006$ for adult male and $p = 0.0005$ for adult female, respectively). Pupae and adults from larvae that were fed nightshade foliage were significantly heavier than those from larvae fed potato foliage. Pupal females were

heavier than males, so were adult females than males. Adults were lighter than pupae (Table 5). ANOVA failed to demonstrate significant source host effects or a significant interaction of source host with feeding host ($p > 0.05$).

Percent survival of larvae was similar for both source hosts and for both feeding hosts. For nightshade as source host, survival of post-hatching immatures (first instar through pupa) was 70% when nightshade foliage was provided as a feeding host, and 80% when potato foliage as a feeding host. Similarly, for potato as source host, survival was 80% on nightshade foliage, and 65% on potato foliage.

DISCUSSION

Hairy nightshade is an important host plant of the Colorado potato beetle in Washington and other areas (Horton & Capinera 1990). This weed is locally abundant in potato growing regions in the Pacific northwest (Callihan *et al.* 1990), and serves as an alternative food source for the beetle (Brown *et al.* 1980). Adults readily deposited eggs on hairy nightshade (Table 4).

The performance of Colorado potato beetles on the two feeding hosts was independent of source host, indicating that the beetle is not adapted to a particular source host. Movements of beetles between the two hosts were found in Washington, so the lack of specificity on the source host is not surprising. The first summer generation of the beetle develops primarily on potato, because the weed seeds generally do not germinate until after growth of the potatoes. However, adults of this generation readily move off potato to nightshade for oviposition (Xu & Long, unpublished data). Thus, a given female may deposit eggs on both host species. Population densities of the second summer generation were much higher on this weed species than on potato (Xu & Long, unpublished data). We conclude that populations of the beetle have adapted to the potato-nightshade plant system in the Pacific Northwest, especially in Washington.

Developmental rates of the beetle depend upon the host species (Brown *et al.* 1980, Melville 1985), but variation occurs between geographic populations. We found that larvae fed on nightshade foliage developed more slowly than those fed on potato foliage (Table 5). In Colorado, however, larval growth rates were significantly faster on hairy nightshade than on potato, both early and late in the season (Horton *et al.* 1988, Horton & Capinera 1990).

Survival of the beetle differs among different host plants (Hare & Kennedy 1986). Wild species are less acceptable host plants for the Colorado potato beetle (Melville 1985, Neal *et al.* 1991). We found that there were no significant differences in larval or pupal mortality between the two hosts (Table 2).

Fecundity of the beetles is also affected by different host plants (Brown *et al.* 1980). The beetle may prefer one host plant for oviposition over another, and higher fecundity can be seen on wild species than on the cultivated potato (Jansson *et al.* 1989). Based on the field observations made in 1992 - 1994 in central Washington, we found much higher egg mass densities on hairy nightshade foliage than on potato in mid - and late - season. The free-choice tests conducted in the laboratory indicated that adults of the first summer generation preferred nightshade to potato foliage for oviposition (unpublished data). Females fed on nightshade foliage deposited 6 more egg masses than those fed on potato foliage (Table 4). In paired preference tests conducted by Horton and Capinera (1990), females deposited 92% of egg masses on the hairy nightshade.

Hairy nightshade plays a very important role in the life history and population dynamics of the Colorado potato beetle. The importance of this species as a good

alternative host plant, and the beetle's movements between the nightshade and potato should be considered in monitoring the development of insecticide resistance and integrated management of the beetle.

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Detection of *Pissodes strobi* (Coleoptera: Curculiondae) using large-scale 70 mm colour photography

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ABSTRACT

A 17 year old white spruce plantation with a current rate of white pine weevil infestation of 23% was photographed using 70 mm colour photography at scales of 1:500 and 1:650. The two photo-scales were then interpreted by two different sets of photo-interpreters, with varying degrees of experience, and compared to ground surveys. Results showed that the use of skilled photo-interpreters improved the accuracy of interpretation of current weevil attacks by 18% to 79% over the use of unskilled interpreters. A significant relationship was also observed between the amount of red foliage remaining on the leader and the accuracy of interpretation of current attacks. Large-scale 70 mm photography can detect currently attacked spruce leaders as small as 35 by 30 cm with an accuracy approaching 90% providing at least 30% of the red needles remain on the damaged leader and experienced photo-interpreters assess the results.

Key words: white pine weevil, *Pissodes strobi*, colour photography, aerial survey

INTRODUCTION

The white pine weevil, *Pissodes strobi* (Peck), is rapidly becoming a serious problem in British Columbia. For example, the Prince George Forest Region (PGFR) of British Columbia has about 0.4 million ha of white spruce, *Picea glauca* (Moench) Voss * *engelmannii* (Parry ex Engelm.) and approximately 36% of this area may be susceptible to attack by the weevil according to an assessment of the hazard using threshold temperatures for weevil brood development and oviposition (Spittlehouse *et al.* 1994).

In early spring the weevil lays its eggs in the terminal leader from the previous year (Stevenson 1967). The eggs hatch and the larvae mine downwards consuming the phloem. Successful attacks kill the top whorl of the tree resulting in leaders that first droop when half grown (Mitchell *et al.* 1990) and then the needles turn yellow and red before dropping off in late autumn. Damaged leaders then show deformities that can reduce the merchantibility of the tree (Alfaro 1989).

Effective management of the weevil depends on the ability of Forest Managers to accurately predict the attack status over large areas of forest land. If high levels of weevil attack are predicted then either mixed species management or partial brush manipulation can be used to reduce the damage (Taylor and Cozens 1994, Taylor *et al.* unpublished observations). Accordingly, survey methods must be developed that are both inexpensive and accurate, to survey the large areas of plantations contained in the PGFR. Such methods will undoubtedly involve a combination of aerial and ground techniques.

Large-scale 70 mm colour photography was demonstrated to be 90% accurate in detecting the weevil on white pine and cost 20% less than conventional ground detection (Aldrich *et al.* 1959). However, the ability of colour photography at a large-scale to distinguish between current versus old attacks was not assessed in that study. The success of colour photography at a large-scale is dependent on good photo-interpretation and pest symptoms (Wallis and Lee 1984), hence the distinctions between current and old attacks must be considered.

The purpose of this study was to use 70 mm colour photography at a large-scale to determine the effect of weevil attack symptoms and photo-interpreter experience on the accuracy of photo-interpretation of leaders attacked by the weevil.

METHODS

Ground Survey

A 17 year old white spruce plantation with a current rate of weevil attack of 23% was selected for study. The criteria for selecting this area were: easily accessible and within 50 km of the city of Prince George; a high current rate of weevil attack; a pure white spruce plantation; the majority of the trees at or greater than a height of 1.0 meters and therefore would be susceptible to the weevil; relatively little brush to complicate aerial photography and interpretation; and the plantation was located in the wet cool sub-boreal spruce subzone (See Pojar *et al.* 1987 for details of this classification system), which is a highly susceptible subzone for weevil attack in the PGFR.

Eight separate 5.64 m radius plots (0.01 ha) were established on the ground and marked for subsequent large-scale aerial photography. The plot center was marked on the ground with a cross of white plastic strips oriented north and south, and the perimeter of the plot was marked with white plastic at the cardinal directions. Within each plot the bearings and distances of all coniferous trees from plot center were measured. The tree species were recorded as were the attack status of each spruce tree. The attack on the top whorl of each tree was recorded as:

i) **current**: an attack which occurred that year (1994). This type of attack was distinguished on the ground based on: the presence of red foliage, the sap exuding from the oviposition sites was still sticky, and the date of attack was traced back from the nearest uninfested lateral branch;

ii) **old**: an attack which had occurred in the previous year or earlier. These attacks had no foliage at all; the sap had hardened and dried; and the attack was traced back from the nearest uninfested lateral branch; and

iii) **healthy**: a leader where no weevil damage was present and the needles exhibited normal colouration.

For current attacks the amount of red foliage was recorded to the nearest five percent. Further, the length of damage down the leader and the radius of the damage was recorded for all old and current attacks. The volume of damage to the leader was then calculated in cubic centimetres using the formula for a conoid (Area of base x height /3).

Photographic Specifications

On October 18, 1994 all eight plots were photographed under a high overcast sky between 1:00 pm and 3:00 pm. At this time of year some attacked leaders have lost their needles allowing the relationship between red foliage and correct identification to be determined. We recognized that this was not the optimum time of year to otherwise photograph the damage.

The Ministry of Forests Camera Boom System (Timberline version) was utilized to collect the large-scale photography for the eight plots (MOF 1981). This camera boom consists of two remote-controlled, synchronized, Hasselblad MK 70 cameras mounted 6.1 m apart on a flight-aligned boom which attaches to the underside of a Bell Jet Ranger helicopter. The cameras were fitted with 100.555 mm focal length lenses. Agfa Avichrome 200 colour film was exposed using skylight filters. All plots were flown at heights of approximately 50 to 65 m giving scales of 1:500 and 1:650, respectively.

Interpretation from the 70 mm diapositives was done using a Ross SFS-3 stereocomparator. Five independent observations were made for all plots at the two photo-scales, therefore requiring ten photo-interpreters. Three of the ten interpreters had both extensive field and photo-interpretation experience. The remaining interpreters had no previous experience and were students from the University of Northern British Columbia.

All photo assessments were conducted independently of each other and were supervised by the authors. The supervisor first determined which tree was to be assessed before the photo-interpreters viewed the damage to minimize any mistakes in viewing the wrong trees.

Analysis

Analysis of variance with a nested factorial structure was conducted to test whether there were significant differences between photo-scales (1:500 to 1:650), among plots and between skill level, and between experienced versus non-experienced photo-interpreters based on the percentage of correct decisions. Three dependent variables were used for the analysis. They were percentage of correct observation for red trees, percentage correct observation for old trees, and percentage of correct observation for healthy trees. The following linear model was used for the analysis of variance:

$$Yijkl = u + Si + Xj(i) + Pk + Eijkl$$

- where u is grand mean, Si is scale effect (i from 1 to 2), Xj(i) is skill effect (j from 1 to 2) and Pk is plot effect (k from 1 to 8) and Eijkl is the residual.

Analysis of variance was conducted to test whether there were significant differences between photo-scales (1:500 to 1:650) and among categories of percentage of red foliage and categories of volume. Thus the dependent variable was the percentage of correct identification. The following linear model was used for the analysis of variance:

$$Yijk = u + Si + Cj + Eijk$$

- where u is grand mean, Si is photo scale effect (i from 1 to 2), Cj is category effect (% red foliage or volume) and Eijk is the residual.

A curvilinear polynomial regression was then conducted to relate percentage of correct decision of current attack with percentage of red foliage. The model used was:

$$Y = a + bx + c\,x^2 + e$$

- where Y is percentage of correct decision, a is a regression constant, b and c are regression coefficients, x is the percentage red foliage and e is the residual.

All statistical analyses were done using SAS software (SAS Institute 1990).

RESULTS

On the eight plots a total of 645 trees were examined which contained 165, 175 and 305 trees that had current attacks, old attacks, and healthy leaders respectively. The mean dimensions of the current and old attacks were: 34.5 cm ± 12.8 (Standard Deviation) for the length of damage and 29.1 cm ± 12.8 for the diameter of the damage.

Table 1 shows a comparison of percent correct choices of current attacks, old attacks and healthy leaders between different skill levels of photo-interpreters. The initial analysis of variance revealed that there was a significant difference between the accuracy rate of 60.6% for non-skilled interpreters and that of 78.8% for skilled ones in identifying current attacks. Also, the variation of skilled interpreters, as represented by the standard deviations, was less than that of non-skilled interpreters. No significant differences were observed between old attacks and healthy leaders, and skill levels.

Table 1

A comparison of percent correct choices of current, old and healthy leaders between different skill levels of photo-interpreters.

	Percent Correct Choice (Mean ± SD)	
Health of Leader	3 Skilled Interpreters	7 Non-skilled Interpreters
Current Attack	78.8(8.8)a*	60.6(12.7)b
Old Attack	37.2(1.6)a	20.0(17.2)a
Healthy	90.2(3.4)a	86.9(16.3)a

Current: currently attacked leader with red foliage
Old: an old attack from previous years with no foliage.
Healthy: a healthy leader with green foliage.
* Means in each row followed by the same letter are not significantly different, ($p \geq 0.01$) according to an analysis of variance.

An analysis of variance showed no differences between the correct selection of current attacks, old attacks, and healthy leaders and the two photo-scales (Table 2). Healthy leaders, old attacks and current attacks were identified with a 85 - 90%, 29 - 37% and 60 - 71% success rate, respectively.

Table 2

A comparison of percent correct choices of current, old and healthy leaders between the two photo-scales.

	Percent Correct Choice (Mean ± SD)	
Health of Leader	Photo-scale 1:500 (n=5)	Photo-scale 1:650 (n=5)
Current Attack	60.2(14.1)a*	70.6(15.9)a
Old Attack	28.6(12.7)a	37.1(19.5)a
Healthy	85.2(18.2)a	90.2(4.1)a

Current: currently attacked leader with red foliage
Old: an old attack from previous years with no foliage.
Healthy: a healthy leader with green foliage.
* Means in each row followed by the same letter are not significantly different, ($p \geq 0.01$) according to an analysis of variance.

The analysis of variance indicated that percent red foliage is significantly correlated with correct selection of current attacks (df = 5, F = 4.26, p = 0.0025), but not with volume. Further, the curvelinear relationship (percentage correct selection = 49.08 + 1.81 (percentage red foliage) - 0.02 (percentage red foliage)^2 was highly significant (R^2 = 0.926, $p < 0.05$) (Fig. 1).

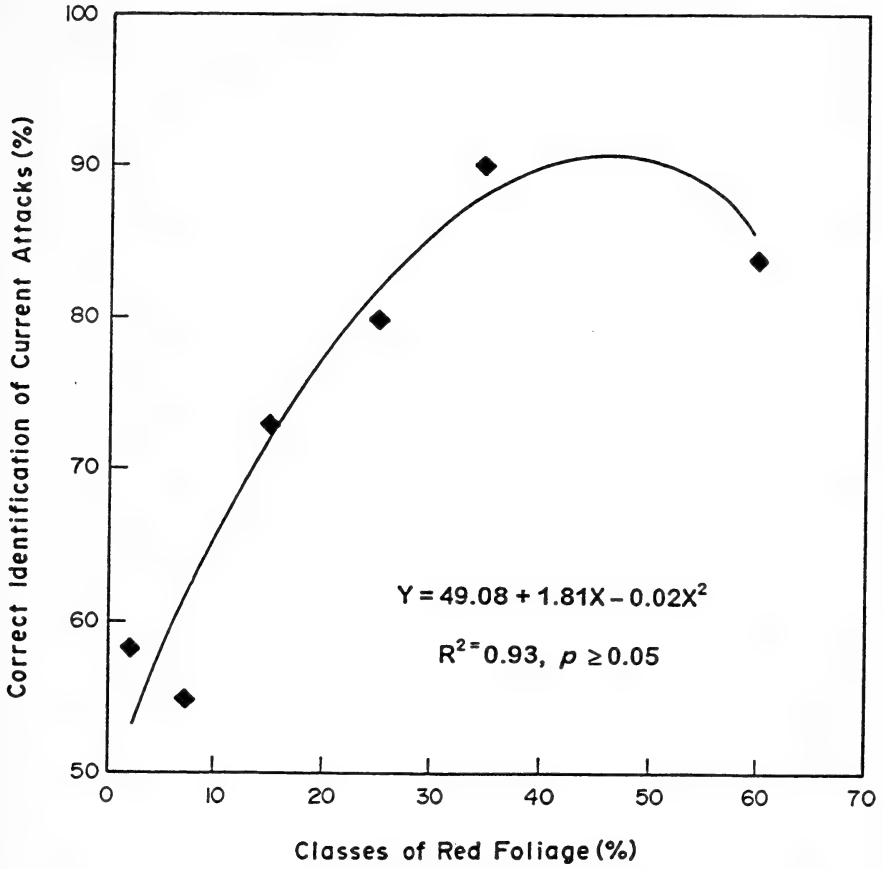

Figure 1. The relationship between the correct identification of current attacks and the percentage of red foliage.

DISCUSSION

The use of skilled photo-interpreters resulted in a 18% increase in accuracy from 61 to 79%. A skilled interpreter is one that has two seasons of both field and photo-interpretation experience. Such an individual is more able to determine differences in foliage colourations due to brush or other factors from those due to the white pine weevil. Separating different colourations is important as the optimum period for photography coincides with the beginning of leaf abscission for deciduous species, and hence coloured foliage on brush and deciduous species is visible.

A relationship between the amount of red needles on the currently attacked leaders and the accuracy of the photo-interpretations exists. When the retention of red needles is at 30 - 40% the accuracy of correct interpretation seems to level off at about 85%. More date is required to study this relationship beyond 60% red foliage. Therefore, colour photography should be timed to coincide with the period of maximum red needle

retention for the best accuracy. In the PGFR this period will probably vary between the last two weeks of August and the first two weeks of September depending on the annual weather conditions. After this, rain and wind will wash or blow away the red needles, causing a considerable decrease in the accuracy of detection.

The combinations of using skilled photo-interpreters and taking the photographs at the optimum period may increase the accuracy of selecting current attacks to over 90% when compared to ground detection. If the cost savings of 20% mentioned in Aldrich *et al.* 1957 can be realized then 70 mm photography represents a realistic option for detecting current weevil attacks.

The results also indicate that any damage on a tree's canopy that is at least as big as 35 cm by 29 cm is likely to be observed on aerial colour photographs at a scale of 1:500 to 1:650 as long as the colouration is distinct and located in a prominent position on the canopy. Further, low-level observation of weevil attacks from the air, without photography, at heights of 65 m or less is likely to provide comparable accuracy. Aerial detection of weevil attacks may provide another survey option or an option to be used in conjunction with 70 mm photography.

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A new species of *Copablepharon* (Lepidoptera: Noctuidae) from British Columbia and Washington

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ABSTRACT

A new species of *Copablepharon*, known from sandy ocean beaches in Washington and British Columbia, is described. Larvae feed on yellow sand verbena (*Abronia latifolia* Eschsch.) (Nyctaginaceae). This is the first report of a species of the genus *Copablepharon* from west of the Cascade Mountains.

Key words. *Copablepharon*, Noctuidae, *Ammophila arenaria, Abronia latifolia*, sand dunes.

INTRODUCTION

Recent study of the noctuid fauna of northwestern Washington and southwestern British Columbia has shown that several species previously known from beaches farther south in Oregon and California occur on similar beaches in our area. *Lasionycta wyatti* (B. and Benj.), *Euxoa wilsoni* (Grt.), *Trichoclea edwardsii* Sm., *Apamea maxima* (Dyar), and *Agrotis gravis* Grt. are restricted to sandy ocean beaches, usually with foreshore dunes. Each of these species occurs on suitable beaches on the Strait of Juan de Fuca and the Gulf of Georgia. In addition to these species, a new species of *Copablepharon* has been found on unstable foreshore dunes at Deception Pass, WA, and at Saanichton, B.C.

Copablepharon fuscum new species

Description

Adult. Males and females similar. Eyes round. Frons smooth. Antennae ciliate, dorsal surface with white scales; scape white with small patch of golden brown scales dorsally. Palpi white, second segment with a small patch of gray scales dorsally. All tibiae with stout setae. Head and thorax golden brown, base of thoracic collar and edges of tegulae paler. Forewing length 17-19 mm. Forewing ground colour golden brown, slightly darker than thorax; trailing margin darker gray-brown; costa and anal margin white; medial vein and M1 edged posteriorly with a pale yellow line, this line edged posteriorly within discal cell with a black line which follows vein M2 to within 2 mm of margin; a diffuse black line follows vein R5 to within 2 mm of margin; a second pale yellow line borders the cubital vein and vein CuA2; postmedian line a series of black dots on veins; fringe concolourous with forewing basally, white to pale gray-brown distally. Hindwing dark gray-brown, fading to very light gray or white basally; fringe white in distal half, dark gray-brown basally. Undersurface of wings predominantly dark gray,

light gray on hindwing base and along forewing costa, vein M2 distal to cell and anal margin.

Male genitalia: Uncus curved, thin, tapered distally. Tegumen broad with penicillus lobes. Juxta broad, flat. Clavi long, cylindrical, slightly expanded distally. Valve 4X as long as wide, rounded distally, widest distal to sacculus due to triangular process of ventral margin; corona present; sacculus 2/5X length of valve; clasper as long as valve width, parallel to dorsal valve, broadest at base, tip curved slightly dorsad, basal sclerite strong, joined to clasper proper at 90° angle; digitus very short. Aedoeagus 3X as long as wide with a long, thin extension onto inner curve of coiled vesica; inflated vesica spirals 360° ventrad and leftward to project distal to tip of aedoeagus, distal vesica bulbous, median diverticulum finger-like with a single spine-like cornutus at apex.

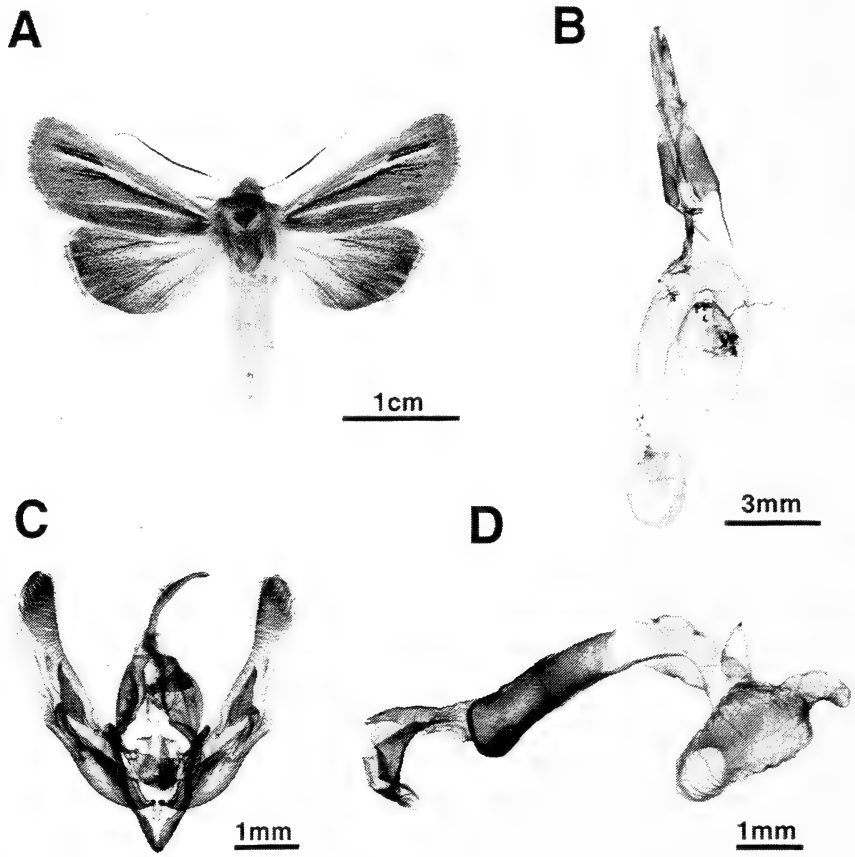

Figure 1. *Copablepharon fuscum*: A. holotype male; B. female genitalia; C. male genital capsule; D. aedoeagus and everted vesica.

Female genitalia: Ovipositor lobes elongate, cone-shaped, covered with long and short setae; ductus bursae very lightly sclerotized, joined to posterior corpus bursae; bursa copulatrix bisaccate, without signa; corpus bursae straight, 4X as long as narrow, swollen anteriorly; appendix bursae joined to right side of posterior corpus bursae, curved 360° ventrad, its distal end swollen and fiddlehead-shaped; ductus seminalis joined to right side of distal appendix bursae.

Type specimens

Holotype male: USA, Washington, Island County, Deception Pass State Park, 26 May,

1995, Troubridge and Crabo in the Canadian National Collection (CNC). Paratypes (16 males, 18 females): 15 males, 15 females, same data as holotype; 1 female, 1 July, 1994, Saanichton, B.C., Troubridge; 1 male, 2 females, 1 July, 1995, Saanichton, B.C., Troubridge. Paratypes to be deposited in the CNC, American Museum of Natural History, and United States National Museum.

Derivation of the name

The specific epithet is derived from the Latin word *fuscus*, which means dark or swarthy. This refers to the wing colour, which is unusually dark for the genus.

Diagnosis

Adults of *C. fuscum* are easily separated from all other species in the genus by their dark colour and the presence of the contrasting yellow and black forewing lines. It is the only species with a predominantly gray underside to both forewing and hindwing -the ventral forewing of other species may be dark, but their vental hindwing is white or off-white. Structurally, *C. fuscum* is most closely related to *C. absidum* (Harv.). The male and female genitalia are nearly identical to those of *C. absidum*, but the clasper of *C. fuscum* is wider (ca. 0.16 mm near tip vs. 0.12mm in *C. absidum*) and is rounded distally, while that of *C. absidum* is slightly pointed.

Distribution

Copablepharon fuscum is known from unstable foreshore dunes at Saanichton, B.C., and Deception Pass State Park, WA. The foodplant is found on uncollected ocean beaches on the Southern Gulf Islands, B.C., the San Juan Islands, WA, the west coast of Vancouver Island, and the Queen Charlotte Islands, B.C., as well as on open ocean beaches in Washington, Oregon, and California. The introduced European beachgrass, *Ammophila arenaria* (L.) (Gramineae), has stabilized most of the dune habitat on the Pacific Coast, supplanting the native beach vegetation. It is not known if *C. fuscum* occurs or once occurred at these other localities.

DISCUSSION

Copablepharon fuscum is found associated with yellow sand verbena, *Abronia latifolia* Eschsch. Eggs are laid on the inflorescence and larvae feed at night by chewing through the leaf epidermis and mining the fleshy leaf interior. During the day the larvae burrow in the sand. The presence of the larvae can be easily determined by the characteristic feeding damage resulting in large blisters on the leaves of the foodplant.

As with many other beach noctuids, the flight period of *C. fuscum* is very long. In 1995, adults were observed from mid May until late July.

Where it occurs, *C. fuscum* can be relatively abundant. It was the most common noctuid at Deception Pass, WA, in late May and June, 1995.

Copablepharon fuscum is the only member of the genus known from west of the Cascade Mountains, a region known for its wet climate. Other members of this genus occur in more arid regions, including interior British Columbia and the Columbia Basin. Most species are associated with well-drained soils, especially sand. Both of the known localities for *C. fuscum* lie within a rain shadow, with annual precipitation of about 60-80 cm. In contrast, the coast of Oregon receives at least 180 cm. annually (Franklin and Dyrness, 1988). This may explain the limited distribution of this species, although it could also be an artifact of lack of collecting in suitable habitats.

Copablepharon fuscum and the other beach noctuids are restricted to sandy ocean

beaches and are a unique feature of this habitat. Although these species can be locally abundant, they are known from a few localities in the inland coastal region of Washington and British Columbia. The destruction of the dune ecosystem by invading European beachgrass, development or intensive recreational use of their high value ocean-front habitat could threaten their existence in our area.

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The vertical distribution of mites and aphids on hops in southcentral Washington during the summer of 1993.

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ABSTRACT

The distribution of a predatory mite, *Galandromus occidentalis*, was determined along with its prey, the twospotted spider mite, *Tetranychus urticae*, at five elevations on unsprayed hops grown on a 5-6 m trellis. The prey species was well established at all elevations when the study began on July 20, 1993. The predator did not reach the uppermost elevations sampled until two weeks later. Early in the study whole plant predator:prey ratios were 1:90 or more compared to 1:20 in late August. Counts of hop aphids, *Phorodon humuli* Schrank, were also made. At high densities, hop aphids and resultant honeydew on leaves interfere with mite population development. Aphid densities of 100 or more/leaf occurred during the last three weeks of this study and reduced mite numbers. Identification of predator mites indicated ca 6% were *Amblyseius* (=Neoseiulus) *fallacis* (Garmen) which had not previously been reported on hops in Washington.

Key words: Acari, Phytoseiidae, Tetranychidae, Eastern Washington, Humulus, *Phorodon humuli*, *Tetranychus urticae*, *Galandromus occidentalis*.

INTRODUCTION

Hops, *Humulus lupulus* (Urticales:Cannibinaceae), are a specialty crop used for bittering and flavoring beer. Most of the world's hops are produced in Europe (Germany, Czech Republic, and England) and in northwestern U. S. (Washington, Oregon, and Idaho). Two key arthropod pests are the twospotted spider mite (TSSM), *Tetranychus urticae* Koch, (Acari:Tetranychidae) and the hop aphid, *Phorodon humuli* Schrank, (Homoptera:Aphididae). Left uncontrolled, either pest can cause complete loss of the crop. Recent emphasis in most crop systems has been the decreased use of petrochemical-based pesticides and the increased use of natural enemies. A number of predatory insects and mites (Anthocoridae, Coccinellidae, Chrysopidae, and Cecidomyidae) has been recorded from hops (Zelený *et al.* 1981; Cranham, 1982; Campbell and Cone, 1994). Phytoseiid predators of twospotted spider mite are not regarded as viable biological control agents of *T. urticae* in Europe because of the annual nature of the management of the hop crop (Cranham, 1985). Sites and Cone (1985) found *Typhlodromus* (=Metaseiulus)(=Galendromus) *occidentalis* (Nesbitt) dispersed over the hop plant along with its prey, *Tetranychus urticae*, and in an earlier study Pruszynski and Cone (1972) found *Galandromus occidentalis* to be a much better adapted predator on hops than the introduced predator, *Phytoseiulus persimilis*, in Washington.

Hops grow rapidly in May and June and are trained on a trellis 5-6 m high. Little is known about the ability of *G. occidentalis* to forage over the entire hop foliage canopy in search of its

prey, the twospotted spider mite. This study describes the distribution of the two key pests and *G. occidentalis* through one growing season.

MATERIALS AND METHODS

The study was conducted during the 1993 growing season in a block of hops, *Humulus lupulus,* cv. Galena, at WSU-IAREC, Prosser, Washington. The hops were unsprayed. Twenty plants were selected for uniformity and sampled weekly from 20 July to 7 September, 1993 at height intervals of 0-1, 1-2, 2-3, 3-4, and 4-5 m. Three leaves were collected from each plant at each height interval. A pruning pole and ladder were used to pick leaves from the three higher elevations. Samples were returned to the laboratory in plastic bags where mites and aphids were counted under a binocular dissecting microscope (10x). Each leaf was subsampled five times by placing a heavy paper template over it with a 3x3 cm exposed area from which the counts were made. The number of mites and aphids in the five observations per leaf was totaled for each leaf and the mean of these totals was calculated from the three leaves per height for each plant resulting in the number of mites and aphids per 45 cm^2. The mean for each height was then calculated for the 20 plants, resulting in 20 observations per height per date. Counts included eggs and mobile stages of both *Tetranychus urticae* and *Galandromus occidentalis,* and all hop aphids.

Representative specimens of predatory mites were removed from the samples, mounted on microscope slides in Hoyer's fluid, and prepared for identification. A total of 180 slides was prepared.

RESULTS AND DISCUSSION

The mean number of twospotted spider mite, hop aphid, and the predator mite, *Galandromus occidentalis,* per 45 cm^2 leaf area from July to September are in Fig. 1. Mean numbers of each species found at different heights on the plants during the sampling period are plotted in Fig. 2.

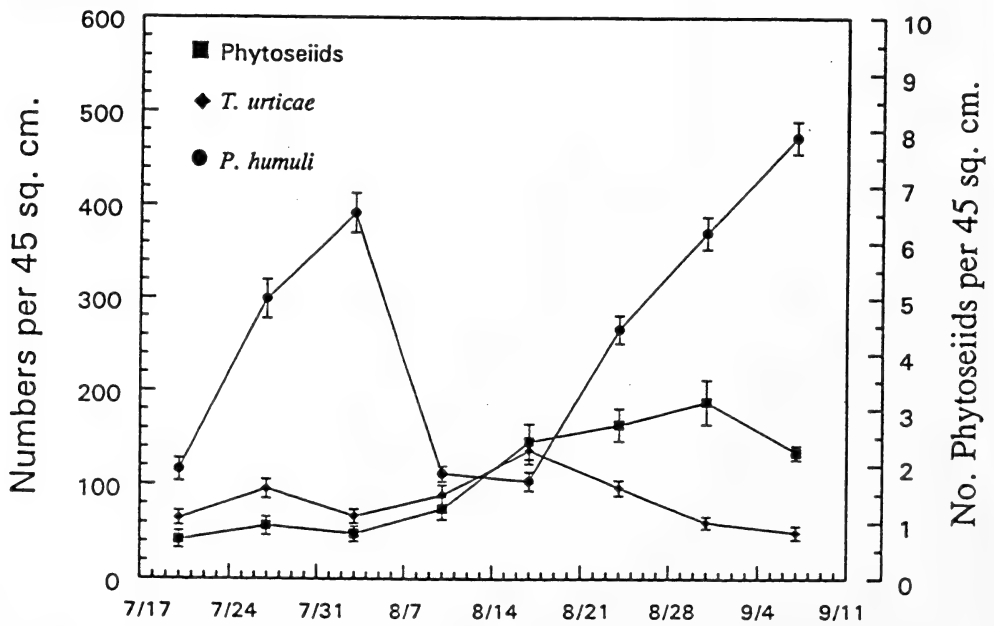

Figure 1. Mean number of aphids (*P. humuli*), spider mites (*T. urticae*) and predator mites (Phytoseiids) per 45 cm^2 subsample per leaf (300 leaves from 20 plants) ± SEM for each date.

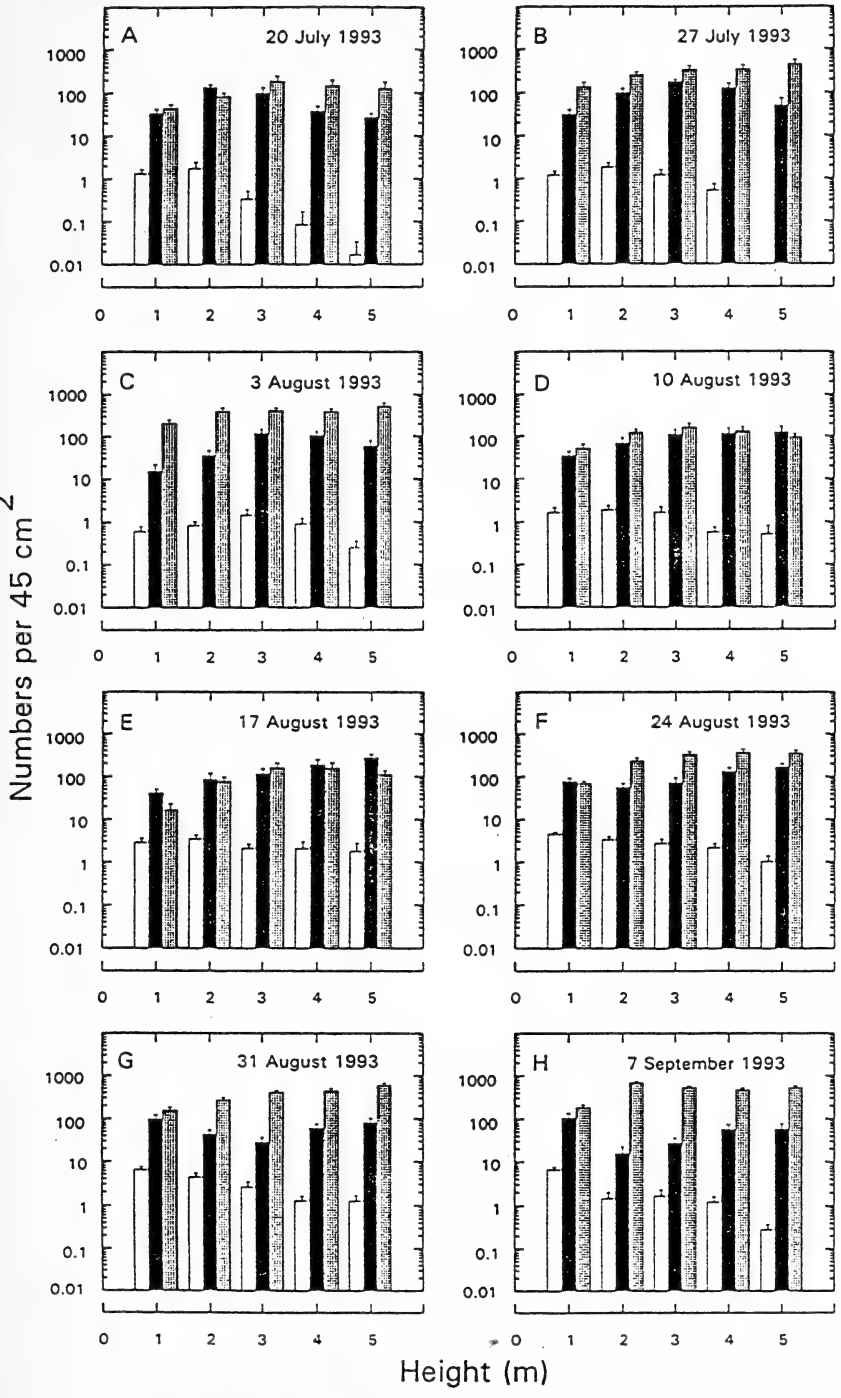

Figure 2. (A-H). Mean numbers ± SEM of *Galandromus occidentalis*, *Tetranychyus urticae*, and *Phorodon humuli* per 45 cm^2 subsample per leaf at different elevations on hop plants, July 20-Sept. 7, 1993. Phytoseiid numbers are represented by the white bar, *T. urticae* by the black bar, and *P. humuli* by the cross-hatched bar

There were two peaks of aphid numbers; one August 3, and the second peak was still increasing when the study ended on September 7 (Fig. 1). Based on field experience, there is usually an increase in aphid numbers in July followed by a sharp decline in numbers with the onset of hot, dry weather. A second increase in numbers usually begins in late August (associated with cooler weather) with peak abundance coming in September. Aphids were least numerous near the ground throughout the study period (Fig. 2).

The twospotted spider mite population showed a small peak in late July and a larger peak in August; these are generally associated with hot, dry weather. In 1993, the peak of TSSM abundance was August 17 (Fig.1). Growth of the predator population, *G. occidentalis,* usually begins slowly but generally follows the prey curve. In 1993 total predator numbers were low (0.70 - 1.24 per 45 cm^2) until August 17 when 2.43 per 45 cm^2 were found. The season peak (3.14 per 45 cm^2) was reached on August 31 (Fig.1).

The first orange (diapause) female TSSM appeared in the population on August 25. The onset of diapause in TSSM is controlled by photoperiod (Veerman, 1985) and triggers a downward migration from the hop plant to overwintering sites. These sites may be plant debris on the soil surface, the hop crown, crevices in the soil or cracks or other openings around the base of wooden hop poles that are part of the trellis.

The distribution of *G. occidentalis* on the hop plant is shown in Figs. 2A-H. TSSM was well established at the tops of the plants when this study began July 20. The number of predators declined with increasing height above the 2 to 3 m heights until August 17 when the numbers among heights were relatively uniform. Predator numbers at the upper elevation (4-5 m) peaked on August 17. After that time (Figs. 2F,G,H) more predator mites were found at 0-1 and 1-2 m elevations, and by September 7 nearly all predators were found close to the ground (0-1 m). This may be a reflection of the foraging ability of the predator following its prey as they move down the plant. The predators do follow TSSM into their overwintering sites (Cone *et al.*, 1993).

The weekly predator:prey ratio was 1:90, 1:104, 1:82, 1:73, 1:61, 1:38, 1:20, and 1:23 during the study period. The actual effectiveness of the predator in reducing TSSM numbers was obscured by the abundance of hop aphids during the last three weeks of the study. Aphids secreted 'honeydew' which seriously interfered with TSSM population development and possibility interfered with Phytoseiid development as well.

Of the 180 slides of predators, 168 were identified as *G. occidentalis* and 12 as *Amblyseius fallacis* (Garmen). *A. fallacis* was the most abundant predator mite reported in a survey of hop yards in Oregon (Strong and Croft, 1993), but this is the first time it has been reported on hops in Washington.

CONCLUSIONS

These data indicate the variation in numbers of pests and predators on hops. The interaction between the two pest species where one (the aphid) by physical means reduces the population of the second (the mite) means that a second type of management may be needed when weather patterns favor aphid development.

These data also indicate that the initial numbers of *Galandromus occidentalis* are too low to maintain *Tetranychus urticae* numbers below their economic threshold.

Partial solutions may rest with the use of selective aphicides that spare natural enemies and with the augmentative release of predatory mites earlier in the season for control of twospotted spider mites. The role that *A. fallacis* plays in the biological control of TSSM on hops in Washington remains to be determined.

ACKNOWLEDGEMENTS

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Grooved board traps for monitoring the black vine weevil (Coleoptera: Curculionidae) in raspberry fields

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ABSTRACT

A grooved board trap was tested to determine the effects of trap size (two sizes) and bait (apple pomace) on capturing the black vine weevil, *Otiorhynchus sulcatus* on raspberries, *Rubus idaeus*. Large traps (30 x 30 cm) caught significantly more weevils than small ones (15 x 15 cm). Large traps were also more sensitive in capturing weevils than small ones, which will be important when the weevil density is low. Apple pomace bait did not significantly enhance the attractiveness of grooved board traps to the black vine weevil. Grooved board traps may also be useful for weevil monitoring in other crops.

Key words: black vine weevil, board trap, raspberry, apple pomace.

INTRODUCTION

The black vine weevil, *Otiorhynchus sulcatus* (F.), is one of the most important pests of raspberries, *Rubus idaeus* L., in the Fraser Valley of British Columbia. This parthenogenetic species overwinters primarily in the larval stage. Overwintering larvae resume development in spring and emerge as adults in June. Adult weevils are nocturnal, feeding on foliage during the night and hiding in the debris or in the soil during the day. However, some weevils hide in the dense raspberry foliage during the day. These weevils often contaminate machine-harvested fruit because the mechanical harvester is indiscriminate in its collection of dislodged berries and insects. Although leaf-feeding by adults is not economically significant, contamination by adults greatly downgrades the harvested berries.

Monitoring is the first step in effective weevil control. In British Columbia, the two techniques most commonly used to detect weevils are visual searches for leaf notching and shaking or tapping bushes to dislodge weevils. Visual searches are accurate early in a growing season but, as the season advances, fresh notches are difficult to distinguish from old ones. Shaking or tapping bushes is most accurate when done after dark, which is inconvenient. As fruit ripens, shaking may also dislodge many berries. Weevil monitoring could be improved if a convenient, non-destructive, daytime monitoring method were developed.

Traps are alternatives to visual searches and shaking. Maier (1983) and Hanula (1990) discuss the relative efficiencies of different types of traps. Maier (1983) concluded that board traps, which shelter weevils during the day, were more effective than pitfall traps, but Hanula (1990) found that pitfall traps were more effective. Growers in Hanula's (1990) study area were reluctant to use high-maintenance pitfall traps so he tested and recommended a deep-pan trap, which is easier to install and maintain.

Neither pitfall nor deep-pan traps are as easy to use as board traps. In British

Columbia, many growers and entomologists have remarked that the effectiveness of board traps seems correlated with several factors, including weather and the type of board used. Rough or creviced boards have seemed to be more reliable weevil monitoring tools than smooth plywood. Therefore, it is possible that board traps can be improved.

Here we report tests of two sizes of a grooved board trap for monitoring black vine weevils in raspberries. Within a trap size, we tested the addition of apple pomace bait on trap effectiveness. Apple pomace has long been recognized as an attractive bait for weevils (e.g., Smith 1932).

MATERIALS AND METHODS

All tests were done in a 6-ha field of 10 year-old Chilcotin raspberries (about 1.6 m high) in Langley, British Columbia, in June and July 1995. Clear, dry fir (2-cm thick) was used to make traps of two sizes: 30 x 30 cm (large) and 15 x 15 cm (small). Parallel grooves (1-cm deep, 0.8-cm wide, 2-cm apart) were cut with a Dado saw in the underside of each trap. One set of grooves ran in one direction (e.g., north to south) and the other set was perpendicular (e.g., west to east). This provided weevil access from all four edges (Fig. 1). Twenty-three large and 23 small traps were baited with apple pomace wrapped in cheesecloth pinned to the centre of the underside of the trap.

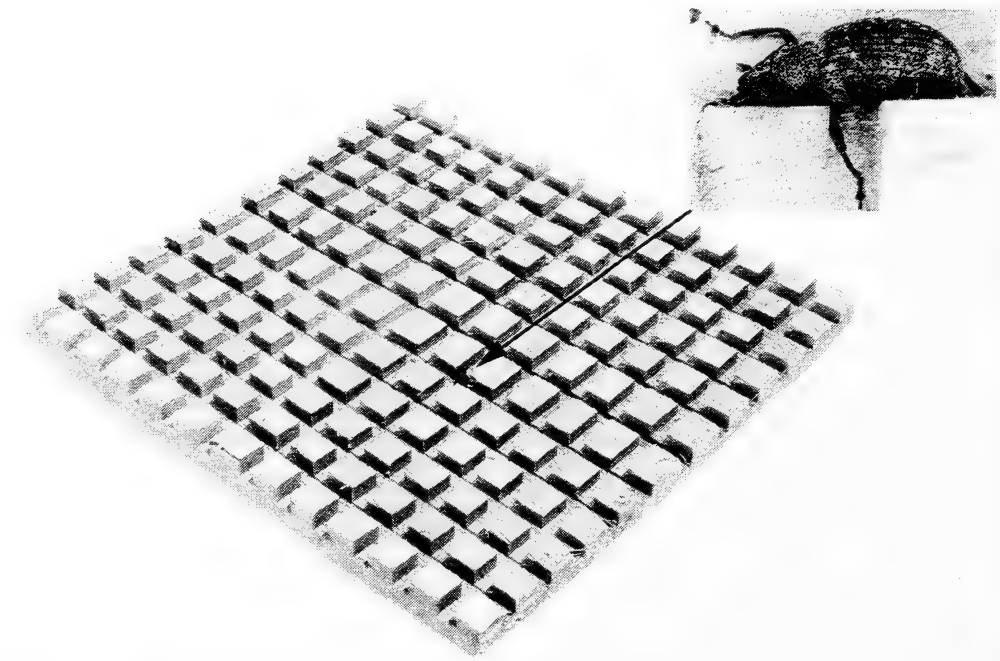

Figure 1. Underside of a large (30 x 30 cm) grooved board trap. Inset shows a closeup of a black wine weevil sheltering in a groove. Arrow shows actual location of weevil in the trap.

Tests were conducted in a 0.3-ha rectangular area (120 x 25 m) along one edge of the field. Considerable leaf notching in this area indicated that weevils were present. Traps were placed at the bases of canes having notched leaves. At each of 23 test locations, 2 large and 2 small traps (one of each size with bait and the other without) were arranged randomly groove-side-down on the soil as close to the canes as possible. Traps were

checked the morning after placement. Seven observations (trap checks) were made during the first monitoring period (June 13-23); 9 were made during the second (July 7-20). Trapped weevils were removed from the field. Apple pomace bait was changed every 2-3 days.

Trap-capture data were square-root transformed as $\sqrt{(x+5)}$ before ANOVA, where x is the total number of weevils caught in each trap during each monitoring period of the study. The effects of trap size and bait on weevil capture were determined by a two-way ANOVA, with trap size, bait and block (location and time) as the main effects (Abacus Concepts 1989). There were 46 blocks in the model: 23 locations for two periods of monitoring time. To determine which trap size was more sensitive for capturing weevils, the percentage of traps that caught at least one weevil was calculated for large and small traps for each of the 16 observations, and compared using a *t*-test.

RESULTS AND DISCUSSION

On average, large traps caught significantly more *O. sulcatus* than small ones [large: 0.6060 $\pm$ 0.0499 (mean number weevils per trap per observation $\pm$ SE), small: 0.3478 $\pm$ 0.0349, $F = 37.08$, df = 1, 135, $p = 0.0001$]. More weevils may shelter in large traps because large traps cover more surface beneath the raspberry canopy and provide more shady shelter for weevils than small ones. There was no difference in the numbers of weevils in traps with or without apple pomace bait (with bait: 0.5041 $\pm$ 0.0457, without bait: 0.4497 $\pm$ 0.0443, $F = 1.70$, df = 1, 135, $p = 0.1941$). This shows that apple pomace does not enhance the attractiveness of grooved board traps to weevils.

On average, 76.89 $\pm$ 4.10% (SE) of large traps caught weevils during the 16 observations, while the percentage for small traps was 58.81 $\pm$ 4.34% (SE). This difference is significant ($t = 3.03$, df = 30, $p < 0.05$), and suggests that the probability of trapping at least one weevil is greater in large traps. This will be important when the weevil density is low.

The results show that large traps were superior to small ones in terms of monitoring weevil presence in the field. The grooved board traps may replace shaking or tapping the bushes if there is a correlation between numbers captured by these two monitoring methods.

All weevils caught by either large or small traps rested inside grooves which provided shelter for them. Some beneficial insects, such as carabid beetles, were also found in the grooves. Unlike the pitfall traps, all beneficial species were alive in these grooved board traps and easily released to the field. This implies that grooved board traps are not harmful to beneficials. We also found some cutworm larvae in the traps, suggesting that grooved board traps may also be useful for cutworm monitoring. Board traps are easy to set up in the field, easy to check and do not require maintenance. They are readily moved from one location to another, and can be reused for several years. Therefore, the grooved board trap is a useful monitoring tool for black vine weevil in raspberry fields. It may also be useful for weevil monitoring in strawberries and blueberries.

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Mating disruption of Douglas-fir tussock moth one and two years after the application of pheromone

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ABSTRACT

Mating disruption of the Douglas-fir tussock moth, *Orgyia pseudotsugata* was monitored in 15 plots, near Keremeos, B.C. in 1993, one and two years after treatment with a synthetic pheromone, *Z-6-heneicosen-11-one*. Six plots were aerially treated, 3 were treated from the ground and 6 received no treatment. Total male moth catches from both the ground- and aerially-treated plots were significantly reduced, compared with control plots, when a synthetic pheromone was used as bait. However when virgin females were used as bait, only the ground treatment was significantly different from the control and only for one year after treatment.

Key words: tussock moth, Lymantriidae, biological control, mating disruption, *Orgyia*, pheromone

INTRODUCTION

The Douglas-fir tussock moth *(Orgyia pseudotsugata* McDunnough*)* occurs in outbreak numbers approximately every ten years (Shepherd *et al.* 1985) and these outbreaks are usually in the same geographical area. The outbreaks last from 1 to 4 yr and can cause complete defoliation of Douglas-fir (*Pseudotsuga menzeisii ssp. glauca* (Beissn.) Franco). Since 1989, the Forest Insect and Disease Survey of the Canadian Forest Service has monitored Douglas-fir stands with known history of tussock moth outbreaks, thus providing an early warning system of impending outbreaks. We have used this monitoring system since 1991 to plan early treatment of stands with *Z-6-heneicosen-11-one,* the tussock moth's sex pheromone. A synthetic pheromone was applied in polyvinyl chloride (PVC) beads, 250 to 400 μm diameter (Hulme and Gray 1994) to Douglas-fir forests near Keremeos, B.C. During the year of treatment this technique of mating confusion is highly effective in reducing the number of fertile eggs without detrimental effects on the parasites that attack Douglas-fir tussock moth (Daterman 1990). Sower *et al.* (1990) reported that traps baited with synthetic pheromone caught few moths one year after plots were treated with pheromone-filled black hollow fibres. The object of this study was to see if synthetic pheromone applied in polyvinyl chloride beads continued to confuse male Douglas-fir tussock moths one and two years after application.

MATERIALS AND METHODS

Applications of synthetic tusssock moth sex pheromone were made to 3 plots in 1991 and 6 different plots in 1992. In 1991, the larval density was determined by beating three lower branches on each of 20 trees from random locations in each plot. Densities ranged

from 4.2 to 27.3 larvae/plot (Shepherd 1985). Three plots: Winters Creek (3.9 ha), Larcan Creek (2.2 ha) and Shoemaker Creek (1.6 ha) were treated with *Z-6-heneicosen-11-one* at 36 g/ha. The application was by a Bell 206 helicopter equipped with a "Simplex" boom and nozzle spray system (Shepherd and Gray 1992). The D-6 nozzles were calibrated to produce a spray swath of 20 m on the ground. The spray mixture contained, 0.2% adjuvant (Nalco-Trol), 0.1% surfactant (Triton B-1956), 2.0% latex sticker (Gelva RA-1990), 97.7% water and pheromone-impregnated PVC beads. They were measured out for each plot at a mixing site before being added to the helicopter's holding tanks and applied on August 2, 1991. Cocoons marked with flagging tape were also monitored, by observing whether or not the wingless female had emerged, weekly from August 5 to September 10 to determine if mating had occured.

In 1992, six 2-ha plots, different from those used in 1991, were treated with *Z-6-heneicosen-11-one* at 72 g/ha. Three plots were treated aerially and three from the ground. Larval densities were determined as for 1991. There was no significant difference in the mean number of larvae between treated and control plots ($p > 0.05$, $\chi^2 = 8.9$; plot mean = 82 SD = 9). Aerial application was by a Hiller UH12E helicopter equipped with a boom and nozzle spray system using D-6 nozzles calibrated to produce an 18 m spray swath on the ground. A ground application was made to the other three plots with a Grinder sprayer Model PS 325-3 (W-W Grinder, Kansas City, KA) with a 30 m hose and a D-6 nozzle. The sprayer was driven through the stand in the back of a 4 x 4 pickup truck. Each host tree was sprayed for approximately 5 s to a height of approximately 10 m. The mixture contained the same ingredients as the 1991 spray. Mixture components were measured for each plot in the laboratory and mixed at the spray site before adding them to the helicopter's holding tanks or the Grinder sprayer. They were all applied on 30 July 1992.

In 1993, the monitoring program after treatment consisted of 6 plots left as untreated controls and of the remaining 9 plots, three which were sprayed in 1991, and six in 1992. Sticky delta milk carton traps, with three sides providing a total trapping surface of 855 cm^2, were baited with the synthetic pheromone, in a polyvinyl chloride rod 3 mm diam x 5 mm long, (Daterman 1974) at the rate of 0.01% wt/ wt, similar to that produced by an unmated female. Ten traps with synthetic bait were set out in each plot from August 10 to October 28. Traps were placed 1.5 to 2 m above ground in trees and spaced 40 m apart. Traps that caught 15 or more male moths were replaced with new traps but the old lure was reused. Trap catches were counted and recorded weekly. Each plot also contained ten sticky delta milk carton traps, each baited with a virgin female confined in 30 dram pill vials with insect screening at each end. These traps were hung in a similar pattern to the synthetic pheromone baited traps. Female pupae were held in the laboratory in Victoria, B.C. at three different temperatures to provide fresh, actively-calling females for the duration of the field tests. The calling period of unmated females is usually from 3 to 5 days after eclosion and therefore caged females in field traps were replaced weekly, if emergence had occurred.

Larval densities (beating samples per treatment) were analyzed by a chi-square test (Zelen and Severo 1964). Male moth catches were grouped by treatment and subjected to a Kruskal-Wallis test and each pair of the group was tested for significance between treatments using a Mann-Whitney test (Wilkinson 1992).

RESULTS AND DISCUSSION

Pheromone-baited trap catches. The efficacy of the application of pheromones to control insects is usually measured in the year of application and residual effects are seldom measured. Although different concentrations of synthetic pheromone were applied, 36 g/ha and 72 g/ha in 1991 and 1992 respectively, both were considered sufficient by the authors to disrupt the mating processes of the tussock moth (Hulme and Gray 1994). Significantly more male moths were trapped with synthetic baits in the control plots one year after treatment than in either the ground- or aerially-treated plots (Fig. 1A).

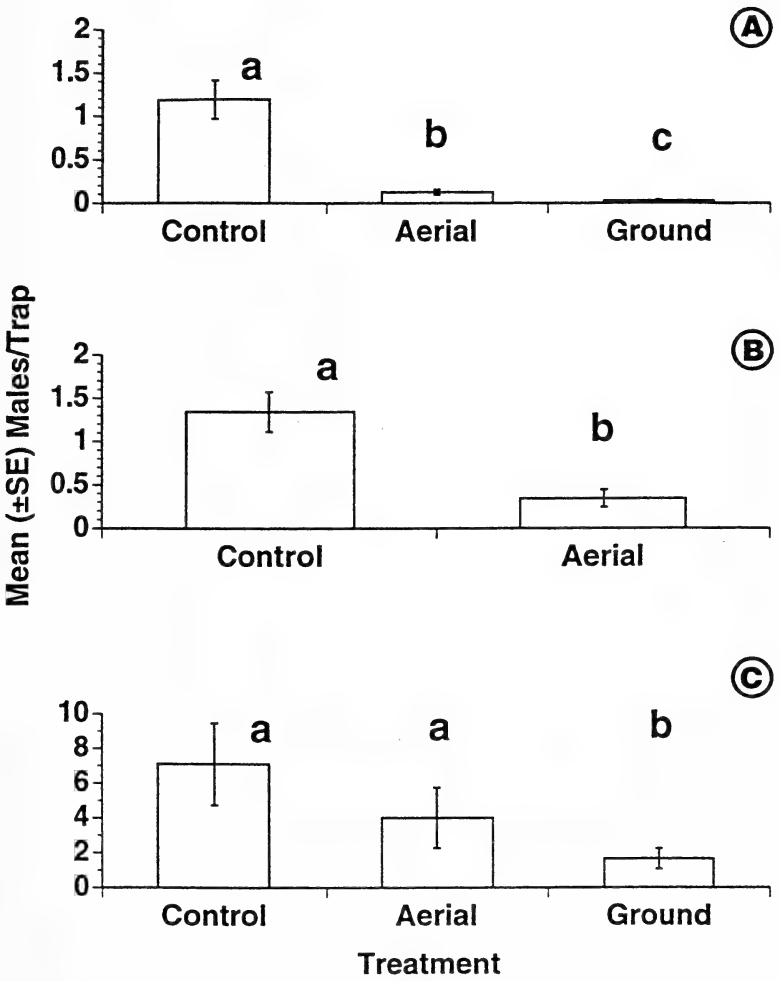

Figure 1. Mean number of male Douglas-fir tussock moths, *Orgyia pseudotsugata*, per trap caught in delta sticky traps at Keremeos, B.C., 1993 after treatment with synthetic pheromone. Means having different letters are significantly different ($p<0.05$). A) One year after treatment, synthetic lures (n=150); B) Two years after treatment, synthetic lures (n=150); C) One year after treatment, unmated female lures (n = 23)

Male moth catches in the control plots were also significantly higher than those from the aerially-treated plots two years after treatment (Fig.1B). We did not treat any plots from the ground in 1991, and were therefore unable to determine the two-year residual effect of a ground treatment. Results suggest the beads continued to emit enough pheromone to impair some of the males ability to find the pheromone-baited traps. The results may indicate that less synthetic pheromone was being emitted from the aerially-applied beads than from ground-applied beads one year after treatment. Different distribution of the beads probably explains why. The ground spray was applied up the tree trunks and was probably protected from degradation by the sun, and less exposed to wind, rain and snow then the aerially-applied treatment where most beads were probably on exposed foliage.

Effect on trap catches using virgin females. The female-baited traps caught significantly more males in the control than in the ground-treated plots one year after treatment but there was no significant difference between the controls and the aerially-treated plots (Fig. 1C). These results suggest that virgin females are more attractive to males than *Z-6-heneicosen-11-one*. Hulme and Gray 1994 also found female baited traps to be more attractive to males than the synthetic pheromone baited traps. These results are partly explained by our knowledge that the synthetic lures lack minor components of the pheromone.

Impact of continued pheromone release on pest management. Results showed that the beads continue to emit pheromone for at least two years after application but that the release of pheromone was probably reduced. The pheromone released from ground applied beads after one year was sufficient to reduce trap catches to near zero with either synthetic pheromone or female baits. Extensive natural disruption of mating would thus be expected in these ground-applied plots. Although trap catches in the aerially-applied plots were reduced by over 50% one year after application, many moths were still caught in most traps, particularly those baited with virgin females. Thus while pheromone continued to be released in our tests it seems unlikely that natural mating would be severely disrupted. Our results confirm that pheromone applied in beads can continue to confuse males as shown by the reduced trap catches for one and two years after treatment.

Although we were able to achieve 100% mating disruption of tussock moths (Hulme and Gray 1994) using high dosages, the cost of pheromome was also high. We will report later on studies using reduced dosages of pheromones which makes this type of treatment more cost effective.

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First record of orange mint moth (Lepidoptera: Pyralidae) on commercial peppermint in Idaho[1]

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ABSTRACT

The orange mint moth, *Pyrausta orphisalis* Walker was encountered in a peppermint (*Mentha piperita* L.) field in the Indian Cove area, in Owyhee county, along the Snake River 10 km west of Hammett, Idaho. This is the first known record of orange mint moth in commercial mint in Idaho. Subsequent examination of fields in the main mint production area in Treasure Valley of western Idaho found another population of orange mint moth established in a field west of Boise, Idaho.

Key words: Orange mint moth, *Pyrausta orphisalis*, peppermint oil, essential oil.

DISCUSSION

Orange mint moth, *Pyrausta orphisalis* Walker (Lepidoptera: Pyralidae) is a widespread species indigenous to the region along the Canada-U.S.A. border and south down the Atlantic and Pacific coasts (Munroe, 1976). It has a broad host range on plants in the Menthaceae, including the genera *Mentha* and *Monarda*. It has been reported by Pike, *et al.*, (1987) to be a common insect in commercial mint fields in Washington state (Fig. 1), with occasionally high population levels. Pike, *et al.* (1986) reported that larval feeding on the mint canopy stimulated oil production, and indicated that orange mint moth was a beneficial insect.

Orange mint moth overwinters as prepupae in chambers spun of silk combined with fragments of soil and leaf debris at the soil surface. In central Washington, Pike, *et al.* (1986) reported pupation from 20 April through 20 May, with emergence of adults beginning 5 May. There are three generations per year with oviposition of the first generation from 10 May to 10 June. Mated females lay individual eggs on new growth at the shoot apices. First generation larvae feed on new foliage, but second and third generation larvae feed primarily on inflorescences, typically with one larva per inflorescence. There are five larval instars; the first generation begin to form prepupae around 10 June, and adults emerge on approximately 25 June. This first generation of adult moths is present until the end of July. Second generation adults are present from the first week of August until mid-September in central Washington (Pike, *et al.*, 1986). Prepupae of the third generation begin forming by the end of September, but some fifth instar larvae were found as late as 15 November.

Pike *et al.*, (1986), described how larvae feeding on peppermint foliage increased oil production by stimulating axillary branch development, which resulted in increased leaf production. Peppermint oil from Idaho typically contains from 2 to more than 7 % menthofuran, an undesirable component produced in the inflorescence. Because second

and third generation orange mint moth larvae feed on and consume inflorescences, their presence in the crop could reduce the percentage of menthofuran. Consequently, the orange mint moth might benefit mint oil production both by improving its quality and its quantity.

Figure 1. Range of orange mint moth (OMM) *Pyrausta orphisalis* (Pyralidae) in commercial mint grown in the Pacific Northwest.

The first orange mint moth was captured in a peppermint field 10 km west of Hammett, Idaho (Fig. 1). At approximately 10 a.m. on 23 Sept., 1994 the adult moth was seen flying above the canopy and was collected for identification. Field searches were therefore initiated in the main mint production area in Canyon and Ada counties in southwestern Idaho, west and south of Boise. On 27 Sept. two more orange mint moths were collected in a field 11 km west of Boise in a field of second-year peppermint. Subsequent searches in fields detected no additional locations where the moth could be found. Return visits to the field near Boise resulted in 4 more moths netted on 28 Sept., 11 on 29 Sept., and 6 on 4 Oct. A return visit to the original field on 7 Oct. resulted in collection of 6 more moths. Specimens were sent for identification and preservation to the entomology collections at Albertson's College of Idaho, Caldwell; the University of Idaho, Moscow; and the Irrigated Agriculture Research and Extension Center, Prosser, Washington. Dr. Keith Pike (Prosser) confirmed the identification of the specimens (personal communication) as orange mint moth, *Pyrausta orphisalis* Walker (Lepidoptera: Pyralidae). The University of Idaho entomological museum contained orange mint moth specimens collected from Wallace, Idaho, probably associated with wild mint. The Wallace, Idaho area has never been a site of commercial mint production.

It is not known how widespread orange mint moth is in Idaho mint production. The insect has probably been present for some time and is established on wild mints. Applications of insecticides to mint during spring to control cutworms (*Euxoa* and *Peridroma* spp.), during summer to control loopers (*Autographa* and *Trichoplusia* spp.),

or post-harvest to control mint root borer (*Fumibotys fumalis* Guenee; Lepidoptera: Pyralidae) could suppress orange mint moth populations. Winter tillage, although not usually done in Idaho from fear of spreading Verticillium wilt, would also suppress the moth.

The orange mint moth is an active and evasive flier. They take wing well ahead of a person walking through the mint field, and after a brief, erratic flight, dive into the canopy, so they are unlikely to be discovered in sweep net sampling. Adult moths are approximately 15 mm overall length (Campbell and Pike, 1984), so they are smaller than mint root borer moths, and may escape observation by persons unfamiliar with orange mint moth. More research is needed to determine the distribution and abundance of the moth in Idaho.

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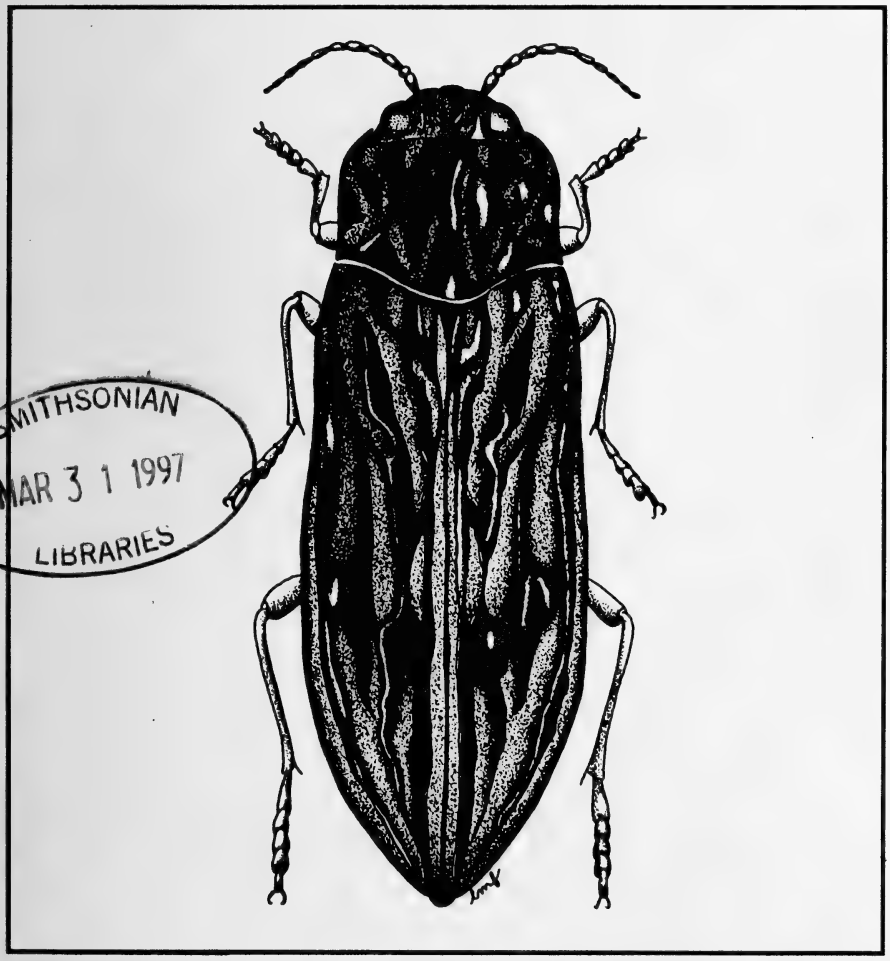

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COVER : Sculptured pine borer, *Chalcophora virginiensis* (Drury) (Coleoptera: Buprestidae). Adults of this species reach 31 mm and as such are the largest of the western species of flatheaded borers. As their common name suggests, they have a uniquely sculptured dorsal surface. Their abdomen is equally remarkable with its beautiful iridescent bronze lustre, common in this family of insects. Larvae feed on dead and dying pine, fir and Douglas-fir. Pen and ink drawing by Laurie Friskie. Specimen caught near Kamloops, BC, by artist.

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Effects of a neem seed extract against the white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae), in Sitka and white-Engelmann spruce.

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ABSTRACT

A botanical insecticide based on extracts of seeds from the neem tree, *Azadirachta indica* A. Juss, was applied systemically to Sitka spruce and white-Engelmann spruce hybrids and sprayed directly onto the leaders of white-Engelmann spruce to test its efficacy in controlling the white pine weevil, *Pissodes strobi* Peck. Neither treatment had any effect on weevils or damage in the white-Engelmann spruce, and control was not economical.

Key words: neem, weevil, azadirachtin

INTRODUCTION

The white pine weevil, *Pissodes strobi* Peck, is a transcontinental pest of spruce, *Picea* species, attacking such important timber species as Sitka spruce, *P. sitchensis* (Bong.) Carr, Engelmann spruce, *P. engelmannii* Parry, and white spruce, *P. glauca* (Moench) Voss. Larval feeding in the phloem can girdle the leader causing the terminal growth to wither. This in turn leads to stunted trees, stem deformities, decreased lumber volume, and repeatedly attacked trees are short and overtopped by competing vegetation to the point where a severely attacked plantation may be unmerchantable (Alfaro 1989).

In British Columbia, planting of Sitka spruce has been greatly reduced and is limited to areas of low beetle attack (Heppner and Wood 1984). This is despite the fact that it outgrows all other conifer species on alluvial and rich, low-elevation coastal sites and that log values for second growth Sitka spruce timber are higher than for other species on those sites (B.C. Min. of Forests 1990). Thousands of hectares of young spruce plantations also are in danger of becoming unmerchantable unless a suitable method can be found to control *P. strobi*. Spruce is also being affected in the interior of B.C. where salvage of bark beetle infestations of naturally-occurring white-Engelmann hybrids has produced large spruce plantations. Intensive silvicultural practices, such as the creation of open-grown stands through spacing and clearing brush, have produced particularly susceptible trees (McLean 1989, Taylor *et al.* 1994).

At present, there is no economically viable control method for *P. strobi*. Clipping of attacked leaders is expensive and time consuming and augmentation of natural enemies has not proven successful (Rankin & Lewis 1994). Foliar sprays of insecticides such as oxydemeton-methyl and acephate will give complete control of white pine weevil in the year of application and some control the following year (Gara *et al.* 1980), however widespread aerial sprays of insecticides are increasingly out of favor. Fraser and Heppner (1993) demonstrated that systemic applications of oxydemeton-methyl and acephate decreased leader attack of Sitka spruce.

Seed extracts of the neem tree, *Azadirachta indica* A. Juss (Meliaceae), have a number of desirable properties for managing insect pests including repellency, feeding and oviposition deterrence, insect growth regulation, low mammalian toxicity, and rapid degradation (Mordue & Blackwell 1994, Schmutterer 1990). Because the anti-feedant and IGR effects are seen mostly against immature insect stages that have ingested neem, it may also be safer to non-target insects than most conventional insecticides (Hoelmer *et al.* 1990, Lowery and Isman 1994, McCloskey *et al.* 1993, Stark 1992). The most important constituent of neem seed extracts (NSE) is the limonoid compound, azadirachtin.

The translocation of azadirachtin has been demonstrated in agricultural crops (Larew 1988, Osman & Port 1990, Saxena 1987) and trees (Marion *et al.* 1990). Naumann *et al.* (1994) found that systemic applications of NSE could decrease the numbers of mountain pine beetle, *Dendroctonus ponderosae* Hopkins, larvae surviving within lodgepole pine trees, *Pinus contorta* Douglas var. *latifolia*.

In this study, we examined whether systemic applications or sprays of NSE directly onto the leaders can be used to protect against loss of leaders from weevil attack and to destroy white pine weevil larvae within Sitka spruce and hybrid trees of the white-Engelmann spruce complex.

MATERIALS AND METHODS

A solution of NSE in methanol, containing 2.5% azadirachtin (25,000 ppm), was obtained from Phero Tech Inc. (Delta, B.C. Canada).

Systemic treatments were applied to Sitka spruce in the Benson River area, near Port McNeill, on Vancouver Island, B.C., and to white-Engelmann spruce at two sites near Williams Lake B.C. : Gavin Lake and Quesnel Lake. Leader sprays were tested only on white-Engelmann spruce at Gavin Lake.

Systemic Treatments. Two treatments were used: NSE at 25,000 ppm azadirachtin, and a control of methanol only. The treatments were administered by drilling holes, 6 mm in diameter, 1.5 cm deep, and sloping downwards, into the trees at breast height and then filling the holes with one or other of the liquids. One hole was drilled for approximately every 2.5 cm of trunk diameter at breast height (dbh). Each hole received approximately 0.4 ml of fluid, i.e., 0.01 g of azadirachtin.

Two tests were conducted at the white-Engelmann spruce sites. The first (pre-attack treatment) tested the effectiveness of an NSE application in saving leaders from destruction, the second (post-attack treatment) more closely examined the potential lethal effects on weevil larvae within already attacked leaders. In the pre-attack test, treatments were applied to a total of 60 trees at each of the two white-Engelmann spruce sites immediately before oviposition, during the first week of May, 1994. Post-attack injections were applied to different trees on July 4. Twelve and 14 trees per treatment group were used at Gavin Lake and Quesnel Lake, respectively. By that time, weevil-

attacked trees could be identified by their drooping leaders. Only a pre-attack trial was conducted in Sitka spruce; 30 trees per treatment group were injected in the third week of April.

Pre-attack test trees at all sites were chosen for healthy appearance, tall leaders and relatively open locations, i.e., high susceptibility to weevil attack. Transects were run through the test stands, and suitable trees within 10 m of the transect lines assigned alternately to the neem and control treatments. Trees within the Sitka spruce plantation averaged approximately 10 cm dbh. Trees at the Gavin Lake site averaged 7.6 cm dbh and those at Quesnel Lake 8 cm dbh. There were no significant differences in tree diameters between treatments.

Leaders were cut from the white-Engelmann spruce trees in the second week of August, before the most mature weevils had completed pupation. The parameters measured were overall frequency of attack and leader destruction (for the pre-attack treatment only), and numbers of feeding punctures, oviposition punctures, larvae, pupae, and natural enemies per leader. Leaders from the Sitka spruce trees were collected in mid-October and compared for overall frequency of leader destruction, and numbers of larvae, pupal cocoons, adult exit holes, and natural enemies per leader. At all three locations, the great majority of natural enemies collected were larvae of the Dipteran genus *Lonchea*.

Data were analyzed by Chi-square test (frequency of attack and leader destruction), t-tests (numbers of different events per leader), and linear regression (to determine the strength of the relationship between numbers of natural enemies and hosts within the leaders)(Zar 1984). All analyses were run using Statistix statistical software (Anonymous 1991).

Leader Sprays. NSE (diluted with water to 100 ppm AI) was applied to tree leaders until runoff. Leaders were sprayed from the tip to the penultimate whorl of branches. Four treatments were used: a neem spray applied approximately 1 week after the main period of weevil oviposition (June 20, 1995), neem applied 2 weeks later, neem applied on both dates, and an unsprayed control. There were 30 trees in each treatment group. Leaders were cut from the trees in August and dissected to determine numbers of adult exit holes, pupal (chip) cocoons, surviving larvae, and surviving natural enemies. The sum of larvae and pupal cocoons per leader was used as a measure of total weevil survival. Data were analyzed by one way analysis of variance (Anonymous 1991).

RESULTS

Systemic NSE applications had no observed effects on *P. strobi* survival in white-Engelmann spruce (Tables 1, 2). The frequency of leader destruction was also not diminished by a pre-attack treatment of NSE. Conversely, a pre-ovipositional application to Sitka spruce caused significant reductions in the frequency of leader destruction, numbers of pupae/leader, number of successfully emerging adults, and number of natural enemies per leader (Table 3). There was no correlation between the number of individual natural enemies and number of hosts in the Sitka spruce leaders ($r^2 = 0.04$). Leader spraying to white-Engelmann spruce had no significant effects on any of the parameters measured (Table 4).

Table 1

Effects of pre-oviposition systemic application of NSE on white pine weevils in white-Engelmann spruce near Williams Lake. Means ± SE. Significant differences ($p \leq 0.05$) marked by *.

	control	NSE	
% trees with attacked leaders[1]			
Gavin Lake	46%	63%	$X^2 = 1.78, p = 0.19$
Quesnel Lake	29%	23%	$X^2 = 0.05, p = 0.82$
% trees with killed leaders			
Gavin Lake	23%	13%	$X^2 = 1.08, p = 0.30$
Quesnel Lake	23%	23%	$X^2 = 0$
# feeding punctures/leader			
Gavin Lake	28.3 ± 9.5	16.5 ± 5.6	$t = 1.07, p = 0.29$
Quesnel Lake	65.2 ± 9.9	76.4 ± 15.0	$t = 0.62, p = 0.53$
# oviposition holes/leader[2]			
Gavin Lake	16.4 ± 2.5	13.3 ± 3.9	$t = 0.67, p = 0.51$
Quesnel Lake	13.3 ± 2.7	32.0 ± 7.4	$t = 2.63, p = 0.05$*
Total surviving weevils/leader[3]			
Gavin Lake	7.0 ± 2.7	2.0 ± 1.1	$t = 1.72, p = 0.10$
Quesnel Lake	4.3 ± 2.0	4.1 ± 1.4	$t = 0.07, p = 0.94$
# natural enemies/leader			
Gavin Lake	11.9 ± 8.2	6.7 ± 3.6	$t = 1.41, p = 0.13$
Quesnel Lake	11.6 ± 4.5	8.1±10.9	$t = 0.56, p = 0.59$

[1] Leaders with two or more oviposition holes were considered to have been attacked.

[2] Values for numbers of egg holes and survivors are attacked leaders only.

[3] Value includes all stages alive when leader dissected plus number of exit holes.

Table 2

Effects of post-oviposition systemic applications of NSE on white pine weevils in white-Engelmann spruce near Williams Lake. Means ± SE.

	Control	Neem	*t*	*p*
# feeding punctures/leader				
Gavin Lake	88.6 ± 18.5	102.5 ± 21.5	0.49	0.62
Quesnel Lake	149.3 ± 22.3	88.7 ± 20.3	1.98	0.06
# egg holes/leader[1]				
Gavin Lake	63.8 ± 18.5	38.9 ± 11.0	1.16	0.26
Quesnel Lake	29.4 ± 5.4	34.5 ± 7.5	0.56	0.26
# living weevils/leader[2]				
Gavin Lake	21.3 ± 5.1	20.2 ± 5.4	0.16	0.88
Quesnel Lake	11.9 ± 3.1	7.5 ± 1.4	1.29	0.22
# natural enemies/leader				
Gavin Lake	7.3 ± 2.2	26.2 ± 10.1	1.82	0.09
Quesnel Lake	6.6 ± 1.6	5.5 ± 1.1	0.29	0.77

[1] Values for numbers of egg holes and survivors for attacked leaders only.

[2] Value includes all stages alive when leaders dissected plus number of exit holes.

Table 3

Effects of pre-oviposition systemic application of NSE on white pine weevils in Sitka spruce near Port McNeill. Means ± SE. Significant differences ($p \leq 0.05$) marked by *.

	control	neem	
% trees with weevil-killed leaders	87%	50%	$X^2 = 11.60, p < 0.001$*
# pupal cocoons/leader[1]	102.0 ± 7.7	65.9 ± 9.7	$t = 2.84, p < 0.001$*
# adult emergence holes/leader	16.1 ± 3.2	0.8 ± 0.6	$t = 4.91, p < 0.001$*
# live larvae/leader	3.2 ± 0.7	6.1 ± 2.3	$t = 1.19, p = 0.25$
# natural enemies/leader	27.7 ± 5.6	8.9 ± 2.5	$t = 3.07, p = 0.006$*

[1] Values for this category and those below are for killed leaders only.

Table 4

Effects of post-oviposition sprays of NSE on white-Engelmann spruce near Williams Lake. Means ± SE. Sample size = 30. No significant differences (critical value of $p \leq 0.05$).

Spray 1 ~ week after oviposition	Spray ~ 3 weeks after oviposition	Spray on both dates	Control	F	p
# pupal cocoons/leader					
13 ± 2	7 ± 2	8 ± 2	12 ± 3	2.13	0.10
# adult exit holes/leader					
32 ± 6	18 ± 4	22 ± 4	28 ± 5	1.95	0.12
# larvae + pupal cocoons					
33 ± 6	20 ± 4	22 ± 4	30 ± 6	1.52	0.21
# natural enemy larvae per leader					
8 ± 2	4 ± 1	6 ± 2	5 ±1	1.08	0.36

DISCUSSION

In our study, systemic applications of NSE to spruce did not control white pine weevil to the same degree as has been reported for mountain pine beetle in lodgepole pine (Naumann *et al* 1994). However, pre-attack systemic applications of NSE did reduce the frequency with which white pine weevils destroyed Sitka spruce leaders and caused significant decreases in the numbers of weevils surviving to pupae and adults. The NSE also decreased the numbers of natural enemies within the leaders. This reduction was not due solely to a decreased availability of hosts because there was no correlation between the two values. The insecticidal effects of NSE applications have been reported to extend to a higher trophic level (McCloskey *et al*, 1993), although NSE has often been reported to be safe to non-target species (Stark 1992, Lowery & Isman 1994).

The absence of any neem-induced effects in the interior spruce may have been due to inherent differences in translocation or metabolism of azadirachtin as compared to Sitka spruce, or to temperature-related differences in translocation between the warmer, interior and cooler, coastal sites. Differences in tree size was unlikely to have been a factor

because mean diameters at breast height differed by approximately one cm, and larger trees received relatively greater volumes of neem formulation.

Direct sprays of neem onto the leaders of the white-Engelmann spruce hybrids also had no effect on the survival of white pine weevils or the frequency of leader destruction. The dose used was approximately twice that shown to be effective for controlling phytophagous pests in agricultural ecosystems (Isman 1995). Lack of efficacy could have been due to insufficient absorption of azadirachtin into the phloem, i.e., to where the larvae were feeding.

The results of our study suggest that NSEs are unlikely to be an important option for protecting large areas of spruce from the white pine weevil. Testing higher doses may be worthwhile but difficulty in obtaining NSE formulations with high enough concentrations of azadirachtin, especially for systemic applications, is an obstacle. Greater numbers of applications are unlikely to be cost effective. The Sitka spruce results are encouraging enough to suggest that systemic NSE applications may be of value for protecting individual, high-value trees from some phytophagous insects. Further evidence for this comes from the success of systemic NSE in killing the mountain pine beetle in lodgepole pine (Naumann *et al.* 1994). Efforts should be directed towards understanding the mechanism by which the NSE affects phytophagous insects within trees, i.e., repellency or larvicidal action, the dose-response relationship for azadirachtin and various forest pests, and the rate and nature of azadirachtin translocation in trees of different species.

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Monitoring and predicting seasonal flight of *Orthosia hibisci* (Lepidoptera: Noctuidae) in the Okanagan and Similkameen Valleys of British Columbia

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ABSTRACT

Seasonal flight activity of the speckled green fruitworm, *Orthosia hibisci* Guenée, was monitored from 1990 - 1993 with a commercial sex attractant in Pherocon 1-C sticky traps and UV light-traps hung in unsprayed apple orchards in the Okanagan (Summerland and Kelowna) and Similkameen Valleys (Cawston). Flights in the Similkameen began in late February each year but not before the second week of March in the Okanagan. Catches with sex attractant peaked around the end of March or early April in the Similkameen and peaked about 5 - 14 days later in the Okanagan. Males were caught earlier in light-traps than in sex-attractant traps, but females were caught in light traps about 6 days after the first males were caught with the sex-attractant. After this time lag, female catches in light traps paralleled male catches. Moths were caught in light traps for 1 - 2 weeks after catches with sex attractants had ended. Weibull functions were fitted to curves of cumulative percent catch with sex-attractant traps plotted against days or degree-days above 3°C air temperature ($DD_{3°C}$) using Summerland traps. Among models fitted to the Summerland data, one using $DD_{3°C}$ after 1 January was the best predictor of flight activity in Kelowna and Cawston, where the errors in predicting 50% catch were about 1 and 2 days, respectively. A model using the date of first catch in a sex-attractant trap to start DD summations, called the *biofix* because it serves as a biological indicator of moth activity, predicted 50% catch within 3 - 4 days. The biofix model is recommended because it provides biological realism and less chance for error in years with unusual weather conditions. Models fitted to 10 data sets combined, predict that 50% catch will occur 166 $DD_{3°C}$ after 1 January, and 96 $DD_{3°C}$ after biofix, respectively. These models should aid in timing pest control measures, especially biorational pesticides that require accurate information on insect phenology to be most effective.

Key words: *Orthosia hibisci*, green fruitworm, monitoring, flight activity, degree days, modelling.

INTRODUCTION

The speckled green fruitworm, *Orthosia hibisci* Guenée, belongs to a North American complex of green fruitworms that feed on leaves and young fruits of many trees, including apple and pear (Chapman and Lienk 1974, Rings 1970). Although Madsen and Procter

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(1985) never mentioned *O. hibisci* in their list of insects feeding on pome fruits in British Columbia, it is currently the most common green fruitworm pest in Okanagan and Similkameen orchards (Cossentine and Jensen 1995). *Orthosia hibisci* has one generation each year and overwinters as a pupa in the soil (Rings 1970). Adults emerge in early spring, eggs are thought to be laid shortly thereafter and young larvae begin to feed on apple buds in the tight-cluster stage (British Columbia Ministry of Agriculture, Fisheries and Food 1995). There are six larval instars and the later ones cause most of the damage to young fruit, but this depends on the phenology of fruit development (J.E. Cossentine, unpublished observations, Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, B.C.).

Historically, green fruitworms have only been sporadic pests of pome fruits in British Columbia, because routine insecticide sprays for codling moth, *Cydia pomonella* (L.), control them (Madsen and Procter 1985). However, a recent sterile insect release (SIR) programme to eradicate codling moth from British Columbia's interior fruit-growing valleys (Dyck and Gardiner 1992), has forced changes to existing tree-fruit pest-management programmes. More damage from early season pests like *O. hibisci* and a greater need for specific controls of these pests is expected after the removal of insecticides aimed at codling moth (Judd and Gardiner 1992).

An ability to predict the seasonal flight activity of adult *O. hibisci* using traps and heat unit accumulation could be useful in designing an optimal control strategy. Although the life history of *O. hibisci* in British Columbia (Judd *et al.* 1994) is the same as reported by Rings (1970), its seasonal phenology is probably different. In New York (Weires *et al.* 1980) and Québec (Vincent and Simard 1986), adults apparently begin to emerge in late March or early April, respectively, and moths fly until late May, but moth activity has been seen as early as February in British Columbia (G.J.R.J. and D.R.T., unpublished data). Flight activity of adult *O. hibisci* can be monitored with attractant-baited traps (Lienk and Chapman 1978, Weires *et al.* 1980, Vincent and Simard 1986) or UV light traps (Paradis 1978) and Judd *et al.* (1994) provided a physiological basis for predicting development in overwintering pupae. Therefore, our objectives were: 1) to describe the seasonal flight activity of adult *O. hibisci* at three sites over four years by monitoring with a commercially available sex attractant and UV light-traps; 2) to compare and contrast the flight activity of males and females; 3) to describe the relationship between flight activity and temperature, and 4) to develop a method of predicting seasonal flight activity using this information.

MATERIALS AND METHODS

Monitoring Adult Flight Activity Patterns. One certified commercial "organic" apple orchard at Cawston, 5 km south of Keremeos in the Similkameen Valley, and two unsprayed experimental apple blocks in the Okanagan Valley, one at the Agriculture Canada Research Centre in Summerland and the other at its Kelowna Substation, were used in this study. Two Pherocon 1-C style wing traps baited with commercial sex-attractant lures for *O. hibisci* (Ecogen, formerly Scentry®, Buckeye, Arizona, USA) were hung about 1.5 m above ground in the centre of each orchard-block. Monitoring began in mid-February each year (1990 - 1993) and continued until June. Lures were replaced at four-week intervals and the adhesive trap bottoms were replaced as required to avoid saturation with moth scales. At Summerland, traps were examined daily, whereas at Cawston and Kelowna, traps were examined weekly by one of us and daily by growers. Captured specimens were identified by wing patterns and genitalia. No other

lepidopteran species were caught in the sex-attractant-baited traps.

Flight activity of males and females was also monitored with UV light-traps placed approx. 20 m from the attractant-baited traps at the Cawston and Summerland sites. Light-traps were emptied daily at Summerland and weekly at Cawston. All moths were taken to the laboratory where they were frozen until sorted and sexed.

Weather Data. Hourly air temperatures were recorded throughout 1990 - 1993 at each site using two-channel DP-212 datapods (Omnidata Int., Logan, Utah) housed in Standard Stevenson screens placed in the centre of each orchard block. Daily degree-day (DD) summations for each site and year were calculated by fitting a sine wave (Allen 1976, case 4) to daily air-temperature minima and maxima using the computer program described by Higley *et al.* (1986). A developmental minimum temperature of 3°C was used in these calculations as this is the approximate threshold for pupal developmental (Judd *et al.* 1994). Although pupae overwinter in the soil, they do so near the surface (Judd *et al.* 1994), hence, air temperatures were found to be more useful than soil temperatures for predicting adult emergence (G.J.R.J., unpublished data). Air $DD_{3°C}$ summations were accumulated from 1 January until one week after the last moth had been caught at each site.

Data Analyses. As traps were only checked weekly at Cawston and Kelowna, all trap catches were summed over weekly intervals and plotted against days starting 1 January, the Julian date. Catches were also converted to percentages and cumulative percentages of seasonal total trap catches for each sex and trap-type for a given site and year, were plotted against Julian date. These sigmoid curves were rendered linear, by transforming percentages to probits (Finney 1971). Least-squares linear regression of probits on date was used to estimate the dates when chosen percentiles between 5 and 95% of the catch occurred; often these dates could not be identified exactly from a weekly sampling regime. All statistical calculations and tests were performed with SigmaStat™ Statistical Software (Version 1.0 for Windows, Jandel Corp.).

The nonlinear relationships between cumulative percentage trap catch and various predictor variables were also modelled with cumulative Weibull functions, which described the tails of the cumulative catch curves more accurately than linear regression. Often used to describe variation in insect development times (Wagner *et al.* 1984), this function can also be used to describe the relationship between cumulative trap catches and time or temperature (Cockfield *et al.* 1994). A cumulative Weibull function in the form,

$$f(X) = 100 \times \left(1 - e^{-\left(\frac{x}{a}\right)^b}\right)$$

was used to describe or model the curves of cumulative catches, where (X) is the cumulative percentage trap catch, x is a chosen predictor variable, and a and b are parameters that define the shape of the distribution. Estimated values for the parameters defining each cumulative distribution or curve were calculated using the nonlinear regression procedure in SigmaStat™.

Predictive models of cumulative moth catch in relation to days and $DD_{3°C}$ were developed using sex-attractant trap catches at Summerland (1990 - 1993). Two starting dates for initiating accumulations of days and DD were chosen: 1) 1 January was chosen as a convenient but arbitrary chronological start to a new season, and 2) first catch in a sex-attractant trap, hereafter referred to as the *biofix*, was chosen as an identifiable biological reference point for the beginning of emergence of this insect. First trap catch using pheromones is a convenient method of incorporating biological realism into insect phenology models that has proven useful in predicting seasonal activity of other pests of

tree-fruit crops (Reidl *et al.* 1976).

Four model combinations (1 January start using days or DD, and a biofix start using days or DD) were used to predict cumulative catch curves for sex-attractant traps monitored in Kelowna (1990 - 1992) and Cawston (1990, 1992 and 1993) using weather data from the respective sites. Due to an equipment failure there were no weather data from Cawston in 1991. The observed dates for 50% catch at Cawston and Kelowna, as estimated from probit regression lines, were compared with the predicted values from the Weibull models fitted to Summerland data. A paired-sample *t*-test ($\alpha = 0.05\%$) was used to test the null hypothesis that the mean deviations between observed and predicted values were zero (Zar 1984).

RESULTS AND DISCUSSION

Seasonal Flight Activity Determined with Sex-attractant Traps. Weekly catches of male *O. hibisci* in sex-attractant traps showed significant differences in the start of flight among Cawston, Summerland and Kelowna populations during 1990 - 1992 (Fig. 1).

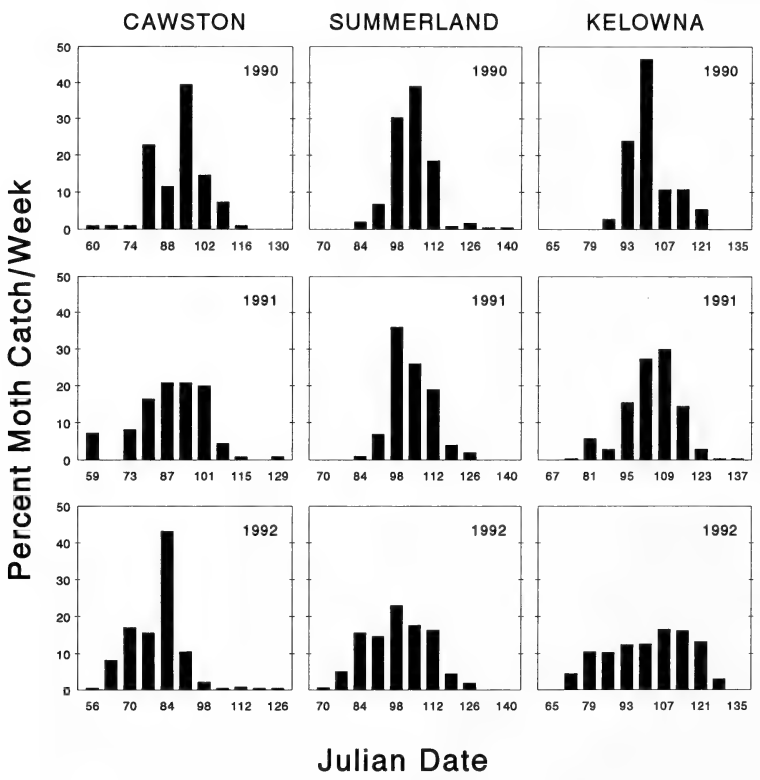

Figure 1. Weekly percentages of total catches of male *O. hibisci* in sex-attractant-baited Pherocon 1-C traps during 1990-1992 at Cawston, Summerland and Kelowna. Julian date = days from 1 January. Totals caught in 1990, 1991 and 1992, respectively, were: Cawston 96, 110, 216; Summerland 253, 95, 305; and Kelowna 75, 310, 480.

Flight activity in Cawston began in the last week of February or about 50-60 days after 1 January each year, while flights in Summerland and Kelowna never started before the second week of March, about 75 days after 1 January. Located in the Similkameen Valley,

Cawston is the most south western location in this study and generally accumulates heat units earlier than sites in the Okanagan Valley (Judd and McBrien 1994).

At all sites and in most years, catches with the sex-attractant traps had a single well defined peak as reported in Québec (Vincent and Simard 1986), but occasionally curves were flattened and skewed (eg. Kelowna 1992). Differences in flight activity among sites were less pronounced as the flights reached their peaks, usually in late March or early April (Fig. 1). Catches in Cawston usually peaked 5 - 14 days earlier than at Summerland or Kelowna. Flight activity of *O. hibisci* in the Okanagan and Similkameen Valleys began about 32 and 75 days earlier than the first captures in New York and Québec, respectively (Weirs *et al.* 1980, Vincent and Simard 1986). Cumulative catches in Pherocon 1-C traps during each year of this study were also higher in British Columbia than those reported for Québec (Vincent and Simard 1986).

Comparison of Male and Female Flight Activity. In contrast to studies in Québec (Paradis 1978), males were twice as abundant as females in light traps (Fig. 2).

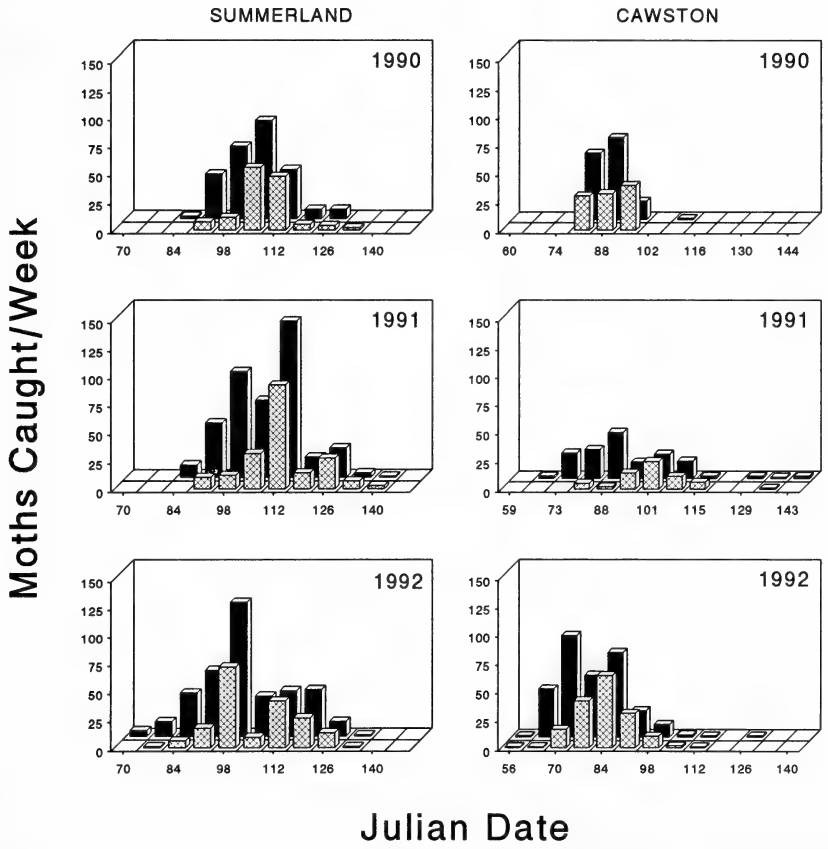

Figure 2. Mean weekly catches of male (solid bars) and female (hatched bars) *O. hibisci* in UV light-traps during 1990-1992 at Summerland and Cawston. Julian date = days from 1 January. Total moths (male:female) caught in 1990, 1991 and 1992, respectively were: Cawston 147:101, 146:63, 298:165 and Summerland 242:131, 409:196, 363:185.

Weekly catches in UV light-traps at Cawston and Summerland may indicate that *O. hibisci* is protandrous (Fig. 2), with males being caught about 11 days before females (Table 1). Protandry was not evident among adults emerging from field-collected pupae

held in the laboratory (Judd *et al.* 1994), but could arise from sex-related differences in depths of overwintering sites, or when diapause ends. However, differences in trap catches may simply reflect sex-related differences in adult maturation rates or flight behaviour. As light-trap catches of both sexes usually peaked and ended on the same date in each site (Table 1), a later emergence of females would mean that females have a shorter flight activity period than males.

Phenology of Flight Using Sex-attractant and Light-trap Catches. At Summerland, where traps were examined daily and first-trap catches could be identified exactly, first catches of males in light traps preceded catches in attractant traps by about 2 days (Table 1). First catches of females in light traps occurred about 9 days after the first males were caught in attractant traps and this difference in cumulative catches remained constant at least half way through the flight (Table 1). Different phenological patterns produced by these different traps may result from differences in their relative attractiveness. Generally it is assumed that light-traps capture a more local population than do sex-attractant traps because attractants carried on the wind can attract males from hundreds of metres (Wall and Perry 1984), whereas light traps may only be visible over a few metres. In fact, capture of males in attractant traps before emergence is expected, is often explained as the attraction of males from warmer microenvironments outside the local area where emergence was confirmed by other means (Reidl *et al.* 1976). If light traps catch the earliest locally emerging moths then later first catches in attractant traps, may indicate that the response of male *O. hibisci* to sex attractants under the prevailing conditions was delayed for at least a few days after emergence. If males emerge first, they may disperse for some time during which they do not respond to sex attractants, but do respond to light-traps, explaining their earlier capture in light traps (Table 1). Such a delay might increase outbreeding as it would allow males to disperse from their sisters before searching for mates. To answer this question more work is needed to establish the relationship between trap catches and actual emergence.

Differences in phenological events as measured by the different traps were less pronounced during the middle and peak periods (50%) of flight activity (Table 1). Catch curves for light-traps tended to have longer tails than those for the sex-attractant traps, often not reaching the 95th percentile until days or weeks after the sex-attractant traps (Fig. 2; Table 1). This may indicate that older adults, past their peak reproductive phase, are attracted to light- traps after mating opportunities have declined, along with responses to sex attractants. For this reason, sex-attractant traps probably detect local mating populations better, and may be more useful for integrated pest management in tree fruits. Although twice as many males were caught in light-traps, they required much more laborious and time consuming sorting. Although not identified as a pheromone, the commercial sex-attractant acted quite specifically in our geographic region. We agree with Vincent and Simard (1986) that sex-attractant traps are a useful method of monitoring seasonal flight activity of *O. hibisci*.

We also conclude that despite a time lag in capture rates, male catches in attractant traps could be used to estimate flight patterns of females, at least in the first half of the season. While the intercepts of linear regression lines for catch curves of each sex at a given site were different, their slopes were similar and parallel (*t*-tests, $p > 0.05$).

Day and Degree-Day Indices for Flight Curves. Differences in dates of first capture accounted for much of the yearly and geographic differences between the flight-activity curves generated by the two types of raps (Table 1; Figs. 1,2). However, after the first catch, the number of days to various catch percentiles was similar among years. At Summerland, dates of first, 5, 50 and 95% capture in sex-attractant traps and days

Table 1.

Observed day and degree-day (DD) summations from 1 January to various trapping events for *Orthosia hibisci* during 1990 - 1993 at Summerland using sex attractant (ST) and UV light-traps (LT).

	First trap catch			5% cumulative catch			50% cumulative catch			95% cumulative catch		
Statistic[a]	ST	LT		ST	LT		ST	LT		ST	LT	
	♂♂	♂♂	♀♀	♂♂	♂♂	♀♀	♂♂	♂♂	♀♀	♂♂	♂♂	♀♀
						DAYS						
Median	80	78	89	89	89	91	99	100	104	112	118	120
$\bar{x}$	77.7	74.3	83.7	84.7	85	89.3	97.7	99.3	102.3	111	118.7	121.7
SD	7.7	9.1	10.1	8.4	6.9	2.9	3.2	5.0	6.1	2.6	2.1	3.1
C.V.	9.9	12.2	12.1	9.9	8.1	3.2	3.3	5.1	5.9	2.4	1.7	2.5
						DD[b]						
Median	89.1	79.4	111.3	114.6	107.6	123.1	181.3	181.3	208.5	243	311.1	343.5
$\bar{x}$	87.4	79.4	111.3	115.2	116.4	141.2	186.5	195.0	216.1	272.5	327.1	350.4
SD	11.4	4.9	3.7	10.1	17.1	31.8	34.8	24.8	13.7	51.5	36.5	36.1
C.V.	13.0	6.2	3.3	8.7	14.7	22.5	18.6	12.7	6.4	18.9	11.1	10.3

[a]SD = Standard Deviation and C.V. = Coefficient of variation

[b]Degree days above 3°C air temperature

between these events, generally had smaller standard deviations (SD) and coefficients of variation (C.V.) than did the DD accumulations for the same events (Table 1). Nonlinear regression models confirmed this and based on r^2 values and standard errors (SE's) of regression coefficients, both days starting 1 January and days after biofix described flight curves at Summerland somewhat more accurately than DD after 1 January or biofix, respectively (Table 2). According to the fitted models (Table 2), on average 50% catch should occur on day 100 of the year, 19 days after biofix, or 170 DD starting 1 January, 86 DD after biofix.

Table 2.

Estimated values for parameters of Weibull functions and their goodness of fit to cumulative percent catch in sex attractant traps at Summerland (1990 - 1993) using different predictor variables and model starting dates.

Predictor variable	Model started	Weibull parameter	Estimated values (± SE)	Model SE	r^2 (p value)
Days	1 January	a	101.92 ± 0.45	6.05	0.98
		b	14.21 ± 1.05		(0.001)
	First catch	a	21.66 ± 0.88	10.21	0.94
		b	2.17 ± 0.27		(0.001)
Degree Days[a]	1 January	a	192.59 ± 10.09	18.33	0.82
		b	2.97 ± 0.56		(0.001)
	First catch	a	105.89 ± 5.67	10.99	0.93
		b	1.77 ± 0.23		(0.001)

[a]Degree days above 3°C air temperature

Predicting Seasonal Flight Activity. The accuracy of these different models was tested by using them to predict flight activity curves for independent data sets from Cawston and Kelowna. Using days starting 1 January the Summerland model predicted 50% catch, 7 - 22 days after it occurred at Cawston, but the prediction error ranged from 2 days early to 3 days late at Kelowna. Greater accuracy at Kelowna is not unexpected because catches at Summerland and Kelowna were similar and always began several days later than at Cawston (Figs. 1, 2). Use of a first-catch biofix, with days as a predictor variable resulted in early, but similar predictions for both Cawston and Kelowna (Table 3). The reason for these early predictions probably arises because catch curves at Cawston and Kelowna were more skewed than at Summerland (Fig. 1), meaning that while biofix may have occurred on a similar date in some cases, it took less time for catches to reach 50% at Summerland, hence the early predictions.

Generally, prediction errors based on DD were smaller than corresponding predictions based on days (Table 3) and the errors in prediction were similar in magnitude, and consistently biased in the same direction for Cawston and Kelowna. If the underlying assumption that flight activity can be modelled by temperature and DD is correct, then this similarity in errors is expected. Differences in the rates of DD accumulation at different sites as a result of altitude, slope and aspect are taken into account, whereas models based on date alone do not do this. However, models based on days are useful when weather data is not available or is inaccurate. If the difference between two sites is

Table 3.

Deviation between observed and predicted days from 1 January to 50% cumulative catch in sex-attractant traps at different locations and years using different predictor variables and model starting dates for prediction models based on Weibull functions fitted to Summerland data (1990 - 1993).

Model started	Location	Year	Observed days from and including start date	Predicted days from start date using days or DD as predictor variables			Mean error of prediction (±SD) in days using days or DD as predictor variables[a]	
				Days	DD		Days	DD
1 January	Cawston	1990	90	100	90			
		1992	78	100	75		-13.0 ± 7.9	1.7 ± 5.7
		1993	93	100	101			
	Kelowna	1990	97	100	101			
		1991	102	100	107		-0.3 ± 2.5	-1.3 ± 7.2
		1992	100	100	91			
						Grand $\bar{x}$	-6.7 ± 8.7 ns	-1.5 ± 5.8ns
First catch	Cawston	1990	90	79	85			
		1992	78	74	76		-6.0 ± 4.4	-4.3 ± 2.1
		1993	93	90	87			
	Kelowna	1990	97	97	97			
		1991	102	92	101		-6.7 ± 5.8	-3.0 ± 4.4
		1992	100	90	92			
						Grand $\bar{x}$	6.3 ± 4.6*	3.7 ± 3.1*

[a] Significance level for paired comparisons (Paired t-test, $\alpha = 0.05$) between grand means of observed and predicted dates indicated by: ns = $p > 0.05$; * = $p < 0.05$)

known, then traps monitored at Summerland could be used to predict flights in orchards in the Similkameen Valley or other regions of the Okanagan by simply adding or subtracting an appropriate number of days

Calculating the mean error of prediction by taking the signs into account (- being early and + being late predictions, respectively), then a model using DD starting 1 January was the most accurate predictor of 50% catch at all sites combined (Table 3). The mean deviations based on 1 January were not significantly different from zero, while those based on a biofix were (Table 3). This is somewhat misleading because predictions based on a biofix had smaller SD's than those based on 1 January, which probably contributed to the paired *t*-test being significant (Zar 1984). Ignoring the sign of the prediction errors and using absolute deviations, predictions based on DD in conjunction with a biofix provided slightly more accurate predictions with a smaller SE. Given that initiation of flight was the most significant difference among catch curves at different sites (Fig. 1), it was surprising to find that predictions based on a biofix were only marginally better than those using 1 January (Table 3). One obvious source of error were the dates of first catch at Kelowna and Cawston, which were not known with certainty, as they were at Summerland. Another reason may be that unlike some other species (eg. codling moth), biofix for *O. hibisci* occurs very early in the season before errors in DD calculation can accumulate.

Having shown that DD are slightly more accurate than days at predicting flight activity, we combined the sex-attractant trap-catch data from all sites and years (10 data sets), and fitted Weibull functions using DD from both 1 January and biofix. The model based on 1 January (a = 190.53, b = 2.43) had a SE of 16.57 and an r^2 of 0.79, while the model based on a biofix (a = 118.39, b = 1.72) had a SE of 11.04 and an r^2 of 0.91. There is little difference between the r^2 values, regression coefficients, or the SE's of these models based on the complete data set and those using the partial data set (Table 2). Based on this analysis a model using DD with a biofix can probably be recommended over using 1 January only. While it appears possible to predict catch curves using 1 January as a starting date for DD accumulations (Table 3), this might introduce potential errors that could be eliminated by using traps to establish a site-specific annual biofix. We recommend using a biofix to start DD summation, but if this is not available, as is sometimes the case, DD from 1 January can be used.

A scatter of the relationships between DD after biofix and cumulative catches at all sites and years (complete data set) and a fitted Weibull function are shown in Fig. 3. This plot contains more scatter than a similar plot for Summerland only (partial data set), but a model based on the entire data set should be more robust than the partial model. The former model would provide the most accurate table of catch percentiles on which to base spray recommendations. For comparison, a curve fitted to the complete data set using DD after 1 January is also shown in Fig. 3, but the data points were excluded for clarity. Curves fitted to the complete data set (Fig. 3) predict that on average, 50% of the moths will be caught 166 DD after 1 January and 96 DD after biofix.

Apple and pear growers in British Columbia's interior fruit-growing regions are attempting to benefit economically from the codling moth SIR programme by growing and marketing insecticide-free fruit. To achieve this objective, growers must not use conventional synthetic insecticides after apple and pear trees bloom. Pest management experts would like to recommend greater use of biorational pesticides (eg. Dipel® or Confirm®) against secondary pests like *O. hibisci*. These must be applied at optimal times because many are most effective against specific larval instars (Charmillot 1994a,b). Poor timing will reduce the efficacy of biorational insecticides and growers will be reluctant to

use them in their pest management programmes, especially if they are more expensive; to be effective the target insects' phenology must be known or accurately predicted.

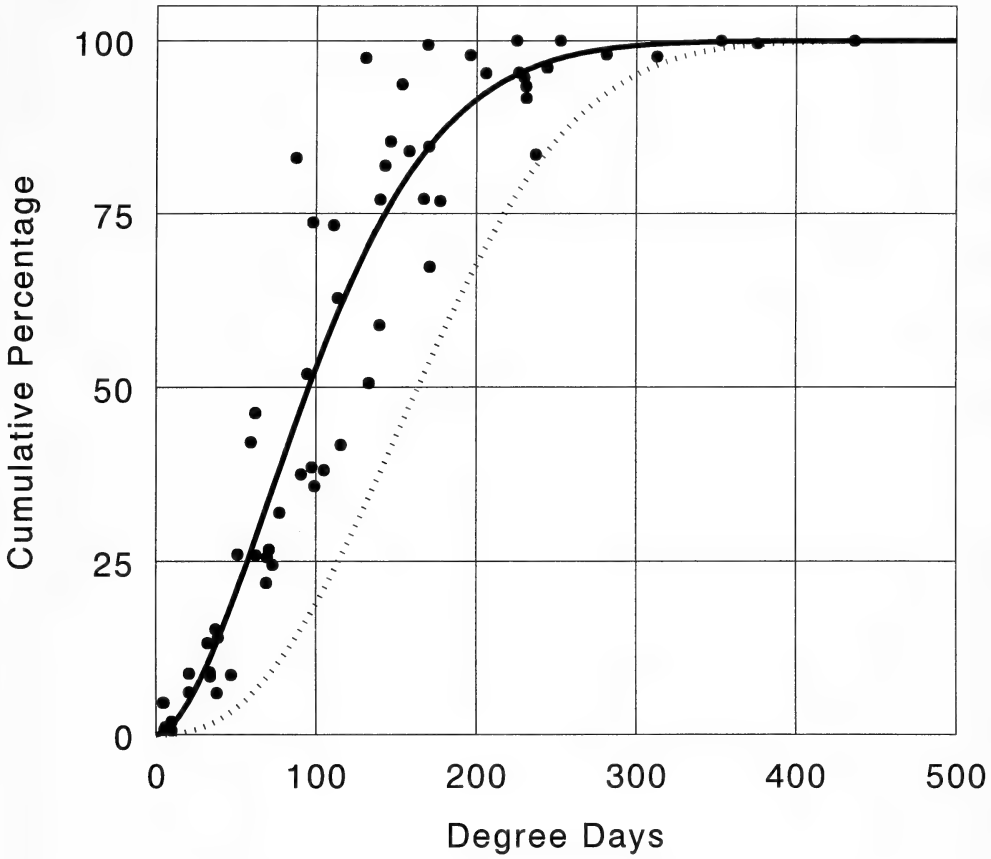

Figure 3. Cumulative catches of males (circles) in sex-attractant traps at Cawston (1990, 1992, 1993), Summerland (1990-1993) and Kelowna (1990-1992) plotted against cumulative degree days (DD) above 3°C after first trap catch (biofix). Solid line - a Weibull function fitted to these points, dotted line - a Weibull function fitted to a similar scatter (not shown for clarity) of same data plotted against cumulative DD after 1 January.

Our data show that for *O. hibisci*, DD after first catch in a sex-attractant trap is a good predictor of adult flight activity in the interior of British Columbia. Prediction of dates of peak or 50% cumulative catch using this model should be useful for timing controls, but any percentile can be predicted. To make better use of this model in timing controls against *O. hibisci*, further study is needed to describe the relationship between male flight activity, as measured by sex-attractant traps, and female emergence and oviposition.

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Commercial trials of pheromone-mediated mating disruption with Isomate-C® to control codling moth in British Columbia apple and pear orchards

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ABSTRACT

Pheromone-mediated mating disruption to control codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), was tested in commercial apple and pear orchards in 1991 and 1992 using Isomate-C® dispensers. In 1991, a single treatment of 1000 dispensers/ha released the pheromone, *E,E*-8,10-dodecadien-1-ol (codlemone), at calculated rates of 14.9, 15.2, 16.6 and 17.5 gm/ha from 1 May to 30 September in Kelowna, Summerland, Cawston and Oliver, respectively. At the same four sites, but during the 1-hr dusk flight periods, when most mating occurs, codlemone was released at calculated median rates of 7.6, 8.2, 8.3 and 12.7 mg/ha/h during first brood and 2.4, 2.3, 4.7 and 5.3 mg/ha/h during second brood, respectively. Damage in 22 pheromone-treated apple orchards ranged from 0.02 - 6.75%, with a median of 0.42%, whereas damage in 12 pheromone-treated pear orchards ranged from 0.02 - 6.23%, with a median of 0.87%. Three insecticide-treated apple orchards had a mean of 0.06% damage and one insecticide-treated pear orchard had 4.21% damage. Untreated apple and pear orchards had 56.9 and 2.23% damage, respectively. In pheromone-treated orchards, few male codling moths were caught in Pherocon 1-C wing traps baited with 1 mg of codlemone ($\bar{x}$=2.9 moths/trap/orchard/season) compared with identical traps hung in insecticide-treated orchards ($\bar{x}$=29.2 moths/trap/orchard/season). Traps baited with 10 mg of codlemone caught codling moths in 96% of the pheromone-treated apple orchards and weekly catches showed seasonal flight patterns similar to those in insecticide-treated orchards. A significant linear relationship between mean cumulative catches in traps baited with 10 mg of codlemone during flight of first-brood moths and damage at harvest, can be used to warn growers if mating disruption is failing and that additional treatment may be needed for the second brood. In 1992, treatment of apple orchards in Cawston with 1000 dispensers/ha as a single application on 1 May, released codlemone at calculated median rates of 13.3 and 4.6 mg/ha/h during first and second brood, respectively. A split application of 650 dispensers on 1 May and an additional 350 on 1 July released codlemone at median rates of 8.7 and 7.8 mg/ha/h during first and second broods, respectively. Damage in 5 orchards with a single pheromone treatment ranged from 0 - 1.52%, and 2 orchards with the split application had 0.08 and 0.97% damage. Damage in an untreated control orchard was 43.5%. Used as described here, pheromone-mediated mating disruption using Isomate-C® is commercially viable in British Columbia.

Key words: Codling moth, mating disruption, Isomate-C, codlemone release rates

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INTRODUCTION

Codling moth, *Cydia pomonella,* (L.), is the key insect pest of pome fruits in the Okanagan and Similkameen Valleys of British Columbia and has been controlled successfully by broad-spectrum organophosphate insecticides for more than thirty years. Reports of resistance to organophosphates (Varela *et al.* 1993) and a desire to market insecticide-free fruit have hastened development and implementation of alternative controls (Dyck and Gardiner 1992). Pheromone-based mating disruption has been studied as an alternative technique for controlling codling moth in Australia (Vickers and Rothschild 1991), Canada (Trimble 1995, Judd *et al.* 1997), France (Audemard 1988), Switzerland (Charmillot 1990), The Netherlands (van Deventer *et al.* 1992), and the United States (Moffitt and Westigard 1984, Barnes *et al.* 1992, Howell *et al.* 1992, Pfeiffer *et al.* 1993, Knight 1995a).

These studies gave varied and sometimes conflicting results, ranging from complete success (Barnes *et al.* 1992), to total failure (Trimble 1995). Most studies reporting failures have involved only a few treated sites (1 - 5), used small plots, which are not applicable to testing pheromone disruption technology, or were conducted at inappropriate population densities. Comparing the efficacy of mating disruption among experiments is also confounded by differences in the voltinism of codling moth in different geographic areas, or the application of supplemental insecticide controls (Knight 1995a). Furthermore, the use of pheromone dispensers with varying and sometimes unknown, or poorly measured release rates, makes comparisons of the efficacy and quantities of pheromone used difficult.

In spite of varied experimental results, disruption of mating in codling moth using pheromones, has been commercialized on every continent where apples are grown (Thomson 1994) and several pheromone formulations and dispensers are now available. Isomate-C® is one pheromone system that has been used extensively in northern Italy, Australia and the Pacific Northwest apple growing areas (Thomson 1994). Yet, apart from a few reports in trade journals (Gut and Brunner 1991, Howell 1992, Judd and Gardiner 1992, Waldner 1996), there is little scientific publication on its successful commercial application (Knight 1995a), leading to the conclusion that routine use against codling moth is not practical (Cardé and Minks 1995). Successful commercial use of mating disruption as a stand-alone technology for control of codling moth in Canada has not been reported, although its use in "organic" apple orchards has been studied (Trimble 1995, Judd *et al.* 1997).

After successful trials with Isomate-C® in organic apple orchards during 1990 (Judd *et al.* 1997), Pacific Biocontrol Corp. expressed interest in registering it in Canada. Unlike the United States and some European countries (Weatherston and Minks 1995), Canadian regulatory policy requires that any new pest control product must be extensively tested and its efficacy demonstrated before it can be registered. Therefore, we undertook a large-scale evaluation in commercial apple and pear orchards to provide data on the efficacy of the Isomate-C® pheromone dispensing system. Our primary objective was to evaluate mating disruption in a few orchards with known histories of codling moth damage, and a majority for which we had no history, but where growers claimed to have had low populations in 1990. Our secondary objective was to relate the observed efficacy of Isomate-C® dispensers to their emission rates (McDonough *et al.* 1992) under British Columbia weather conditions to provide baseline data for comparison with other dispensing systems.

MATERIALS AND METHODS

Description and Selection of Test Orchards. Seventy-five growers, representing 140 ha of apple and pear orchards in the Okanagan, Similkameen and Kootenay Valleys, Vancouver Island and Lilooett participated in this study. Growers were introduced to the technology through

local information meetings organized by B.C. Ministry of Agriculture, Fisheries and Food personnel. Growers volunteering to treat their orchards with pheromone were solicited and where possible sites with no more than 3% damage the previous year and no less than 0.5 ha in size were chosen; these are known requirements for successful pheromone-based disruption of codling moth mating (Charmillot 1990).

Of the 75 orchards treated with pheromone in 1991, results from 34 in the Okanagan and Similkameen Valleys, where 99% of B.C.'s fruit production is concentrated and could be supervised adequately, are given here. Twenty-two apple and 12 pear orchards treated with pheromone were monitored and sampled for damage. For comparison, 4 insecticide-treated orchards (3 apple, 1 pear) and 2 untreated orchards (1 apple, 1 pear) were also monitored and sampled. In 1992, 7 of the original 22 pheromone-treated apple orchards and an untreated orchard were monitored and sampled for damage.

The location, physical description, and varieties of each of the 40 orchards are given in Table 1. Location of towns are mapped in Cossentine and Jensen (1992, pg. 19). The median size of apple orchards was 1.12 ha with 646 trees/ha. The 14 pear orchards had a median size of 0.93 ha with 278 trees/ha. Individual tree canopy volumes were calculated by multiplying the height (measured from the first scaffold limb coming off the trunk to the top of the central leader) by the base width at the first scaffold limb. An average for 10 trees in each orchard was multiplied by the area of the orchard to give the canopy volume/orchard. The median canopy volume of pear orchards (42,900 m^3) was slightly larger than apple orchards (34,900 m^3), but because they were smaller in area, pear orchards had greater volume to area ratios to treat with pheromone.

Pheromone Disruption Treatment. Pheromone was released by Shin-etsu rope-type dispensers containing a 155 mg blend of, 58.8% *E,E*-8,10-dodecadien-1-ol (codlemone), 29.5% dodecanol, 5.3% tetradecanol and 3.1% antioxidants including vitamin E. This dispenser was a 20-cm long, sealed, translucent polyethylene tube (1.1 mm ID) containing pheromone and a metal wire running through its length for support. This dispenser was marketed in the United States under the trade name Isomate-C® (Pacific Biocontrol Corp., Davis, California, U.S.A.), but its commercial efficacy had not been demonstrated when this study was conducted.

Pheromone dispensers were usually deployed at a standard rate of 1000/ha, except on the outermost row of trees which had the equivalent of 2000 dispensers/ha. Dispensers were tied to branches in the upper third of the tree canopy about 0.5 - 1.0 m from the top of the central leader on the first lateral branch. Dispensers were usually tied on the north-east side of trees to minimize exposure to direct sunlight. All dispensers were deployed a few days before the first codling moth was expected to emerge, but no later than 1 May. In 1991, 2 orchards (A-22 and P-36) received an additional 1000 dispensers/ha on 1 July and in 1992, 2 orchards (A-13 and A-14) received a split application of 650 dispensers/ha on 1 May (A-13) or 7 May (A-14), and an additional 350 dispensers/ha on 1 July. With the exception of 2 pear orchards (P-37 and P-38) no insecticides were applied to pheromone-treated orchards after the blossom period.

Pheromone Dispenser Emission Rates. Pheromone emission from the Isomate-C® dispenser is complicated and cannot be described accurately by changes in weight or length of the liquid column. Release rates for each of the dispenser's components as a function of temperature, dispenser age and the thickness of polymerized pheromone and dust which accumulates on the dispenser, were described mathematically by McDonough *et al.* (1992). These equations were incorporated into a computer programme (Knight 1995b) that can be used to predict the rate of release of each of the dispenser's components based on ambient temperature and the dispenser's age. Hourly air temperatures, recorded with DP-212 Datapods (Omni Data Int., Logan Utah) housed inside standard Stevenson Screens placed in four representative orchards, were used in Knight's (1995b) model to calculate the release of codlemone in mg/ha/h as a function of

Table 1

Location, physical description and fruit varieties of commercial apple (A) and pear (P) orchards used for evaluating pheromone-based mating disruption of codling moth with Isomate-C in 1991 and 1992.

Crop	Orchard number	Location	Varieties[a]	Area	Tree x row spacing	Tree density	Canopy volume
				ha	m x m	/ha	m^3 x 1000
Apple	A- 1	Oliver	R,G	1.54	2.4 x 4.6	891	39.3
	A- 2	Oliver	R,G	1.43	4.3 x 5.5	643	37.2
	A- 3	Summerland	S,M	0.78	4.3 x 4.6	577	38.5
	A- 4	Summerland	S,M	1.71	2.6 x 4.6	819	38.5
	A- 5	Naramata	S,M	0.61	4.9 x 4.9	418	44.8
	A- 6	Naramata	S,M	0.44	4.9 x 4.9	418	42.6
	A- 7	Westbank	B,E	2.20	1.5 x 3.0	2272	16.0
	A- 8	Westbank	G	1.11	2.0 x 4.0	1257	40.0
	A- 9	Keremeos	R,G	0.61	2.4 x 4.6	907	38.2
	A-10	Keremeos	R,G	0.75	2.4 x 4.6	909	38.2
	A-11	Keremeos	S,M	1.17	2.0 x 4.2	1230	35.1
	A-12	Cawston	R	1.68	6.1 x 6.1	270	42.4
	A-13	Cawston	R,G,S	0.82	3.0 x 5.0	673	40.2
	A-14	Cawston	R,G,S	1.27	3.6 x 4.6	598	39.1
	A-15	Cawston	M,S	1.41	3.0 x 5.5	626	32.9
	A-16	Cawston	R,G,S	1.11	3.6 x 4.6	649	38.7
	A-17	Cawston	R	0.57	3.0 x 6.1	618	42.4
	A-18	Cawston	R	1.28	2.4 x 4.2	1020	27.7
	A-19	Cawston	M,S	2.00	3.6 x 5.5	603	37.0
	A-20	Cawston	S	0.93	3.0 x 5.5	615	47.0
	A-21	Cawston	M	1.12	2.4 x 4.6	938	29.4
	A-22	Cawston	R,G,S,M	2.30	4.6 x 4.6	473	46.2
	A-23	Cawston	S	0.68	4.6 x 4.6	473	41.4
	A-24	Cawston	S	0.97	3.0 x 5.5	615	47.0
	A-25	Cawston	S	0.48	3.6 x 4.6	664	36.0
	A-26	Summerland	R,G,S,M	0.30	2.3 x 4.6	1040	32.8
Pears	P-27	Winfield	A,Bt	1.04	3.3 x 5.9	513	37.7
	P-28	Kelowna	A,Bt	1.72	3.6 x 6.1	456	40.5
	P-29	Kelowna	A,Bt	1.18	6.1 x 6.1	278	35.9
	P-30	Westbank	A,Bt	1.05	5.8 x 5.8	300	47.0
	P-31	Westbank	A,Bt	2.16	6.1 x 6.1	278	46.2
	P-32	Naramata	Bt	0.25	4.9 x 5.1	395	44.0
	P-33	Cawston	A,Bt	0.66	3.0 x 5.4	648	33.1
	P-34	Cawston	A,Bt	4.69	7.5 x 7.5	183	42.2
	P-35	Cawston	A,Bt	0.82	6.1 x 6.1	278	44.8
	P-36	Cawston	A,Bt	0.42	6.1 x 6.1	278	44.6
	P-37	Cawston	A,Bt	0.68	6.1 x 6.1	278	47.1
	P-38	Cawston	A,Bt	0.60	6.1 x 6.1	278	42.6
	P-39	Kelowna	Bt	0.64	6.1 x 6.1	278	35.9
	P-40	Kelowna	A,Bt	1.83	3.6 x 6.1	456	40.5

[a]Abbreviations for apple varieties are: Braeburn (B), Elstar (E), Golden Delicious (G), McIntosh (M), Spartan (S), Red Delicious (R), and pear varieties are Anjou (A) and Bartlett (Bt)

temperature, time of day, dispenser age and number of dispensers applied. The release of other components was not considered because they are not active pheromone components (McDonough *et al.* 1995). A similar approach to modelling pheromone delivery rates was used by Howell *et al.* (1992) and Suckling *et al.* (1994) and has been validated by Knight (1995b).

Monitoring Seasonal Flight of Male Codling Moths. Most orchards were monitored with Pherocon 1-C style wing traps (Phero Tech Inc., Delta, B.C.) baited with commercial codlemone (99% isomeric and chemical purity, Shin-etsu, Fine Chemicals Division, Japan) loaded on to red rubber septa. In 1991, pheromone-treated orchards were monitored with traps baited with 1 or 10 mg of codlemone and in 1992 with 10 mg traps only. All other orchards were monitored with 1 mg traps. Traps were hung 1.5 - 2.0 m above ground in the interior of each block at a density of 1/ha. Trap positions were fixed throughout the season and checked weekly to record numbers of male moths captured. Pheromone baits were changed every three weeks throughout the season.

Fruit Damage. All orchards were sampled for damage during harvest, as fruit maturity and growers dictated. Each sampled tree was completely picked and all fruit were inspected for damage from codling moth. Damage estimates include surface feeding (stings) and deep entries. We sampled a minimum of 5 trees and a maximum of 3% of all the trees in each orchard using a stratified, cluster sampling procedure where the outer border row of trees and interior trees represent 2 strata, and each tree represents a cluster of fruit, respectively. As border trees usually have more damage than interior trees and damage is often aggregated on trees, this division seems logical. The estimated percentage of damage for each whole orchard is a weighted average for both strata, with weighting based on the proportion of total fruit in each stratum and the variability in damage between trees within a stratum. The estimated percentages of damage in each orchard are expressed with ± 2 standard deviations (SD), which provides an approximate 95% confidence interval for the estimates (Mendenhall *et al.* 1971).

Paired Insecticide and Pheromone Treatments. In 1991, 3 conventionally-managed apple orchards and 1 conventionally-managed pear orchard were subdivided and each half received either a standard insecticide programme (B.C. Ministry of Agriculture, Fisheries and Food 1991) or a pheromone treatment. Each orchard was monitored with pheromone traps as described earlier and insecticides were applied when trap catches were above the specified threshold (2 moths/trap/week for 2 consecutive weeks) and degree-day accumulations. The numbers of damaged and undamaged fruit found in samples taken in each of these paired orchard blocks were compared with χ^2 tests.

RESULTS

Dispenser Release Rates. Applying 1000 Isomate-C® dispensers/ha is equivalent to treating each ha with 91 gm of codlemone, but according to McDonough *et al.* (1992) and Knight (1995b), most of it is never released into the air because of photodegradation, isomerization and polymerization. According to Knight's (1995b) model, the total amount of codlemone released in orchards in Kelowna, Summerland, Cawston and Oliver during both the first and second broods of moths was 14.9, 15.3, 16.6 and 17.5 gm/ha, respectively, about 16 - 19% of the total in dispensers (Table 2). The seasonal total amounts of codlemone delivered at dusk (Table 2), during which time most of the mating takes place, represented less than 1% of the 91 gm applied in dispensers. Changes in temperature greatly affected daily pheromone release rates as the ranges at dusk indicate. In 1991, estimated release rates at dusk ranged from 1.3 - 18.4 mg/ha/h in Cawston, 2.4 - 24.7 in Oliver, 0.6 - 17.0 in Summerland, and 0.2 - 20.6 in Kelowna. Average release (means and medians) varied between sites, years and particularly between generations within a year (Table 2). In 1991, codlemone release rates on nights when temperatures were suitable for flight (≥15°C), and presumably mating, never fell below 2 and rarely below 6

mg/ha/h during first brood at any site (Table 2). During the second brood, dusk release rates were frequently below 2 mg/ha/h. As expected, an additional 1000 dispensers in summer released over twice as much pheromone during the second brood, as did a single application of 1000 dispensers (Table 2).

Similar pheromone release rates were calculated for 1992 (Table 2). Splitting an application of 1000 dispensers (650 first brood and 350 second brood) in 1992, produced a lower mean release rate during first brood, but a higher rate during second brood, than did a single application of 1000 dispensers (Table 2). This split application distributed pheromone more evenly throughout the season, and application rates never fell below 2 mg/ha/h during second brood, unlike the standard treatment (Table 2).

Table 2

Summary statistics for the estimated codlemone evaporation rates at different locations during 1991 and 1992.

Year-Brood	Location	Dispenser number /ha	Dusk mean mg/ha/h	Dusk median mg/ha/h	Dusk range mg/ha/h	Seasonal dusk total gm/ha	Seasonal daily total gm/ha	% nights when dusk temp ≥ 15°C and codlemone release ≥ given mg/ha/h thresholds 2	4	6	8	10
1991-1	Oliver	1000	12.3	12.7	2.4-24.7	0.87	12.3	100	100	96.6	89.8	76.3
	Cawston	1000	9.0	8.3	1.3-18.4	0.57	12.1	100	100	96.1	68.6	43.1
	Summerland	1000	8.3	8.2	0.6-17.0	0.65	11.4	100	98.3	90.0	68.3	45.0
	Kelowna	1000	8.4	7.6	0.2-20.6	0.70	11.3	100	96.8	84.1	57.1	47.6
1991-2	Oliver	1000	5.3	5.3	1.5-11.4	0.28	5.2	90.7	66.7	38.9	14.8	3.7
	Cawston	1000	4.1	4.7	0.7-8.3	0.21	4.5	86.2	58.8	13.7	3.9	0
		2000[a]	16.1	18.4	2.9-32.6	0.80	17.5	100	100	88.5	84.6	73.0
	Summerland	1000	3.1	2.3	0.2-7.6	0.20	3.9	56.3	39.0	7.8	0	0
	Kelowna	1000	3.2	2.4	0.3-8.2	0.21	3.6	68.2	40.9	16.7	3.0	0
1992-1	Cawston	1000	13.2	13.3	1.8-37.3	0.66	14.6	100	100	97.7	93.2	86.3
		650	8.6	8.7	1.1-24.2	0.43	9.5	100	97.7	90.9	68.2	36.4
1992-2	Cawston	1000	4.7	4.6	0.9-11.9	0.23	5.3	93.8	60.4	20.8	6.3	4.2
		1000[b]	8.1	7.8	1.8-14.7	0.39	8.8	100	89.6	75.0	47.9	29.2

[a]Isomate-C applied at a rate of 1000 dispensers/ha on May 1 plus an additional 1000/ha on July 1
[b]Isomate-C applied at a rate of 650 dispensers/ha on May 1 plus an additional 350 dispensers/ha on July 1

Pheromone Trap Catches and Seasonal Flight of Male Codling Moths. Catches in each of 23 apple orchards and 11 pear orchards where traps were maintained are shown in Table 3. In pheromone-treated apple orchards, few moths were caught in traps baited with a standard 1 mg load of codlemone (x= 2.9 moths/trap/orchard/season), compared with identical traps in insecticide-treated apple orchard (x= 29.2 moths/trap/orchard/season). So few moths were caught in 1 mg traps hung in pheromone-treated orchards in 1991 that their use was discontinued in 1992. Traps with 10 mg baits in pheromone-treated orchards were attractive enough to show seasonal flight patterns of codling moth similar to those seen in insecticide-treated orchards (Fig. 1). Despite the low density of traps used, 10 mg baits attracted codling moths in 96% of the pheromone-treated apple orchards, whereas 1 mg baits attracted moths in only 61% of the pheromone-treated orchards in 1991.

In pheromone-treated apple orchards the x ± standard error (SE) cumulative number of first brood moths caught in traps with 10 mg baits (7.15 ± 1.27) was 4.2 times greater than the mean with 1 mg baits (1.7 ± 0.23). During second brood the mean number (5.26 ± 1.53) of moths in 10 mg traps was only 2.7 times greater than the mean number in 1 mg traps (1.93 ± 0.82), suggesting that 10 mg traps were becoming comparatively less attractive later in the season.

Fruit Damage. In 1991, damage to pheromone-treated apples ranged from 0.02 - 6.75 %, with a median level of 0.42% (Table 3). In three paired comparisons (A-16 *vs* A-25, A-17 *vs* A-23 and A-20 *vs* A-24) damage in the pheromone-treated halves of these apple orchards was not significantly different (χ^2 tests, $p < 0.05$) from the insecticide-treated halves. Damage in an untreated control (A-26) was substantially greater than that in any treated orchard (Table 3), showing there was potential for codling moth damage.

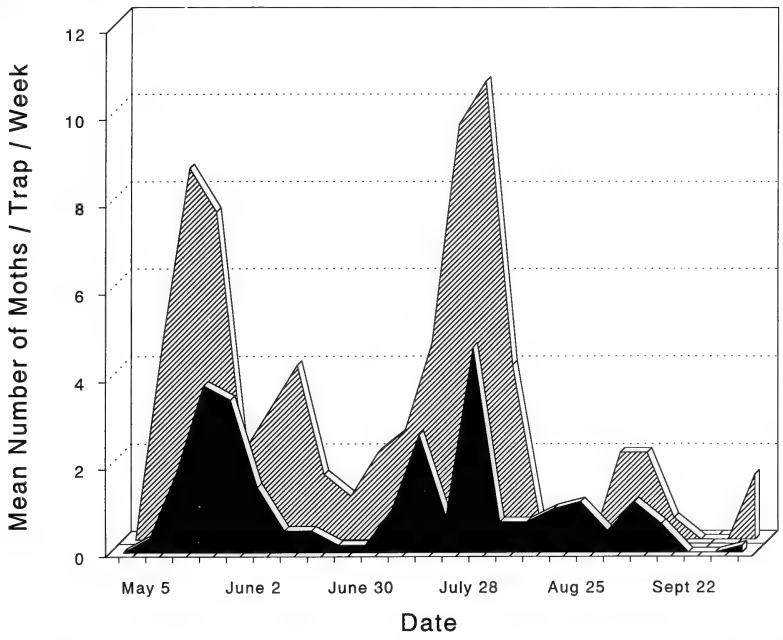

Figure 1. Comparison of weekly catches of male codling moths in traps baited with 10 mg of codlemone and hung in a pheromone-treated apple orchard (black) or with 1 mg in an adjacent insecticide-treated orchard (hatched) during 1992.

Damage to pheromone-treated pears ranged from 0.02 - 6.23% with a median of 0.87%, almost twice that of apples, which is surprising because pears are generally less susceptible to damage from codling moth than apples. Damage in one insecticide-treated pear block (P-39) was significantly higher (χ^2 test, $p < 0.05$) than a paired pheromone-treated block (P-29).

In 1992, damage to apples ranged from 0 - 2.5%, with a median of 0.5%, and in an untreated orchard it was 43.5% (Table 3). Despite a split application, and consequently less pheromone during first brood flight, orchards A-13 and A-14 had damage levels of 0.08% and 0.97%, respectively, i.e. less than the conventional economic threshold.

Trap Catch and Damage Correlation. In pheromone-treated apple orchards damage at harvest was nearly always preceded by catches in 10 mg traps during first brood (Table 3), whereas no first brood moths were caught with 1 mg baits in several pheromone-treated orchards having damage (e.g. orchards A-5, A-6, A-12, A-13, A-14, A-16). Using 18 apple orchards that received one standard pheromone disruption treatment, and for which we also had suitable damage and trap-catch data (orchards A-7, A-8, and A-22 were excluded on this basis; A-21 was excluded as an outlier that appeared to sustain damage due to immigration into the block), damage at harvest in 1991 was regressed against mean cumulative catches of first brood males in traps with 10 mg baits. Although the data were highly variable, the regression was significant

Table 3

Mean cumulative number of male codling moths caught in traps baited with 1 or 10 mg of codlemone during first (1st) and second (2nd) brood flights and % damage at harvest in pheromone-treated, insecticide-treated and untreated apple (A) and pear (P) orchards in 1991 and 1992.

			Mean cumulative number of moths per trap						Number of trees sampled, fruit load and damage at harvest		
			1 mg codlemone			10 mg codlemone					
Year	Orchard	Treatment	No. of traps	1st flt.	2nd flt.	No. of traps	1st flt.	2nd flt.	No. of trees	Fruit/tree $\bar{x} \pm$ SD	Damage % ± 2 SD
1991	A-1	Isomate-C	4	0.8	0.3	4	7.3	0.8	15	434 ± 219	0.01 ± 0.01
	A-2	Isomate-C	2	1.0	0	2	1.5	0	10	308 ± 138	0.61 ± 0.44
	A-3	Isomate-C	2	0	0	2	2.0	1.0	13	249 ± 96	0.06 ± 0.05
	A-4	Isomate-C	2	0	1.0	2	1.0	2.0	16	241 ± 85	0.05 ± 0.03
	A-5	Isomate-C	1	0	0	1	9.0	6.0	6	484 ± 303	0.70 ± 0.69
	A-6	Isomate-C	2	0	0	1	0	1.0	5	392 ± 138	0.18 ± 0.24
	A-7	Isomate-C	0	-	-	0	-	-	70	15 ± 9	6.75 ± 1.94
	A-8	Isomate-C	0	-	-	0	-	-	23	170 ± 122	1.61 ± 0.81
	A-9	Isomate-C	1	2.0	8.0	1	11.0	12.0	10	244 ± 127	0.90 ± 0.54
	A-10	Isomate-C	1	2.0	1.0	1	10.0	15.0	10	348 ± 130	0.92 ± 0.45
	A-11	Isomate-C	1	1.0	3.0	1	0	0	18	237 ± 78	0.37 ± 0.02
	A-12	Isomate-C	2	0	0	2	4.0	1.0	5	376 ± 125	0.10 ± 0.07
	A-13	Isomate-C	1	0	0	1	1.0	0	18	411 ± 275	0.17 ± 0.09
	A-14	Isomate-C	1	0	0	1	3.0	7.0	23	411 ± 275	0.47 ± 0.22
	A-15	Isomate-C	1	3.0	0	1	11.0	5.0	16	133 ± 52	0.67 ± 0.38
	A-16	Isomate-C	1	0	0	1	1.0	5.0	24	298 ± 185	0.15 ± 0.06
	A-17	Isomate-C	1	1.0	0	1	3.0	1.0	12	217 ± 134	0.13 ± 0.12
	A-18	Isomate-C	1	2.0	11.0	1	22.0	21.0	10	178 ± 13	0.94 ± 0.76
	A-19	Isomate-C	3	0.3	0.3	2	1.0	1.0	28	94 ± 63	0.12 ± 0.05
	A-20	Isomate-C	1	3.0	1.0	1	2.0	2.0	14	465 ± 214	0.11 ± 0.06
	A-21	Isomate-C	1	0	1.0	1	1.0	1.0	27	52 ± 39	2.40 ± 1.02
	A-22	Isomate-C	3	7.0	10.2	3	32.3	19.3	23	390 ± 214	2.27 ± 0.98
	A-23	APM x 2[a]	2	16.0	23.5	0	-	-	11	245 ± 147	0.14 ± 0.09
	A-24	APM x 2[a]	1	14.0	17.0	0	-	-	14	379 ± 148	0.04 ± 0.02
	A-25	APM x 3[a]	2	8.5	8.5	0	-	-	12	859 ± 129	0.02 ± 0.02
	A-26	Untreated	0	-	-	0	-	-	12	116 ± 97	56.87 ± 2.65
	P-27	Isomate-C	1	0	0	1	2.0	2.0	14	143 ± 58	0.27 ± 0.16
	P-28	Isomate-C	2	1.0	1.0	2	9.0	2.0	20	127 ± 20	2.28 ± 1.01
	P-29	Isomate-C	2	0	1.0	1	0	1.0	6	346 ± 68	1.09 ± 1.16
	P-30	Isomate-C	0	-	-	0	-	-	14	455 ± 168	6.23 ± 3.64
	P-31	Isomate-C	0	-	-	0	-	-	14	499 ± 110	7.10 ± 4.10
	P-32	Isomate-C	0	-	-	0	-	-	10	265 ± 19	0.66 ± 0.61
	P-33	Isomate-C	1	0	0	1	6.0	11.0	12	103 ± 53	0.17 ± 0.12
	P-34	Isomate-C	4	0.8	0.3	4	14.5	0.8	17	413 ± 200	0.16 ± 0.09
	P-35	Isomate-C	1	0	0	1	0	0	10	360 ± 50	0.02 ± 0.01
	P-36	Isomate-C[b]	0	-	-	1	5.0	2.0	10	278 ± 133	3.31 ± 2.41
	P-37	Isomate-C[c]	1	4.0	0	1	16.0	1.0	6	157 ± 61	1.51 ± 1.51
	P-38	Isomate-C[c]	1	5.0	0	1	12.0	3.0	10	238 ± 135	0.37 ± 0.26
	P-39	Imidan x 2[c]	1	26.0	25.0	0	-	-	9	396 ± 112	4.21 ± 3.15
	P-40	Untreated	2	13.0	9.0	0	-	-	20	117 ± 31	2.23 ± 0.99
1992	A-01	Isomate-C	0	-	-	4	1.0	0.8	15	427 ± 215	0 ± 0
	A-12	Isomate-C	0	-	-	2	0.5	0	5	346 ± 116	0.07 ± 0.03
	A-13	Isomate-C[d]	0	-	-	2	1.5	2.0	18	455 ± 168	0.08 ± 0.05
	A-14	Isomate-C[d]	0	-	-	2	1.0	1.0	23	499 ± 110	0.97 ± 0.42
	A-15	Isomate-C	0	-	-	2	16.0	2.0	16	165 ± 56	0.74 ± 0.38
	A-19	Isomate-C	0	-	-	2	1.0	0	28	101 ± 51	0.11 ± 0.07
	A-21	Isomate-C	0	-	-	2	2.0	1.0	27	62 ± 41	1.52 ± 0.78
	A-26	Untreated	0	-	-	0	-	-	12	64 ± 31	43.5 ± 2.95

[a]APM is azinphosmethyl applied at 0.84 kg a.i./ha indicated number of times

[b]Isomate-C applied at a rate of 1000 dispensers/ha on May 1 and 1000/ha on July 1

[c]Imidan applied as a single supplemental or indicated number of primary treatments at 0.8 kg a.i./ha

[d]Isomate-C applied as a split application of 650 dispensers/ha on May 1 and 350 dispensers July 1

(%Damage = 0.154 +0.043[Catch]), r^2= 0.55, $p < 0.05$). A similar regression analysis for pears was not significant ($p > 0.05$).

DISCUSSION

During 1991 and 1992 pheromone-mediated mating disruption using 1000 Isomate-C® dispensers/ha controlled codling moth as well as conventional insecticides, under British Columbia conditions. The large number of commercial orchards involved in this study with more successes than failures, leads us to conclude that this is a commercially viable technology for British Columbia's Interior apple and pear industry.

The wide range of damage we observed makes it easy to understand why studies using one (Barnes *et al.* 1992) or two pheromone-treated sites (Trimble 1995), have resulted in contradictory conclusions about the efficacy of Isomate-C®. Intentional or possibly random selection of 1 or 2 orchards at either extreme of the damage range seen (Table 3), could have led us to two completely opposite conclusions about the effectiveness of Isomate-C® depending which extreme we chose. Our selection of orchards was not entirely random, so it is difficult to know whether mating disruption in a completely random sample of orchards would be as successful as shown here. However, in our experience, growers volunteering to use mating-disruption technology have usually experienced difficulty controlling codling moth by other means. This observation has held true for both conventional and organic growers (Judd *et al.* 1997), so if applied industry wide, the proportion of orchards where mating disruption is successful might actually be greater than shown here, as most growers keep codling moth populations low with conventional insecticides.

Pheromone-based mating disruption is a more complex pest control technology than are insecticides and growers will require clear instructions and strict guidelines. Based on our analysis of 34 orchards, failure of the disruption technique could be attributed to three main factors: 1) high population densities, 2) incomplete or uneven tree canopy structure, and 3) immigration of mated females into treated areas. Charmillot (1990) developed a set of criteria necessary for effective control of codling moth by pheromone-based mating disruption. Population density was high on his list. Unlike pesticides, the efficacy of mating disruption as a control for codling moth appears to be lower at higher densities. For this reason we specifically chose orchards with low population densities, because failure to control high population densities is not a failure of the technique, but merely a restriction for its use that is sometimes not considered (Trimble 1995). It is not known at this time whether this density effect results from a greater percentage of mating at higher population densities, or simply, that a greater number of larvae, and consequently damage, arise from a greater number of adults.

With few exceptions, orchards with less than 3% damage the year before pheromone treatment, usually had similar or lesser amounts of damage after it (Table 3), indicating there is probably a relationship between past and potential damage using pheromone treatment. However, percent damage is such a variable factor and not always correlated with population density (Judd *et al.* 1997), that its use as a predictor is often unreliable. Trimble (1995) found that Isomate-C® failed to control codling moth in organic apple orchards with damage ranging from as low as 1.1 - 3.3% after the first year of treatment, indicating population densities were probably much higher than the damage indicated.

Charmillot (1990) concluded that if a threshold of 2 - 3 overwintering larvae/tree was exceeded, mating disruption would not keep codling moth damage below economic levels. Our studies (Judd *et al.* 1997) support this conclusion, but we think this threshold should be flexible

to accommodate the effects of tree density, crop load and varietal susceptibility that will raise or lower the probability of damage at similar population densities. If a larval threshold is to be used it may be better to express it as larvae/hectare than larvae/tree (Judd *et al.* 1997).

Providing growers with a definitive larval threshold and measuring that threshold are so difficult, especially in pears, that traps containing 10 mg of pheromone may be the most convenient way to determine whether an orchard is above threshold during the first year of disruption. We detected males in all but 1 apple orchard where 10 mg baits were used. Apple orchards with mean cumulative catches of >10 males during first brood had damage above the 1.0% economic threshold. Therefore, this number and our regression model showing a relationship between catches of first-brood moths in 10 mg traps and damage, can be used as a rough guide for effective control. When population densities are above this threshold and if growers wish to keep damage below 1%, then other management tactics may be needed to complement pheromone disruption (Judd *et al.* 1997). We now advise growers to use additional controls before or during the first year of disruption if their orchard is above a given threshold.

Monitoring male codling moths does not always guarantee that damage will be detectable. Orchard A-21 had a mean cumulative catch less than 10 males and had 2.4% damage. Damage in this orchard was concentrated along a southern border adjacent (20 m) to an untreated orchard with about 20% damage. Damage decreased with distance into the pheromone-treated orchard, suggesting that immigrant mated females caused the damage. Immigration of mated females will remain a threat to disruption programmes unless larger areas can be treated or supplemental controls can be applied to borders.

The greatest amount of damage was seen in some pear orchards that had been managed with a minimum of pesticides for the previous 2 - 3 years as part of a soft approach to pear psylla management. These orchards probably had more damage or greater populations of codling moth than the growers realized. It also seems reasonable that larger canopy volumes in pears compared with apples (Table 1), may have decreased the average concentration of pheromone per volume of air in the canopy. Also, recent measurements of pheromone concentrations within treated crops (Bengtsson *et al.* 1994, Karg *et al.* 1994) showed that leaves function as secondary pheromone dispensers by adsorbing and re-releasing pheromones. Differences in pear and apple leaf structure may affect the amounts of pheromone adsorbed on to leaves (Karg *et al.* 1994). It remains to be seen whether the efficacy of pheromone disruption can be improved in these pear orchards by distributing the 1000 dispensers/ha more evenly throughout the canopy at varying heights, or whether more dispensers will be required. Other controls may be needed before pheromone disruption is successful in these orchards. Pear trees have extremely rough bark which provides many overwintering sites for codling moth larvae, therefore tree banding (Judd *et al.* 1997) is not likely to be successful.

Small narrow plantings with a high edge to area ratio, young high-density plantings, and widely spaced mature plantings with missing trees were also among the mostly highly damaged orchards. Concentrations of pheromones might be lower in orchards with less dense canopies because wind velocities are greater and may carry pheromones away before leaves can take them up, and areas of orchards with missing trees (broken canopy effect) may provide spaces where insects can escape constant exposure to pheromone, allowing their sensory system to regain sensitivity. Any reduction in pheromone levels or increase in pheromone-free space could increase mating chances. Where possible, pheromone-treatment beyond crop borders could help eliminate edge effects, but there is no simple solution for orchards with many missing trees.

Our work raises questions about the amount of pheromone needed to control codling moth. Previous research has shown that effective mating disruption requires from 2 (Cardé *et al.* 1977) to 10 or 40 mg of codlemone/ha/h (Charmillot 1990). This wide range of doses is due in part to the different ways that dispenser release rates have been measured (Knight 1995b). We

controlled codling moth with 2 complete generations a year using a calculated codlemone release of about 6 mg/ha/h, albeit from 1000 dispensers. Charmillot and Pasquier (1992) tested many commercial pheromone formulations against codling moth and demonstrated efficacy with a wide range of release rates and with dispenser densities much lower than those we used. An improved understanding of the relationship between the level of mating disruption, dispenser release rates, their density and potential interplay with canopy structure might make large-scale efficacy testing of different release systems unnecessary if the release rates of dispensers were known. However, pheromone companies seem reluctant to disclose the release-rates of their dispensers, especially under variable temperatures found in the field. This lack of information forces researchers to determine these values themselves (McDonough *et al.* 1992) and slows the development of the technology.

This study also shows that there is a need to improve dispenser efficiency, because 80% of the codlemone in the Isomate-C® dispenser never reaches the orchard air. Codlemone is the most expensive component of these pheromone dispensers and a more efficient release of codlemone could greatly reduce the costs of mating disruption of codling moth. Until this research is completed however, the Isomate® pheromone system is suitable for commercial use in the British Columbia fruit industry, particularly for organic production (Judd *et al.* 1997). Furthermore, pheromone-based mating disruption should provide an alternative approach to area-wide control of codling moth should the SIR programme fail to meet its objective.

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Apple and spirea aphids (Homoptera:Aphididae) on apples in south central Washington

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ABSTRACT

Aphids were collected from 75 different apple orchards in south central Washington during 1994 and 1995. In 1994, 88% of those examined were spirea aphid (*Aphis spiraecola* Patch). In 20 orchards we found only spirea aphids; in 11, most were spirea aphids and in 2, all were apple aphids (*A. pomi* deGeer). In 1995, 76% of those examined were spirea aphids. In 13 orchards we found only spirea aphids; in 22, most aphids were spirea; in one, all, and in 6 most, were apple aphids. In the two years combined, 33 orchards (44%) had only spirea aphids, 33 (44%) had predominantly spirea aphids, 6 (8%) had mainly apple aphids and 3 (4%) had only apple aphids. There were no clear differences in distribution of the two species over time or on different apple cultivars.

Key words: Aphid, *Spirea*, apple, orchard

INTRODUCTION

The apple aphid (*Aphis pomi* deGeer) was first reported from Washington in 1883 (Pfeiffer 1991). Since then it has probably became the dominant species on apples. The spirea aphid (*A. spiraecola* Patch) is indistinguishable from the apple aphid under field conditions. Spirea aphid was first recorded in British Columbia from Vancouver on *Calycanthus fertilis* in 1976 and later from Osoyoos on *Morus alba* in the Okanagan Valley in 1981 (Forbes and Chan 1989). Beers *et al.* (1993) lumped the two together as "green aphids" on apple in the Pacific Northwest. We are not sure how long the spirea aphid has been in Washington, but Halbert and Voegtlin (1992) found spirea aphids in pan traps in Washington wheat fields in 1984.

Spirea and apple aphids have distinct life histories. Apple aphids feed mainly on apple foliage and occasionally on that of pear and hawthorn. Spirea aphids alternate between the primary host, spirea, and a wide variety of other, secondary hosts. Apple aphids overwinter as eggs on apple whereas spirea aphids overwinter as eggs on spirea, citrus or other plants and only infest apple trees during the summer. Therefore, dormant and delayed dormant sprays applied to apple trees would not affect spirea aphid. Hogmire *et al.* (1990, 1992) showed differences in insecticide susceptibility between these two species.

Pfeiffer *et al.* in 1989 found the spirea aphid to predominate over the apple aphid in Virginia, West Virginia and Maryland. They interpreted their findings as the possible result of a recent shift in aphid species composition on apple.

Our study was conducted to determine the distribution of the spirea aphid infestation in apple orchards in south central Washington to improve the integrated management of the aphid.

MATERIALS AND METHODS

Aphids were collected from 75 different randomly selected "green aphid" infested apple orchards in south central Washington during 1994 and 1995. No orchards were sampled twice. At each orchard we collected alate aphids from at least 15 different randomly selected shoots from at least 5 trees to obtain 30 aphids. However, if it was difficult to find alate aphids in an orchard with a low infestation, aphids were collected from more than 15 shoots to obtain 30 aphids. Aphids from individual orchards were stored in alcohol until their distal rostral segments were measured under a microscope with 40X magnification using a ocular micrometer reticle with 0.025 mm gradations. Thirty aphids from each sample were examined and identified as apple or spirea aphids. Halbert and Voegtlin (1992) reported the length of the ultimate rostral segment was most useful for separating the two species. We used their method. The length of the ultimate rostral segment is greater than 0.12 mm in the apple aphid and less than 0.12 mm in the spirea aphid.

Table 1.

Occurrence of the apple and spirea aphids in south central Washington in 1994-1995. BR = Braeburn; FU = Fuji; GA = Gala; GD = Golden Delicious; RD = Red Delicious; RO = Rome.

Date	Location	Variety	% Spirea	% Apple	Date	Location	Variety	% Spirea	% Apple
5/9/94	Zillah	GA	0	100	5/23/95	Prosser	RD	93	7
5/10/94	Prosser	RO	0	100	6/5/95	Prosser	GD	0	100
8/24/94	Moxee	GD	91	9	6/5/95	Prosser	RD	7	93
8/25/94	Basin City	RD	64	36	6/5/95	Prosser	RD	4	96
8/25/94	Moxee	RD	5	95	6/5/95	Sunnyside	BR	93	7
8/26/94	Moxee	GA	75	25	6/6/95	Moxee	BR	52	48
8/26/94	Parker Hts	RD	100	0	6/6/95	Prosser	FU	38	62
8/26/94	Parker Hts	RD	100	0	6/6/95	Wapato	GD	94	6
8/26/94	Parker Hts	RD	94	6	6/6/95	Zillah	RD	92	8
8/26/94	Parker Hts	RD	100	0	6/7/95	Prosser	RD	79	21
8/29/94	Prosser	BR	95	5	6/7/95	Yakima	RD	76	24
8/29/94	Prosser	FU	100	0	6/7/95	Yakima	RD	86	14
8/29/94	Prosser	FU	100	0	6/7/95	Yakima	RD	96	4
8/29/94	Prosser	GA	100	0	6/7/95	Yakima	RD	13	87
8/29/94	Prosser	GA	100	0	6/7/95	Yakima	RD	90	10
8/29/94	Prosser	GA	100	0	6/7/95	Yakima	RD	60	40
8/29/94	Prosser	RD	90	10	6/30/95	Selah	RD	95	5
8/29/94	Prosser	RD	97	3	7/10/95	Parker	RD	100	0
8/29/94	Prosser	RD	100	0	7/10/95	Pasco	RD	97	3
8/29/94	Prosser	RO	100	0	7/20/95	Prosser	RD	52	48
8/29/94	Prosser	RO	100	0	8/15/95	Prosser	FU	77	23
8/31/94	Moxee	FU	100	0	8/15/95	Prosser	FU	90	10
8/31/94	Moxee	GD	100	0	8/15/95	Prosser	FU	83	17
8/31/94	Moxee	RD	100	0	8/15/95	Prosser	GA	100	0
8/31/94	Moxee	RD	100	0	8/15/95	Prosser	RD	100	0
9/2/94	Moxee	BR	97	3	8/15/95	Prosser	RD	80	20
9/2/94	Moxee	FU	100	0	8/15/95	Prosser	RD	93	7
9/2/94	Moxee	RD	100	0	8/15/95	Prosser	RD	13	87
9/2/94	Moxee	RD	100	0	8/15/95	Prosser	RD	100	0
9/2/94	Moxee	RD	100	0	8/15/95	Prosser	RO	56	44
9/7/95	Donald	FU	100	0	8/18/95	Moxee	GD	93	7
9/7/94	Moxee	BR	100	0	8/21/95	Prosser	GA	100	0
9/7/94	Moxee	GD	92	8	8/22/95	Moxee	GD	100	0
9/7/94	Moxee	RD	6	94	8/22/95	Moxee	RD	23	77
5/15/95	Prosser	RD	100	0	8/22/95	Moxee	RD	93	7
5/16/95	Prosser	RD	100	0	8/29/95	Moxee	BR	100	0
5/21/95	Prosser	RD	100	0	8/31/95	Prosser	GD	100	0
					9/10/95	Parker	RD	100	0

RESULTS AND DISCUSSION

We found spirea aphid in all but 3 samples and apple aphid in 42 of the 75 samples (Table 1). Neither species was clearly prevalent on a particular apple variety (Table 1). We suspected that there might be more apple than spirea aphids during May and June as compared to August and September but the data do not show any such trend.

In 1994, 88% of the 930 individuals examined were spirea aphids. In 20 orchards we found spirea aphid only, but in 11, most of the aphids were spirea and in 2, all were apple aphids. In 1995, 76% of the 1,260 aphids examined were spirea aphids. In 13 orchards we found only spirea aphids, in 22 others most aphids were spirea, in one all were apple aphids and in 6 most were apple aphids. In the two years combined, 33 orchards (44%) had spirea aphids only, 33 (44%) had predominately spirea aphid, 6 (8%) had mainly apple aphid and 3 (4%) had apple aphids only.

In 1994 and 1995, most of the green aphids found infesting apple trees in south central Washington were spirea. Clearly, the area has experienced a shift in aphid species composition on apples as reported from other parts of the world (Zehavi and Rosen, 1987; Pfeiffer et al. 1989). The extent of spirea aphid infestations on apple needs to be determined for other apple growing areas in Washington and neighboring British Columbia. For proper biological and chemical integrated pest management we need further information on the biology of spirea aphid in Washington. Possible differences between the species in effective natural enemies have not been examined to date.

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Interaction between the bluestain fungal associates of mountain pine, and pine engraver beetles, (*Dendroctonus ponderosae* and *Ips pini*, Coleoptera: Scolytidae) and their effects on the beetles

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ABSTRACT

We investigated the potential antagonism between the fungal associates of the pine engraver and mountain pine beetles. We measured and compared their rates of growth in bolts of lodgepole pine and in living trees: *Ophiostoma ips* from *Ips pini* against *O. clavigerum* from *Dendroctonus ponderosae*. We measured the length of lesions shown by discolored xylem, but we found both fungi outside of visibly stained areas, which showed that mere staining is not a reliable indicator of fungal growth. There were no significant differences in brood development or survival between the two beetle spp., when bolts were inoculated with either fungal associate.

Key words: Coleoptera:Scolytidae, bluestain fungi, *Pinus contorta*, Princeton, Williams Lake, B.C.

INTRODUCTION

The mountain pine beetle, *Dendroctonus ponderosae* Hopk., is one of the most destructive insect pests of mature pines in British Columbia (B.C.) (Unger 1993). In 1993, an average year for bark beetle activity, losses to the mountain pine beetle amounted to 4.8 million trees on nearly 45,000 hectares (Wood and Van Sickle 1992). Forest management for timber and other resources is often greatly disrupted by mountain pine beetle outbreaks. Current short-term management techniques to reduce timber losses from mountain pine beetle attack include sanitation logging, single-tree treatments, and the use of trap trees baited with pheromones (Unger 1993, Safranyik 1995).

A novel biological control technique is to bait trees attacked by mountain pine beetles with the aggregation pheromone of the pine engraver beetle, *Ips pini* Say. This approach is based on observations that secondary attacks by pine engraver beetles at very high densities often results in high mortality of mountain pine beetle broods (Andrews 1987, Humphreys and Ferris 1987, Rankin and Borden 1991). The reasons for this mortality are unknown, but Rankin and Borden (1991) speculated that the fungal associate of the pine engraver may have a direct antagonistic effect on brood development of the mountain pine beetle or on its fungal associate.

Ophiostoma ips is the bluestain fungus most closely associated with the pine engraver (Mathre 1964, Raffa and Smalley 1988, Furniss *et al.* 1995). Both *O. clavigerum* and *O. ips* are associated with the mountain pine beetle (Robinson 1962, Reid *et al.* 1967, Whitney 1971) although *O. clavigerum* is frequently the only bluestain fungus recovered (H.S. Whitney personal communication). Antagonism between the two fungi has been demonstrated by the reduced pathogenicity of *O. clavigerum* to seedlings of ponderosa

pine, *P. ponderosa* Laws, when inoculated in combination with *O. ips* (Owen *et al.* 1987). Similar antagonism was also demonstrated when other bluestain fungi were inoculated in combination compared with separate inoculations (Owen *et al.* 1987; Parmeter *et al.* 1989, 1992; Nevill *et al.* 1995). Our own investigations show that *O. ips* appears to inhibit the growth of *O. clavigerum* when grown on malt extract agar (unpublished data).

Because an antagonistic effect on brood survival has been shown to occur between the southern pine beetle, *Dendroctonus frontalis* Zimmerman, and its fungal associate, *Ophiostoma minus* [(Hedgc.) H.&P. Syd. = *Ceratocystis minor* (Hedgc.) Hunt] (Barras 1971, Franklin 1970) and between the California five-spined ips, *Ips paraconfusus* Lanier, and its fungal associate, *O. ips* (Rumb.), as well as other bluestain fungi (Fox *et al.* 1992) we investigated potential antagonism of *O. ips* and *O. clavigerum* (Robins. Jeff. & Davids) to brood development of the mountain pine beetle and the pine engraver.

The objectives of this study were to investigate the antagonism between the respective fungal associates of the mountain pine beetle and the pine engraver and to determine whether this antagonism has an effect on mountain pine beetle brood survival and development

MATERIALS AND METHODS

The mountain pine beetle fungal associate, *O. clavigerum,* was taken from a mountain pine beetle egg gallery in lodgepole pine collected at Saturday Creek near Princeton, B.C. The pine engraver associate, *O. ips*, was obtained from the bodies of adult *I. pini* beetles collected from duff at Sunday Creek also near Princeton. Both fungi were maintained on 1.5% malt extract agar (MEA) at room temperature, 20° C.

a. Bioassays of antagonism of fungal associates in lodgepole pine bolts. To investigate antagonism between the two fungi, 20- to 30-cm dbh lodgepole pine growing at Sunday Creek were felled and cut into 45 cm bolts. The exposed ends of the bolts were dipped in melted paraffin to prevent drying. The bolts were stored at 5°C and used at two week intervals

Inoculum consisted of the respective fungi grown on MEA at room temperature for 2 - 4 weeks.

Each bolt set vertically received six, randomly assigned, inoculations evenly spaced around the circumference of the bolt. The treatments were: 1) inoculation with sterile malt extract agar (MEA) - control, 2) MEA colonized by *O. clavigerum,* 3) MEA colonized by *O. ips*, 4) combination inoculations of *O. clavigerum* and *O. ips* , *O. clavigerum* placed first, 5) combination inoculations of *O. clavigerum* and *O. ips* , *O. ips* placed first, and 6) single inoculations of *O. clavigerum* and *O. ips* separated along the vertical axis by 5 cm. Treatments were assigned to five bolts (replicates) and repeated four separate times (blocks), at two week intervals, for a total of 20 bolts.

The inoculation sites were prepared by smoothing the bark with a drawknife at six places around the circumference of the bolt approximately at midpoint. The bark was sprayed with 95% ethanol and flamed, and a hole was made with a flame-sterilized leather punch 5 mm in diameter. Using an ethanol-dipped and flamed spatula, a 5-mm plug of colonized or sterile MEA was placed into the hole (two plugs for combination inoculations), a sterile cotton roll was dipped in distilled water placed over the agar, and the area was sealed with duct tape. Single inoculations of *O. clavigerum* and *O. ips* separated by 5 cm were made by establishing two points along the vertical axis of the bolt 5 cm apart. One end of the bolt was marked with a red felt pen with the *O. clavigerum* inoculation closest to the pen mark "above" the *O. ips* inoculation.

The bolts were examined 3 weeks after inoculation by removing the bark with a drawknife sprayed with 95% ethanol and flamed. The evidence of colonization by the fungi (e.g. blue/black stain) was measured above and below the inoculation point. Colonization of the xylem was confirmed by removing disks with a flame-sterilized 5 mm dia leather punch at 3.0 cm intervals to 12.0 cm above and below the inoculation point. The disks were placed on to MEA amended with 5% cycloheximide (McCall and Merrill 1980) and incubated 10 days at 20°C. For inoculations of *O. clavigerum* and *O. ips* 5 cm apart, wood samples were taken at 3.0 cm intervals to 12.0 cm above the *O. clavigerum* inoculation point and below the *O. ips* inoculation point. One sample was also taken between the inoculation points

Lesion lengths for each treatment, as measured by visible staining in the wood, were compared by a 2-way analysis of variance, blocking for treatment and replicate, using the SAS Proc-GLM procedure (SAS Institute 1989). When significant differences were indicated by the *F*-test within the ANOVA, means were separated using the Student Neuman-Kuels test at $p < 0.05$.

b. Bioassays of antagonism fungal associates in living lodgepole pines. For inoculation, ten 20- to 30-cm dbh lodgepole pine trees were selected in two stands, five at Saturday Creek and five at Sunday Creek near Princeton, B.C. Both sites are in the IDFd biogeoclimatic zone (Mitchell and Green 1981).

Each tree received the same six inoculation treatments as described for the bolts. Treatments were assigned to five trees (replicates) at each stand for a total of 10 trees. Inoculations were made in early August to correspond with mountain pine beetle flight (Unger 1993, Safranyik 1995).

The inoculation sites were prepared by smoothing the bark with a drawknife at six places approximately equidistant around the tree at breast height. The bark was sprayed with 95% ethanol and flamed, and a hole was made with a flame-sterilized leather punch 5 mm in diameter. Using an ethanol-dipped and flamed spatula, a 5-mm plug of colonized or sterile MEA was placed into the hole (two plugs for dual inoculation), a sterile cotton roll dipped in distilled water placed over the agar, and the area sealed with duct tape.

The trees were felled after 8 weeks. The bolts were examined as above with the exception that wood disks were taken at 5.0-cm intervals to 25.0 cm above and below the inoculation point. For inoculations of *O. clavigerum* and *O. ips* spaced 5 cm apart, wood disks were taken at 5.0-cm intervals to 25.0 cm above the *O. clavigerum* inoculation point and below the *O. ips* inoculation point. One sample was also taken between the inoculation points.

Lesion lengths for each treatment, as measured by visible staining in the wood, were compared by a 2-way analysis of variance, blocking for treatment and replicate, using the SAS Proc-GLM procedure (SAS Institute 1989). When significant differences were indicated by the *F*-test within the ANOVA, means were separated using the Student Neuman-Kuels test at $p < 0.05$.

c. Bioassays of brood establishment. Pine engraver beetles were collected from duff beneath trees attacked by them near Sunday Creek, and from bolts cut from lodgepole pine logs attacked by them near Williams Lake B.C. Mountain pine beetles were collected from bolts taken from beetle-killed trees at Sunday Creek.

To establish brood, living lodgepole pine trees of 20- to 30-cm dbh were felled and cut into 45 cm bolts. The bolts were split in half and the exposed side and ends of the bolts were dipped in melted paraffin to prevent drying.

Adult mountain pine and pine engraver beetles were caged separately on lodgepole pine bolts inoculated with either *O. clavigerum*, *O. ips* or sterile agar as a control. The three inoculation treatments were replicated seven times with the mountain pine beetles for a total of 21 bolts. Treatments with the pine engravers were replicated six times for a total of 18 bolts. Inoculation of the bolts was similar to "*a*" above except that the bolts were inoculated at three sites that were 5 cm apart and 15 cm from one end of the bolt.

Beetle attack was induced immediately after inoculation by carefully cutting the bark to the cambium with a 5-mm-diameter cork borer so that the resulting bark disk was not removed. A 2-mm hole was made with a hand drill into the centre of the bark disk and either a single pine engraver male or mountain pine beetle female was caged on the bolt with a gelatin capsule. Beetle attack points were 2.5 cm from the end of the bolt and 12.5 cm from the inoculation sites. Twenty-four hours after successful attack (e.g., frass appearing at an entrance hole) two female pine engraver beetles or a single male mountain pine beetle were caged with their respective species onto the bolts using gelatin capsules as described. Once both sexes had entered the bolts, the bolts were placed in nylon mesh bags and stored on end with the beetle entrance point nearest the floor.

Emerging beetles were counted over 10 weeks after which the bolts were examined for remaining brood. Success of mountain pine beetle brood development was measured by length of adult female gallery and numbers of emerging beetles whereas success of pine engraver development was measured only by numbers of emerging beetles. Length of mountain pine beetle egg galleries and numbers of both species of bark beetles emerging from the inoculated bolts were compared by analysis of variance using the SAS Proc-GLM procedure. When significant differences were indicated by the *F*-test within the ANOVA, means were separated using the Student Neuman-Kuels test at $p < 0.05$.

RESULTS

a. Bioassays of antagonism of fungal associates in lodgepole pine bolts. Although lesion length, as measured by visible staining, was significantly different among inoculation treatments and among blocks, lesion length was not a reliable indicator of fungal growth. In almost all instances the fungi could be recovered from the wood up to 12.0 cm above and below the inoculation point - at least 2.5 cm beyond visible staining (Table 1). Differences of staining lengths between blocks appeared to be related to bolt age as staining lengths were longest in the bolts inoculated immediately after the trees were harvested and decreased with the period of time the bolts were stored.

Characteristics of *O. clavigerum* growing in culture included appressed to effuse growth, colorless at first but rapidly becoming dark brown to grayish black; color of the colony from the reverse side to the Petri plate was black; mycelial growth of 10-day-old colonies was superficial and immersed. Both mononematous and synnematous conidiophores and conidia resembling the description of *O. clavigerum* by Upadhyay (1981) were observed. Although perithecia were not seen, the distinctive, almost club-shaped conidiospores differentiated this fungus from *O. ips*.

Characteristics of *O. ips* growing in culture included appressed to effuse growth, colorless at first becoming pale yellow to light brown; color of the colony from the reverse side of the Petri plate was pale yellow; mycelial growth of 10-day-old colonies was superficial and immersed. Conidiophores mononematous 1.5-4.5 X 1-2 mm, pale brown at base becoming hyaline. Perithecia were not observed, but the round to oval (prolate) conidiospores differentiated this fungus from *O. clavigerum*.

Table 1.

Mean lesion length and recovery of *Ophiostoma clavigera* (*O.c.*) and *O. ips* (*O.i.*) from inoculated living lodgepole pine trees.

		Distance from inoculation point and percent of bolts from which fungi were collected											
	Mean lesion		3.0 cm			6.0 cm			9.0 cm			12.0 cm	
Inoculation Treatment	Length (cm) ±S.E.	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both
O.c. only	7.5 ± 0.8 bc [5]		100.0			100.0			100.0			100.0	
O.i. only	9.7 ± 0.6 a	100.0			100.0			100.0			100.0		
O.i./O.c. [1]	7.6 ± 0.5 bc			100.0			100.0			100.0			100.0
O.c./O.i. [2]	9.5 ± 0.7 a			100.0			100.0			100.0			100.0
O.c.-O.i. [3]	6.3 ± 0.5 c			100.0		13.3	87.7		60.0	40.0		100.0	
O.c.- O.i. [4]	8.6 ± 0.7 ab			100.0			100.0			100.0			100.0

Table 2.

Mean lesion length and recovery of *Ophiostoma clavigera* (*O.c.*) and *O. ips* (*O.i.*) from inoculated lodgepole pine trees.

		Distance from inoculation point and percent of bolts from which fungi were collected											
	Mean lesion		5.0 cm			10.0 cm			15.0 cm			20.0 cm	
Inoculation Treatment	Length (cm) ±S.E.	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both	O.i. only	O.c. only	Both
O.c. only	11.1±0.9 ab [5]		100.0			10.0							
O.i. only	13.2±0.7 a	100.0			50.0			20.0					
O.i./O.c. [1]	9.7±0.8 b		70.0	30.0		10.0							
O.c./O.i. [2]	12.5±1.0 ab			100.0			70.0	20.0			10		
O.c.-O.i [3]	10.5±1.1 ab		100.0										
O.c.- O.i. [4]	12.4± 0.7 ab	100.0			80.0			20.0					

[1] combined inoculation, *O. c.* placed first. [2] combined inoculation, *O.i.* placed first. [3] single inoculations of *O.c* and *O. i.* 5 cm apart, collected below *O.c* inoculation point.
[4] single inoculations of *O.c.* and *O.i.* 5 cm apart, collected above *O.i.* inoculation point.
[5] treatments followed by the same letter are not significantly different ($p > 0.05$, GLM procedure and Student Neuman-Keuls test).

Fungal growth characteristics of combination inoculations of *O. ips* and *O. clavigerum* on MEA, whether *O. clavigerum* or *O. ips* was placed first, most closely resembled those of *O. ips*. However, the distinctive conidiophores and conidia of *O. clavigerum* could be recovered together with those of *O. ips* up to 12.0 cm from the inoculation point in all but 3 of 20 inoculations.

Samples taken from wood of single inoculations separated by 5 cm revealed that both fungi could be recovered to 12.0 cm below the *O. ips* inoculation in all instances. Both fungi could also be isolated from all samples taken between the inoculation points although all colonies closely resembled those of *O. ips*. Fungal growth at 3.0 and 6.0 cm above the *O. clavigerum* inoculation point produced distinct colonies of *O. ips* or *O. clavigerum* which contained conidiospores of both fungi. However, at 9.0 cm above the *O. clavigerum* inoculation point conidiospores of both fungi were recovered from only 40% of the samples and for the remainder only conidiospores of *O. clavigerum* were observed. At 12.0 cm, only distinctive colonies of *O. clavigerum* and conidiophores of that fungus were observed.

b. Bioassays of antagonism fungal associates in living lodgepole pines. Although lesions in living trees in response to either single or combined inoculations of *O. clavigerum* or *O. ips* were similar to those in the bolts, lesion lengths were significantly different only between two treatments. In addition, the fungi were only consistently recovered from stained wood or wood disks taken 5.0 cm from the inoculation point (Table 2). At 10 cm from the inoculation point, recovery dropped to 50-80% of wood disks for single and combination inoculations in which *O. ips* had been placed first. Recovery from inoculations in which *O. clavigerum* had been placed first was poor. Otherwise, fungal growth patterns were similar to those described for the bolts.

Characteristics of combination inoculations in which *O. ips* was placed first resembled typical colony growth for single inoculations of that fungus although both fungi were recovered from wood disks taken at 10 cm. However, at 15 and 20 cm only conidiospores typical of *O. ips* were seen. Combined inoculations in which *O. clavigerum* was placed first either showed growth typical of single inoculations of that fungus or had a portion of the Petri plate with growth typical of *O. ips*. In portions with growth typical of *O. clavigerum* only conidiospores of that fungus could be recovered while in portions with growth typical of *O. ips* conidiospores of both fungi were observed.

For single inoculations separated by 5 cm, both fungi could be recovered from samples taken between the inoculation points, but in contrast to the bolts, distinct colonies of both fungi were observed. At 5.0 cm from the *O. ips* or the *O. clavigerum* inoculation points only distinct colonies and conidiophores of the respective fungi were seen.

c. Bioassays of brood establishment. Analysis showed no significant effect of inoculation with either fungus on adult gallery length or numbers of emerging adult mountain pine beetles (Table 3). Similarly, fungal inoculations had no significant effect on numbers of emerging pine engraver beetles.

Mountain pine beetle broods were established in five of seven control bolts inoculated with sterile agar, four of seven bolts inoculated with *O. ips* and four of seven bolts inoculated *O. clavigerum*. In one of the control bolts, the adult beetle exited after creating a 7-cm egg gallery and in a second bolt the beetle created a 2-cm egg gallery before exiting. There was no obvious reason why either beetle exited (e.g.: no visible staining or decay). Dissection of the bolts inoculated with either fungus showed that the adult beetles exited before encountering stained areas in all but one instance.

Table 3

Mean Gallery length (cm) and number of adult beetles emerging from lodgepole pine bolts inoculated with the fungal associates of the mountain pine beetle and the pine engraver.

	Dendroctonus ponderosa		*Ips pini*	
	Gallery	No. adults	Gallery	No. adults
Inoculation	length (cm) ± S.E.	± S.E.	length (cm) ± S.E.	± S.E.
Control	45.8 ± 12.0 [1]	37.4 ± 11.8 [1]	nm [2]	24.3 ± 5.9 [1]
O. ips	54.1 ± 10.6	36.5 ± 9.4	nm	25.0 ± 12.7
O. clavigera	48.5 ± 8.5	25.0 ± 4.5	nm	33.5 ± 16.2

[1] no treatments were significantly different $p > 0.05$ GLM procedure and Student Neuman-Keuls test).
[2] not measured

Larval galleries in bolts inoculated with either fungus were indistinguishable from controls and larvae created typical galleries at right angles from the adult gallery. These galleries did not deviate if the inoculated fungus was encountered.

Pine engraver broods were established in all six of the control bolts and in four of the bolts inoculated with either *O. clavigerum or O. ips*. Adult beetles which exited without ovipositing did so before encountering areas stained by the inoculated fungus. In all instances where oviposition took place larvae developed in the stained areas.

DISCUSSION

Because of the negative effect on brood survival of the southern pine beetle and the California five-spine ips of their respective fungal associates we thought it prudent to test whether this effect could be observed with the mountain pine beetle and the pine engraver beetle. However, we found no significant reduction of brood development and survival of the mountain pine beetle or pine engraver after inoculation with *O. clavigerum* or *O. ips*. This was not entirely unexpected because both *O. clavigerum* and *O. ips* are recorded as associates of the mountain pine beetle (Robinson 1962, Reid *et al.* 1967, Whitney 1971). Therefore, we conclude that introduction of foreign fungi by the pine engraver does not explain the decreased success of mountain pine beetle brood when both insects attack the same host.

While longitudinal growth of the fungi was recorded up to 20 cm from the inoculation point we were not concerned about interference between the different treatments from horizontal growth around the bolts. Both Parmeter *et al.* (1992) and Nevill *et al.* (1995) have shown that horizontal growth of blue stain around the bolts is minimal within the inoculation period used in this study.

We found little or no antagonism between *O. clavigerum* and *O. ips* when inoculated together either in the bolts or in living trees. Although in both cases there were significant differences in lesion lengths, the length of lesions produced by single inoculations were not significantly different from those lengths produced by combination inoculations in which the respective fungus was placed first. For example, the average lesion length of single inoculations of *O. ips* was not significantly different from combination inoculations in which *O. ips* was placed first (Table 1,2). Moreover, lesion length is generally not a good indication of the growth of blue stain fungi in the sapwood and these fungi can often be recovered in apparently clear wood beyond the lesions (Owen *et al.* 1987; Parmeter *et al.* 1989, 1992; Nevill *et al.* 1995).

It is not entirely clear which is the more aggressive fungus. Owen *et al.* (1987) found *O. clavigerum* to be more virulent than *O. ips* to ponderosa pine. Solheim (1995) observed that when the two fungi were found together in beetle-attacked trees, *O.*

clavigerum was always at the leading edge of fungal colonization. From the combination inoculations in living lodgepole pine trees our results showed that when inoculated first, *O. clavigerum* was recovered more frequently alone than when *O. ips* was inoculated first. However, when *O. ips* was inoculated first, it was found alone at further distances from the inoculation point than *O. clavigerum*. Thus, for combined inoculations the recovery of the fungi could be interpreted as either a positional effect or as antagonism.

As previous studies have shown that combined inoculations of blue stain fungi may demonstrate both antagonism and non-antagonism (Owen *et al.* 1987, Parmeter *et al.* 1989, 1992; Nevill *et al.* 1995) we decided to determine whether prior colonization by the fungi would demonstrate any effect by inoculating them 5 cm apart. In living trees, both fungi could be readily recovered from wood disks taken between the inoculation points, but only the inoculated fungus could be recovered from wood disks distal from the inoculation. This was not entirely the case with the bolts where both fungi could be recovered between the two inoculation points and distal from the *O. ips* inoculation point to 12 cm. Both fungi could also be recovered distal from the *O. clavigerum* inoculation point to 3 cm, but starting at 6 cm *O. clavigerum* was progressively isolated alone up to 12 cm where it was the only fungus recovered. Both sets of observations refute our earlier results when growing the two fungi together on MEA. Thus, when growing in its host environment, *O. clavigerum* appears to be the more aggressive of the two fungi as suggested by Solheim (1995).

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A survey of grassland and montane arthropods collected in the southern Okanagan region of British Columbia.

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ABSTRACT

The arthropods of the Osoyoos - Mt. Kobau area (119° 40' W, 49° 05' N) in the southern Okanagan valley of BC were surveyed in the summer of 1991. Mt. Kobau is a high ridge with south-facing slopes covered in grassland and sagebrush from valley bottom to summit. A variety of insect traps and active collecting techniques was used to obtain the greatest possible diversity of arthropod species in the samples. Collections were made in a roughly vertical transect of Mt. Kobau from 300m at Osoyoos to the summit at 1861m. Eighty-eight samples were sorted to select the greatest number of taxa possible. A total of 5566 specimens was prepared for identification and of this, 5023 were identified to species (or morphospecies) by March, 1994. We collected at least 1101 species, including 12 new distributional records for Canada, 15 new distributions for BC, 30 possible new records for Canada and 14 possible new records for BC, 2 new species, and 84 species considered rare, restricted or potentially endangered. Most of the rare species and records were found at low elevations and are typical of deserts and arid sagebrush grasslands of the Great Basin and Columbia Plateau to the south. Comparison of catches made by different collecting techniques indicates that pantraps catch the most species and are the most cost effective.

Key words: faunistics, biogeography, grassland, steppe, desert

INTRODUCTION

The Southern Okanagan Basin and Okanagan Range Ecosections in southern British Columbia (BC) (Demarchi, 1996) represent the northern limit of distribution of many plants and animals of the arid regions in the Great Basin and Columbia Basin, between the Rocky Mountains and the Cascade and Sierra Nevada ranges in the western USA (Scudder, 1992). Munro and Cowan (1947) termed this area the Osoyoos Arid Biotic Zone. Many of the plant and animal species living there occur nowhere else in Canada and this, combined with the threat of habitat loss through agricultural development and rapidly expanding urban development, have focussed the attention of conservationists on this region. The Nature trust of BC targeted it for special conservation measures and research and subsequently joined with other organizations and goverment agencies to create the Southern Okanagan Conservation Areas Program (SOCAP) (Erikson and Torrance, 1989). This program has evolved into the South Okanagan Conservation Strategy.

Mount Kobau is a high (1861m) ridge straddling the south Okanagan and Similkameen Valleys with south-facing slopes covered in grassland and sagebrush shrubland from valley bottom to summit. The grasslands straddle five biogeoclimatic zones: Bunchgrass, Ponderosa Pine, Interior Douglas-fir, Montane Spruce, and Engelmann Spruce-Subalpine Fir (Meidinger and Pojar, 1991). More interesting is the

fact that some of the grassland plants associated with the dry steppes of the valley bottom, such as big sagebrush (*Artemisia tridentata* Nutt.) and bitterroot (*Lewisia rediviva* Pursh), are common on the summit of Mt. Kobau. These high altitude sagebrush shrublands are rare in Canada and restricted to this immediate area. Finally, although it lies across the deep Similkameen Valley from the Cascade Mountains, earlier collections on Mt. Kobau indicate that its peak is home to some interesting invertebrate species associated with the Cascades and otherwise rare or unknown in Canada.

Some invertebrates of special interest were previously included with a list of other endangered, threatened or sensitive plant and animal species (Erickson and Torrance, 1989). That list was based primarily on historical records and observations by the authors and contributors. Most collections from the area were of specific taxonomic groups, widely scattered in space and time, and did not employ the passive trapping techniques commonly used today. We used intensive sampling to obtain a large and diverse collection of arthropods from grassland habitats in the main biogeoclimatic zones in the south Okanagan.

Our primary objective was to provide baseline information on the arthropod community of Mt. Kobau and the Osoyoos region. We used several collecting techniques to maximize the diversity of the collection. Selective sorting of the raw samples into groups that could be identified by cooperating systematists was also a concern. We sampled Mt. Kobau in a vertical transect from valley bottom to the summit obtaining specimens from the main biogeoclimatic zones.

METHODS

Site Selection. Three main trapping stations were established on the slopes of Mt. Kobau (Fig. 1; LOW, MID, HIGH). Each consisted of a Malaise trap, 6 `permanent' aluminum pantraps (in place from May 28-Aug. 28), and 10 additional yellow plastic pantraps. We collected May 28 - June 3, July 8 - 13, and Aug. 24 - 28, 1991.

Station LOW (E) was below Richter Pass (560m) in the Bunchgrass biogeoclimatic zone (**BGxh1**=Bunchgrass, xeric, hot) (Fig. 1). Vegetation in this area was primarily sagebrush (*Artemisia tridentata* Nutt.) with scattered clumps of bunchgrass (*Agropyron spicatum* (Pursh.)), cactus *Opuntia fragilis* (Nutt.), *Artemisia frigida* (Willd.), *Onobrychis viciifolia* Scop., *Ipomopsis aggregata* (Pursh) V.Grant, *Cynoglossum officinale* L., *Lupinus sericeus* (Pursh.), *Phacelia linearis* (Pursh.) Holz., *Balsamorhiza sagittata* (Nutt.), *Oxytropis campestris* (DC.), and a number of exotic species.

Station MID (C) was at about 990m near the road up Mt. Kobau. It was in a forb meadow near the transition of the Ponderosa Pine and Interior Douglas-fir Zones (**PPxh1**=Ponderosa Pine, xeric, hot; and **IDFxh1**=Interior Douglas Fir, xeric, hot). Common plants in this area were *L. sericeus*, *A. tridentata*, *Stipa columbiana nelsoni* (Scribn.), and various other grasses.

Station HIGH (A) was at about 1750m near the lower margin of the Engelmann Spruce/Subalpine Fir Zone (**ESSFxc**=Engelmann Spruce/Subalpine Fir, xeric, cool) and upper extent of Interior Douglas-Fir Zone (**IDFdk1**=Interior Douglas-Fir, dry, cool). Typical plants near the traps were *A. tridentata* var. *vaseyana* (Rydb.), *Hackelia micrantha* (Eastw.), and *Aquilegia flavescens* S.Wats.

In addition, yellow pantraps were placed by a roadside spring at 800m (D), and near the Osoyoos city dump (DUMP)(370m) (Fig. 1). A carrion-baited pitfall trap was at 1100m (B). Hand collecting and aerial sweeps were done at other sites on Mt. Kobau and at the Haynes Lease Ecological Reserve (300m). Light-traps, aquatic nets, and Berlese

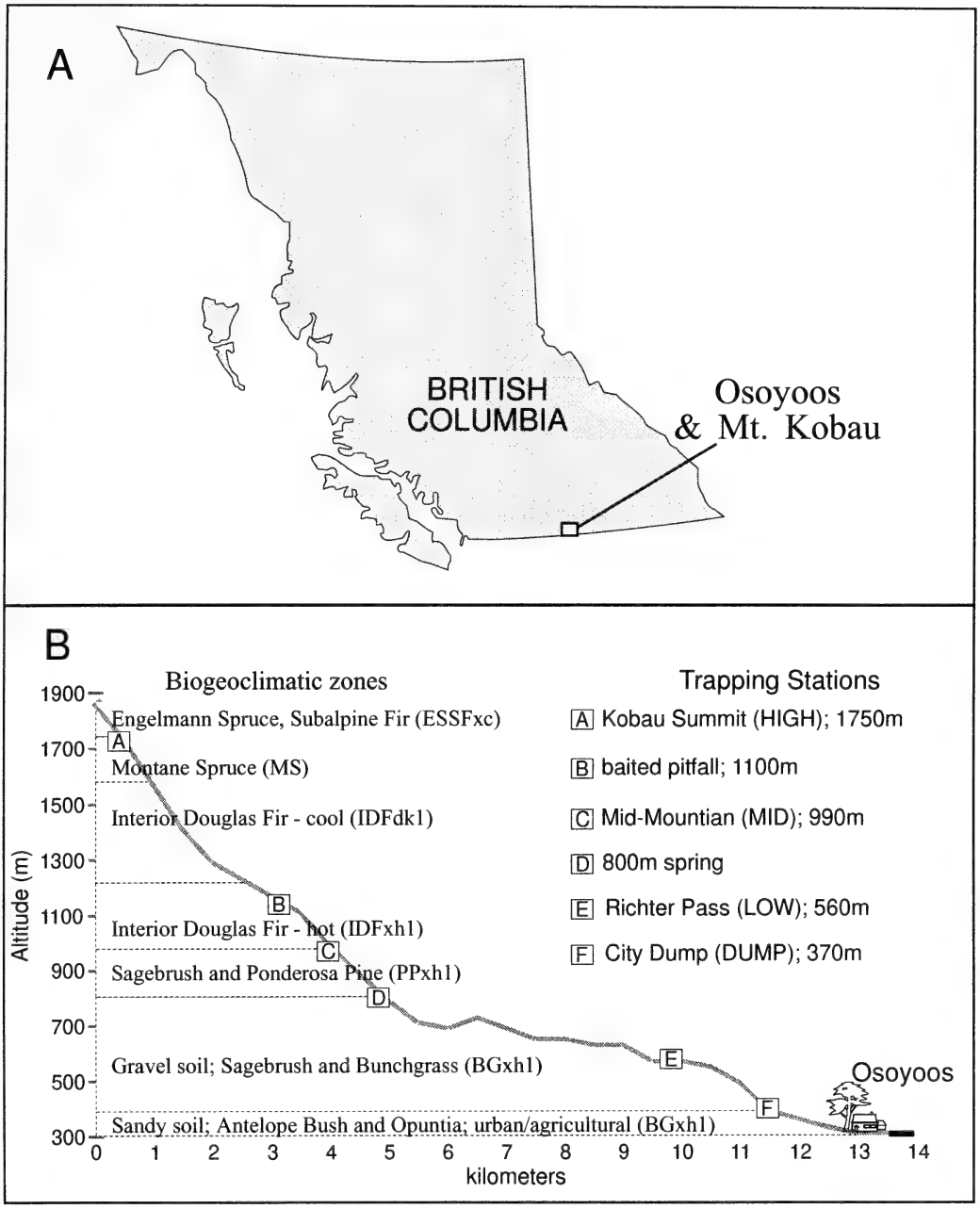

Figure 1. **A)** Location of study area in British Columbia. **B)** Stylized cross-section of Mt. Kobau transect showing approximate trap locations and habitat types. Based on topographic map 82E/4 (Keremeos) and Ministry of Environment biophysical maps 82E.002, 82E.003, and 82E.012.

funnels were also used to obtain samples. Detailed 1:20,000 scale maps of biophysical regions are published by the Wildlife Branch, Ministry of Environment, Lands and Parks, Victoria, BC.

Collecting Methods. The traps used were: Malaise traps; aluminum pantraps (25x10x10cm) set into the soil and filled with Prestone® antifreeze; yellow plastic pantraps (12cm diameter) filled with salt saturated water and a few drops of Sunlight® dishwashing liquid; a sheep's tongue-baited pitfall trap; and a portable BioQuip® UV light trap. At LOW MID and HIGH, a Malaise trap had two aluminum pans below the central panel to collect flying insects that drop on encountering a barrier. Four additional aluminum pantraps were placed within 5m of each Malaise trap. Ten yellow pantraps were then set in a vertical transect on a nearby steep slope. The aluminum pantraps were left in place between collecting trips, whereas the Malaise and yellow pans were reset at the beginning of each active collecting period. The Malaise traps and pantraps collected many specimens, especially nymphs of grasshoppers. Some of the samples contained over a litre of specimens. Some traps were overturned or destroyed by foraging cattle at stations D, MID and High.

In addition, we used active collecting techniques such as sweeps with aerial and aquatic nets, spot (hand) collecting, and berlese funnels.

Preparation and Identification. Specimens collected in traps and sweeps were rinsed with tap water before transfer to 70% ethanol. Spot collected specimens were killed with ethyl acetate or alcohol and pinned or preserved as required for the particular taxon (Martin, 1977).

Catches from traps were sorted selectively, groups that could be identified or were likely to contain rare or endangered species were pulled out preferentially. We subsampled by removing at least one specimen of each apparent species from every sample. Sorting was done under a dissecting microscope and only adult specimens were removed. The remaining unsorted specimens were labelled and stored in 70% ethanol at the Royal BC Museum (RBCM). Acari, Collembola, Homoptera: Sternorrhyncha, most Staphylinidae, Diptera: Nematocera, and Hymenoptera: Parasitica were not sorted further. A subsample of the Hymenoptera: Parasitica was donated to the Canadian National Collection (CNC) in Ottawa.

Some of the pinned specimens (mainly Diptera) were freeze-dried to reduce collapsing of the body during drying. Odonata were placed in envelopes either in the field or after removal from alcohol. Each specimen (or vial of specimens) was then labelled with the date and location information and given an accession number for the RBCM collection.

The prepared specimens were then identified to family and taxonomic specialists were asked to provide further identifications. The specimens were identified to the lowest practical level by specialists with only a few taxa (Psocoptera, Homoptera: Psyllidae, Siphonaptera, and Hymenoptera: Pompilidae) remaining undetermined. Taxa for which specialists were not found, or which have adequate keys, were identified by D. Blades to species or morphospecies.

Each specimen was catalogued in a computer database. This contains all information for each specimen in the format required by the Canadian Heritage Information Network (CHIN). Typically the locality (including altitude, UTM coordinates, habitat descriptions, etc.), RBCM collection information, taxonomic group, sex, and developmental stage were recorded for each specimen.

RESULTS AND DISCUSSION

Collection Characteristics. The selective sorting yielded a diverse collection, but tended to over-represent some species and under-represent others compared with the raw samples. This limits the interpretation of the data to analyses based on presence or absence of species and investigations of broad ecological patterns. Numbers of specimens therefore indicate the available pool of prepared specimens from which species were identified. Morphospecies are taxa which represent morphologically distinct entities within the collection but are not identified to a specific name. Morphospecies are useful in measures of species richness, but cannot be used for analyses of biogeographical or ecological traits.

Status of determination	Species	%	Specimens	%
Identified to species	819	74.4	4,046	72.6
Identified to morphospecies	282	25.6	977	17.6
Not identified to species			543	9.8
Total	1,101	100.0	5,566	100.0

Over 1100 probable species (or morphospecies) in 195 families from 23 orders in 5 classes of arthropods were identified. An estimated 50 to 150 species are contained in the 543 prepared specimens not yet identified and there may be another 200 to 500 additional species in residues of the unsorted raw samples.

Numbers of species and specimens were greatest in groups typical of arid grasslands and deserts (Table 1. and Appendix 1) such as Megachilidae, Sphecoidea, Vespidae, Tiphiidae, Mutillidae, and Chrysidoidea, Tenebrionidae, Carabidae, Asilidae, and orthopteroid insects. Other species-rich taxa included Cicadellidae, Miridae, Elateridae, Curculionidae, Scarabaeidae, Syrphidae, Sphaeroceridae, Tachinidae, Lycaenidae, and Formicidae.

Biogeographical characteristics. The southern Okanagan and Similkameen Valleys have a distinct flora and fauna in Canada because of their geography and climate. Lying at the eastern edge of the Thompson Plateau, the valleys are an extension of the dry Great Basin and Columbia Plateau of the western USA. They are bordered on the southwest by the Cascade Mountains, and on the east by the Okanagan Highlands. The northern boundary of this ecological region is difficult to define, but Demarchi (1996) draws the border between South and North Okanagan basins just south of Penticton. Although many of the species collected in this survey are common throughout much of North America and not restricted to grassland habitats, a number of species are representative of the Intermountain grasslands to the south. This is especially true for species found below about 600m. Species collected at higher altitudes (above 1000m) are more typical of the montane and subalpine habitats found throughout much of the BC interior. Many of our species are described as restricted to sagebrush or arid grassland habitats. Only a few species found in our samples are primarily coastal or boreal species.

Species that are new records (and possible new records) for Canada and BC, and species that are rarely collected, endangered, or restricted to the south Okanagan are indicated in Appendix 1. Possible new records for Canada and BC are species for which published information indicates a record, but confirmation of the record is pending. Many of the species noted as possible new records belong to families of aculeate Hymenoptera.

Table 1

Summary of higher taxa collected near Osoyoos, BC, 1991. Numbers are based on specimens identified to species or morphospecies.

Class	Order	Families	Species	Specimens
ARACHNIDA	Solpugida	1	1	1
	Araneae	19	82	403
	Opiliones	2	2	28
CRUSTACEA	Isopoda	1	1	1
DIPLOPODA	Julida	1	1	3
	Chordeumatida	1	1	7
CHILOPODA	Lithobiomorpha	1	1	2
INSECTA	Microcoryphia	1	1	120
	Ephemeroptera	2	2	2
	Odonata	3	13	53
	Plecoptera	1	1	2
	Dermaptera	1	1	22
	Grylloptera	5	13	85
	Orthoptera	1	17	67
	Hemiptera	18	80	370
	Homoptera	8	70	393
	Raphidioptera	2	4	29
	Neuroptera	4	8	24
	Coleoptera	39	202	1108
	Diptera	39	280	1155
	Lepidoptera	14	70	252
	Trichoptera	3	4	6
	Hymenoptera	28	246	890
Totals		195	1101	5023

Some of these aculeates are listed in Krombein *et al.* (1979) as being found only in the southwestern U.S.A. (New Mexico, California, Arizona, Texas). Other aculeates like *Aphelopis varicornis* Brues and *Aphelopis albopictus* Ashmead are recorded from Massachusetts and Virginia, and Washington, D.C., respectively (Krombein *et al.*, 1979). If these distributions are valid, then the Okanagan records represent considerable range extensions. Most of those species in Appendix 1 that are considered rare, endangered, or restricted to the south Okanagan are listed and discussed by Scudder (1994) in his review of rare and endangered invertebrates in BC.

Table 2 summarizes the species assemblage in terms of the known range of each species in Canada as described in the literature or by the identifier. Distributions of species in Canada (and the USA) were obtained for 746 of the 819 (91.1%) named species. Most species in the collection are transcontinental or are widely distributed throughout southwestern Canada and the USA. About 20% of species have more

restricted distributions. Several species are restricted to the Okanagan valley in Canada and most of these are species characteristic of the Great Basin and Sonoran regions of the USA.

At least 36 of the species we collected are introductions to North America. Many of them are associated with cattle dung (*Cercyon* spp., *Sphaeridium* spp., *Aphodius* spp., *Onthophagus nuchicornis* L.). The ladybird beetle, *Coccinella septempunctata* (L.), was introduced for biological control projects in the eastern United States several times this century and has spread rapidly across the continent (Gordon, 1985). In 1990 the first specimens of this species were collected in BC and by 1993, Blades found it on Vancouver Island. The metallic wood-boring beetle, *Sphenoptera* sp.nr. *jugoslavica* Obenberger, and a tephritid fly, *Urophora affinis* Frauenfeld, are European species introduced to control knapweed (*Centaurea* spp.) (Story *et al.* 1984, 1987). Introduced species commonly found throughout North America included *Philaenus spumarius* (L.), *Apis mellifera* L., *Forficula auricularia* L., *Pterostichus melanarius* (Illiger), and *Pieris rapae* L..

Table 2

Distributional characteristics of species in the collection from Osoyoos and Mt. Kobau, 1991. Distributions obtained from identifiers and/or literature. Based on specimens determined to species or morphospecies.

Distribution	Species	%	Specimens	%
Widely distributed in Canada	521	47.3	2655	52.8
Found only in BC in Canada	139	12.6	752	15.0
Restricted to Okanagan in BC	35	3.2	147	2.9
Restricted to Okanagan in Canada	65	5.9	205	4.1
Unknown distribution	341	31.0	1264	25.2

The dominance of introduced species feeding on cattle dung reflects the nature of the dung itself. Dung of native vertebrates is much dryer than cattle dung and native dung feeding insects have not been particularly successful at exploiting this new resource in the dry interior of BC (MacQueen and Beirne, 1974). Of the 67 species of dung-inhabiting mites and insects listed by MacQueen and Beirne (1974), we collected at least 16. The beetle fauna (especially Histeridae and Scarabaeidae) is most similar to that found near Kamloops by MacQueen and Beirne (1974).

Altitude comparisons. Comparisons of collections at each altitude (Haynes Lease 300m; Osoyoos Dump 370m; low 380-800m; mid 801-1500m, and high 1501-1850m) showed that most species (710, 64.5%) were collected at only one elevation, 293 species (26.6%) were found at two elevations, 85 (7.7%) at three elevations, 13 (1.2%) at four, and none at all five elevations. This low overlap indicates that most species are restricted, within the Okanagan valley, to particular altitudes and associated conditions. We expected that valley bottom (below 370m; sandy soils; *Purshia tridentata*) and mountain top (above 1700m; Engelmann spruce subalpine) habitats would contain the greatest proportion of rare, endangered, and restricted species because they are effectively small islands separated from like habitats by the larger interconnected habitats of middle elevations. Too few specimens were collected at the Haynes Lease and Osoyoos dump to

compare the fauna living below 370m with the other elevations. However, when these collections are combined with other collections below 800m, some interesting patterns do emerge (Table 3.). The largest percentage of species with restricted distributions was at low elevations, whereas proportions of widespread and exotic species increase somewhat with altitude. This pattern seems to correlate with the distributions of the habitats found at each of these altitudes. Low altitude Bunchgrass/sagebrush habitat is found only in a few valleys in BC, whereas Ponderosa Pine, Douglas-fir and Engelmann/Subalpine Spruce zones are more generally distributed and occupy a greater area in south central BC.

Comparison of collecting techniques. Marshall *et al.* (1994) discuss the benefits and limitations of various collecting methods for conducting faunistic surveys of arthropods. They also note the difference between passive collecting (traps) and active collecting methods. Passive trapping relies on insect behaviour to acquire specimens whereas active collecting depends also on the skill of the collector and time of day (passive traps work continuously). Marshall *et al.* (1994) indicate that passive traps require less labour in the field and collect more cryptic species than do active collecting methods.

Table 3

Division of species, grouped by distribution, at different altitudes.

Distribution	Altitude					
	300-800m	%	801-1500m	%	1501-1850m	%
Species widely distributed in Canada	428	59.8	460	66.8	262	67.3
Exotic species	24	3.3	27	3.9	17	4.4
Restricted to Okanagan in Canada or BC	95	13.2	58	8.4	24	6.2
Unknown distribution	170	23.7	144	20.9	86	22.1

A total of 234 species (21.3%) was found only in active collections compared to 654 species (59.4%) caught exclusively in traps. Only 213 species (19.3%) were present in both active and passive collections. Pantraps collect a more diverse sample than Malaise traps (Table 4). One quarter of all species collected were not found in either Malaise or pantraps. Although traps collect more species, they may be biased in their representation of the fauna.

Other experimental comparisons of various collecting techniques measure efficacy in terms of number of specimens caught per order or family (Canaday, 1987; Disney *et al.*, 1982) and generally indicate that white or yellow pantraps collect the largest number of higher taxa and specimens. These quantitative comparisons do not address either the species diversity or the quality of the catch. In our study, quality of the catch relates to the species diversity, composition, and presence of rare or endangered species.

Pantraps yielded a greater proportion of rare and restricted species than the other methods. Eighty-four species restricted to the Okanagan or considered rare were caught in pantraps, whereas only 41 were found in Malaise samples and 33 in other collections. Fifty-five of these species were found exclusively in pantraps as compared to 18 in Malaise traps and 16 by other sampling methods.

Table 4

Division of species among Malaise traps, pantraps and other collecting techniques.

Occurrence of species	Species	%	Specimens	%
Found only in Malaise traps	135	12.3	240	4.8
Found in Malaise and other*	52	4.7	289	5.8
Found only in pantraps	341	31.0	1155	23.0
Found in pantraps and other*	104	9.4	1028	20.4
Found only in pantraps and Malaise	103	9.4	597	11.9
Found in pantraps, Malaise and other*	83	7.5	1148	22.8
Not found in pantraps or Malaise	283	25.7	566	11.3

* Other collecting techniques include sweep net, spot collections, aquatic net, Berlese funnel, baited pitfalls, and light traps.

Many species in pantrap samples belonged to taxa that were difficult to identify to known species. About 56% of all morphospecies were caught in pantraps whereas the Malaise and other samples each contained less than 39% of all morphospecies. This is probably because earlier collectors paid more attention to conspicuous aerial fauna than to cryptic soil and surface dwelling arthropods (Marshall *et al.*, 1994).

In terms of the cost of materials, collecting effort, sample diversity and quality, pantrapping is the most efficient single sampling technique. However, the large sample volumes and debris do increase sorting and preparation time compared with most other techniques, as noted by Marshall *et al.* (1994) .

Summary and Conclusions. Our objective, to document the arthropod fauna of the Osoyoos/Mt. Kobau region, was accomplished but the species list (Appendix 1) represents only a fraction of all the arthropods of the area. This information is important for at least four reasons. First, the number of new distributional records and rare, restricted and endangered species collected, has added significantly to our understanding of the arthropod fauna of this unique habitat in Canada. Second, the database can act as a model for comparisons with future surveys of this study site and others. Third, the collection serves as a taxonomic reference for future studies and is also a source of information for natural history and community ecology studies. This information could also help to develop a habitat monitoring and management plan for the south Okanagan valley.

Several species previously reported from this area (Erickson and Torrance, 1989), were not found, and more collecting is required to assess the total complement of species (Danks, 1979). Ideally, long-term trapping stations (i.e. trap collections made throughout the year and from year to year) supplemented by spot collections and more examination of historical collections are needed. This approach would provide more than a "snapshot" of the fauna and may be more valuable to other research and land management decisions. Research on climatic change, effects of human activity, and ecology of the region's flora and fauna could all draw upon such a study. Coordination with studies of the flora, non-arthropod fauna, and physical aspects of the region would assist with the development of conservation strategies and habitat management policies.

If similar studies on the arthropod fauna are planned for the southern Okanagan near Osoyoos, there are a number of locales, both natural and disturbed, to consider. Undisturbed areas include Anarchist Mountain, Kilpoola Lake/Mt. Kruger, Chopaka, and

regions representing the original riparian, spring, and alkaline lake habitats. These areas could be compared with similar adjacent, but developed, locales. This would provide information on the effects of human activity on the arthropod assemblages and would complement similar studies of other fauna and flora.

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APPENDIX 1: LIST OF TAXA

The higher taxa listed below are arranged in phylogenetic order of class, order, and family following the schemes used by Danks (1979), and Platnick (1993). Species names appear in alphabetic order within each family. Distribution and natural history information on which records, possible records, and status indicators are based was provided by the identifiers and/or synoptic catalogs and other literature sources. These sources included Dondale and Redner (1976, 1978, 1982, 1990), Cannings and Stuart (1977), Vickery and Kevan (1985), Hatch (1953, 1957, 1961, 1965, 1971), Anderson and Peck (1985), Stone et. al. (1965), Krombein *et al.* (1979), Stephens (1957), Leech and Brown (1994), Lariviere (1994), Marshall and Wheeler (1991), Marshall and Smith (1990), Marshall (1986), McGuffin (1972), Hamilton (1972, 1975), Platnick and Dondale (1992), Leech (1972), Beirne (1956), Kelton (1955), Gregg (1963), Wheeler (1963), Richardson (1905), Slater and Barankowski (1978), Bright,1987), Bousquet (1991), Teskey (1990), Cole (1969), Vockeroth (1991), Goulet (1992), Brown (1990), Sharplin,1966), Cannings (1989), Scudder (1994), Story and Nowierski (1984), Story *et al.* (1987), and Gordon (1985).

Abbreviations and explanation of codes:
nr. = near
prob. = probably
poss. = possible
sp. = one species
spp. = more than one species
sp.grp. = species group

Status of taxon:
x = exotic (introduced)
† = rare, endangered, or restricted
1 = found only in Okanagan in Canada
2 = found only in Okanagan in British Columbia
3 = found only in BC in Canada

N = number of specimens
Elevation: L = collections from 300 to 800m; trapping station at 560m
M = collections from 801 to 1500m; trapping station at 990
H = collections from 1501 to 1850m; trapping station at 1760m
Record: NSP = New species
Cdn = First published record of taxon in Canada
Cdn? = Possible first published record of taxon in Canada
BC = First published record of taxon in British Columbia
BC? = Possible first published record of taxon in British Columbia

Taxon	Elevation	N	Record
ARACHNIDA			
SOLPUGIDA			
Eremobatidae			
† 2 *Eremobates* sp.	L	1	
ARANEAE			
Antrodiaetidae			
† 1 *Antrodiaetus hageni* (Chamberlin)	H	3	
Theridiidae			
Dipoena nigra (Emerton)	L	1	
Enoplognatha marmorata (Hentz)	MH	2	
x *Enoplognatha ovata* (Clerck)	L	3	
Euryopis sp.grp. *funebris* (Hentz)	LM	4	
Latrodectus hesperus Chamb. & Ivie	L	2	
x *Steatoda albomaculata* (De Geer)	M	5	
3 *Steatoda hespera* Chamberlin & Ivie	M	1	
Theridion neomexicanum Banks	M	3	
Unidentified Theridiidae	M	1	
Linyphiidae			
3 *Collinsia ksenia* (Crosby & Bishop)	H	4	
Erigone aletris Crosby & Bishop	LH	2	
† 1 *Erigone dentosa* O.P.-Cambridge	L	1	BC
3 *Erigone* sp.nr. *blaesa* Crosby & Bishop	H	1	
Sciastes truncatus (Emerton)	H	1	
3 *Walckenaeria tricornis* (Emerton)	L	1	
Tetragnathidae			
Tetragnatha sp.	M	2	
Araneidae			
Araniella displicata (Hentz)	MH	4	
x *Argiope trifasciata* (Forskal)	L	3	
Metepeira grandiosa (Chamb. & Ivie)	L	1	
Unidentified Araneidae	M	1	
Lycosidae			
Alopecosa aculeata (Clerck)	LMH	21	
Alopecosa kochi (Keyserling)	M	1	
Hogna frondicola (Emerton)	LM	3	
† 2 *Pardosa altamontis* Chamberlin & Ivie	L	1	
† 1 *Pardosa coloradensis* Banks	LH	16	
Pardosa concinna (Thorell)	H	2	

Taxon	Elevation	N	Record
Pardosa dorsalis Banks	MH	29	
Pardosa groenlandica (Thorell)	L	4	
Pardosa moesta Banks	L	1	
Pardosa sp.	LMH	11	
† 3 *Pardosa wyuta* Gertsch	LH	4	
Schizocosa mccooki (Montgomery)	LM	78	
Unidentified Lycosidae	LM	2	
Agelenidae			
† 1 *Agelenopsis oklahoma* (Gertsch)	LM	7	
Agelenopsis sp.	L	1	
Hahniidae			
3 *Cryphoeca exlineae* Roth	M	1	
Dictynidae			
Dictyna major Menge	H	2	
† 1 *Emblyna borealis cavernosa* Jones	M	1	
† 1 *Emblyna reticulata* Gertsch & Ivie	L	1	
Amaurobiidae			
3 *Callobius canada* (Chamberlin & Ivie)	H	1	
Callobius sp.	M	1	
Titanoecidae			
Titanoeca nigrella (Chamberlin)	L	1	
Titanoeca sp.	L	1	
Oxyopidae			
Oxyopes scalaris Hentz	L	6	
Clubionidae			
2 *Cheiracanthium inclusum* (Hentz)	L	1	
Corinnidae			
† 2 *Castianeira alteranda* Gertsch	L	3	
† 3 *Castianeira walsinghami* (O.P.-Cambr.)	M	1	
Gnaphosidae			
† 3 *Callilepsis eremella* Chamberlin	LM	2	
Drassodes neglectus (Keyserling)	LM	6	
Drassodes sp.	LM	3	
Drassyllus lamprus (Chamberlin)	L	2	
† 1 *Gnaphosa californica* Banks	L	4	
Gnaphosa muscorum (L. Koch)	LM	8	
Gnaphosa sp.	LM	3	
Haplodrassus signifer (C.L. Koch)	M	1	
Micaria coloradensis Banks	M	2	
Micaria riggsi Gertsch	H	1	
Micaria rossica Thorell	H	2	
Nodocion rufithoracicus Worley	L	1	
Orodrassus sp.	M	1	
Sergiolus montanus (Emerton)	M	1	
Zelotes fratris Chamberlin	L	2	
Zelotes puritanus Chamberlin	LM	20	
Unidentified Gnaphosidae	LMH	5	
Philodromidae			
Philodromus cespitum (Walckenaer)	L	2	
Philodromus rufus pacificus Banks	M	2	
Philodromus sp.	LM	4	
Tibellus sp.	M	1	
Thomisidae			
Misumenops celer (Hentz)	L	1	
Misumenops sp.	LM	4	
† 2 *Thanatus altimontis* Gertsch	L	2	
Thanatus formicinus (Clerck)	LM	9	
Xysticus benefactor Keyserling	MH	3	
Xysticus cunctator Thorell	LMH	17	
Xysticus luctuosus (Blackwall)	H	1	
Xysticus sp.	LM	4	
Salticidae			
Evarcha hoyi (Peckham & Peckham)	M	3	
† 3 *Habronattus hirsutus* (Peckh. & Peckh.)	L	3	
† *Habronattus sansoni* (Emerton)	LM	28	
Phidippus johnsoni (Peckh. & Peckh.)	LM	9	
Phidippus sp.	M	1	
3 *Sassacus papenhoei* Peckh. & Peckh.	L	3	
Synageles occidentalis Cutler	L	1	
Tutelina similis (Banks)	MH	2	
Unidentified Salticidae	LM	19	
Anyphaenidae			
Anyphaena pacifica (Banks)	M	1	
OPILIONES			
Phalangidae			
Leiobunum paessleri (Roewer)	M	1	
Gagrellidae			
Togwoteeus biceps (Thorell)	LMH	27	
CRUSTACEA			
ISOPODA			BC
Porcellionidae			BC
x *Porcellio scaber?* Latreille	L	1	
DIPLOPODA			
JULIDA			
Parajulidae			
Parajulidae sp.	M	3	
CHORDEUMATIDA			
Conotylidae			
Conotyla sp.	LM	7	
CHILOPODA			
LITHOBIOMORPHA			
Lithobiidae			
Lithobius sp.?	LM	2	BC
INSECTA			
MICROCORYPHIA			
Machilidae			
Petrobius? sp.	LM	120	
EPHEMEROPTERA			
Baetidae			
Callibaetis sp. (subimago)	L	1	
Heptageniidae			
Cinygmula sp.?	L	1	
ODONATA			
Coenagrionidae			
Amphiagrion abbreviatum (Selys)	L	2	
† *Argia vivida* Hagen	L	1	
Enallagma boreale Selys	LM	2	
Enallagma carunculatum Morse	L	4	
Enallagma clausum Morse	M	1	
Enallagma cyathigerum (Charpentier)	LMH	27	
Aeshnidae			
3 *Aeshna californica* Calvert	L	1	
Aeshna interrupta Walker	M	1	
Libellulidae			
3 *Libellula forensis* Hagen	L	6	
Libellula quadrimaculata Linnaeus	L	1	
Sympetrum corruptum (Hagen)	L	1	
Sympetrum madidum (Hagen)	M	1	
Sympetrum occidentale Bartenev	LM	5	
PLECOPTERA			
Perlodidae			BC
Isoperla sp.	H	2	
DERMAPTERA			
Forficularidae			
x *Forficula auricularia* Linnaeus	LM	22	
GRYLLOPTERA			
Raphidophoridae			
Ceuthophilus agassigii (Scudder)	M	12	
3 *Ceuthophilus alpinis?* Scudder	M	1	
Ceuthophilus fusiformis Scudder	LM	6	

Taxon	Elevation	N	Record
3 *Pristoceuthophilus pacificus?* (Thomas)	LH	5	
Prophalangopsidae			
3 *Cyphoderris monstrosa* Uhler	M	5	
Tettigoniidae			
3 *Anabrus longipes?* Caudell	M	1	
Anabrus simplex? Haldemann	M	1	
3 *Steiroxys* sp.	L	11	
Oecanthidae			
2 *Oecanthus nigricornis* F.Walker	LM	14	
Oecanthus quadripunctatus Beuten.	L	1	
Gryllidae			
Allonemobius allardi? (Alex. & Thom.)	L	1	
Gryllus pennsylvanicus Burmeister	L	2	
Gryllus veletis (Alexander & Bigot)	L	25	
Unidentified Gryllidae	L	9	
ORTHOPTERA			
Acrididae			
Arphia pseudonietana (Thomas)	L	1	
3 *Buckellacris chilcotinae* (Hebard)	M	2	
Camnula pellucida Scudder	L	1	
Chloealtis abdominalis? (Thomas)	L	1	
Dissosteira carolina (Linnaeus)	L	1	
Melanoplus alpinus Scudder	H	1	
Melanoplus bivittatus (Say)	L	14	
Melanoplus borealis (Fieber)	M	1	
3 *Melanoplus cinereus* Scudder	L	8	
Melanoplus femurrubrum (DeGeer)	L	1	
Melanoplus sanguinipes (Fabricius)	LM	24	
3 *Metator nevadensis* (Bruner)	L	1	
3 *Pseudomopala brachyptera* (Scudder)	L	3	
Spharagemon equale (Scudder)	L	4	
3 *Trimerotropis gracilis* (Thomas)	M	1	
3 *Xanthippus corallipes buckelli?* Hebard	L	2	
3 *Xanthippus vitellinus?* Saussure	L	1	
HEMIPTERA			
Thyreocoridae			
Corimelaena extensa Uhler	LMH	12	
Cydnidae			
† *Amnestus pallidus* Zimmer	L	2	
Pentatomidae			
Chlorochroa granulosa (Uhler)	LM	15	
Chlorochroa uhleri (Stal)	L	1	
Holcostethus abbreviatus Uhler	L	1	
Holcostethus tristis (Van Duzee)	M	6	
Perillus exaptus (Say)	M	1	
Prionosoma podopioides Uhler	L	2	
Scutelleridae			
Eurygaster sp.	M	1	
Homaemus aeneifrons consors Uhler	LM	13	
Acanthosomatidae			
Elasmucha lateralis (Say)	M	2	
Coreidae			
Coriomeris humulis (Uhler)	M	1	
Rhopalidae			
Arhyssus sp.	LM	4	
Harmostes reflexulus (Say)	M	3	
Liorhyssus hyalinus (Fab.)	L	1	
Stictopleurus punctiventris (Dallas)	MH	2	
Alydidae			
Alydus pluto Uhler	M	1	
Tollius curtulus (Stal)	M	1	
Lygaeidae			
† 1 *Botocudo modestus* (Barber)	L	1	Cdn
Crophius bohemani (Stal)	H	1	
Emblethis vicarius Horvath	LM	12	
Geocoris atricolor Montandon	L	1	
Geocoris pallens Stal	LH	4	
Geocoris sp.	L	1	
Megalonotus sabulicolus (Thomson)	L	1	
† 1 *Neosuris castanea* (Barber)	L	2	
Nysius sp.	LMH	38	
† 3 *Sisamnes claviger* (Uhler)	LM	17	
Slaterobius insignis (Uhler)	LMH	18	
Berytidae			
Jalysus wickhami Van Duzee	M	2	
Neides muticus (Say)	LMH	6	
Tingidae			
Acalypta lillianus Torre-Bueno	L	1	
Reduviidae			
Fitchia aptera Stal	L	3	
Rhynocoris ventralis (Say)	L	1	
Nabidae			
Nabicula vanduzeei (Kirkaldy)	M	1	
Nabis alternatus Parshley	LMH	13	
Nabis rufusculus Reuter	H	3	
Pagasa fusca (Stein)	L	1	
Unidentified Nabidae	MH	4	
Miridae			
x *Adelphocoris lineolatus* (Goeze)	LM	9	
Adelphocoris rapidus (Say)	M	5	
x *Capsus ater* (L.)	M	2	
Ceratocapsus sp.	L	8	
Chlamydatus associatus (Uhler)	L	2	
Chlamydatus obliquus (Uhler)	LMH	7	
Chlamydatus pallidicornis Knight	L	2	
Chlamydatus pullus (Reuter)	H	1	
1 *Chlamydatus schuhi* Knight	L	8	
Coquillettia insignis Uhler	L	1	
Deraeocoris brevis (Uhler)	LMH	4	
Europiella sp.	LH	12	
Hadronema militare Uhler	M	1	
† 2 *Irbisia shulli* Knight	M	2	
Labops hesperius Uhler	MH	4	
Leptopterna ferrugata (Fallen)	MH	2	
Litomiris curtus (Knight)	LMH	7	
Lygus borealis (Kelton)	M	2	
Lygus elisus Van Duzee	L	3	
3 *Lygus hesperus* Knight	L	3	
Lygus nigropallidus Knight	H	1	
Lygus robustus (Uhler)	H	11	
Lygus shulli Knight	M	1	
Lygus solidaginis (Kelton)	M	2	
Melanotrichus sp.	LMH	3	
Parthenicus sp.	L	2	
Phytocoris sp.	LM	10	
Plagiognathus sp.	LMH	14	
Polymerus diffusus (Uhler)	H	1	
Polymerus rufipes Knight	H	1	
Prepops sp.	H	1	
3 *Pronotocrepis clavicornis* Knight	M	1	
Psallus piceicola Knight	M	1	
Slaterocoris sp.	L	1	
Stenodema pilosipes Kelton	LMH	15	
Anthocoridae			
Orius tristicolor (White)	LM	10	
Tetraphleps uniformis Parshley	H	1	
Saldidae			
Saldula sp.	L	2	
Gerridae			
Gerris buenoi Kirkaldy	H	1	

Taxon	Elevation	N	Record
Gerris incurvatus Drake & Harris	H	1	
Gerris remigis Say	H	6	
Unidentified Gerridae	H	8	
Notonectidae			
Notonecta kirbyi Hungerford	H	3	
HOMOPTERA			
Cicadidae			
Okanagana occidentalis (Walker)	M	3	
† *Okanagana vanduzeei* Distant	L	1	
Cercopidae			
Aphrophora permutata Uhler	LM	8	
x *Philaenus spumarius* (Linnaeus)	LM	9	
Membracidae			
Ceresa inermis Fabricius	L	2	
Cicadellidae			
3 *Aceratagallia californica* (Baker)	LM	10	
† 1 *Aceratagallia okanagana* Hamilton	L	1	NSP
2 *Aceratagallia siccifolius* (Uhler)	LM	12	BC?
Aceratagallia sp.	L	2	
2 *Aceratagallia uhleri* (Van Duzee)	H	1	BC?
† 1 *Aceratagallia zacki* Hamilton	L	2	NSP
Aphrodes sp.	L	1	
Auridius auratus (Gillette & Baker)	H	1	
Auridius sp.	M	2	
Balclutha neglecta (DeLong & David.)	L	7	
Balclutha punctata (Thunberg)	LMH	10	
† 1 *Ballana callipera* DeLong	LM	3	Cdn
† 2 *Carsonus aridus* (Ball)	LH	21	
Chlorotettix unicolor Fitch	L	2	
3 *Colladonus geminatus* (Van Duzee)	LMH	10	
3 *Colladonus reductus* (Van Duzee)	L	1	
Colladonus sp.	H	1	
Cuerna cuesta Hamilton	LM	9	
Dikraneura sp.	H	2	
Dikraneura variata Hardy	LMH	30	
Diplocolenus brevoir Ross & Hamilton	LMH	16	
x *Doratura stylata* (Boheman)	L	1	
Empoasca columbiana Hamilton	L	1	
Empoasca filamenta DeLong	LMH	18	
3 *Empoasca nigra* Gillette & Baker	LMH	9	
Empoasca rossi Hamilton	L	1	
3 *Empoasca typhlocyboides* Gill. & Bkr.	LMH	26	
† 1 *Errhomus calvus* Oman	M	1	
Euscelis alpinus Ball	H	2	
Euscelis sp.	L	4	
Exitianus exitiosus (Uhler)	H	1	
3 *Gyponana hasta* DeLong	LM	5	
† 1 *Hardya* sp.	LH	4	Cdn
Hecalus major (Osborn)	LMH	11	
Helochara communis Fitch	H	1	
Idiodonus aurantiacus (Provancher)	H	2	
Latalus missellus (Ball)	LM	10	
Macrosteles fascifrons (Stal)	LH	3	
Macrosteles quadrilineatus (Forbes)	LH	4	
Mesamia sp.	L	1	
Neokolla hieroglyphica (Say)	L	1	
Norvellina columbiana (Ball)	MH	5	
Norvellina rubida (Ball)	LMH	5	
Oncopsis interior Hamilton	H	1	
Osbornellus borealis DeLong & Mohr	LM	4	
Paraphlepsius lascivius (Ball)	L	3	
Paraphlepsius occidentalis (Baker)	LMH	14	
Platymetopius sp.	L	1	
3 *Psammotettix attenuens* (DeL. & Dav.)	LMH	14	
Rosenus sp.	H	1	
Scaphytopius acutus (Say)	L	2	
† 1 *Scaphytopius diabolus* (Van Duzee)	LH	5	
3 *Sorhoanus debilis* (Uhler)	LMH	25	
3 *Texananus oregonus* (Ball)	L	1	
3 *Texananus proximus* Crowder	L	1	
† 1 *Unoka* sp.nr. *gilletti* Metcalf	L	8	
Xerophloea zionis Lawson	L	1	
Delphacidae			
Javasella sp.	M	1	
Laccocera vanduzeei Penner	MH	3	
Liburnia sp.	MH	3	
† 1 *Prokelisia salina* (Ball)	L	9	
Cixiidae			
Oliaris sp.	L	1	
Dictyopharidae			
Scolops abnormis Ball	L	3	
Scolops angustata Uhler	L	1	
Issidae			
Bruchomorpha beameri Doering	LM	8	
RAPHIDIOPTERA			
Raphidiidae			
Agulla adnixa (Hagen)	H	23	
Agulla arizonica (Banks)	M	2	
Agulla bicolor (Albarda)	L	3	
Inocellidae			
† 1 *Negha inflata* (Hagen)	M	1	Cdn
NEUROPTERA			
Coniopterygidae			
Coniopteryx sp.?	M	1	
Myrmeleontidae			
Brachynemurus sp.1	L	1	
Brachynemurus sp.2	L	4	
Hemerobiidae			
Hemerobius dorsatus Banks	H	6	
Hemerobius neadelphus Gurney	M	3	
Wesmaelius coloradensis Banks	MH	4	
Chrysopidae			
Chrysopa oculata Say	H	4	
† 1 *Eremochrysis punctinervis?* McLauch.	M	1	
Unidentified Chrysopidae	M	1	
COLEOPTERA			
Cupedidae			
3 *Priacma serrata* LeConte	M	2	
Cicindelidae			
Cicindela nebraskana Casey	MH	2	
Carabidae			
Amara confusa LeConte	H	1	
Amara discors Kirby	L	1	
Amara ellipsis (Casey)	LH	12	
Amara erratica (Duftschmid)	H	8	
Amara littoralis Mannerheim	LM	4	
Amara obesa Say	LM	30	
Bembidion dyschirinum LeConte	H	4	
Calathus advena (LeConte)	H	1	
† *Calleida viridis* Dejean	M	1	
Calosoma luxatum LeConte	LM	11	
3 *Calosoma tepidum* LeConte	M	1	
3 *Calosoma wilkesi* LeConte	LMH	86	
3 *Carabus taedatus* Fabricius	LMH	60	
Cymindis planipennis LeConte	L	10	
Discoderus parallelus (Haldeman)	L	4	
Euryderus grossus Say	L	2	
Harpalellus basilaris (Kirby)	L	2	
Harpalus fraternus LeConte	L	25	
3 *Harpalus obnixus* Casey	M	2	

Taxon	Elevation	N	Record
Harpalus quadripunctatus Dejean	H	1	
Lebia viridis Say	H	1	
Microlestes curtipennis (Casey)	LM	14	
Pterostichus adstrictus Eschscholtz	M	2	
3 *Pterostichus herculeanus* Mannerheim	H	1	
x *Pterostichus melanarius* Illiger	LM	2	
3 *Pterostichus neobrunneus* Lindroth	MH	2	
Scaphinotus marginatus Fischer	H	1	
Stenolophus conjunctus (Say)	LM	2	
Syntomus americanus (Dejean)	M	1	
Unidentified Carabidae	L	1	
Gyrinidae			
Gyrinus picipes Aube	H	7	
Hydrophilidae			
x *Cercyon pygmaeus* (Illiger)	LMH	3	
x *Cercyon quisquilius* (Linnaeus)	L	1	
Hydrobius fuscipes (Linnaeus)	L	1	
Paracymus subcupreus (Say)	L	1	
x *Sphaeridium bipustulatum* Fabricius	M	1	
x *Sphaeridium lunatum* Fabricius	MH	8	
x *Sphaeridium scarabaeoides* Linnaeus	MH	14	
Histeridae			
Hister abbreviatus Fabricius	L	2	
3 *Margarinotus umbrosus* (Casey)	LM	2	
Saprinus lugens Erichson	LM	4	
Saprinus oregonensis LeConte	LMH	8	
Xerosaprinus lubricus (LeConte)	LM	11	
Leiodidae			
Agathidium sp.1	H	2	
Agathidium sp.2	L	1	
Catops basilaris (Say)	LM	21	
Hydnobius sp.1	L	1	
Leiodes sp.1	MH	6	
Leiodes sp.2	H	1	
Ptomophagus sp.	L	2	
Scydmaenidae			
† 2 *Euconnus* sp.	L	2	BC
Silphidae			
Heterosilpha ramosa (Say)	L	1	
Nicrophorus defodiens Mannerheim	LMH	40	
Nicrophorus guttula Motschulsky	LM	29	
Nicrophorus investigator Zetterstedt	M	5	
Thanatophilus lapponicus (Herbst)	M	3	
Agyrtidae			
3 *Apteroloma tenuicorne* (LeConte)	H	1	
Staphylinidae			
3 *Anthobium reflexicolle* Casey	H	2	
Ontholestes cingulatus (Gravenhorst)	M	3	
Oxyporus occipitalis Fauvel	M	1	
Lucanidae			
Platycerus piceous marginalis Casey	MH	10	
Scarabaeidae			
x *Aphodius fimetarius* (Linnaeus)	MH	5	
x *Aphodius fossor* (Linnaeus)	MH	15	
x *Aphodius granarius* (Linnaeus)	H	1	
x *Aphodius haemorrhoidalis* (Linnaeus)	M	3	
† 3 *Aphodius hirsutus* Brown	L	1	
† 1 *Aphodius incommunis* Fall	M	1	
Aphodius opacus LeConte	H	10	
3 *Aphodius subaeneus* LeConte	H	1	
Bolboceras obesus (LeConte)	LM	2	
Canthon simplex LeConte	M	11	
3 *Cremastocheilus armatus* Walker	M	1	
Cremastocheilus crinitus LeConte	LM	2	
3 *Cyclocephala longula* LeConte	L	1	

Taxon	Elevation	N	Record
Dichelonyx backii (Kirby)	MH	3	
Diplotaxis brevicollis LeConte	L	1	
3 *Diplotaxis subangulata* LeConte	L	14	
3 *Glaresis medialis* Gordon	LM	10	
Ochodaeus luscinus Howden	M	1	
x *Onthophagus nuchicornis* (Linnaeus)	LMH	34	
Serica anthracina LeConte	M	7	
Serica curvata LeConte	M	6	
Trichiotinus assimilis (Kirby)	M	2	
Byrrhidae			
Byrrhus kirbyi? LeConte	LM	4	
Cytilus alternatus? Say	M	1	
Morychus oblongus (LeConte)	L	7	
Heteroceridae			
Heterocerus collaris? (Keisenwetter)	H	1	
Buprestidae			
3 *Acmaeodera idahoensis* Barr	L	1	
Anthaxia inornata (Randall)	LMH	12	
3 *Chrysobothris caurina* Horn	M	1	
x *Sphenoptera* sp.nr. *jugoslavica* Obenb.	L	5	
Elateridae			
Agriotella occidentalis Brown	MH	3	
Agriotes criddlei Van Dyke	LM	4	
Agriotes opaculus (LeConte)	M	3	
Ampedus pullus Germar	H	1	
† 1 *Cardiophorus amplicollis* Motschulsky	L	2	Cdn
3 *Cardiophorus edwardsi* Horn	L	3	
Cardiophorus tenebrosus LeConte	M	1	
Ctenicera aeripennis (Kirby)	MH	2	
Ctenicera bombycina (Kirby)	MH	3	
Ctenicera cruciata festiva (LeConte)	MH	5	
Ctenicera glauca (Germar)	LM	9	
3 *Ctenicera maura* (LeConte)	L	1	
Ctenicera morula (LeConte)	M	1	
Ctenicera pudica (Brown)	MH	2	
Ctenicera semimetallica (Walker)	M	3	
Ctenicera umbripennis (LeConte)	M	2	
Dalopius fucatus Brown	H	3	
Danosoma brevicorne (LeConte)	MH	4	
3 *Dolerosomus blaisdelli* (Van Dyke)	L	1	
† 1 *Horistonotus pilosus* Lanchester	L	1	Cdn
† 1 *Megapenthes aterrimus* (Motschulsky)	L	1	Cdn
3 *Melanotus longulus oregonensis* (LeC.)	LM	8	
Cantharidae			
3 *Malthodes piperi* Fender	L	1	
Podabrus pruinois diversipes? Fall	M	1	
Podabrus sp.1	M	1	
Podabrus sp.2	H	1	
Silis difficilis LeConte	H	6	
Dermestidae			
Dermestes sp.	M	3	
3 *Novelsis perplexa* Jayne	L	1	
Trogositidae			
Calitys scabra (Thunberg)	M	1	
Cleridae			
3 *Cymatodera decipiens?* Fall	LM	23	
Melyridae			
Amphivectura monticola (Blaisdell)	H	1	
3 *Anthocomus nigrinus* Fall	L	2	
Dasytinae sp.	LM	11	
Hypebaeus bicolor (LeConte)	LH	2	
Sphindidae			
3 *Odontosphindus clavicornis* Casey	M	1	
Nitidulidae			
2 *Carpophilus lugubris* Murray	L	2	BC

Taxon	Elevation	N	Record
x *Nitidula carnaria* (Schaller)	LM	5	
Thalycra sp.1	M	1	
Thalycra sp.2	M	1	
Cryptophagidae			
Atomaria sp.	MH	12	
Cryptophagus sp.	M	1	
Coccinellidae			
Coccinella novemnotata Herbst	LMH	9	
x *Coccinella septempunctata* Linnaeus	H	1	
Coccinella trans. richardsoni Brown	LH	9	
Coccinella trifasciata perplexa Mulsant	MH	13	
3 *Hippodamia apicalis?* Casey	LMH	18	
Hippodamia caseyi Johnson	MH	12	
Hippodamia quinquesignata (Kirby)	M	1	
Scymnus lacustris? LeConte	M	3	
Scymnus marginicollis Mannerheim	LMH	6	
Endomychidae			
3 *Aphorista laeta* (LeConte)	M	1	
3 *Mycetina idahoensis* Fall	M	1	
Lathridiidae			
3 *Corticaria fenestralis?* (Linnaeus)	L	1	
Enicmus fictus Fall	H	2	
Stephostethus montanus? (Fall)	H	1	
Tenebrionidae			
Blapstinus substriatus Champion	L	1	
3 *Coniontis ovalis* LeConte	LM	20	
† 3 *Eleodes hispilabris imitabilis* Blaisdell	L	14	
3 *Eleodes humeralis* LeConte	L	10	
† 1 *Eleodes nigrinus difformis* Blaisdell	LM	6	
Eleodes novoverruculus Boddy	L	18	
3 *Eleodes rotundipennis* LeConte	LMH	11	
3 *Eleodes vandykei modificata* Blaisdell	M	3	
Alleculidae			
3 *Mycetochara procera?* Casey	MH	5	
Mycteridae			
3 *Mycterus concolor* LeConte	M	1	
Melandryidae			
Anaspis sp.	LM	4	
3 *Rushia californica* Fall	M	1	
Mordellidae			
Mordella sp.	LM	12	
Mordellistena sp.	MH	2	
Meloidae			
Epicauta normalis Werner	L	1	
Lytta cyanipennis LeConte	M	3	
Meloe niger Kirby	M	1	
2 *Nemognatha lutea* LeConte	L	8	BC?
Anthicidae			
Ischyropalpus nitidulus (LeConte)	L	5	
Notoxus serratus (LeConte)	L	2	
Cerambycidae			
Cortodera longicornis (Kirby)	M	2	
Cortodera subpilosa (LeConte)	LM	10	
Stenocorus nubifer (LeConte)	L	1	
Stenocorus obtusus (LeConte)	H	4	
Stictoleptura canadensis (Oliver)	M	1	
Xylotrechus longitarsus Casey	H	1	
Chrysomelidae			
Altica sp.	H	7	
Chaetocnema sp.	H	2	
Chrysolina sp.	L	1	
Chrysomela aeneicollis (Schaeffer)	H	1	
Glyptina atriventris Horn	L	6	
Longitarsis sp.	MH	12	
Phyllotreta sp.	LH	7	
Psylloides sp.	H	1	
3 *Saxinis saucia saucia* LeConte	M	4	
3 *Syneta albida* LeConte	H	4	
Syneta hamata Horn	H	1	
3 *Trirhabda pilosa* Blake	L	1	
Unidentified Chrysomelidae	L	1	
Anthribidae			
† 2 *Trigonorhinus annulatus* (Carr)	L	1	
Curculionidae			
Acalyptus carpini (Herbst)	MH	8	
Anthonomus squamosus LeConte	L	3	
x *Ceutorhynchus erysimi* (Fab.)	MH	2	
Ceutorhynchus neglectus Blatchley	H	2	
x *Ceutorhynchus punctiger* Gyllenhal	LH	3	
† 1 *Ceutorhynchus* sp.nr. *persimilis* Dietz	LM	2	Cdn
† 1 *Cylindrocopturus helianthus* (Hatch)	H	1	Cdn?
Gymnetron tetrum (Fabricius)	L	2	
Lepesoma alternata (Horn)	M	1	
Lepidophorus pumilus Buchanan	M	1	
3 *Omias saccatus* (LeConte)	H	1	
x *Otiorhynchus ovatus* (Linnaeus)	LM	11	
Rhyncholus brunneus Mannerheim	M	1	
x *Sitona cylindricollis* (Fahraeus)	LH	2	
Tychius lineellus LeConte	M	1	
DIPTERA			
Bibionidae			
Bibio sp.1	H	1	
Bibio sp.2	M	1	
Bibio sp.3	MH	4	
Bibiodes sp.1	L	2	
Dilophus sp.	H	1	
Unidentified Bibionidae	H	1	
Anisopodidae			
Sylvicola sp.	L	1	
Simuliidae			
Simulium sp.	H	1	
Tabanidae			
Hybomitra enigmatica Teskey	H	1	
Hybomitra osburni (Hine)	MH	11	
3 *Hybomitra rupestris* (McDunnough)	L	1	
† 1 *Stonemyia californica* (Bigot)	LH	5	
3 *Tabanus stonei* Philip	L	2	
Rhagionidae			
Symphoromyia atripes Bigot	L	3	
3 *Symphoromyia johnsoni* Coquillett	L	13	
3 *Symphoromyia kincaidi* Aldrich	H	2	
Xylophagidae			
3 *Xylophagus decorus* Williston	M	1	
Stratiomyidae			
Euparyphus (Aochletus) sp.	L	2	
Microchrysa sp.?	L	3	
Odontomyia (Catatasina) sp.	H	1	
Sargus (Sargus) sp.	LM	21	
Stratiomyiidae sp.	L	1	
Therevidae			
1 *Thereva cingulata* Krober	H	2	Cdn?
3 *Thereva furcata* Loew	M	2	
3 *Thereva nigripilosa* Cole	H	1	
Thereva sp.nr. *comata* Loew	MH	4	
Scenopinidae			
Scenopinus sp.grp. *velutinus* (Krober)	L	1	
Asilidae			
Cyrtopogon bimacula (Walker)	H	4	
3 *Cyrtopogon inversus* Curran	M	1	
Cyrtopogon montanus Loew	M	12	
Cyrtopogon willistoni Curran	M	6	
† 1 *Dicolonus nigricentrum* Adis. & Wood	M	4	

Taxon	Elevation	N	Record
† 1 *Dioctria henshawi* Johnson	LM	9	
† *Efferia albibarbis* (Macquart)	L	6	
3 *Efferia benedicti* (Bromley)	L	33	
3 *Efferia harveyi* (Hine)	L	3	
Eucyrtopogon calcarata Curran	MH	8	
3 *Holopogon stellatus* Martin	L	2	
Laphria felis Osten Sacken	M	2	
3 *Laphria partitor* (Banks)	M	1	
Lasiopogon monticola Melander	MH	23	
Machimus callidus (Williston)	LMH	8	
3 *Machimus occidentalis* (Hine)	LM	6	
Machimus sp.1	LM	3	
Machimus sp.2	L	1	
Machimus sp.3	LM	4	
Machimus sp.nr. *paropus* Walker	L	1	
Proctacanthus milbertii Macquart	L	6	
3 *Regasilus auriannulatus* (Hine)	M	2	
Stenopogon inquinatus Loew	LM	6	
† 3 *Willistonina bilineata* (Williston)	M	3	
Nemestrinidae			
† *Neorhynchocephalus* sp.	L	2	
† Unidentified Nemestrinidae	L	1	
Bombyliidae			
Anastoechus barbatus Osten Sacken	L	18	
Anthrax irrorata Say	L	3	
Anthrax plesia Curran	L	1	
Bombylius lancifer Osten Sacken	H	4	
Geron sp.	L	4	
Geron? sp.	L	1	
Hemipenthes spp.	LMH	32	
Lepidanthrax sp.	L	1	
Metacosmus sp.	L	1	
Poecilanthrax spp.	L	2	
3 *Systoechus oreas* Osten Sacken	M	2	
Systoechus sp.	H	1	
Thevenemyia sp.	M	1	
Villa spp.	LMH	15	
Empididae			
Dolichocephala sp.	H	1	
Drapetis sp.	MH	2	
Euhybus sp.	L	2	
Heleodromia sp.	M	3	
Hilara sp.1	LMH	8	
Hilara sp.2	LMH	4	
Iteaphila sp.	H	1	
Microphor sp.	LMH	9	
Platypalpus sp.1	H	1	
Platypalpus sp.2	H	1	
Platypalpus sp.3	LH	3	
Rhamphomyia sp.1	H	2	
Rhamphomyia sp.2	M	1	
Rhamphomyia sp.3	M	2	
Rhamphomyia sp.4	H	1	
Rhamphomyia sp.5	M	1	
Tachypeza sp.1	M	1	
Tachypeza sp.2	H	1	
Dolichopodidae			
Condylostylus sp.	L	1	
Dolichopus spp.	LMH	12	
Hercostomus spp.	LMH	6	
Medetera sp.	LMH	13	
Neurigona spp.	M	2	
Lonchopteridae			
Lonchoptera sp.1	H	1	
Platypezidae			
Pleisioclythia sp.	L	1	
Phoridae			
Aenigmatias sp.	H	1	
Anevrina sp.	MH	2	
Borophaga sp.	H	1	
Conicera sp.	M	2	
2 *Megaselia barberi* Brown	LH	2	BC?
2 *Megaselia eccoptomera* Schmitz	M	1	BC?
Megaselia rufipes (Meigen)	H	1	
Megaselia sp. (unidentified)	LMH	45	
Phora sp. (unidentified)	MH	12	
Phoridae sp.	M	2	
Triphleba sp.	MH	3	
Syrphidae			
Arctophila flagrans Osten Sacken	H	1	
3 *Brachypalpus femorata* Williston	M	1	
Cheilosia sp.	H	1	
Chrysotoxum fasciatum (Muller)	LMH	14	
Chrysotoxum sp.	H	1	
Dasysyrphus pauxillus (Williston)	L	1	
Epistrophe nitidicollis (Meigen)	M	1	
Eristalis hirta Loew	MH	2	
Eristalis tenax (L.)	M	1	
Eupeodes lapponicus (Zetterstedt)	H	1	
Eupeodes latifasciatus (Macquart)	M	1	
Eupeodes snowi (Wehr)	LH	2	
Eupeodes sp.	MH	2	
Eupeodes volucris Osten Sacken	LM	7	
Ferdinandea croesus? Osten Sacken	L	1	
Helophilus hybridus Loew	MH	5	
Heringia sp.	L	1	
Ocyptamus diversifasciatus (Knab)	LH	2	
Orthonevra pulchella Williston	M	1	
Orthonevra sp.	LH	2	
Paragus haemorrhous Meigen	LMH	12	
Paragus sp.	LMH	6	
Paragus variabilis Vockeroth	M	1	
Parasyrphus insolitus Osburn	M	1	
Pipiza sp.	MH	2	
Platycheirus albimanus (Fab.)	H	1	
Platycheirus rufimaculatus Vockeroth	MH	2	
Platycheirus sp.	MH	6	
Scaeva pyrastri (L.)	LH	4	
Sphaerophoria philanthus (Meigen)	M	1	
Sphaerophoria sp.	M	2	
Sphegina sp.	M	1	
Syrphus opinator Osten Sacken	MH	4	
Syrphus torvus Osten Sacken	H	1	
Trichopsomyia sp.	L	1	
Volucella bombylans (L.)	MH	4	
Xylota flavitibia Bigot	M	1	
Xylota subfasciata Loew	M	1	
Pipunculidae			
Cephalops varius (Cresson)	M	1	
1 *Eudorylas loewii* (Kertesz)	L	1	BC?
Eudorylas subopacus industrius (Knab)	LM	4	
3 *Tomosvaryella coquilletti* (Kertesz)	LM	3	
Tomosvaryella sp.	L	3	
1 *Tomosvaryella tumida* Hardy	LM	2	Cdn?
Conopidae			
Myopa sp.	LMH	9	
Physocephala texana Williston	M	1	
Zodion sp.	LM	3	
Otitidae			
Physiphora sp.	L	1	
Tephritidae			
Eutreta diana (Osten Sacken)	LH	5	

	Taxon	Elevation	N	Record
	Paraxyna sp.	LH	3	
x	*Urophora affinis* Frauenfeld	LH	3	
	Urophora sp.	L	1	
	Agromyzidae			
	Phytoliriomyza sp.	L	1	
	Unidentified Agromyzidae	H	3	
	Milichiidae			
	Paramyia nitens (Loew)	L	2	
	Carnidae			
	Meoneura sp.	LMH	5	
	Dryomyzidae			
	Dryomyza setosa (Bigot)	M	1	
	Sepsidae			
	Saltella sphondylii (Schrank)	L	3	
	Sepsis sp.	M	1	
	Lauxaniidae			
	Lauxania nigrimana Coquillett	M	1	
	Minettia lupulina (Fab.)	M	1	
	Heleomyzidae			
	Aecothea sp.	H	3	
	Amoebaleria sp.	H	1	
	Eccomoptera simplex (Coquillett)	H	3	
3	*Pseudoleria crassata* Garrett	L	1	
	Pseudoleria intermedia Garrett	MH	6	
	Pseudoleria robusta Garrett	LM	5	
1	*Pseudoleria similis* Garrett	L	1	Cdn?
	Pseudoleria sp.	LM	2	
2	*Suillia barberi* Darlington	M	8	BC?
	Trixoscelididae			
	Trioxscelis fumipennis Melander	L	3	
	Sphaeroceridae			
3	*Aptilotus luctuosus* (Spuler)	MH	17	
	Aptilotus nigriscapus Marshall	MH	4	
	Copromyza sp.	H	3	
x	*Copromyza stercoraria* (Meigen)	H	11	
	Ishiolepta scabra (Spuler)	M	2	
	Lotophila atra (Meigen)	LMH	39	
	Minilimosina nasuta (Spuler)	LMH	38	
	Minilimosina parva (Malloch)	LM	4	
	Minilimosina vitripennis (Zetterstedt)	MH	7	
	Nearcticorpus canadense Roh. & Mars.	LM	2	
	Pseudocoelinella sp.	H	1	
x	*Pullimosina heteroneura* (Haliday)	M	1	
	Pullimosina longicosta (Spuler)	H	1	
	Pullimosina pullula (Zetterstedt)	H	1	
	Pullimosina sp.	H	1	
	Pullimosina woodi? Marshall	H	1	
	Rachispoda sp.	LH	7	
	Rudolfina digitata Marshall	H	1	
	Sclerocoelus sordipes (Adams)	L	1	
3	*Spelobia abundans* (Spuler)	H	4	
x	*Spelobia clunipes* Meigen	LMH	39	
	Spelobia depilicercus Marshall	M	37	
3	*Spelobia lucifuga* (Spuler)	LM	5	
	Spelobia luteilabris (Rondani)	LMH	9	
	Spelobia maculipennis (Spuler)	H	1	
x	*Spelobia ochripes* (Meigen)	H	3	
	Spelobia ordinaria (Spuler)	LM	21	
	Spelobia rimata Marshall	M	27	
	Telomerina flavipes (Meigen)	LM	5	
	Unidentified Sphaeroceridae	LMH	93	
	Ephydridae			
	Ephydra sp.	L	1	
	Chloropidae			
	Fiebrigella sp.	L	1	
	Unidentified Chloropidae	H	2	

	Taxon	Elevation	N	Record
	Scathophagidae			
	Scathophaga furcata (Say)	H	11	
	Scathophaga stercoraria (L.)	LMH	19	
	Anthomyiidae			
	Adia (=Paregle) cinerella (Fallen)	L	1	
	Botanophila acuticauda (Huckett)	H	8	
	Botanophila sp.	M	1	
	Delia concorda (Huckett)	LM	2	
	Delia deviata (Huckett)	L	1	
	Delia garretti (Huckett)	LM	2	
3	*Delia monticola* (Huckett)	M	1	
	Delia neomexicana (Malloch)	MH	2	
†	1 *Delia nivialis* Griffiths	H	1	
	Delia sp.	M	1	
	Delia unispina Yudin	M	1	
	Eutrichota flavicans (Stein)	MH	4	
	Eutrichota major (Malloch)	H	2	
	Eutrichota nigrifemur (Stein)	M	3	
	Hylemya alcathoe (Walker)	M	1	
	Hylemyza partita (Meigen)	M	1	
	Lasiomma collini (Ringdahl)	M	1	
2	*Pegomya setibasis* Huckett	LM	2	BC
	Unidentified Anthomyiidae	H	1	
	Muscidae			
	Helina laxifrons (Zetterstedt)	M	1	
	Hypodermodes solitaria Knab	M	3	
	Limnospila albifrons (Zetterstedt)	L	1	
	Limosia pilosissima Stein	MH	2	
	Limosia sp.	M	1	
	Myospila meditabunda (Fab.)	L	1	
	Pararicia sp.	M	1	
	Phaonia protuberans Malloch	H	1	
	Phaonia rugia (Walker)	H	1	
	Phaonia sp.	M	2	
	Pseudophaonia orichalceoides Huckett	LM	2	
	Calliphoridae			
	Calliphora vomitaria (L.)	M	3	
	Eucalliphora latifrons (Hough)	H	1	
	Sarcophagidae			
	Agria housei Shewell	LM	6	
	Blaesoxipha atlanis (Aldrich)	L	1	
†	1 *Eumacronychia rohweri* Allen	M	1	Cdn?
	Helicobia rapax (Walker)	LM	6	
†	*Hilarella hilarella* (Zetterstedt)	M	1	
3	*Opsophyta opifera* (Coquillett)	L	1	
	Protodexia hunteri (Hough)	L	4	
	Ravinia planifrons (Aldrich)	LM	6	
	Ravinia querula (Walker)	LM	5	
	Sphixapata trilineata (Wulp)	M	1	
	Stenaulacotheca sp.	L	1	
	Taxigramma heteroneura (Meigen)	LM	9	
	Tachinidae			
	Acemya tibialis Coquillett	LM	8	
†	1 *Admontia badiceps* Reinhard	L	1	Cdn?
	Allophorocera sp.	L	2	
	Aphria ocypterata Townsend	LM	5	
	Arctophyta sp.1	H	2	
	Arctophyta sp.2	L	1	
	Campylocheta sp.	M	1	
	Ceromasia auricaudata Townsend	LM	5	
	Chaetogena sp.	M	1	
	Clausicella sp.	LM	7	
	Cylindromyia sp.1	LM	2	
	Cylindromyia sp.2	L	3	
	Dinera grisescens (Fallen)	LM	17	
	Eribella sp.	H	1	

Taxon	Elevation	N	Record
Exorista sp.	L	1	
Graphogaster spp.	LMH	8	
Gymnosoma occidentale Curran	L	1	
Leucostoma sp.	M	1	
Madremyia saundersii (Williston)	M	1	
Melanophrys flavipennis Williston	M	2	
Mochlosoma illocale Reinhard	LH	2	
† 1 *Nimioglossa* sp.	L	1	Cdn
Oswaldia sp.	M	1	
Paradidyma sp.	L	1	
2 *Peleteria cornuta* Curran	H	2	BC?
Peleteria sp.1	H	1	
Peleteria sp.2	LM	5	
Peleteria sp.3	MH	9	
Phytomyptera sp.	L	1	
Platymya sp.	M	1	
Pseudochaeta sp.	L	1	
Ptilodexia spp.	MH	6	
Siphona (Ceranthia) sp.	LM	2	
Siphona (Siphona) sp.	L	1	
2 *Spallanzamia hesperidarum* (Williston)	LM	2	BC?
2 *Tachina robertsoni* (Townsend)	MH	11	BC?
Tachina rostrata (Tothill)	LMH	6	
Tachina sp.1	H	3	
Tachina sp.2	H	1	
Tachinomyia sp.	M	1	
Winthemia fumiferanae Tothill	LMH	19	
Unidentified Tachinidae	L	8	
LEPIDOPTERA			
Tortricidae			
Archips corasivorana (Fitch)	L	1	
Dichrorampha simulana (Clem.)	M	1	
Eucosmini? sp.	L	2	
Hesperiidae			
Hesperia comma (Linnaeus)	L	8	
Ochlodes sylvanoides (Boisduval)	LMH	23	
Pholisora catullus (Fabricius)	L	1	
Papilionidae			
Papilio eurymedon Lucas	L	2	
Papilio oregonius Edwards	LM	2	
Papilio rutulus Linnaeus	M	1	
Papilio zelicaon Lucas	H	3	
Parnassius phoebus (Fabricius)	M	4	
Pieridae			
Anthocharis sara Lucas	MH	6	
Colias philodice Godart	L	11	
Euchloe ausonides (Lucas)	M	4	
x *Pieris rapae* Linnaeus	LH	3	
Pontia beckeri (Edwards)	M	1	
Pontia occidentalis (Reakirt)	MH	3	
Lycaenidae			
Agriades franklinii (Curtis)	H	1	
Callophrys sheridanii (W.H. Edwards)	H	1	
Chalceria heteronea (Boisduval)	M	1	
Epidemia helliodes (Boisduval)	L	1	
† 2 *Epidemia nivalis* (Boisduval)	M	2	
† *Euphilotes batoides* (Behr)	H	2	
Everes amyntula (Boisduval)	M	2	
Glaucopsyche lygdamus (Doubleday)	LH	3	
Icaricia acmon (Westwood & Hewit.)	H	2	
Icaricia icariodes (Boisduval)	LMH	8	
† *Lycaeides melissa* (W.H. Edwards)	LM	25	
† *Mitoura siva* (W.H. Edwards)	L	1	
Satyridae			
Cercyonis oetus (Boisduval)	LMH	4	
Cercyonis pegala (Fabricius)	L	13	
Cercyonis sthenele (Boisduval)	L	1	
Coenonympha tullia (Linnaeus)	H	8	
Erebia epipsodea Butler	MH	5	
Oeneis chryxus Doubleday & Hewitson	L	1	
Nymphalidae			
Aglais milberti (Godart)	MH	2	
Basilarchia lorquini (Boisduval)	LM	4	
Nymphalis antiopa (Linnaeus)	L	1	
Nymphalis vau-album (Dennis & Sch.)	M	3	
Occidryas anicia (Doubleday & Hewit.)	L	9	
Phycoides mylitta (Godart)	H	1	
Phycoides pallida (W.H. Edwards)	L	3	
Phycoides pratensis (Behr)	MH	5	
Phycoides tharos (Drury)	LM	2	
Polygonia faunus (Edwards)	M	3	
Polygonia satyrus (Edwards)	M	1	
Polygonia zephyrus (W.H. Edwards)	MH	3	
Speyeria callippe (Boisduval)	H	5	
Speyeria zerene (Boisduval)	LMH	12	
Vanessa cardui (Linnaeus)	L	4	
Thyrididae			
Thyris sepulchralis Guerin	L	3	
Geometridae			
Dysstroma formosa formosa (Hulst)	M	1	
Lobocleta quaesitata (Hulst)	M	1	
3 *Semiothisa delectata* Hulst	L	3	
Semiothisa neptaria (Guenee)	M	1	
Lasiocampidae			
Phyllodesma americana (Harris)	M	3	
Saturniidae			
Antheraea polyphemus (Cramer)	L	1	
† *Hemileuca hera?* (Harrison)	L	1	
Sphingidae			
Hemaris diffinis (Boisduval)	MH	6	
Arctiidae			
Spilosoma vagans (Boisduval)	M	1	
Unidentified Arctiidae	L	1	
Noctuidae			
Bleptina caradrinalis (Guenee)	L	1	
Caenurgina erechtrea (Cramer)	L	7	
Crymodes devastator (Brace)	L	1	
Euxoa ochrogaster (Guenee)	L	1	
Heliothis sp.	L	1	
Leucania multilinea Walker	L	1	
Marathyssa inficita (Walker)	L	1	
Mniotype miniota (J.B. Smith)	M	1	
Schnia sp.	H	1	
Synedoida nichollae (Hampson)	M	1	
Unidentified Noctuidae	L	1	
TRICHOPTERA			
Hydropsychidae			
Hydropsyche occidentalis Banks	M	1	
Hydropsyche sp.	L	2	
Limnephilidae			
Hesperophylax sp.	M	1	
Leptoceridae			
Ceraclea alagmus? (Banks)	M	2	
HYMENOPTERA			
Xyelidae			
Pleuroneura californica Ashmead	H	1	
Xyela obscura? (Strobl.)	H	22	
Cimbicidae			
Trichiosoma triangulum Kirby	LH	3	
Tenthredinidae			
Ametastegia coloradensis (Weldon)	H	6	
1 *Caliroa hyalina* Smith	L	1	Cdn?

Taxon	Elevation	N	Record
x 2 *Fenella nigrita* Westwood	L	1	BC
Nematus (Pteronidea) sp.	L	1	
Pachynematus sp.	H	2	
Pristophora sp.	H	1	
x 2 *Profenusa thompsoni* (Konow)	H	1	BC
† 2 *Tenthredo alienata* Rohwer	H	1	BC
Tenthredo sp.nr. *pectoralis* Norton	M	3	
1 *Tenthredo obscuripennis* Cresson	M	1	Cdn?
Orussidae			
3 *Orussus occidentalis* (Cresson)	M	1	
Braconidae			
Peristenus sp.	MH	3	
Aulacidae			
Pristaulacus sp.?	M	1	
Bethylidae			
Anisepyris subviolaceus Keiffer	LM	5	
Epyris rufipes (Say)	LM	2	
† 2 *Parasierola breviceps* (Krombein)	M	1	BC
1 *Parasierola gracilicornis* Kieffer	L	1	Cdn?
3 *Pseudisobrachium persimile* Evans	M	1	
Pseudisobrachium sp.	M	1	
Dryinidae			
2 *Aphelopus albopictus* Ashmead	LM	13	Cdn?
1 *Aphelopus varicornis* Brues	LM	4	Cdn?
Dryinidae sp.	LMH	14	
1 *Lonchodryinus bakeri* (Kieffer)	M	2	Cdn?
Chrysididae			
Chrysis coerulans Fabricius	L	1	
1 *Chrysis coloradica* Bohart	LM	4	Cdn?
Chrysis dorsalis Aaron	M	2	
† 2 *Chrysis montana* Aaron	M	1	BC?
† 1 *Chrysis rivalis* Bohart	M	1	Cdn?
3 *Chrysura cobaltina* (Aaron)	M	1	
3 *Chrysura kyrae* Krombein	LM	4	
Chrysura pacifica (Say)	M	2	
† 2 *Cleptes speciosus* Aaron	M	2	BC
Elampus marginatus (Patton)	M	3	
Hedychridium crassum Bohart	M	1	
Hedychridium dimidiatum (Say)	LM	7	
Hedychridium menkei Bohart	L	1	
Hedychridium politum Bohart	M	2	
Hedychrum nigropilosum Mocsary	LM	4	
Holopyga ventralis Say	LM	3	
Omalus plicatus (Aaron)	M	4	
Omalus variatus (Aaron)	L	1	
Unidentified Chrysididae	M	1	
Tiphiidae			
3 *Brachycistis atrata* (Blake)	LM	2	
† 1 *Paratiphia ephippiata* Allen	LH	10	Cdn?
3 *Tiphia anguis* Allen	L	13	
3 *Tiphia fortistriolata* Cameron	LM	3	
Tiphia infossata Allen	LMH	9	
3 *Tiphia nevadana* Cameron	LM	13	
Sierolomorphidae			
† 2 *Sierolomorpha nigrescens* Evans	L	1	BC
Mutillidae			
Dasymutilla bioculata (Cresson)	L	1	
1 *Dasymutilla chiron* (Blake)	L	3	Cdn?
1 *Dasymutilla monticola* (Cresson)	L	2	
Dasymutilla vesta (Cresson)	L	12	BC?
† *Ephuta grisea fuscosericea* Schuster	LM	9	
† 1 *Myrmosa bradleyi* Roberts	LM	2	Cdn?
† 1 *Odontophotopsis erebus* (Melander)	L	1	Cdn?
† 1 *Pseudomethoca athamas* (Fox)	M	1	Cdn?
† 1 *Pseudomethoca bequaerti* Mickel	L	1	Cdn?
† 2 *Pseudomethoca propinqua* (Cresson)	L	4	BC

Taxon	Elevation	N	Record
Sapygidae			
† 1 *Sapyga* sp.	L	1	Cdn?
Formicidae			
Aphenogaster occidentalis Emery	LM	18	
Camponotus laevigatus (F.Smith)	M	2	
Camponotus nearcticus Emery	L	1	
Camponotus pennsylvanicus (DeGeer)	MH	9	
Camponotus vicinus Mayr	LM	23	
Formica argentea Wheeler	LMH	16	
1 *Formica haemorrhoidalis* Emery	LMH	5	Cdn?
1 *Formica integroides* Emery	LM	4	Cdn?
Formica lasiodes Emery	MH	15	
1 *Formica microgyna* Wheeler	H	1	Cdn?
Formica neogagates Emery	L	8	
Formica neorufibarbis Emery	M	2	
Formica podzolica Francoeur	MH	4	
Formica sp.grp. *fusca*	L	3	
Formica sp.grp. *microgyna*	L	1	
Formica subaenescens Emery	H	1	
Formica subnuda Emery	H	1	
3 *Formica subpolita* Mayr	LM	3	
Formica vinculans Wheeler	L	3	
Lasius crypticus Wilson	LM	3	
1 *Lasius fallax* Wilson	M	2	Cdn?
Lasius neoniger Emery	L	2	
Lasius pallitarsis (Provancher)	M	3	
Leptothorax canadensis Provancher	M	1	
3 *Leptothorax nevadensis* Wheeler	LMH	16	
3 *Leptothorax nitens* Emery	L	1	
Leptothorax rugatulus Emery	LM	3	
† 1 *Myrmecocystus testaceus* Emery	L	3	Cdn
Myrmica sp.1	H	4	
Myrmica sp.2	H	1	
3 *Myrmica tahoensis* Wheeler	M	1	
Pheidole sp.	L	3	
Pogonomyrmex owyheei Cole	L	1	
Polyergus breviceps Emery	M	1	
Solenopsis molesta (Say)	L	8	
Tapinoma sessile (Say)	LMH	23	
Unidentified Formicidae	M	1	
Vespidae			
Dolichovespula arenaria (Fabricius)	L	1	
Dolichovespula maculata (Linnaeus)	LM	6	
Polistes sp.	LM	19	
Vespula acadica (Sladen)	LH	2	
Vespula atropilosa? (Sladen)	L	2	
Vespula consobrina (Saussure)	L	1	
Vespula pensylvanica (Saussure)	LM	14	
Vespula vulgaris (Linnaeus)	M	1	
Unidentified Vespidae	LMH	44	
Sphecidae			
Ammophila azteca Cameron	L	2	
† 1 *Ammophila extremitata* Cresson	LM	3	Cdn?
Ammophila kennedyi (Murray)	LM	10	
Ammophila mediata Cresson	M	3	
Ammophila procera Dahlbom	L	3	
Ammophila strenua Cresson	L	2	
3 *Chalybion californicum* (Saussure)	L	1	
Palmodes carbo Bohart & Menke	L	1	
Podalonia communis (Cresson)	LMH	14	
3 *Podalonia mickeli* Murray	L	1	
† 2 *Podalonia sonorensis* (Cameron)	LM	2	BC?
Prionyx atratus (Lepeletier)	L	4	
Prionyx canadensis (Provancher)	L	1	
Sceliphron caementarium (Drury)	L	1	
3 *Sphex lucae* (Saussure)	L	1	

Taxon	Elevation	N	Record
Unidentified Sphecidae	LM	4	
Pemphredonidae			
† 1 *Ammoplanellus apache* (Pate)	LM	8	Cdn
† 1 *Ammoplanellus lenape* (Pate)	LM	6	Cdn
Diodontus boharti Eighme	LH	2	
† 1 *Diodontus leguminiferus* Cockerell	LM	7	Cdn?
2 *Diodontus rugosus* Fox	M	16	BC?
1 *Diodontus striatus* (Mickel)	LMH	4	Cdn?
1 *Mimesa gregaria* (Fox)	LM	5	Cdn?
3 *Pemphredon grinelli* (Rohwer)	M	1	
Pemphredon inornata Say	H	1	
3 *Pulverro columbianus* (Kohl)	LM	12	
Astatidae			
Astata occidentalis Cresson	L	1	
Diploplectron peglowi Krombein	LM	3	
Larridae			
Ancistromma distincta (Smith)	L	6	
Miscophus sp.	L	4	
Solierella sp.	LM	3	
Tachysphex aequalis Fox	L	1	
Tachysphex pompiliformis (Panzer)	LM	8	
Tachysphex tarsatus (Say)	LM	8	
3 *Tachytes pennsylvanicus* Banks	L	1	
Trypoxylon aldrichi Sandhouse	H	1	
Crabronidae			
Belomicrus forbesii (Robertson)	H	4	
Belomicrus sp.	H	1	
Crabro latipes Smith	M	1	
Crabro sp.	L	1	
Crossocerus sp.	M	1	
Crossocerus? sp.	M	1	
2 *Ectemnius dilectus* (Cresson)	LH	2	BC?
Ectemnius? sp.	L	1	
Lestica sp.	LM	2	
Lindenius sp.	L	1	
Rhopalum clavipes (Linnaeus)	M	1	
Rhopalum sp.	M	1	
Nyssonidae			
Bembix americana comata Parker	L	5	
† 1 *Didineis nodosa* Fox	L	1	Cdn?
Epinysson sp.	L	2	
Gorytes sp.	LM	3	
Harpactus sp.a	M	8	
Harpactus sp.b	LM	18	
Nysson sp.	LM	5	
Nysson sp.a	M	16	
Nysson sp.b	M	1	
Nysson sp.c	M	4	
Nysson sp.d	M	2	
3 *Steniolia obliqua* (Cresson)	MH	2	
Philanthidae			
3 *Aphilanthops subfrigidus* Dunning	M	3	
3 *Cerceris convergens* Viereck & Cock.	L	1	
Cerceris crucis Viereck & Cockerell	L	1	
Eucerceris flavocincta Cresson	LM	6	
Philanthus multimaculatus Cameron	L	11	
Philanthus ventilabris Fabricius	L	1	
Colletidae			
Dufourea sp.?	L	1	
Hylaeus sp.	L	1	
Andrenidae			
Andrena sp.1	H	1	
Andrena sp.2	M	1	
Andrena sp.3	L	2	
Andrena sp.4	M	1	
Andrena sp.5	L	6	
Andrena sp.6	L	1	
Andrena sp.7	M	1	
Perdita sp.1	M	2	
Perdita sp.2	L	1	
Perdita sp.3	L	1	
Halictidae			
Agapostemon sp.	LM	10	
Dialictus sp.	LM	2	
Halictus rubicundus? (Christ)	L	3	
Halictus sp.1	L	2	
Halictus sp.2	M	1	
Halictus sp.3	L	3	
Sphecodes sp.1	M	1	
Sphecodes sp.2	L	1	
Sphecodes sp.3	L	1	
Sphecodes sp.4	LH	7	
Unidentified Halictidae	L	5	
Megachilidae			
Anthidiini sp.1	L	1	
Anthidiini sp.2	M	1	
Anthidiini sp.3	M	1	
Anthidiini sp.4	M	1	
Anthidiini spp. (misc.)	M	2	
Coelioxys sp.?	LM	5	
Hoplitus albifrons (Kirby)	M	1	
3 *Hoplitus hypocrita?* (Cockerell)	L	4	
3 *Hoplitus louisae* (Cockerell)	H	1	
Megachile sp.1	L	1	
Megachile sp.2	L	2	
Megachile sp.3	LM	5	
Megachile sp.4	L	2	
Megachile spp. (misc.)	LMH	9	
Osmia sp. 1	LM	5	
Osmia sp. 2	LM	10	
Osmia sp. 3	L	5	
Osmia sp. 4	L	3	
Osmia sp. 5	L	1	
Osmia sp. 6	L	1	
Osmia sp. 7	M	1	
Osmia sp. 8	M	2	
Osmia sp. 9	L	1	
Osmia sp.10	L	1	
Osmia sp.11	L	2	
Osmia sp.12	M	1	
Osmia sp.13	M	1	
Osmia sp.14	L	1	
Osmia sp.15	L	1	
Osmia sp.16	H	1	
Osmia sp.17	L	1	
Osmia sp.18	L	1	
Osmia sp.19	L	1	
Osmia sp.20	L	2	
Osmia sp.21	L	1	
Osmia sp.22	L	2	
Osmia spp. (misc.)	LMH	37	
Anthophoridae			
Ceratina sp.1	L	1	
Ceratina sp.2	L	1	
Ceratina sp.3	L	1	
Nomada sp.	M	1	
Tetralonia sp.?	M	3	
Apidae			
x *Apis mellifera* Linnaeus	L	2	
3 *Bombus appositus* Cresson	LMH	11	
3 *Bombus bifarius nearcticus* Handlirsch	LMH	5	
3 *Bombus centralis* Cresson	LMH	8	

Taxon	Elevation	N Record
3 *Bombus fervidus* (Fabricius)	LH	4
3 *Bombus flavifrons* Cresson	H	1
† 2 *Bombus griseocollis* (DeGeer)	M	1
3 *Bombus melanopygus* Nylander	M	1
3 *Bombus mixtus* Cresson	M	1
3 *Bombus occidentalis* Greene	M	1
3 *Bombus rufocinctus* Vogt	L	1
3 *Bombus vagans* Smith	L	2
Psithyrus insularis Smith	L	1
Psithyrus suckleyi (Greene)	MH	3

Miscellaneous Unidentified Specimens:		
INSECTA		
ODONATA		
Miscellaneous Odonata	H	1
PSOCOPTERA		
Miscellaneous Psocoptera	LH	3
HOMOPTERA		
Unidentified Psyllidae	LMH	28
COLEOPTERA		
Unidentified Corylophidae	M	1
Unidentified Scolytidae	MH	4
DIPTERA		
Miscellaneous Diptera	H	1
SIPHONAPTERA		
Miscellaneous Siphonaptera	LH	3
LEPIDOPTERA		
Unidentified Pyralidae	L	2
Miscellaneous Lepidoptera	LM	7
HYMENOPTERA		
Unidentified Ichneumonidae	L	1
Unidentified Cynipidae	H	1
Unidentified Pompilidae	LMH	142

Identification of the "grey" *Dioryctria* species of British Columbia (Lepidoptera, Pyralidae)

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ABSTRACT

The nine "grey" species of *Dioryctria* coneworms in British Columbia are difficult to distinguish because of very similar morphologies and confusing taxonomic literature. To aid in identifying these moths, illustrations of male and female genitalia, a key to species or groups based on these characters, and brief descriptions of each species or species group are presented here.

Key words: *Dioryctria*, coneworm, taxonomy, genitalia, fir, spruce, pine, hemlock, larch.

INTRODUCTION

The genus *Dioryctria* (Lepidoptera: Pyralidae) contains over fifty species in the Nearctic region (Richmond and Page 1995; Jactel *et al.* 1994; Grant *et al.* 1993; Neunzig 1990a, b; Mutuura and Munroe 1973; Mutuura and Munroe 1972; Mutuura *et al.* 1969a, b; Munroe 1959; Heinrich 1956), twelve of which have been recorded from British Columbia. Adults of nine of these are predominantly grey in colour: *D. abietivorella* (Grote), *D. pseudotsugella* Munroe, *D. reniculelloides* Mutuura and Munroe, *D. okanaganella*, *D. pentictonella*, *D. tumicolella*, *D. contortella*, *D. monticolella* (all of Mutuura, Munroe and Ross) and *D. cambiicola* (Dyar) (Hedlin *et al.* 1980 (e.g., Fig. 79); Mutuura and Munroe 1972, 1973; Mutuura *et al.* 1969a, b). This is in contrast to the other *Dioryctria* species of British Columbia, which are predominantly reddish brown in colour (e.g., Hedlin *et al.* 1980: Fig. 83). This group of grey *Dioryctria* species are important pests of at least six genera of conifers (Bennett 1994). The morphological

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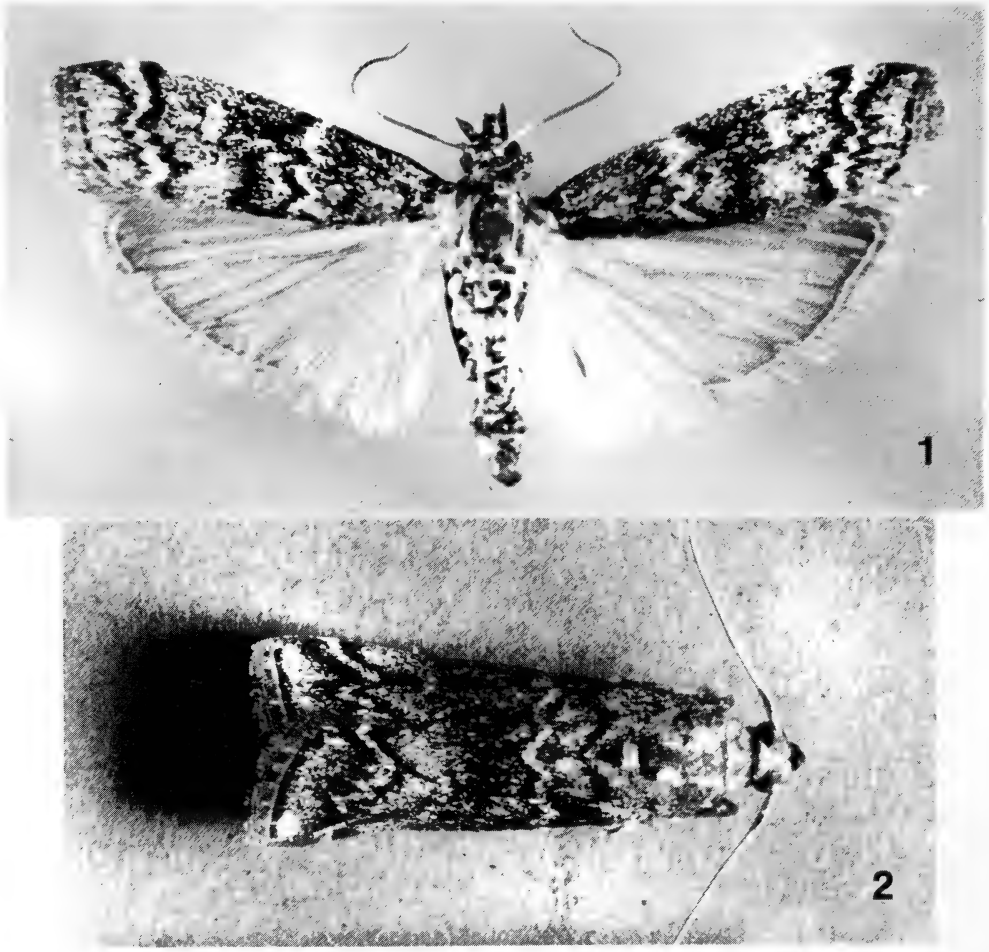
similarity of these species coupled with poorly understood life histories and a scattered and confusing taxonomic literature make reliable species identifications difficult.

We compared these species and sought to prepare a key to separate them, supplemented with illustrations of diagnostic features. We did not aim to revise the status of existing nominal species due to the limited scope of our work. We provisionally accepted these species and sought to differentiate them as clearly as possible. Our results raised more questions than they answered and underlined some of the taxonomic confusion that prevails in the genus. Some of the species seem to display a confusing array of variation in phenology, hosts, distribution, and apparent morphological variation, whereas other, morphologically indistinguishable forms have been recognized as separate species. We were unable, for instance, to find any reliable distinguishing morphological characters for *D. cambiicola*, *D. tumicolella*, *D. contortella*, and *D. monticolella*, thereby raising doubt about their validity as separate species. We found that several primary types had not been dissected and their genitalia not examined. In one instance (*D. okanaganella*) dissection and examination of the genitalia of the holotype significantly changed the species diagnosis from that previously published. Our (unpublished) work also highlighted the fact that the male vesica harbours excellent diagnostic characters to separate species.



Figures 1, 2. *Dioryctria abietivorella*. **1**, BCFS slide No. 992.1.3.13; **2**, lab colony adult at rest.

Everted vesicae have been used successfully to recognize a new *Dioryctria* species from Texas (Blanchard and Knutson 1983): This represents a virtually unexplored character set in the genus as well as in Phycitinae as a whole. Progress in unravelling several species problems will have to include the study of everted vesicae. DNA sequencing could also aid in further efforts to verify the status of closely related species.

Species of *Dioryctria* are reputedly among the most distinct members of the Phycitinae (Heinrich 1956; *idem* for a characterization of Phycitinae). The genitalia of each sex has a characteristic habitus, easily observed in slides or drawings (Heinrich 1956). In males the main distinguishing feature is the enlarged, sclerotized costa that is markedly produced at the apex, projecting beyond the apex of the cuculus (Figs.7-15). In females, the ductus bursae is long and heavily sclerotized, with dense clusters or bands of heavy spines in the entrance (Figs. 22-31).

The forewing pattern is remarkably similar among the grey *Dioryctria* species. All are grey and white with contrasting zigzagged crosslines (Figs. 1, 2), and some have patches of brown scales. The forewings of most species lack the usual black dot at the end of the cell present in other Phycitinae, which is replaced by a pale spot or line on the discocellular vein (located in the distal third of the wing anterior to the transverse postmedial band), analogous to the reniform spot of the Noctuoidea. The forewing patterns do not usually provide reliable diagnostic characters to separate species, especially when specimens have been collected in sticky pheromone traps. Species can only be separated reliably through examination of genitalia. We present illustrations of male and female genitalia of the grey *Dioryctria* species of British Columbia with keys to species or species groups based on these characters.

MATERIALS AND METHODS

Material examined in this study was supplied by the Canadian National Collection of Insects (CNCI -- Agriculture and Agri-Food Canada) and Canadian Forest Service (CFS). CFS specimens came from the Pacific Forestry Centre Forest Insect and Disease Survey (PFC, FIDS) and a Forest Pest Management Institute (Sault Ste. Marie, Ontario) lab colony. These loans comprised all the known grey *Dioryctria* species and subspecies found in British Columbia. Additional specimens of *D. abietivorella* were obtained through a 1995 pheromone trapping trial conducted by the British Columbia Ministry of Forests (BCFS) and Simon Fraser University. An ultraviolet light-trap set up periodically at the pheromone trapping sites provided further specimens. Host and distribution data were gathered from material examined and references cited in the introduction.

Genitalia were prepared by removing abdomens of pinned specimens and macerating them for approximately ten minutes in warm 20% aqueous potassium hydroxide. Then, in 30% ethanol, scales were removed from the abdominal pelt and genitalia severed from abdomens. Dissected parts were examined in glycerine and stored in pure lactic acid. Moths caught in sticky traps were removed from the traps by soaking in ethyl acetate until free of the sticky material (Murphy 1985). The abdomens were subsequently removed and the genitalia dissected as above.

Unsuccessful attempts were made to evert vesicae of male *D. abietivorella* using both an injection technique performed on preserved specimens (by Jim Troubridge, Agriculture Canada, Vancouver, British Columbia, Canada) and chemical induction in which dimethoate was applied directly to live, virgin males (Dang, 1993). The standard eversion technique using a syringe did not work because the numerous cornuti jammed inside the membranous aedeagus tube. Subsequently, we succeeded in pulling vesicae out

carefully with fine tweezers and inflating them with a syringe. Although the vesicae were not perfectly inflated, we observed striking differences between some species. However, technical difficulties, which we are still resolving, prevented us from studying vesicae in sufficient detail to be able to present our results in this paper. We mention briefly under the pertinent species some significant features observed in everted vesicae, but do not illustrate any here and do not use the characters in the key.

Drawings of male and female genitalia were prepared for all available *Dioryctria* species and subspecies with the aid of Wild M3C and Zeiss stereo dissecting microscopes with squared grid lens reticles. Genitalia were drawn in glycerine on depression slides, except for males and females of *D. contortella* and *D. monticolella* which were drawn from permanent CNCI slide mounts.

Scanning electron microscopy was performed using a Jeol JSM-35 SEM at PFC. Specimens were prepared with a Ladd Industries critical point dryer and Hummer IV sputter coater (gold palladium) after mounting on standard SEM stubs. Photographs of female genitalia were taken using a Nikon SMZ-U stereoscope, at magnifications between 20-40x, with transmitted illumination. Ductus bursae were mounted unstained on slides in lactic acid under a cover slip. Close-ups of surface texture of ductus bursae were taken at 100x through a Nikon Optiphot compound microscope.

Key to Grey *Dioryctria* Species of British Columbia

MALES

1. Apical portion of costa with a single, broad, curved process, ventral margin smoothly rounded, without a notch or denticle (Fig. 11) ..... *D. okanaganella*
1'. Apical portion of costa with two teeth or denticular processes, the dorsal larger and more protruded, the ventral smaller (reduced in some specimens, but usually distinct) (Figs. 7-10, 12-15) 2
2. Aedeagus with large anterior cornutus (Figs. 3, 5, 6) 3
2'. Aedeagus without large anterior cornutua (Fig. 4) ..... *D. pseudotsugella* or *D. reniculelloides*
3. Distance between two processes at tip of costal arm of valva approximately half the width of central part of valva (Fig. 7); dorsal process of costal arm short and broad (Figs. 7, 36) ..... *D. abietivorella*
3'. Distance between two processes at tip of costal arm of valva approximately equal to width of central part of valva; dorsal process of costal arm long and narrow (Figs. 10, 12-14) 4
4. Uncus broadest at mid-length (Figs. 20, 21); dorsal process of costal arm of valva strongly recurved into a hook (Figs. 12-15) ..... *D. cambiicola*, *D. tumicolella*, *D. contortella*, or *D. monticolella*
4'. Uncus broadest at base (Fig. 19); dorsal process of costal arm of valva slightly recurved or nearly straight (Fig. 10) ..... *D. pentictonella*

FEMALES

1. Ductus bursae with marked, thick, longitudinal wrinkles (Fig. 25) ..... *D. okanaganella*
1'. Ductus bursae with, at most, very fine longitudinal wrinkles (Figs. 22-24, 28-31), or without wrinkles (Figs. 26, 27) 2
2. Sclerotized portion of ductus bursae with central longitudinal membranous (clear) area (Fig. 22) ..... *D. abietivorella*

2'. Sclerotized portion of ductus bursae without central longitudinal membranous area (Figs. 22-31) 3
3. Surface of sclerotized portion of ductus bursae with reticulate, isodiametric and finely spiculate microsculpture (Fig. 33), of granular appearance at low magnification (Figs. 26, 27), without longitudinal wrinkles ..... *D. pentictonella*
3'. Surface of sclerotized portion of ductus bursae with or without microsculpture, with fine longitudinal wrinkles (Figs. 23, 24, 28-31) 4
4. Sclerotized portion of ductus bursae with recurved process on left side of anterior end (Figs. 23, 24) ..... *D. pseudotsugella* or *D. reniculelloides*
4'. Sclerotized portion of ductus bursae without recurved process on left side of anterior end (Figs. 28-31) .. *D. cambiicola*, *D. tumicolella*, *D. contortella* or *D. monticolella*

Dioryctria abietivorella (Grote), 1878
(Figs. 1-3, 7, 16, 22, 36, 37)

Diagnosis. Genital characters distinguish male and female *D. abietivorella* from all other *Dioryctria* species discussed here. Males are distinguished by a broad valva and a short distance between the two processes at the tip of the costal arm (width of valva about twice the distance between the two costal processes, Fig. 7). Also, in males the aedeagus contains a large anterior cornutus, a cluster of anterior setae and a posterior cluster of smaller cornuti (Fig. 3), and the apical process of the costal arm is short and broad (Figs. 7, 36). Females are distinguished by a central longitudinal membranous area within the sclerotized portion of the ductus bursae (Fig. 22). Additionally there is a small lobe on the right side of the anterior end of the ductus bursae (Fig. 22). Approximately 60 male and 10 female genital preparations were examined.

Hosts. Broad range. Hosts recorded from museum specimens include amabilis fir (*Abies amabilis*), spruces (*Picea abies*, *P. glauca*), yellow (ponderosa) pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*); other hosts reported in British Columbia are grand and subalpine firs (*Abies grandis*, *A. lasiocarpa*), various pines (*Pinus banksiana*, *P. contorta*, *P. flexilis*, *P. monticola*) and spruces (*Picea mariana*, *P. sitchensis*, *P. engelmanni*), western larch (*Larix occidentalis*) and western hemlock (*Tsuga heterophylla*) (hemlock record from BCFS unpublished data).

Distribution. *Dioryctria abietivorella* is widespread in Canada and the north eastern United States and is found in the west from Alaska to northern Mexico.

Material examined. CAN: BC: Woss, 5/iii/1991, 1 male, 1 female ex *Abies amabilis* (PFC); near Keremeos and on southern Vancouver Is., summer 1994, from BCFS pheromone trial, about 50 males (BCFS); NB: St. Basile, 16/viii/1987, at light, 1 female (CNCI); York County, Scotch Lake, 21/iii/1995, 1 female ex *Picea glauca* (CNCI); ON: (CFS lab colony), numerous males and females (BCFS); SK: Indian Head, 22/ii/1953, 1 female ex *Picea abies* (CNCI).

Dioryctria okanaganella Mutuura, Munroe and Ross, 1969b
(Figs. 11, 25, 32)

Diagnosis. Genital characters distinguish male and female *D. okanaganella* from all other *Dioryctria* species discussed here. Males are distinguished by the apical portion of the costal arm of the valve which has a single recurved process without a smaller ventral tooth or process (Fig. 11). Additionally, in males the uncus is widest at mid-length, similar to the *cambiicola* complex (see below) and the aedeagus has one or two moderately large cornuti at the anterior end in most specimens. Mutuura *et al.* (1969b) illustrated and diagnosed the male genitalia of this species based on a specimen lacking a

large anterior cornutus but this assessment was based on an aberrant or damaged specimen. All other specimens we examined had at least one large anterior cornutus. Females are recognized by the strong longitudinal wrinkling of the ductus bursae, which is markedly more pronounced than in the other species treated here (Fig. 25). Twelve male (including holotype) and 16 female genital preparations were examined.

Host. *Dioryctria okanaganella* is associated with old pitch masses or blister rust swellings on *Pinus ponderosa*. The only known reared material with host data appears to be the type series.

Distribution. *Dioryctria okanaganella* is known from the southern interior of British Columbia, through Washington and the Sierra Nevada in California.

Material examined. (All specimens in CNCI): CAN: BC: Type series, 5 males, 13 females, material listed in Mutuura *et al.* 1969b:1047. USA: CA: El Dorado Co., Blodgett Forest, 13 mi E Georgetown, 14/vii/1967, 2 males, 1 female; Tuolumne Co., Twain Harte, 17-26/vii/1961, 1 male, 1 female; Yosemite Ntl Park, 1 mi ESE Yosemite Village, 18/ix/1966, 1 male; WA: 6 mi NW Spokane, 3/ix/1961, 2 males; 8 mi S Tonasket, 11/ix/1960, 1 male, 1 female.

Dioryctria pentictonella Mutuura, Munroe and Ross, 1969b
(Figs. 5, 10, 19, 26, 27, 33)

Diagnosis. Mutuura *et al.* (1969b) separated *Dioryctria pentictonella vancouverella* from the nominal species on the basis of slight colour differences and distribution. For the purposes of this paper, we recognize only the nominal species which may be distinguished from all other species discussed here by the following genitalic characters. In males the dorsal process of the costal arm is long, narrow and not curved into a hook (Fig. 10) and the uncus is widest at its base (Fig. 19). Additionally in males the distance between the two costal arm processes is approximately equal to the width of the central part of the valva (Fig. 10). In females the sclerotized portion of the ductus bursae has granular and finely spiculate microsculpture (Figs. 26, 27, 33) and the anterior portion is folded on itself (Fig. 27) although the fold is easily stretched out during preparation (Fig. 26). Five male and seven female *D. pentictonella* preparations were examined.

Host. *Dioryctria pentictonella* is recorded from *Pinus contorta*, *P. ponderosa*, and *P. sylvestris* (data from museum specimens) and from *P. mugho*, *P. nigra*, and *P. radiata* (Furniss and Carolin 1980, Mutuura *et al.* 1969b).

Distribution. Southern British Columbia.

Material examined. *Dioryctria pentictonella*: CAN: BC: all ex *Pinus ponderosa*: Kamloops, 8/vii/1974, 1 male (PFC); Penticton, 11/v/1966 and 13/v/1966, 2 paratype males (CNCI); Penticton, 22/vi/1966 and 23/vi/1966, 2 paratype females (CNCI); Field Rd., 29/vi/1966, 1 paratype female (PFC). *Dioryctria pentictonella vancouverella*: CAN: BC: Port Moody, 13/vii/1964, 1 female ex *Pinus contorta* (CNCI); all from Vancouver: 24/vii/1961, 1 male ex *P.contorta* (PFC); 9/vii/1963, 1 paratype male ex *P. contorta (CNIC)*; 14/vii/1964 and 16/vii/1964, 2 paratype females ex *P. contorta (CNIC)*; 13/x/1965, 1 paratype female ex *Pinus sylvestris (CNIC)*.

Dioryctria pseudotsugella group
(*D. pseudotsugella* Munroe, 1959 (Figs. 4, 8, 17, 23) and
D. reniculelloides Mutuura and Munroe, 1973 (Figs. 9, 18, 24))

Diagnosis. We could not separate these nominal species confidently. Mutura and Munroe (1973) only discussed alleged differences between *Dioryctria pseudotsugella* and *D. reniculelloides* in relative terms. Some specimens we examined match one or the

other of the original descriptions, but others are intermediate. Alleged differences could be real and significant but proper assessment would require a detailed analysis beyond the scope of this work. Examination of the inflated vesicae of males of both nominal species did not show any differences.

The ranges of the two species (and their hosts) are broadly sympatric. There is no host information on the holotype and allotype of *D. pseudotsugella* (from Seton Lake, BC). Neither the genitalia of the female allotype of *D. pseudotsugella*, nor the primary type of *D. reniculelloides* have been dissected. Given that the reported differences between these two species are inconsistent, the association of the types with other reared specimens of *D. pseudotsugella* cannot be confirmed. A detailed analysis, morphometric and molecular, will be necessary to clarify the status of *D. pseudotsugella* and *D. reniculelloides*.

Both *D. pseudotsugella* and *D. reniculelloides* may be distinguished from the other *Dioryctria* species discussed here by characters of the genitalia as follows: males with aedeagus lacking large anterior cornutus (Fig. 4); females with recurved process on left side of anterior end and without central longitudinal membranous area (Figs. 23, 24). Five male and three female *D. pseudotsugella* and eight male and six female *D. reniculelloides* preparations were examined.

Hosts. *Dioryctria pseudotsugella*: *Pseudotsuga menziesii* and *Picea glauca* were recorded in museum specimen data; other material has been reared from *Abies* sp., *Picea engelmanni*, *Picea* sp. and *Tsuga* sp. (Furniss and Carolin 1980, Mutuura and Munroe 1973). *Dioryctria reniculelloides*: broad host range; material recorded in museum specimen data includes *Picea engelmanni*, *P. glauca* and *Pseudotsuga menziesii;* other reported hosts are *Abies amabilis*, *A. lasiocarpa*, *Larix laricina*, *Picea mariana*, *P. sitchensis*, *Pinus contorta*, and *Tsuga heterophylla* (Furniss and Carolin 1980, Mutuura and Munroe 1973).

Distribution. *Dioryctria pseudotsugella* is found in the southern half of British Columbia and extends to northern California coastally and to the northern interior of Mexico following the Rocky Mountain range. *Dioryctria reniculelloides* is widespread in Canada and the north eastern United States and is found in the west from Alaska to northern Mexico.

Material examined. *Dioryctria pseudotsugella*: CAN: BC: 10 mi E Cranbrook, 28/vii/1960, 1 female (CNCI); Gold Bridge, 22/vii/1974, 1 male ex *Pseudotsuga menziesii* (PFC); Hedley, 3/vii/1975 and 7/vii/1974, 2 males ex *P. menziesii* (PFC); Sidmouth, 4/vii/1953, 1 male ex *P. menziesii* (CNCI); Merritt, 5/viii/1976, 1 female ex *P. menziesii* (PFC); Quesnel, 22/vii/1976, 1 male ex *Picea glauca* (PFC); 25/vii/1945 , 1 female (CNCI). *Dioryctria reniculelloides*: CAN: BC: ex *Picea engelmanni*: Bestwick, 11/vii/1953, 1 paratype male (CNCI); 17/vi/1958, 1 paratype male (CNCI); Smithers, 17/vii/1972, 1 male (PFC); ex *P. glauca*: Azela Lk., 22/vii/1954, 1 paratype female (CNCI); Burns Lk., 10/vii/1972 and 13/vii/1972, 2 males (PFC); Hazelton, 11/vii/1974, 1 male (PFC); Houston, 25/vii/1972, 1 male (PFC); Laird, 4/vii/1972, 1 female (PFC); ex *Pseudotsuga menziesii*: Beechy Head, 9/vii/1956, 1 female (CNCI); Dutch Dairy Log Rd., 25/vii/1949, 1 female (CNCI); Premiere Lk., 5/vii/1961, 1 female (CNCI). US: ID: 4th of July Creek, N of Salmon, 3/viii/1961, 1 female (CNCI); NY: Jefferson Co., Picton Isl., 9/vii/1967, 1 paratype male (CNCI).

Dioryctria cambiicola group

(*D. cambiicola* (Dyar), 1965 (Figs. 6, 12, 20, 28, 35),
D. contortella Mutuura, Munroe and Ross, 1969a (Figs. 14, 29),

D. monticolella Mutuura, Munroe and Ross, 1969a (Figs. 15, 30), and
D. tumicolella Mutuura, Munroe and Ross, 1969a (Figs. 13, 21, 31))

Diagnosis. The four species *D. cambiicola*, *D. contortella*, *D. monticolella*, and *D. tumicolella* closely resemble each other in external morphology and no differences in genitalic characters are apparent. It seems the latter three species were described by Mutuura *et al.* (1969a) solely on the basis of host differences. These species have been treated as a group and may be separated from all others discussed here by characters of both male and female genitalia. In males the dorsal process of the costal arm is long, narrow and curved into a hook and the uncus is widest at mid-length (Figs. 12, 20 (*D. cambiicola*); 13, 21 (*D. tumicolella*); 14 (*D. contortella*) and 15 (*D. monticolella*)). Additionally in males the aedeagus contains a large anterior cornutus and a posterior cluster of smaller cornuti (Fig. 6), and the distance between the two costal processes is approximately equal to the valva width (Fig. 12). In females the sclerotized portion of the ductus bursae is more slender than in previous species, is longitudinally finely wrinkled and has no central longitudinal membranous area, granular-spiculate microsculpture, nor a process on the anterior end (Figs. 28 (*D. cambiicola*), 31 (*D. tumicolella*), 29 (*D. contortella*), and 30 (*D. monticolella*)). The anterior portion of the ductus bursae is folded on itself somewhat as in *D. pentictonella* but the fold is thicker and broader (Figs. 29, 31); it is also easily stretched out in preparations (Figs. 28, 30).

Four male and two female (*D. cambiicola*), four male and six female (*D. contortella*), two male and three female (*D. monticolella*), and six male and two female (*D. tumicolella*) preparations were examined.

Hosts. *Dioryctria cambiicola*: *Pinus ponderosa* was recorded from museum specimens; *P. contorta* and *P. coulteri* are also reported (Furniss and Carolin 1980, Mutuura *et al.* 1969a). *Dioryctria contortella*: *P. contorta*; *D. monticolella*: *P. monticola*; *D. tumicolella*: *P. ponderosa*.

Distribution. *Dioryctria cambiicola* occurs throughout British Columbia and the western United States, including Washington, Oregon, California, Montana, Colorado, Arizona, and New Mexico. *Dioryctria contortella* is recorded from British Columbia, Alberta, and the state of Washington. *Dioryctria monticolella* is recorded from southern British Columbia. *Dioryctria tumicolella* is recorded from southern British Columbia and the states of Washington, Montana, and Colorado.

Material examined. *Dioryctria cambiicola*: CAN: BC: all ex *Pinus ponderosa*: Anarchist Mtn., 7/viii/1951, 1 male (CNCI); Eneas Cr., 26/viii/1951, 1 male (CNCI); Oliver, 29/viii/1953, 1 female (CNCI); Phillips Canyon, 21/vii/1958, 1 female (CNCI); Glenemma, 20/vii/1967, 2 males (PFC). *Dioryctria contortella* (all specimens in CNCI): CAN: BC: all ex *Pinus contorta*: Barriere, 3, 12, 15, 17/vii/1967, 4 paratype males; Beaverdell, 25/vii/1956, 1 female; Carmi, 26/vii/1956, 3 females; Kersley, 22/vii/1966, 1 female. US: CO: Rock Creek Canyon, 27/ix/1957, 1 female. *Dioryctria monticolella* (all specimens in CNCI): CAN: BC: all paratypes ex *Pinus monticola*: Magna Bay, 1 male; 15/iv/1953, 1 allotype female; Salmon Arm, 6/viii/1956, 1 male; 5,6/viii/1955, 2 females. *Dioryctria tumicolella* (all specimens in CNCI): CAN: BC: all paratypes ex *Pinus ponderosa*: Commonage, 13/vii/1967, 1 male; Summerland, 12, 29, 30, 31/vii/1967 and 1/viii/1967, 5 males; 12/vii/1967, 1 female. US: WA: 6 mi NW Spokane, 3/ix/1961, 1 female.

ACKNOWLEDGEMENTS

We are grateful to the following for their support: Dr. D. V. Ellis (University of Victoria, British Columbia) for academic supervision of the senior author, Jim Troubridge (Agriculture and Agri-Food Canada, Vancouver, British Columbia) for dissection and vesica eversion techniques and Leslie Manning (PFC) for assistance with the SEM. The British Columbia Ministry of Forests supported this work financially during two University of Victoria Biology Co-op work terms. The Canadian federal Green Plan supported pheromone trapping field work. Dr. Lee Humble and Robert Duncan loaned us FIDS specimens and Dr. Gary Grant provided lab colony specimens. The comments of two anonymous reviewers substantially improved this paper.

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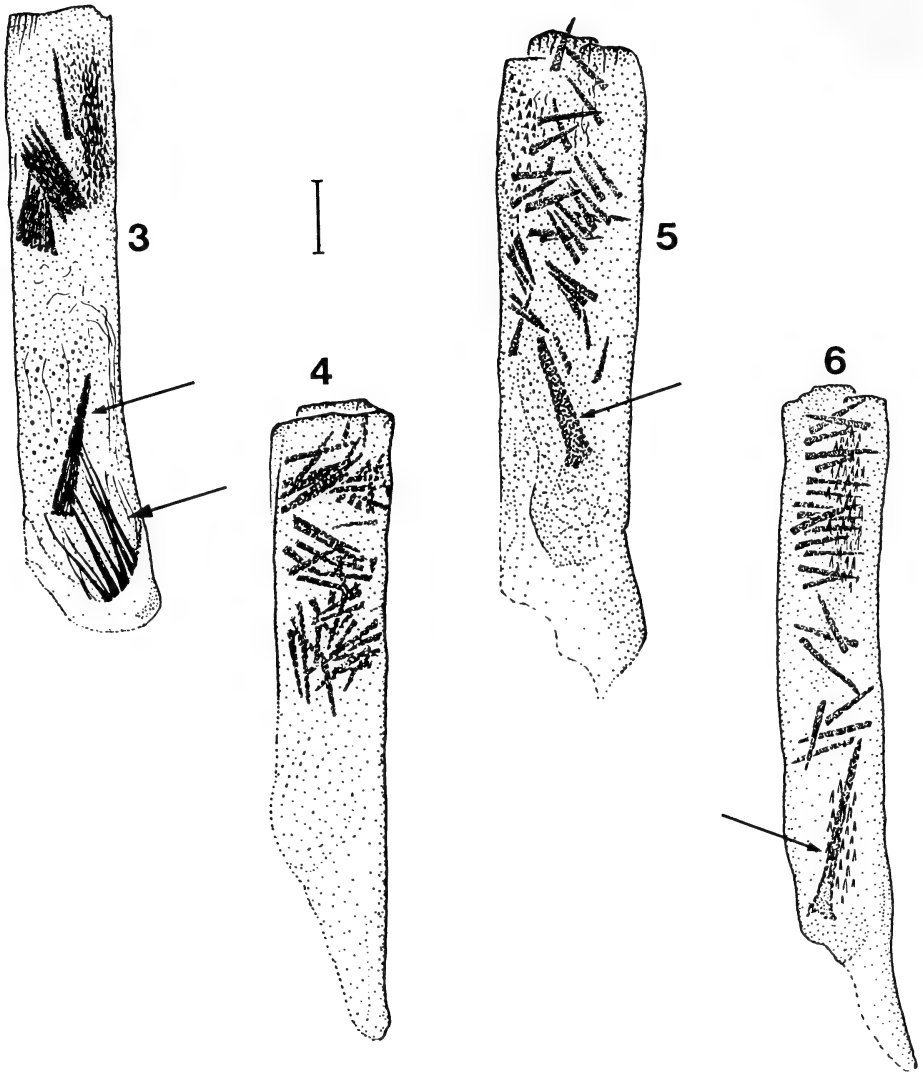
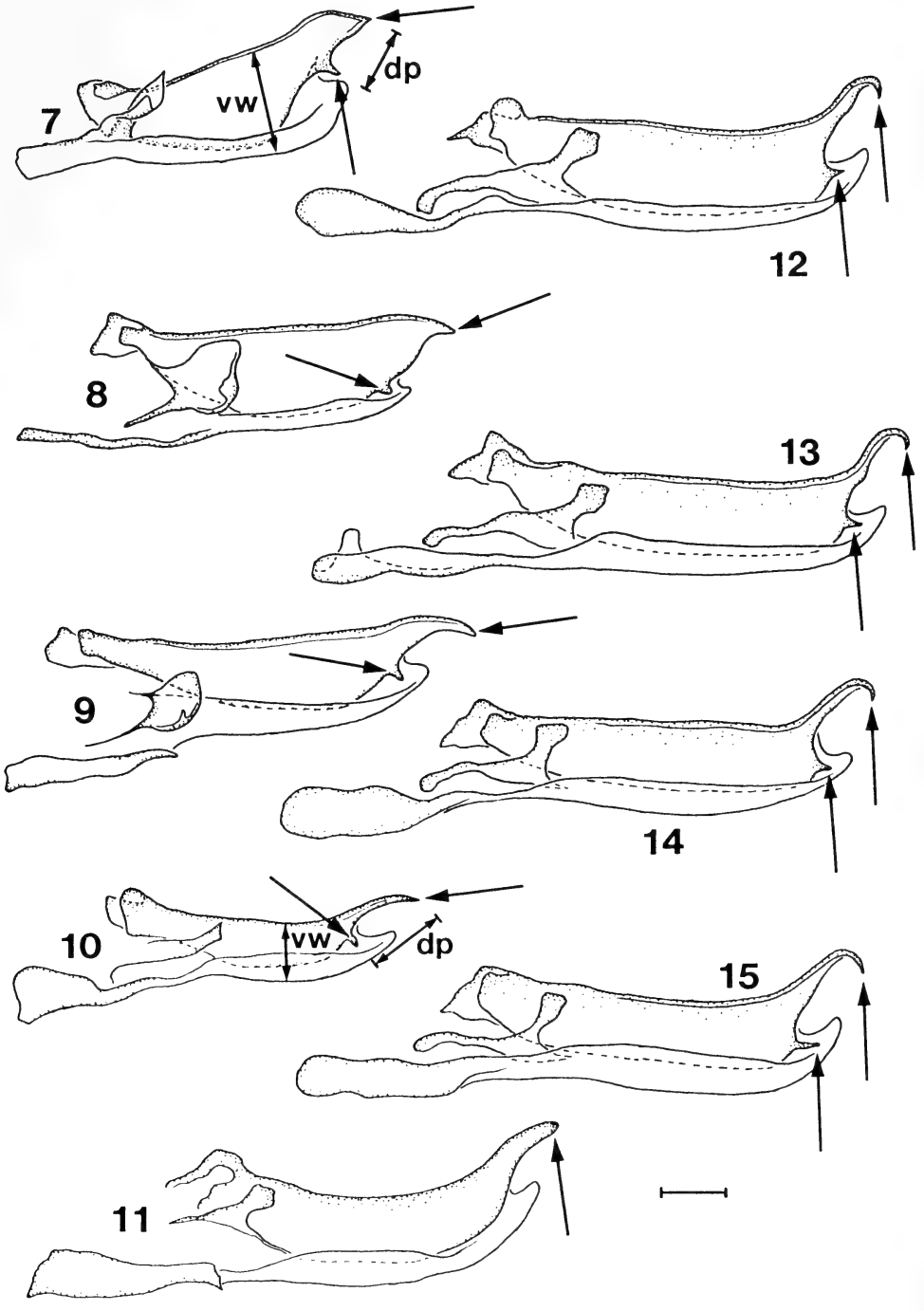
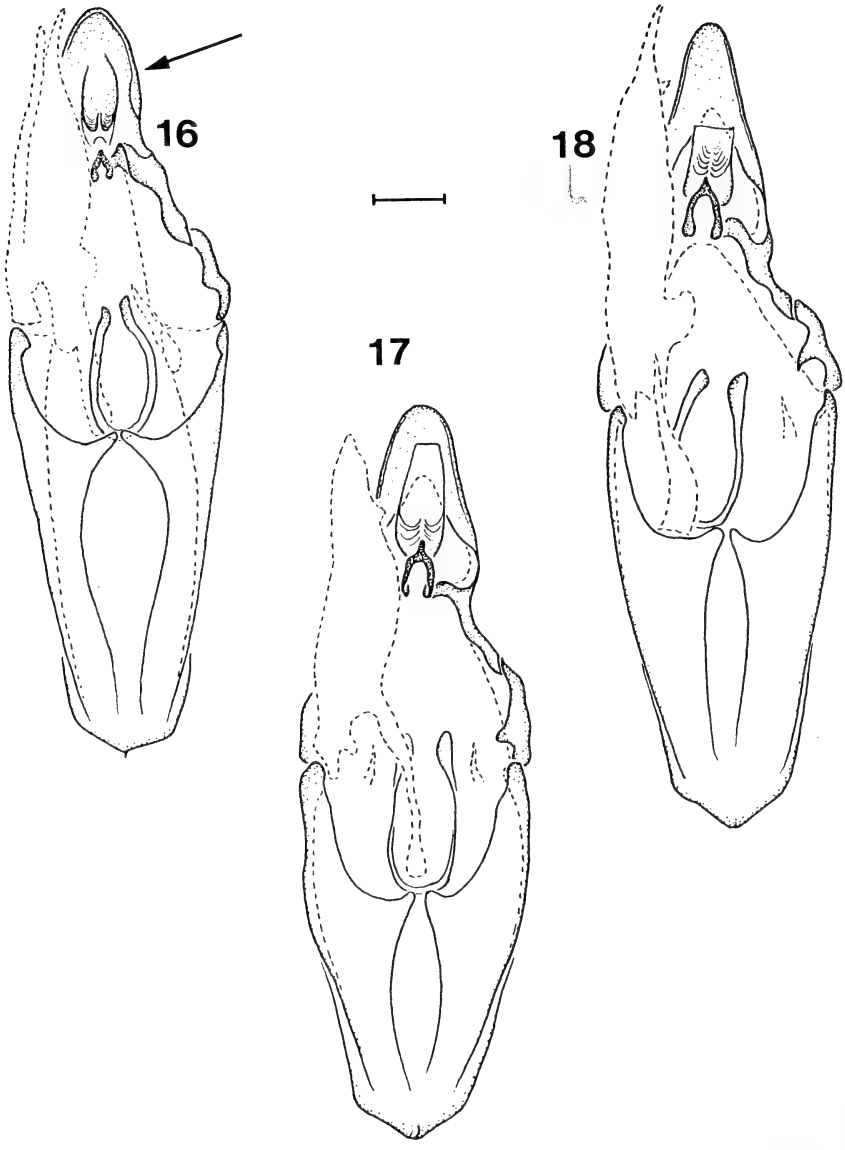


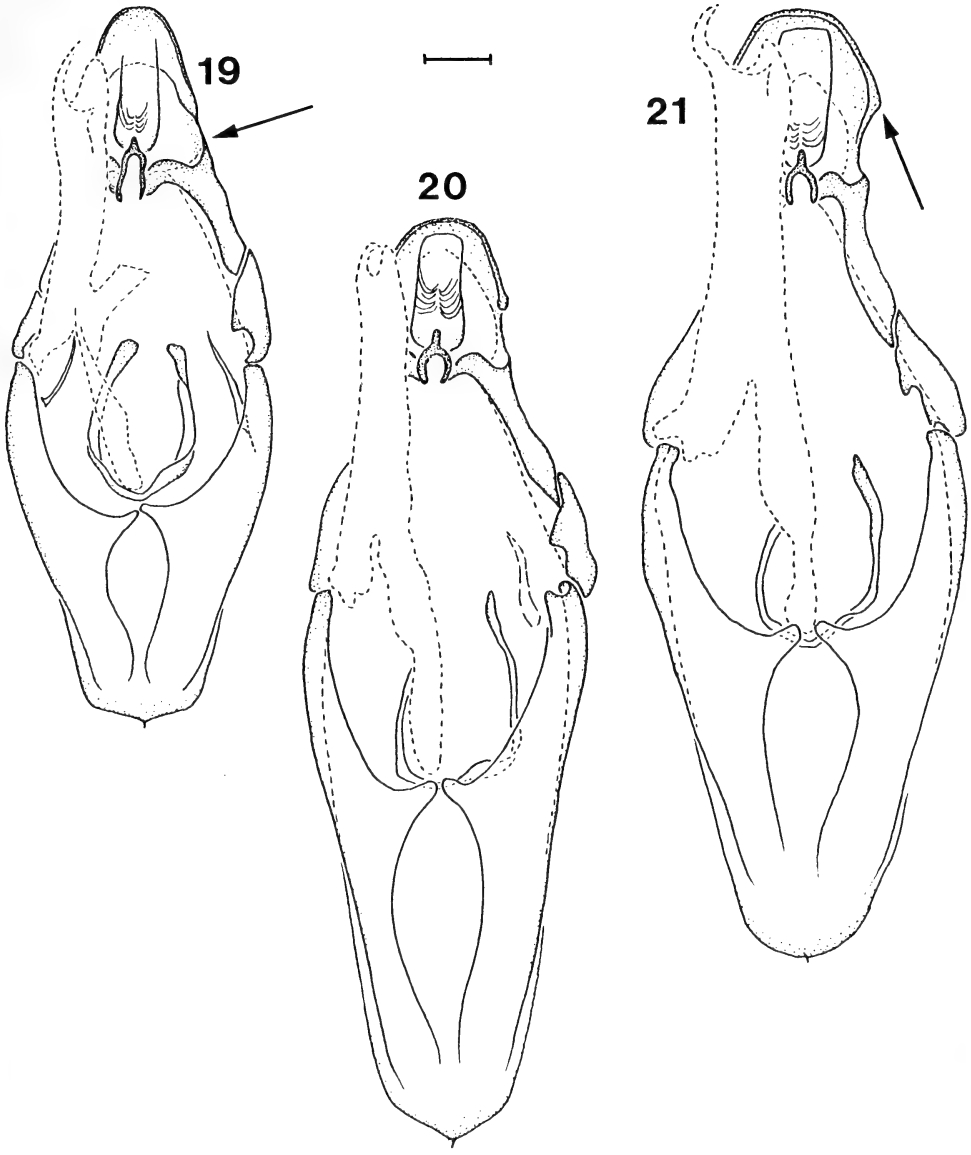
Figures 3-6. *Dioryctria* spp. aedeagi. **3**, *D. abietivorella*, CFS lab colony specimen; **4,** *D. pseudotsugella*, Hedley, BC, ex. *Pseudotsuga menziesii*; **5,** *D. pentictonella vancouverella*, Vancouver, BC, ex. *Pinus contorta*; **6**, *D. cambiicola*, Eneas Cr., BC, ex. *Pinus ponderosa*. Large arrow indicates anterior setal patch (**Fig. 3**), smaller arrows indicate large anterior cornuti. Scale bar = 0.25 mm.



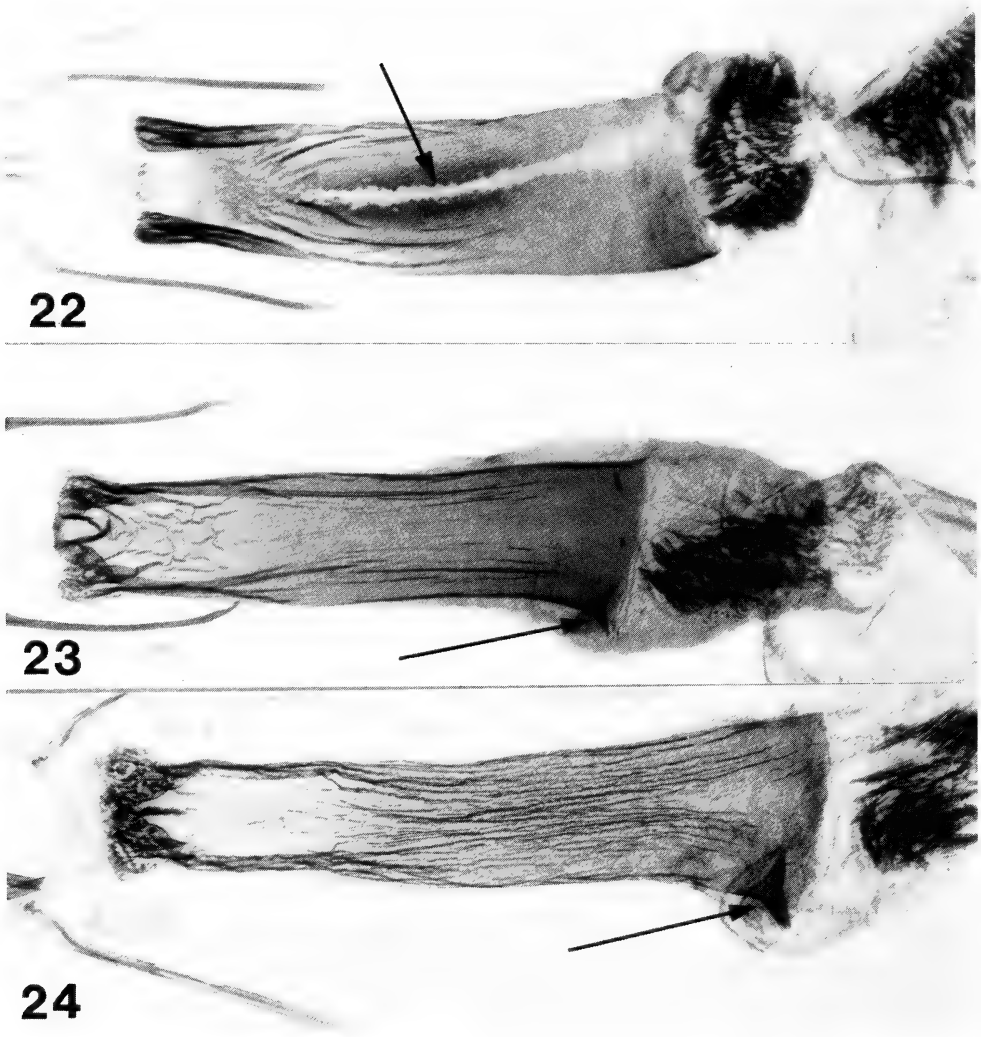
Figures 7-15. *Dioryctria* spp. valvae. **7**, *D. abietivorella*, Keremeos, BC, ex. *Pseudotsuga menziesii*; **8**, *D. pseudotsugella*, Sidmouth, BC, ex. *Pseudotsuga menziesii*; **9**, *D. reniculelloides*, Bestwick, BC, ex. *Picea engelmanni*; **10**, *D. pentictonella*, Penticton, BC, ex. *Pinus ponderosa*; **11**, *D. okanaganella*, El Dorado Co., CA; **12**, *D. cambiicola*, Eneas Cr., BC, ex. *Pinus ponderosa*; **13**, *D. tumicolella*, Summerland, BC, ex. *Pinus ponderosa*; **14**, *D. contortella*, ex. *Pinus contorta*; **15**, *D. monticolella*, ex. *Pinus contorta*. Arrows indicate two processes at tip of costal arm; dp=distance between two processes, vw=valva width. Scale bar = 0.25 mm.



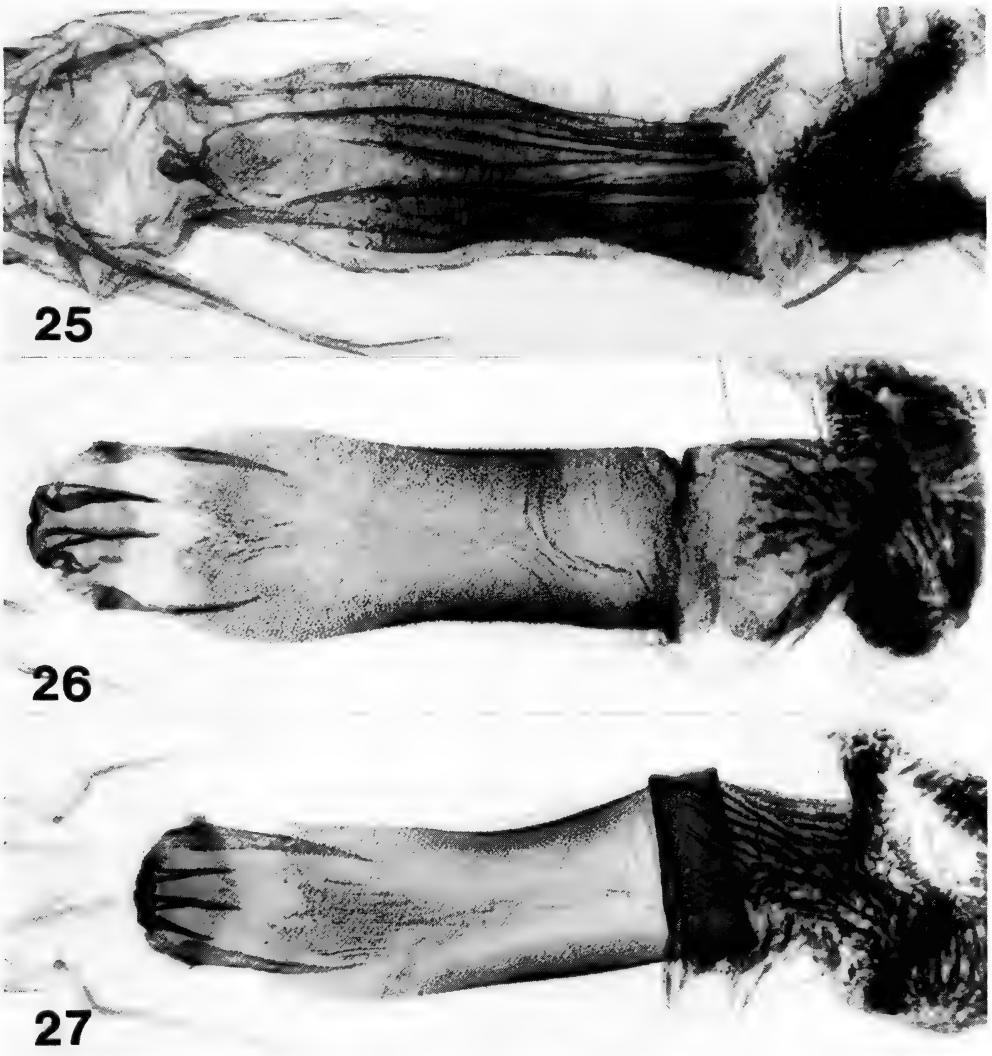
Figures 16-18. *Dioryctria* spp. male genitalia, right valvae and aedeagi removed. **16**, *D. abietivorella*; **17**, *D. pseudotsugella*; **18**, *D. reniculelloides*. Specimens as in **Figs. 7-9**, respectively. Arrow indicates uncus. Scale bar = 0.25 mm.



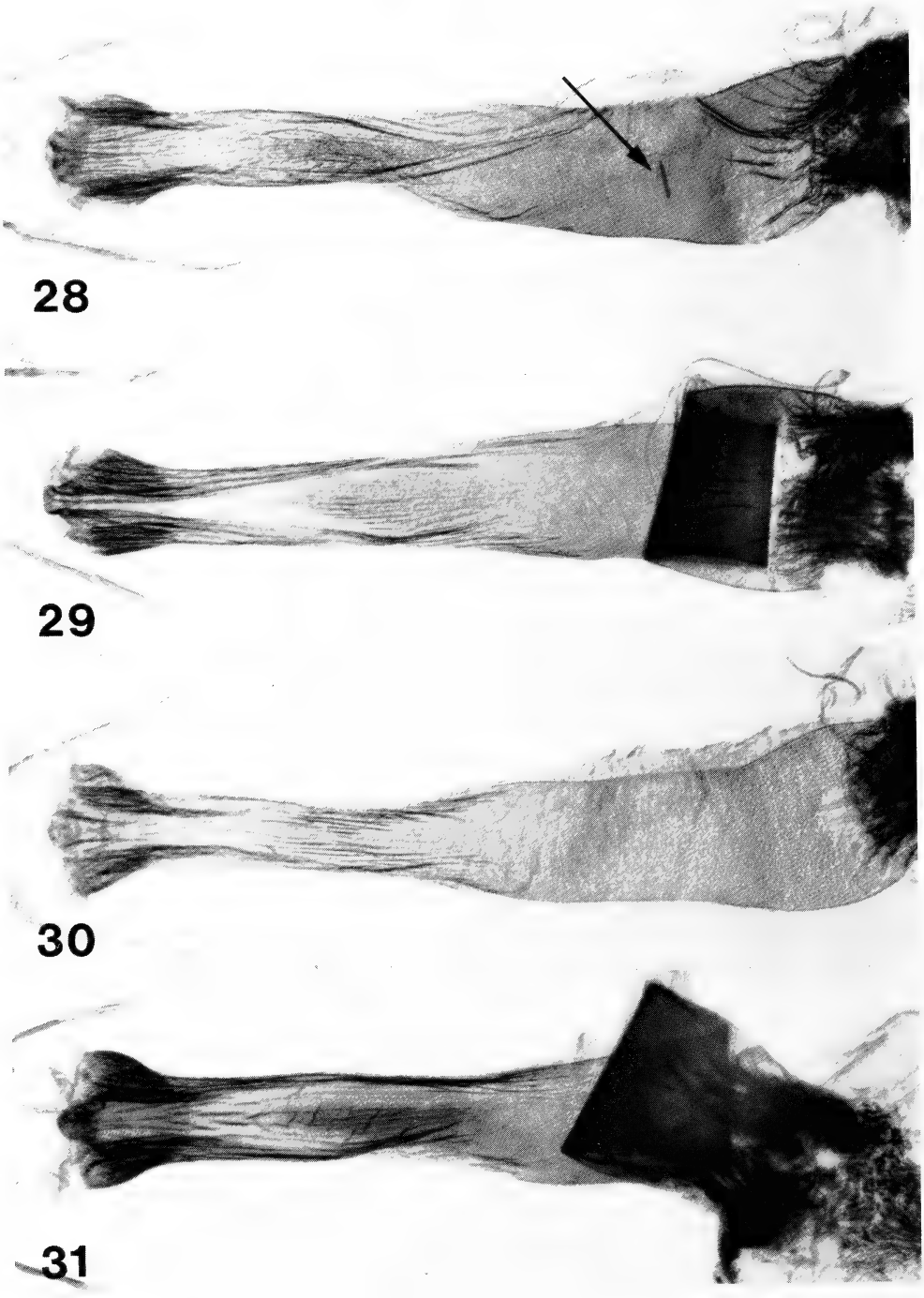
Figures 19-21. *Dioryctria* spp. male genitalia, right valvae and aedeagi removed. **19**, *D. pentictonella*; **20**, *D. cambiicola*; **21**, *D. tumicolella*. Specimens as in **Figs. 10, 12, 13,** respectively. Arrows indicate widest part of unci. Scale bar = 0.25 mm.



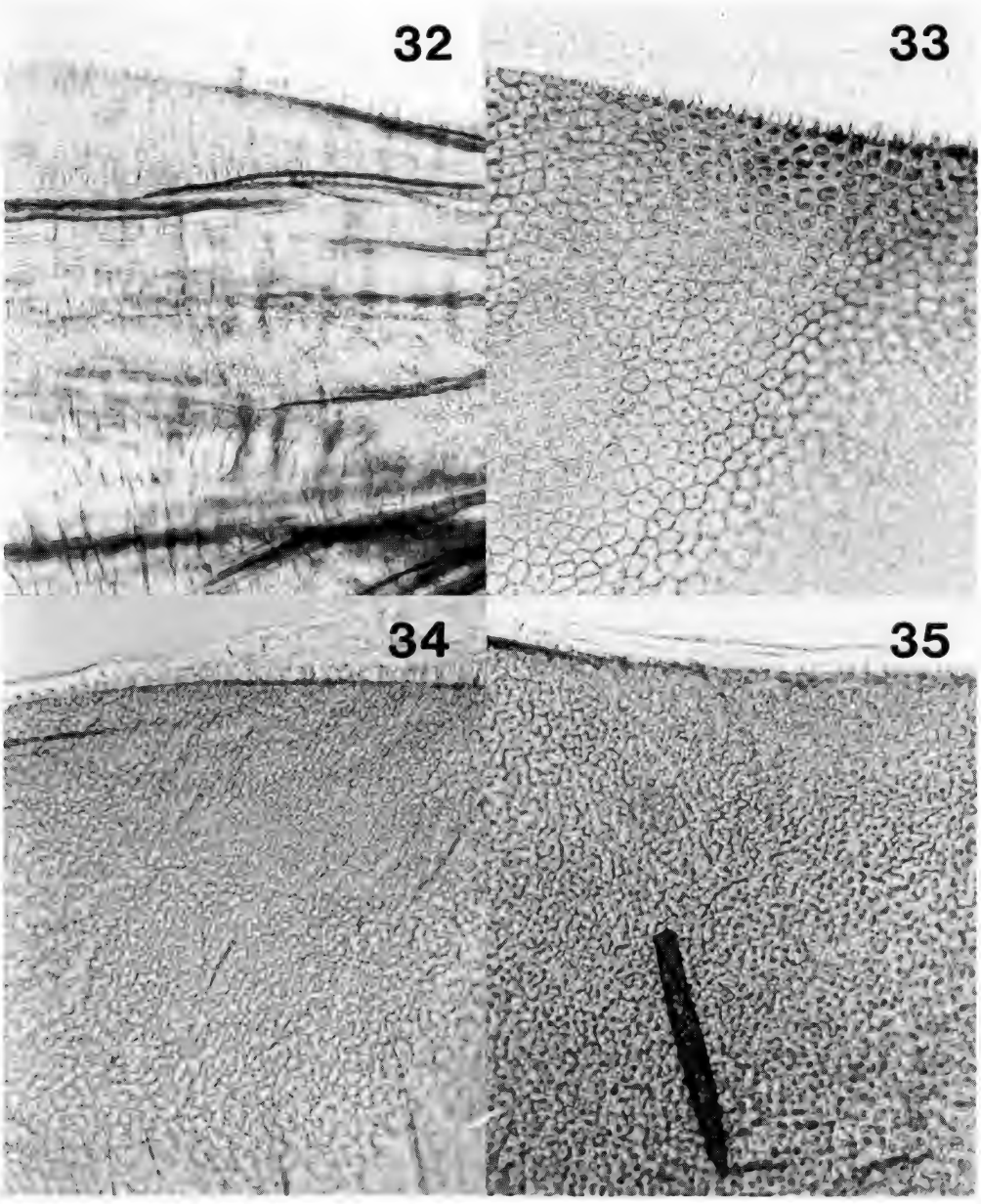
Figures 22-24. *Dioryctria* spp. ductus bursae. **22**, *D. abietivorella*, St. Basile, NB; **23**, *D. pseudotsugella*, Cranbrook, BC; **24**, *D. reniculelloides*, Salmon, ID. Arrows indicate membranous area (**Fig. 22**) and recurved process (**Figs. 23, 24**).



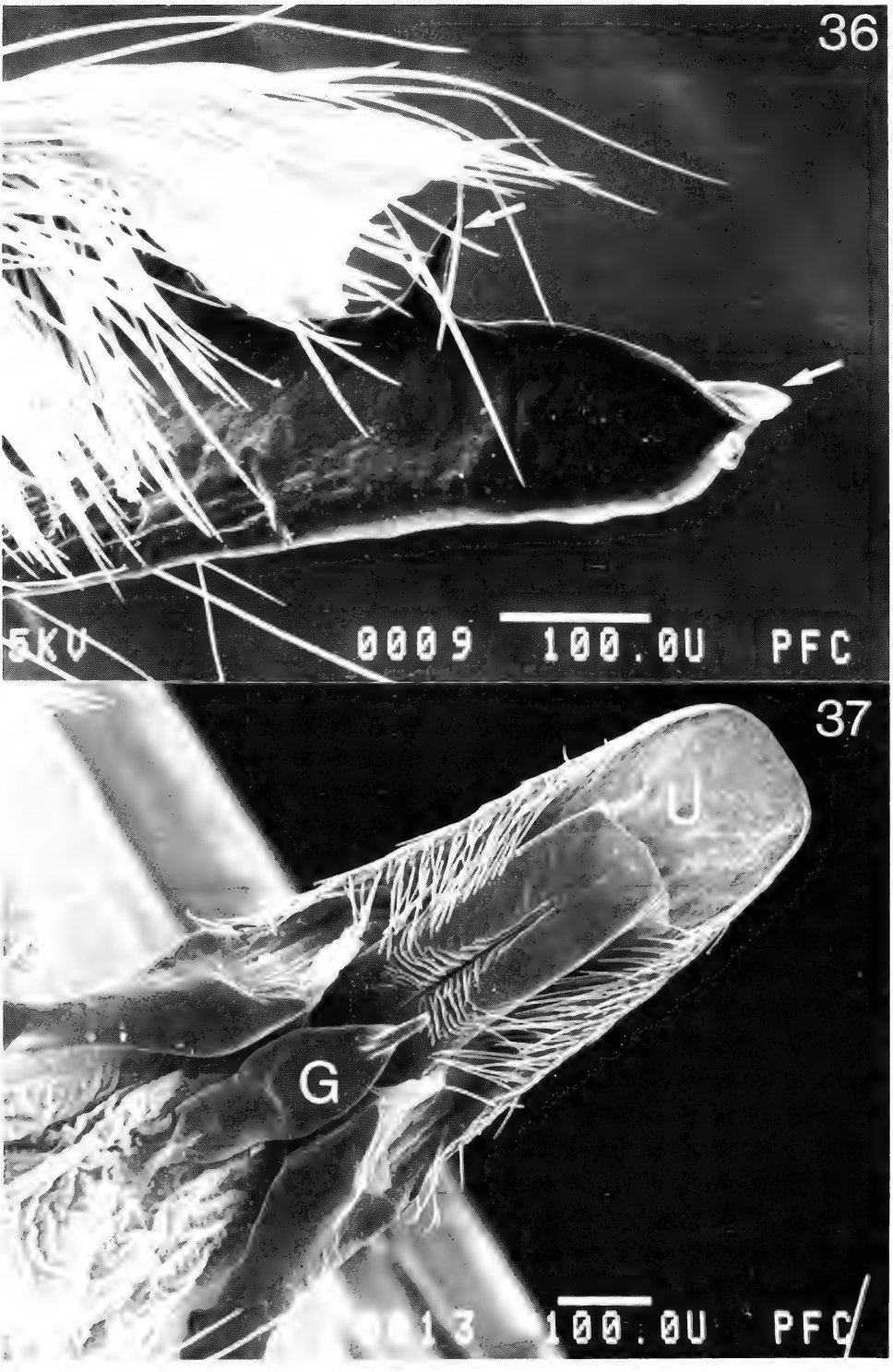
Figures 25-27. *Dioryctria* spp. ductus bursae. **25**, *D. okanaganella*, specimen data as in **Fig. 11**; **26**, *D. pentictonella*, Penticton, BC, ex. *Pinus ponderosa*, with fold stretched out in preparation; **27**, *D. pentictonella vancouverella,* Port Moody, BC, ex. *Pinus contorta.*



Figures 28-31. *Dioryctria* spp. ductus bursae. **28**, *D. cambiicola*, Oliver, BC; **29**, *D. contortella*, Rock Creek Canyon, CO; **30** *D. monticolella*, Magna Bay, BC, ex. *Pinus monticola*; **31**. *D. tumicolella*, Spokane, WA. Arrow indicates cornutus broken from male aedeagus. The fold visible in **Figs. 29** and **31** was stretched out in the preparations illustrated in **Figs. 28** and **30.**



Figures 32-35. *Dioryctria* spp. ductus bursae, surface texture. **32**, *D. okanaganella*; **33**, *D. pentictonella*; **34**, *D. monticolella*; **35**, *D. cambiicola* (note broken cornutus from male vesica). Specimens as in **Figs 25, 26, 30** and **28**, respectively.



Figures 36-37. *Dioryctria abietivorella* male genitalia. **37**, valva; **38**, uncus (U) and gnathos (G). Sechelt, BC, ex. *Pseudotsuga menziesii*. Arrows indicate two processes at tip of costal arm.

Effects of refrigeration on development of the blow fly, *Calliphora vicina* (Diptera: Calliphoridae) and their relationship to time of death

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ABSTRACT

Eggs, larvae, and pupae of the blow fly *Calliphora vicina* reared normally at 24°C were kept for 24 h at an ambient temperature of 3.0±0.14°C during growth and development. This was to simulate the chilling of insects before their collection from cadavers in a morgue at 3°C in forensic entomology cases. Such treatment of any stage induced a 24 h delay in adult emergence because the insects did not appear to develop while chilled. No mortality occurred in any stage, including eggs and 1st instar larvae, during chilling. This information is important for, and should improve the accuracy of forensic investigations.

Key words: Forensic entomology, maggot, British Columbia, refrigeration, development

INTRODUCTION

Forensic entomology which includes the study of the ecology and development of insects colonizing a corpse, is commonly used in investigations of death (Catts and Haskell 1990, Smith 1986). Analysis of the developmental stages of insects on the remains, together with environmental information, in particular temperature at the crime scene, can allow more precise estimates of time of death than are possible by any other means when death occurred at least 3 days before discovery (Sperling *et al.* 1994; Kashyap and Pillai 1989). Ideally, insects should be collected directly from the remains, at the death scene, by the entomologist. But, this is not always possible, and the corpse is often moved to a morgue and chilled before an entomologist can examine it.

The objectives of this work were: to determine whether larvae continue to grow and develop when maintained at 3°C for 24 h periods, or whether development is arrested; if development is arrested, whether the chilled insects complete development normally when returned to a warmer environment; or whether there is a delay which persists during the rest of the development. These points are important in determining the age of the insects when they were collected and therefore, for estimating time of death of the corpse.

METHODS AND MATERIALS

Calliphora vicina Robineau-Desvoidy, a common blow fly found in many forensic entomology cases in B.C. (Anderson 1995) was used in this study. All the flies were from a laboratory colony established from individuals trapped in Burnaby, B.C.

Adult flies were allowed to oviposit on the surface of fresh beef liver. The colony was observed regularly and the liver removed when 1800-2000 eggs were obtained. Seven pairs of 4 litre, wide-mouthed glass jars were set up with 3 cm of moistened sawdust in each, to allow prepupae to burrow. About 100 gm of beef liver were placed in each jar

on paper towels, to prevent newly emerged larvae from drowning. Approximately 100 eggs were placed on the liver in each jar and the jars sealed with two layers of paper toweling secured with elastic bands. The jars were held at a mean temperature of 24.1°C, (monitored in both laboratory and incubator using SmartReader Dataloggers[1] set to record the means of 30 min. temperature readings over 30 days).

The first pair of jars was used as an overall control and kept at 24°C for the entire experiment. One of each of the remaining 6 pairs of jars of larvae was not disturbed until the adults had emerged, whereas the second jar was examined daily. Twenty larvae were randomly selected and removed from this jar daily for brief examination under a dissecting microscope and then replaced. When all 20 larvae examined were at a particular developmental stage the jar was chilled for 24 hours. The developmental stage was determined from their spiracular slits (Fig. 1) and crop size (Fig. 2). First instar larvae have no sclerotization around their spiracular slits (Fig. 1a) and their crops are not visible to the naked eye. Second instar larvae have sclerotization around their 2 pairs of spiracular slits visible under a dissecting microscope (Fig. 1b). During this stage the crop is still not visible to the naked eye. Third instar larvae have sclerotization around all 3 pairs of spiracular slits (Fig. 1c).

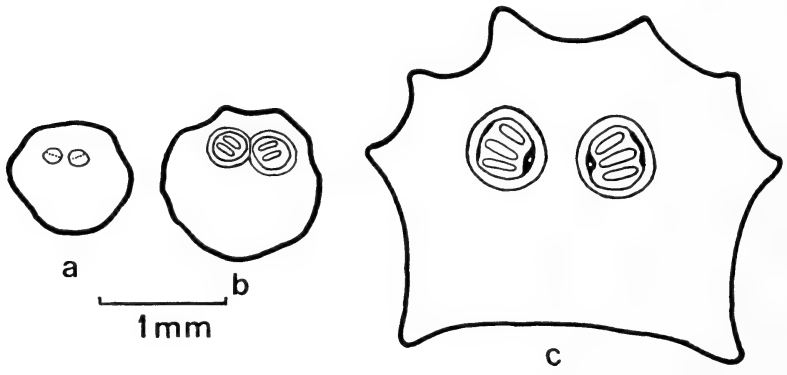

Figure 1. Diagrams of spiracles at posterior of *Calliphora vicina*. a) - First instar, cuticle not sclerotized, b) - Second instar, two pairs of spiracular slits clearly visible, c) - Third instar, three pairs of slits.

Their crops are visible to the naked eye (Fig. 2a) and during this stage the larvae feed voraciously. Then in the latter part of the third instar, they enter a prepupal or non-feeding stage. They leave the food source and scatter throughout the sawdust. They enter this stage with a full crop, but its contents gradually decrease during the prepupal stage (Fig. 2b). The crop shrinks until it can no longer be seen with the dissecting microscope (Fig. 2c) and the larvae contract to about half the length they were at the begining of the third instar. The entire process of crop reduction can be easily monitored (Fig. 2 a-c). Once all the insects in a given jar reached the third instar, all examinations were from the outside only, to avoid further handling. Experimental pairs 2-7, each consisting of an undisturbed and an examined jar, were chilled for 24 hours at a constant morgue temperature of 3.0±0.14°C (30 day mean ± SE) at one of the following developmental stages: pair 2, egg stage; pair 3, 1st instar; pair 4, 2nd instar; pair 5, 3rd instar; pair 6,

[1] Young Environmental Systems, Richmond, BC

prepupal stage and pair 7, pupal stage. The insects were chilled as soon as they entered the stage. Time taken to reach each stage was monitored daily for the 20 insects from all examined jars, and time taken for complete development was monitored in the undisturbed jars. The time taken to reach any one stage of development was the mean of 20 measurements of the total number of hours from the time of oviposition.

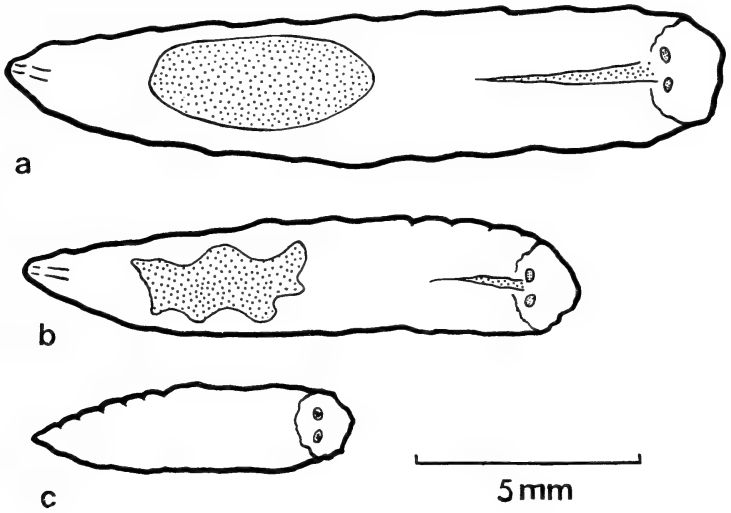

Figure 2. Diagrams of *Calliphora vicina* larvae during a) - early third instar, b) - late third instar, crop shrinking. c) - prepupal stage of third instar, crop invisible.

To observe development of the prepupa, a second experiment was carried out. An eighth pair of jars was set up and treated identically as for pairs 2-7. Insects in one jar were examined daily and in the other were not disturbed, except that at the beginning of the prepupal stage, when the crop was just beginning to decrease in size, the insects in both disturbed and nondisturbed jars were inspected, and 20 specimens at the same stage of development and crop reduction, were selected from each jar. The selected specimens were then placed in two new jars with fresh sawdust. One jar was chilled to 3°C for 24 h and the control jar was kept in the laboratory at room temperature. After chilling, all specimens were examined. The crop size of each of the chilled specimens was determined and compared with those in the control jar. Both jars were monitored later to determine time of adult emergence. No further handling was necessary.

RESULTS

The results of chilling *Calliphora vicina* at various developmental stages are summarized in Table 1. In all cases, larvae chilled for 24 h at some point in their development lagged behind controls in growth and development by 24 h. When chilled before the prepupal stage, there was a similar lag up to that stage. During this period, growth and development was delayed from 1 to 1.51 days compared with the controls. Chilled eggs and larvae reached the prepupal state at the same time as the controls but pupated 24h

later. Specimen chilled as prepupae or pupae, like those chilled as eggs and larvae emerged as adults 24h later than controls

Table 1

Effect of 24 hours of chilling on the duration of development in days of *Calliphora vicina* **(f)** crop full, **(r)** crop reduced, **(C)** stage chilled. Bold numbers indicate delays.

	Days to reach each stage						
Stage	control	eggs	1st	2nd	3rd	prepup.	pupa
Eggs	-	**(C)**	-	-	-	-	-
1st instar	1.00	**2.00**	1.00**(C)**	1.00	1.20	1.20	1.20
2nd instar	2.00	**3.51**	**3.52**	1.99**(C)**	2.01	2.01	2.02
3rd instar **(f)**	3.99	**4.96**	**4.96**	4.00	3.96**(C)**	3.96	4.20
3rd instar **(r)**	4.96	**6.30**	**6.30**	**6.30**	**6.30**	4.96	4.96
Prepupa	6.99	7.00	7.00	7.00	7.00	6.98**(C)**	7.01
Pupa	8.10	**8.99**	**8.99**	**8.99**	**8.99**	**9.00**	8.11**(C)**
Adult emerges	18.10	**19.20**	**19.20**	**19.20**	**19.20**	**19.20**	**19.20**

However, larvae treated in the 2nd instar showed no lag in growth and development until they reached the end of the feeding stage of the third instar. Handling the insects made no difference in their rate of development or time of emergence.

In the second experiment, (Table 2) the larvae were chilled just as they were entering the prepupal stage of the third instar when their crops began to shrink. The insects in both treated and control groups were examined immediately after chilling.

Table 2

Effect in days of 24 hours of chilling on late 3rd instar larvae with reduced crops, **(f)** crop full, **(r)** crop reduced, **(C)** stage chilled. Bold numbers indicate delays.

	Days to reach each stage		
Stage	unhandled, not chilled	handled, not chilled	handled & chilled
Eggs	-	-	-
1st instar	1.00	1.20	1.20
2nd instar	2.00	2.01	2.01
3rd instar **(f)**	3.99	4.20	4.20
3rd instar **(r)**	4.96	4.96	4.96**(C)**
Prepupa	6.99	6.40	6.40
Pupa	8.10	8.10	**9.00**
Adult emerges	18.10	17.11	**19.20**

Those that had been chilled had not developed any further and the crops were the same size as they were before treatment. However, the control insects kept at room temperature continued to develop and their crops were no longer visible. Clearly, chilling had arrested development. When these non-feeding 3rd instar larvae were monitored after chilling, there was an initial increase in the rate of development, and the treated larvae entered the prepupal stage 0.5 days earlier than the overall control (Pair 1). However, the rate of development of the treated group then slowed, and they pupated 0.9 days after the Pair 1 control group. This lag continued through the pupal stage and the adults emerged

1.1 days later. The untreated group also reached the prepupal state 0.5 days before the Pair 1 controls, then slowed down to reach the pupal state at the same time as the Pair 1 controls. However, this group emerged as adults a full day earlier than Pair 1 controls (Table 2).

DISCUSSION

Chilling at any immature stage for 24 h delayed adult emergence by 24 h and no measurable development occurred during the process. Clearly, chilling at 3°C arrested development, which resumed when the insects were returned to room temperature. A time lag equivalent to the time spent under chilling, was evident throughout development up to adult emergence.

The only exception to the above results occurred immediately after chilling in the second instar. In this case, no delay was seen until the insects entered the prepupal stage of the third instar. It is possible that this lack of effect immediately after chilling in the second instar was an anomalous one, because it occurred only at this one stage. All the insects were chilled as soon as they entered a particular stage, but, because there were gaps between examination times, it is possible that these insects had already been in the 2nd instar for several hours. This is a short stage and if moulting had already been initiated before chilling, it might have resumed immediately after the insects warmed up.

In all other cases where the insects were chilled before the prepupal stage, they lagged by 24 h until they were in the third instar. They were delayed entering the third instar by 24 h, then appeared to develop faster and entered the prepupal stage at the same time as the controls. However, development was again delayed 24 h during the pupal stage, and the flies emerged 24 h later than the controls. The fact that all specimens treated before the 3rd instar reacted in this manner indicated that it was not an experimental artifact. The reasons for this behaviour are speculative, and further work is needed to determine whether chilling has some physiological effect which is expressed only during this stage.

The minimal handling used in these experiments did not effect development rate or behaviour. This was also found by Ash and Greenberg (1975) who handled *Phaenicia sericata* (Meigen). Mackerras (1933) in Australia also noted that handling of all stages up to the prepupal stage had no effect on development. However, handling of the prepupal stage resulted in delayed pupation.

As we found development delayed equally in both disturbed and non-disturbed specimens, the effects we saw were clearly a result of the chilling and not the handling.

In the second experiment, 20 insects from each jar, one group disturbed daily, one not disturbed, were separated from the main group to see whether further reduction of the crop and, therefore, development had occurred. Although no development occurred during chilling and an overall 24 h lag in emergence time occured in chilled individuals, those specimens which were not chilled but were placed in a new jar spent less time in the pupal stage than any others and emerged a full day earlier than the control insects. This may have been due to handling, if the larvae are more susceptible to the same amount of handling at this stage than at earlier stages; but that seems unlikely, because handling had no effect at earlier stages, and handled, chilled larvae were affected in the same manner as those in the first experiment.

These specimens were separated from the rest of their group just as they entered the prepupal stage, when, in the wild, specimens wander from the food source to pupate (Smith 1986). It is possible that the low numbers of insects in this experiment resulted in few insect-to-insect encounters as they wandered through the sawdust, which may have contributed to more rapid pupation and emergence. Crowding can have indirect effects on

development in some species (Danks 1987). However, 100 insects/4 litre jar resulted in much less crowding than is usually seen on carrion in a wild situation (personal observations, GSA) so if the rapid development of this group is due to reduced numbers of insects, this is an experimental artifact, and such a situation is unlikely to occur in the wild.

These results have implications for forensic entomology. Determination of time since death is based on several factors, such as temperature, most importantly but also on the developmental stage of the immature insects collected. If the insects have reached a particular stage, for instance third instar, then, knowing recent local weather conditions, the age of these insects can be estimated. However, if the remains have been chilled overnight, and the larvae are in the third instar, they may have been in this stage when the remains were discovered the previous day, or may have continued to develop while chilled. We show here that there is no appreciable development during 24 h chilling. Recent work has shown that *Calliphora vicina* can continue to develop at an extremely low rate, under very cool conditions (103-115 days spent in the pupal stage at 5°C) (Davies and Ratcliffe 1994), but we found that chilling so slows down development as to be forensically insignificant. The delay in development approximates the chilled time.

Caution must be used when interpreting these results, because the chilled specimens in our experiments were in relatively low numbers and so formed only small masses. In such situations, cooling would rapidly affect all the insects in the jar. This would be an equivalent situation to that created by insects collected at the scene by investigators and chilled in small vials with the remains, which often occurs. Similarly, when remains are colonized by low numbers of insects, or when only partial remains are recovered, or when large numbers of insects are present, but are scattered rather than in masses, the insects would probably be affected more rapidly by the cooler temperatures. However, when the remains are colonized by large numbers of larvae, maggot masses are frequently present, raising the temperature of the corpse considerably above ambient. When such corpses are refrigerated it takes several hours before the entire remains are chilled, and in these cases, maggots usually continue to develop, particularly in the first hours of refrigeration (Catts 1992). In one human forensic case, the temperature within a mass of maggots was 20°C even after the remains had been refrigerated for four hours (GSA unpublished observations).

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Effect of pheromone dosage on the mating disruption of Douglas-fir tussock moth

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ABSTRACT

Z-6-heneicosen-11-one, the major synthetic component of the sex pheromone of Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough), was used to disrupt insect mating. Dosages of 72, 36, 18, and 9 g/ha of the synthetic pheromone in polyvinyl chloride beads were each applied to three 2-ha plots using conventional aerial spray equipment. Observation of the spraying operation, and catches of male moths in traps baited with standardized synthetic pheromone indicated that two of the 12 plots were not completely sprayed. The efficacy of mating disruption was monitored over the 9 weeks following spraying, using traps baited with feral females interspersed among the standardized traps. When trap catches by feral females in the two unsprayed plot sections were discarded, the mean catch increased as the synthetic dosage decreased. These catches compared with those in the untreated plots were reduced over 99.5% in plots treated with dosages of 72, 36, or 18 g/ha; and by 97.5% with a dosage of 9 g/ha of synthetic pheromone. In our experimental conditions, the difference in numbers of trapped males among the 72, 36, 18, and 9 g/ha dosage groups was marginally non-significant. Our data thus indicate that in operational use, dosages near or below 9 g/ha would be significantly different in effectiveness from the 3 higher dosages.

Key words: dosage, tussock moth, pheromone, mating disruption, *Orgyia pseudotsugata*, Lepidoptera:Tortricidae, biological control.

INTRODUCTION

The Douglas-fir tussock moth, *Orgyia pseudotsugata* (McDunnough) is one of the most damaging defoliators of interior Douglas-fir, *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco; and also defoliates true firs, *Abies* spp., and pines, *Pinus* spp. (Furniss and Carolin 1977). About every ten years, irruptions of the pest result in defoliation, top-kill or even death of the tree. Eggs are laid by the flightless female on her cocoon in late summer, and larvae emerge late the following spring to feed on the tree foliage. Pupation in midsummer is followed about 2 weeks later by adult eclosion. Males then fly to mate with the female on her cocoon.

Female moths release a pheromone to attract males for mating. A synthetic component, *Z*-6-heneicosen-11-one (Smith et al. 1975), which also attracts males, has been sprayed from aircraft to disrupt mate location and mating. Generally around 75% mating disruption was obtained using dosages ranging from 2.3 to 36 g/ha in Conrel ® fibres (Sower et al. 1979, 1983, 1990). More recently, no mating at all was detected using 72 g/ha of synthetic pheromone in polyvinyl chloride beads (Hulme and Gray 1994).

Our recently published work (Hulme and Gray 1994) was concerned only with establishing if complete mating disruption was possible. We made no attempt to optimize the amount of synthetic pheromone required. Our objective here is to extend our earlier

observations by finding the minimum dose of synthetic pheromone in polyvinyl chloride beads that would disrupt mating as effectively as the 72 g/ha treatment used earlier.

MATERIALS AND METHODS

Plot selection and description. The test area was near Kamloops, BC. (50° 39' N, 120° 24' W). The trees, mostly up to 30 m tall and about 10 m apart, were predominantly interior Douglas-fir and ponderosa pine, *Pinus ponderosa* Laws. Fifteen 2-ha plots separated by at least 300m were selected following a survey for egg masses of Douglas-fir tussock moth in November 1992 using the guidelines of Shepherd and Otvos (1986). Each plot was then randomly assigned to one of five groups. The abundance of first- and second-instar larvae in each plot, estimated in June 1993 by counting the larvae beaten from three branches on each of 20 trees (Shepherd 1985), did not differ significantly between groups ($p > 0.05$, $\chi^2 = 6.8$). Insect defoliation was very light before egg hatch in the year of spraying. During the week before spraying, male Douglas-fir tussock moths were caught in sticky traps baited with the synthetic pheromone (the trap design is described below), but no adult females were found to have emerged from their cocoons.

Formulation and application of the spray mixture. The synthetic pheromone, *Z*-6-heneicosen-11-one (Phero Tech, Delta, BC), was assayed, impregnated in polyvinyl chloride beads, and formulated in a spray mixture as described previously (Hulme and Gray 1994). Batches were prepared for 72, 36, 18, and 9 g/ha of *Z*-6-heneicosen-11-one.

A Hiller UH12E helicopter equipped with a boom-and-nozzle spray system, flying approximately 50 m above ground level, was used for the aerial treatment on 30 July. The equipment, fitted with D-6 nozzles, was calibrated to deliver a swath 20 m wide at ground level. Each plot was completely sprayed in five passes at daybreak. Ground observers watched the descent of the spray cloud to check that all parts of the plot were fully sprayed. The wind measured at Kamloops airport was calm.

Assessment of uniformity of spraying. The attraction of male Douglas-fir tussock moths to a standardized lure of *Z*-6-heneicosen-11-one was assessed with delta sticky traps (trapping surface 855 cm^2) made from 2-liter milk cartons coated inside with Bird Tanglefoot (Tanglefoot, Grand Rapids, MI). The trap baits were 0.01% wt:wt *Z*-6-heneicosen-11-one impregnated into polyvinyl chloride rods 3 mm in diameter and 5 mm long, following the method of Daterman (1974). Within each plot, 10 traps, hung from branches about 2 m above the ground, were spaced in 3 lines 25 m apart and at least 10m from the plot boundary. Within a line, traps were 50m apart. Trap counts were recorded biweekly, starting 1 week after spray application and continuing for 9 weeks after spraying, i.e., until adult flight essentially ended. The sticky milk carton, but not the lure, was replaced when more than 20 moths were found in the trap during counting.

Assessment of mating disruption. The attraction of male Douglas-fir tussock moths to feral females was assessed biweekly for 9 weeks following spraying. Delta sticky traps described above were used, but the lure was a mature female pupa in a cocoon held within a 30-dram pill vial that had been modified by replacing the solid plastic ends with fiberglass mesh 0.3 mm in diameter having openings 1.4 by 1.2 mm. The female pupae were obtained from areas near the test site by collecting mature larvae and allowing them to spin cocoons on fiberglass mesh. One cocoon, attached to a cut piece of mesh, was then inserted into each vial so that the female, expected to emerge within 3 d, could hang naturally from the cocoon. In each plot, 10 traps were spaced along the same 3 lines used for the traps with synthetic bait. Traps baited with synthetic bait and feral females were alternated. All traps were at least 25 m apart. Each of the 3 trap lines thus contained

either 6 or 7 traps. Some traps baited with a live insect did not contain an attractive female during the week the trap was placed in the field, either because no adult emerged during the week, or because a male emerged from the cocoon instead of the expected female. On average, 23 of the 30 traps per treatment baited with live insects contained attractive feral females. Results from the remaining traps without attractive females were not used.

Statistical methods. We followed our published methods (Hulme and Gray 1994). Pretreatment counts of Douglas-fir tussock moth larvae, were analyzed by a chi-square test (Zelen and Severo 1964). Trap catches after spraying were grouped by pheromone dosage (0, 9, 18, 36, and 72 g/ha) and tested for significant intergroup difference with the Kruskal-Wallis test at α =0.05 (Kruskal 1952, Kruskal and Wallis 1952). When a significant intergroup difference was found, the test was rerun with all combinations of 4 dosage groups (i.e. one group deleted) to see whether one dosage group accounted for the significant difference measured among all 5 dosage groups.

RESULTS AND DISCUSSION

In general, the entire area of each plot was seen to be sprayed. However, ground observers noted that 2 plots appeared incompletely sprayed, especially along one edge. The trapping results given below support these observations. Edge spraying would be less important for the overall success of a large operational trial, but is critical for evaluation of results from our small research plots.

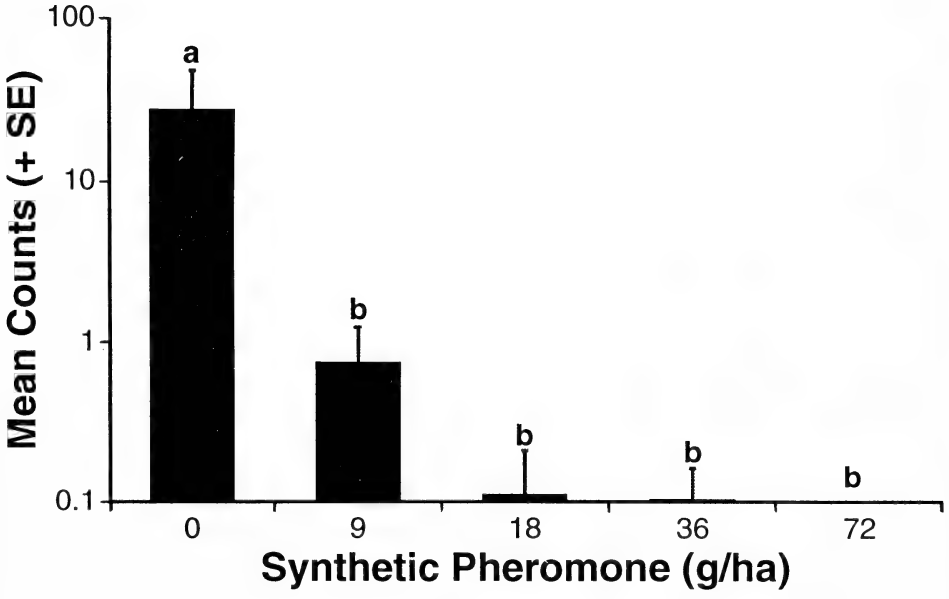

Figure 1. Mean count of male Douglas-fir tussock moths, in delta sticky traps baited with feral females at Kamloops, B.C. after no treatment, or treatment with dosages of 9, 18, 36, or 72 g/ha of *Z*-6-heneicosen-11-one ($\bar{n}$ = 23). Vertical scale logarithmic. Means headed by different letters are significantly different (Kruskal-Wallis test, α = 0.05).

Most of the approximately 1,000 male Douglas-fir tussock moths caught in traps baited with feral females were in the untreated plots, indicating abundant mating opportunities where no synthetic pheromone was applied. Few moths were caught in any of the treated plots except for traps on one edge of one plot treated with 9 g/ha, and in one plot of 18 g/ha of *Z*-6-heneicosen-11-one, the same 2 plots that appeared to be incompletely sprayed. Standardized traps baited with synthetic pheromone also showed the same edge-spraying problem; otherwise these traps caught no moths in the treated plots. Traps baited with synthetic pheromone help to check for uniform spraying since all the baits are equally attractive at any given time, whereas the attractiveness of traps baited with live pupae and adults, depends on the age of the insect bait.

When the results are deleted for moths caught by feral females in the plot sections incompletely sprayed, no significant difference in mating disruption was found among the 72, 36, 18, and 9 g/ha pheromone dosage groups (Fig.1; Kruskal-Wallis test, $p = 0.06$). However, the test p value indicates that the trap catch in plots treated with 9 g/ha has almost reached the number where a significant intergroup difference among these 4 dosage groups would be measured. We thus expect that operational results using 9 g/ha would be significantly less effective than those using the higher dosages we employed.

As expected, the trap catch by feral females increased as the applied synthetic pheromone dosage decreased (Fig.1). Mean trap catches in plots treated with 72, 36, or 18 g/ha of synthetic pheromone were less than 0.5% of the catches in the untreated plots indicating over 99.5% disruption of mating. The trap catch in the 9 g/ha treatment indicated 97.5% disruption of mating.

Our results at Kamloops thus suggest that the dosage of synthetic pheromone sprayed in polyvinyl chloride beads can be reduced 4-fold to 18 g/ha from the 72 g/ha used in our earlier work and still maintain virtually 100% disruption of mating. The amount by which the dosage can be further lowered and still provide successful control will depend on the target set by the applicator for foliage protection. If 95% mating disruption meets this target, then a dosage close to 9 g/ha should be satisfactory. Our related work at Keremeos, showed that the pheromone-impregnated beads continue to emit pheromone for at least 2 years after treatment (Gray and Hulme 1995), further improving the appeal of this new pest control option.

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Zora hespera in British Columbia: a new spider family record for Canada (Araneae: Zoridae)

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ABSTRACT

The collection of specimens of *Zora hespera* from two localities on southern Vancouver Island, British Columbia are the first records of zorid spiders in Canada. To aid identification of this spider, drawings of the species diagnostic characters are presented along with brief discussions of the genus, the family, and genitalic terminology conventions followed.

Key words: *Zora*, Zoridae, Vancouver Island, pitfall trap, distribution diversity.

INTRODUCTION

The spider family Zoridae comprises about a dozen genera (Platnick 1993) probably most closely related to the large and primarily tropical family Ctenidae. The genus *Zora* C. L. Koch has a Holarctic distribution but is most diverse in the Old World. Two species, *Z. pumila* (Hentz) and *Z. hespera* Corey and Mott, are the only known Nearctic zorids (Roth 1993). Until now these species were recorded only from the eastern (*Z. pumila*) and far western (*Z. hespera*) United States (Corey and Mott 1991). In Washington state (previously the northern limit of its range) *Z. hespera* has been collected in the extreme south along the Columbia River basin near Bingen and from north of Yakima (Crawford 1988).

The natural history of zorid spiders is not well documented. Species of *Zora* are known to be active, diurnal, ground and shrub dwelling hunters (Corey and Mott 1991, Kaston 1948, Roberts 1985) which spin no retreats and attach their flattened egg cases to the underside of rocks or other objects (Bristowe 1958, Kaston 1948). They are most likely to be encountered in open, sunny areas with adult females in evidence year round and adult males during the spring and early summer.

This paper reports the first collections of a zorid, *Z. hespera*, in Canada. In late May, 1994 one of us (RGB) collected a single male *Z. hespera* indoors in a rural area of the Saanich Peninsula just north of Victoria, British Columbia (this southern Vancouver Island locality is several hundred kilometres north of the Washington collection localities). Subsequent determination of three other males and a female collected in pitfall traps elsewhere on southern Vancouver Island (during a University of British Columbia arthropod diversity study) convinced us that the species is established in British Columbia.

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The Saanich Peninsula collection site is an office and laboratory building in an open grassy field with adjacent young plantations of Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) and western white pine (*Pinus monticola* Dougl. ex D. Don) seed orchards surrounded by active agricultural fields on two sides and mature, second growth mixed conifers dominated by Douglas-fir and grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) to the north and west. The pitfall trapping site is a recently replanted Douglas-fir regeneration site in the Koksilah River drainage just west of Shawnigan Lake (between Duncan and Victoria). This site is in the dry part of the Coastal Western Hemlock biogeoclimatic zone and is characterized by exposed rocky outcrops, invasive herbaceous plants, and scattered remnant conifers situated among Douglas-fir dominated stands of varying maturity. Because of the presence of forest stands varying in age from recently replanted to old growth and all having similar slope, elevation, and aspect, this regeneration site and the area around it have been the target of several research studies on the effects of forestry practices on biodiversity.

Specimens are preserved in 70% ethanol in the collections of RGB (Saanich specimen) and the University of British Columbia. All specimens and their parts were examined in 70% ethanol with a Leitz MS5 dissecting microscope or in clove oil (female genitalia only) with a Nikon Labophot phase contrast microscope. Drawings were made with the aid of a squared grid reticule in one ocular lens of the Nikon (female genitalia) or the Leitz (male palp). Drawings are included here to facilitate the identification of this species during future work on the British Columbia araneofauna.

TAXONOMY

In British Columbia, *Z. hespera* is likely to be confused only with small lycosids because of its behaviour and preferred habitat (see above), eye arrangement, and general size and shape. Specimens of this species are relatively small (average total length ranging from 3 to 5 mm), light coloured spiders with dark abdominal markings, heavily spotted legs, and two very conspicuous dark bands running from the posterior lateral eyes to the posterior edge of the carapace.

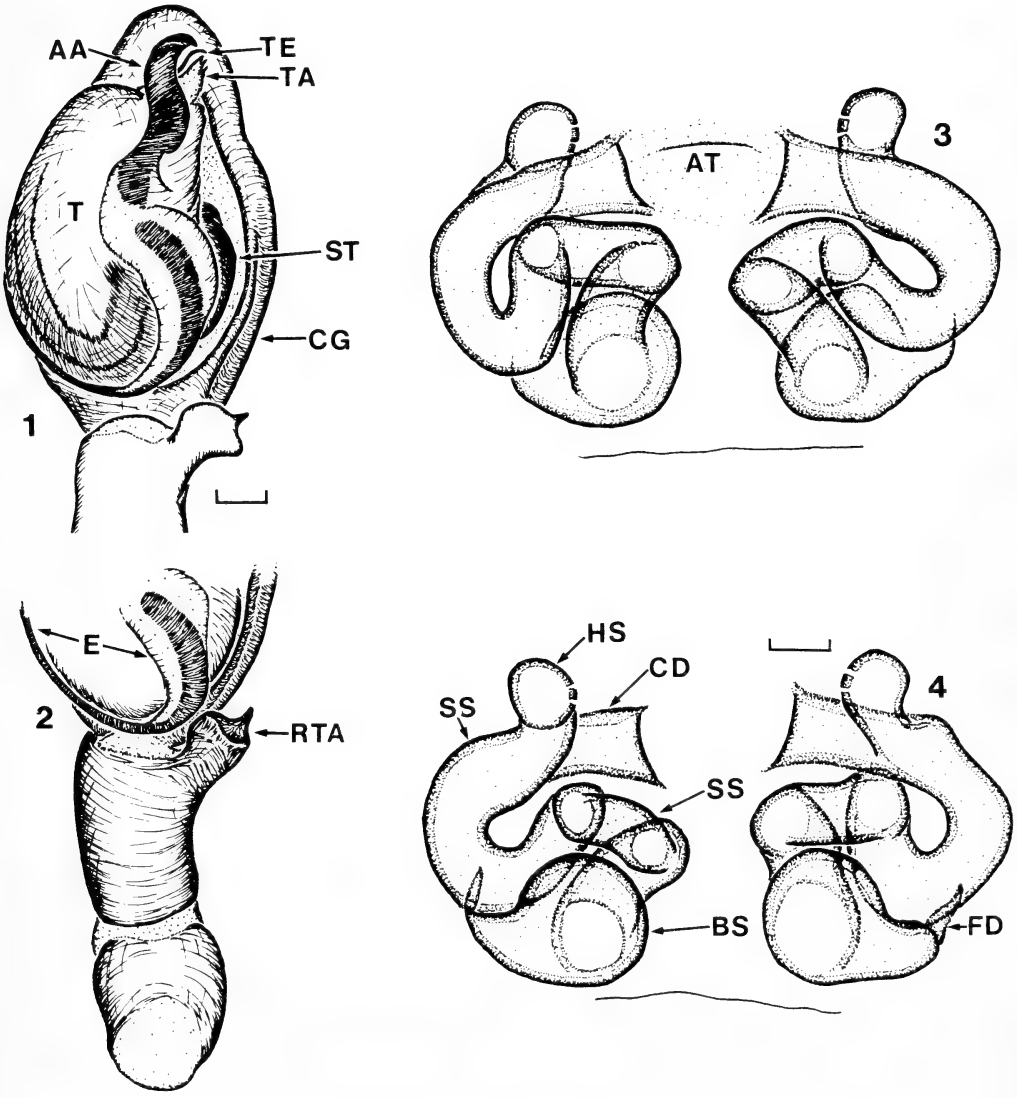
Viewed dorsally the anterior eye row (four eyes) is nearly straight. The remaining four eyes make up a posterior eye row so strongly recurved that there appear to be three rows of eyes on the cephalothorax. The eyes are all small and subequal. This eye arrangement is somewhat lycosid-like and also is typical of the ctenids (which are not known to occur in Canada).

From lycosids (and ctenids) *Z. hespera* is readily distinguished by the distinctive series of six to eight pairs of very long, overlapping, ventral macrosetae on the tibiae of legs I and II. Some small and cryptic phrurolithine clubionid (e.g., *Scotinella* Banks), cybaeid (e.g., *Cybaeota* Chamberlin and Ivie), and hahniid (e.g., *Dirksia* Chamberlin and Ivie) genera sport similar series of distinctive ventral tibial macrosetae but have eyes in only two rows. Additionally, males of *Z. hepera* have a retrolateral tibial apophysis (Figs. 1, 2) (lacking in lycosids) on the pedipalps and females have no distinctive, sclerotized epigynal features (lycosid females generally have distinctive epigyna with variously developed and well sclerotized plates and cavities). Zorids have two tarsal claws on each leg, lycosids have three.

Species Diagnosis. No other zorid species is likely to be encountered in British Columbia but the following characters will serve to distinguish this species from the eastern species *Z. pumila*.

Male (left palpus, ventral view): Retrolateral tibial apophysis with acuminate tip and shallow, ventral, transverse concavity subdistally (Fig. 2); simple, sinusoidal apical apophysis extending anteriorly from base of embolus, with retrolaterally directed, bluntly acuminate tip (Fig. 1).

Female: In ventral view (Fig. 3) atrium a shallow depression bordered laterally by inconspicuous, slit-like atrial openings leading to the internal vulval ducting; in dorsal view (Fig. 4) short, poorly defined copulatory ducts lead laterally from atrial openings to spermathecal stalks; stalks sinuous, moderately convoluted but simple and not coiled.



Figures 1-4. Genitalic characters of *Zora hespera*. **1-2**, male, left palpus, ventral view: **1**, tarsus with genital bulb; **2**, patella, tibia, and base of tarsus; scale bar = 0.1 mm; AA--apical apophysis, CG--cymbial groove, E--embolus, RTA--retrolateral tibial apophysis, ST--subtegulum, T--tegulum, TA--tegular apophysis, TE--tip of embolus. **3-4,** female, cleared vulva: **3**, ventral view; **4**, dorsal view; scale bar = 0.05 mm; AT--atrium, BS--spermathecal base, CD--copulatory duct, FD--fertilization duct, HS--spermathecal head, SS--spermathecal stalk.

Other genitalic characters.
Male: Cymbium of palpal tarsus with pronounced longitudinal groove; subtegulum heavily sclerotized, compact, and slightly visible in ventral view; tegulum simple (i.e., no conspicuous, sclerotized tegular apophyses), convex, and lightly sclerotized with outline of receptaculum seminis visible through integument; inconspicuous membranous tegular apophysis located distally on tegulum; embolus simple, well sclerotized with membranous borders proximally (Figs. 1, 2), narrowing distally and proceeding clockwise around edge of tegulum, terminating inconspicuously between tegular and apical apophyses.
Female: Short spermathecal heads project anteriorly from junction of connecting ducts and spermathecal stalks; simple primary pores present on spermathecal heads (schematically represented in Figs. 3, 4); no complex "dictynoid" pores on spermathecal stalks; stalks lead posteriorly to simple, bulbous spermathecal bases just anterior of epigastric groove; poorly defined fertilization ducts exit anterolaterally from spermathecal bases (Fig. 4).

DISCUSSION

Genitalic terminology follows Bennett (1991, 1992), Coddington (1990), and Sierwald (1989, 1990) "in an effort to standardize names of presumably homologous parts in different taxa" (Bennett 1992). Female terms used here do not differ significantly from those of Corey and Mott (1991) but male terms do.

Here we term the conductor of Corey and Mott (1991) the apical apophysis. A true conductor is a rigid extension of the tegular wall and thus a component of the middle division of the genital bulb (Bennett 1991, Sierwald 1990). (The subtegulum, tegulum, and embolus are sclerites respectively typical of the basal, middle, and apical divisions of the primitive tripartite spider genital bulb.) This structure of *Z. hespera* appears to be a *functional* conductor (i.e. it is closely associated with the tip of the embolus and probably serves to support and guide the embolus during mating) but, because it is membranously attached to the embolar base, it is a sclerite of the apical division and not a *true* conductor (i.e., it is an apical apophysis not a tegular apophysis).

Two sclerites may be associated with the tegulum in male spiders: A true conductor as discussed above and a median apophysis membranously attached to the tegulum (Bennett 1991, Sierwald 1990). Probably the membranous tegular structure associated with the tips of the embolus and the apical apophysis in *Z. hespera* is a median apophysis but, as we did not study it in detail, we maintain a conservative stance and simply refer to it as a tegular apophysis.

Material examined. Specimen deposition noted above. CANADA: BC: *southern Vancouver Is.*; Saanichton, Saanich Seed Orchard, indoors, 26/V/1994 (R.G. Bennett), 1 male; Koksilah, 48°39'25"N 123°46'10"W, 26/V-23/VI/1992 (K.G. Craig), 3 males; 23/VI-28/VII/1992 (K.G. Craig), 1 female.

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The authors thank Dr. G.G.E. Scudder for suggesting to one of us (LJB) the spider diversity project that produced most of the specimens reported on here. Additionally we thank Katherine G. Craig for running the pitfall traps and accumulating a wonderful source of material for this and future studies.

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Sexual biology and mating disruption of orange tortrix, *Argyrotaenia citrana* (Lepidoptera: Tortricidae)

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ABSTRACT

Studies were conducted to characterize the sexual biology of *Argyrotaenia citrana* (Fernald) and to evaluate the potential of sex pheromones to disrupt moth communication. Both males and females are sexually active during their first scotophase. Virgin females start calling 3 hrs into scotophase and continue until sunrise. Calling frequency by virgins is lower during the first than in subsequent nights. Females generally mate once during a scotophase. Calling is reduced after mating for one scotophase and then increases though mated females continue to call less frequently than virgins. Peak calling by mated females is delayed several hours compared with virgins. Females may remate after 1-3 days. Males can mate more than once per scotophase. Oviposition is concentrated during early scotophase. Females laid an average of five egg masses. Communication and mating disruption were evaluated in replicated 0.1 ha plots and 100 m^2 field cages treated with field-aged polyethylene tube dispensers releasing 0.7-1.2 mg/d of either (Z)-11-tetradecenyl acetate alone or in a 15:1 blend with (Z)-11-tetradecenal. Mating of tethered females in field cages and catches of lure and female-baited traps in small field plots were nearly completely disrupted with the two component blend. Dispensers emitting only the acetate pheromone were less effective in disrupting moth communication in similar tests.

Key words: *Argyrotaenia citrana*, orange tortrix, leafrollers, *Rubus*, mating disruption, sexual behavior

INTRODUCTION

The use of mating disruption as an alternative to broad-spectrum insecticides for control of tortricid pests of horticultural crops is being widely investigated (Pfeiffer *et al.* 1993, Deland *et al.* 1994, Felland *et al.* 1995, Suckling and Shaw 1995, Shorey *et al.* 1995, Agnello *et al.* 1996). Many of the tortricid pests found in North American tree fruits share one or more pheromone components (Arn *et al.* 1992). The most important component for these species in western North America is (Z)-11-tetradecenyl acetate (Z11-14:OAc). A generic, multi-species approach to mating disruption may be possible using this single component or in combination with one or more minor components (Knight 1992, Deland *et al.* 1994, Cardé and Minks 1995). Knowledge of the adult sexual behaviors of each of these species is a prerequisite for development of this behavior-based control tactic (McNeil 1991).

The orange tortrix, *Argyrotaenia citrana* (Fernald), is an economic pest of small fruits, tree fruits, and grapes in areas with relatively moderate winter temperatures in the western United States, i.e., Willamette Valley in Oregon and coastal areas of California (Breakey and Batchelor 1948, Madsen and Falcon 1960, Kido *et al.* 1981). Bassinger (1938) provided the first detailed summary of the bionomics of *A. citrana*. He noted that females generally mated only once, but males were polygamous. The sex pheromone of orange tortrix was identified by Hill *et al.* (1975) as a two component blend of Z11-

14:OAc and (Z)-11-tetradecenal (Z11-14:ALD). Sex pheromone traps are used to recommend and time insecticide sprays (Knight *et al.* 1988). Knight *et al.* (1994) used a pheromone-baited timing trap in the field and a laboratory ultrasound motion detector to determine the circadian periodicity of moth activity. Other important aspects of *A. citrana* behavioral ecology such as temporal patterns of calling, mating, and oviposition have not been reported.

The present paper reports on laboratory studies conducted with *A. citrana* to characterize several aspects of its sexual behavior, and field trials to evaluate the effectiveness of using either Z11-14:OAc alone or in combination with Z11-14:ALD to disrupt communication. Dispensers emitting the complete pheromone blend caused nearly 100% disruption over the entire season.

MATERIALS AND METHODS

Laboratory studies. A laboratory colony was established with larvae collected from caneberry *Rubus spp.* in Linn County, Oregon in 1992. Larvae were reared on a synthetic pinto bean diet (Shorey and Hale 1965) at 24°C and a 16:8 (L:D) photoperiod in 30 ml plastic cups. Adult sexual behaviors were studied at 22±2°C, 50-65% relative humidity, and a 16:8 (L:D) photoperiod. A reversed photoperiod was used to facilitate observations of moth behavior. Light levels were controlled by time clocks which switched on a series of incandescent light sources during the 60 min dusk (0800-0900 h) and sunrise (1700-1800 h) periods (Knight *et al.* 1994). Illumination during scotophase was provided by a light covered with a red acetate filter. Adults were supplied with a cotton wick saturated with a 10% honey solution.

The effect of mating on calling behavior was studied by recording the calling behavior of fifty newly-mated and virgin females for 30 s every 30 min for five and six nights, respectively. Observations of calling behavior were made of females in 250 ml waxed paper cups covered with a clear polyethylene film. Calling behavior was distinguished by wing elevation up to 45° and a downward extension of their abdomen for 20-60 s every 1-3 min. Calling frequency (the number of 30-min intervals during which calling was observed in each scotophase) for mated and virgin females was transformed (square root [x+0.01]) and subjected to ANOVA (GLM Procedure, SAS Institute 1985). Means were separated where significant differences occurred with a least significance difference test (LSD). To test whether males and females mate more than once, 100 virgin pairs were placed in cups, and following each successful copulation, males were replaced with a virgin male (< 48 h-old) in half of the cups and females were replaced with virgin females (< 24 h-old) in the other half. Temporal patterns of oviposition on a wax paper substrate were measured for 50 mated females using a clock-driven rotating oviposition apparatus at 20°C and a 16:8 (L:D) with lights-off at 2200 h (Weissling and Knight 1996). Newly emerged females were placed in cups with a male for 24 h and females were transferred to the apparatus between 1000-1100 hours. Oviposition was measured for four nights. Four percent of females laid an egg mass within 30 min of being transferred to the apparatus. These data plus any egg masses laid by unfertilized females were not used in the analysis.

Pheromone dispensers. Two types of polyethylene tube dispensers (Pacific Biocontrol, Vancouver, WA) were evaluated in field studies: Hamaki-con (Lot # TT-52003), a translucent dispenser containing 165 mg 11-14:OAc (94:6 ratio of Z:E isomers); and OT (Lot # OTX53004), a reddish-brown dispenser loaded with 180 mg of pheromone in a 15:1 ratio of 11-14:OAc and 11-14:ALD (94:6 and 93:7 ratio of Z:E

isomers, respectively). Residual pheromone content of new dispensers and those aged in the field and collected every 14 d (n=4) from 21 April to 9 Aug 1993 were analyzed with gas chromatography. Dispensers were cut into 2 cm pieces and rinsed continuously with dichloromethane for 3 h. Undecanol was used as the internal standard. Samples were processed with a HP7673 automatic sampler and a Series II 5890 gas chromatograph (Hewlett Packard, Wilmington, DE) using a 60 m x 0.32 mm capillary column coated with dimethylpolysiloxane (DB-1, J&W Scientific, Folsom, CA).

Field trials. Experiment 1 was run in a mixed planting of boysenberry and marionberry (*Rubus* spp.) located near Woodburn, OR for two weeks beginning 10 Aug 1992. Experiment 2 was conducted in a mixed planting of marionberry and raspberry located near Scholls, OR from 14 April to 17 Aug 1993. Both studies were conducted as randomized complete block designs with five replicates of the two pheromone treatments plus an untreated check. Each plot was ca. 30 m x 30 m and plots were separated by > 50 m. Dispensers were evaluated at a density of 1000 per ha. The canopies of the caneberry fields was ca. 1.5 m in height and dispensers were placed at 1.0 - 1.5 m. In both experiments, one rubber septa-baited sex pheromone trap (wing trap, Scentry Inc., Buckeye, AZ) was placed in the center of each plot. In addition, in the 1992 experiment, five virgin-female-baited wing traps (baited with two 1-3 day-old virgin moths placed in a screened pvc cage) were spaced 10 m apart and 5 m inside the edge of each plot. Virgin females were replaced after seven days. Rubber septa were replaced every four weeks in 1993. No insecticides were applied during either study. The number of males captured in pheromone-baited and female-baited traps and the percentage of female-baited traps catching at least one male were transformed (square root [x + 0.01] and arcsin [x], respectively) and subjected to ANOVA (GLM Procedure, SAS Institute 1985). Where significant differences occurred, means were separated with LSD.

Field cage experiments. Six cages (10 x 10 x 2.5 m) were used to measure the level of mating disruption attained under each pheromone treatment versus an untreated check. Each cage contained nine potted apple trees 2.5 m in height (a mix of 'Delicious' and 'Golden Delicious'). Trees were spaced 2.5 m apart in three rows. Nine dispensers (one on each tree at a height of 2.0 m) were placed in each cage in the pheromone treatments. Virgin female moths were tethered at a height of 1.5 - 2.0 m by tying a fine thread (25 cm) around one forewing and taping the end of the thread to a bamboo pole hung vertically from wires within each cage. Tethered females were situated within 0.5 m of foliage. Fifteen females were tethered per cage for each replicate. The same number of males (20-50) was added to each cage per day. Females were left in cages overnight and dissected the next day to determine their mating status. Approximately 20% of the females were either missing or partially eaten by spiders during these tests. On each date each treatment was replicated twice. Dispensers were removed from cages and treatments were rotated among cages after 48-72 h. Experiments were repeated five times between 25 Aug - 15 Sept 1993. The percentage of females mated was transformed (arcsin [x]) and subjected to ANOVA (SAS Institute 1985).

RESULTS

Calling behavior. Virgin females started calling approximately 3 h into the first scotophase, with peak levels of calling occurring at 4.5 h (Fig. 1A). Moth calling frequency was lower during the first scotophase, but did not differ for 2- to 6-day-old moths ($F = 8.9$; df = 5, 282; $p < 0.0001$). Unmated females called until dawn. Frequency of calling by mated females was significantly lower during the scotophase following

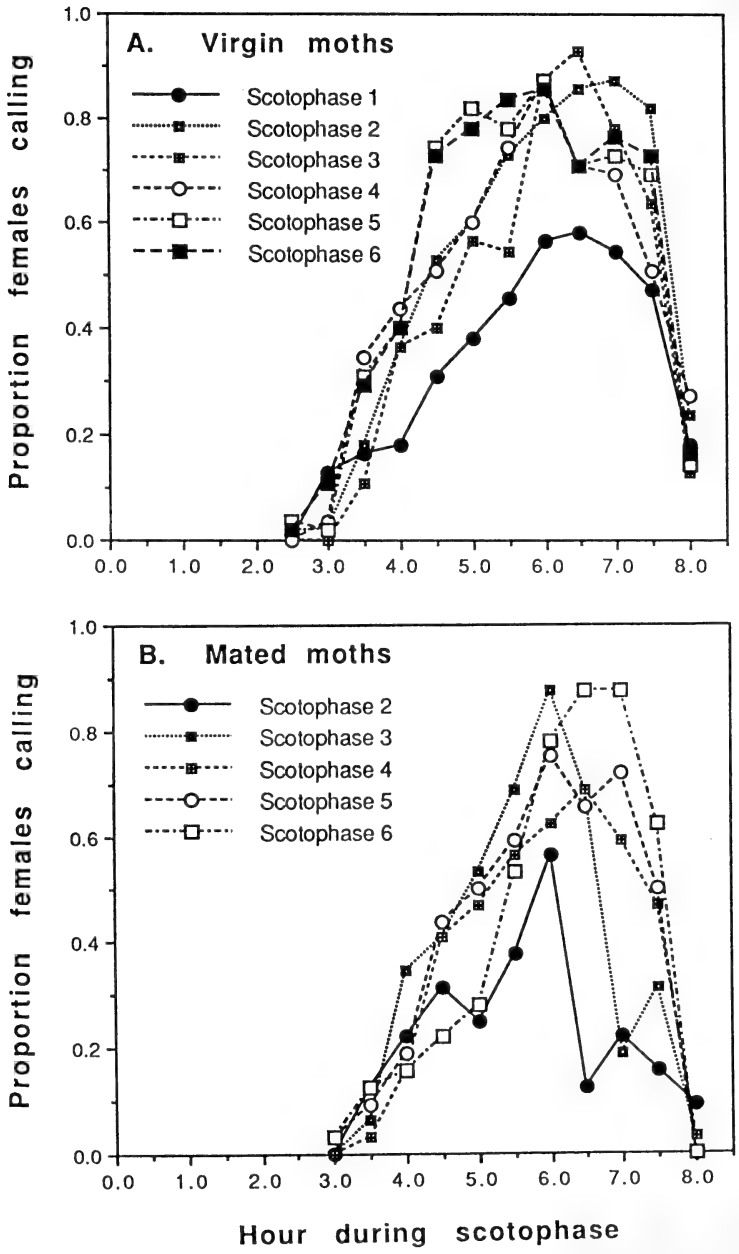

Figure 1. Proportion of female *Argyrotaenia citrana* moths observed calling during an 8-h scotophase. (A) Virgin moths < 12 h-old observed for six nights; and (B) Moths , 36 h-old mated the previous scotophase and then observed for five nights

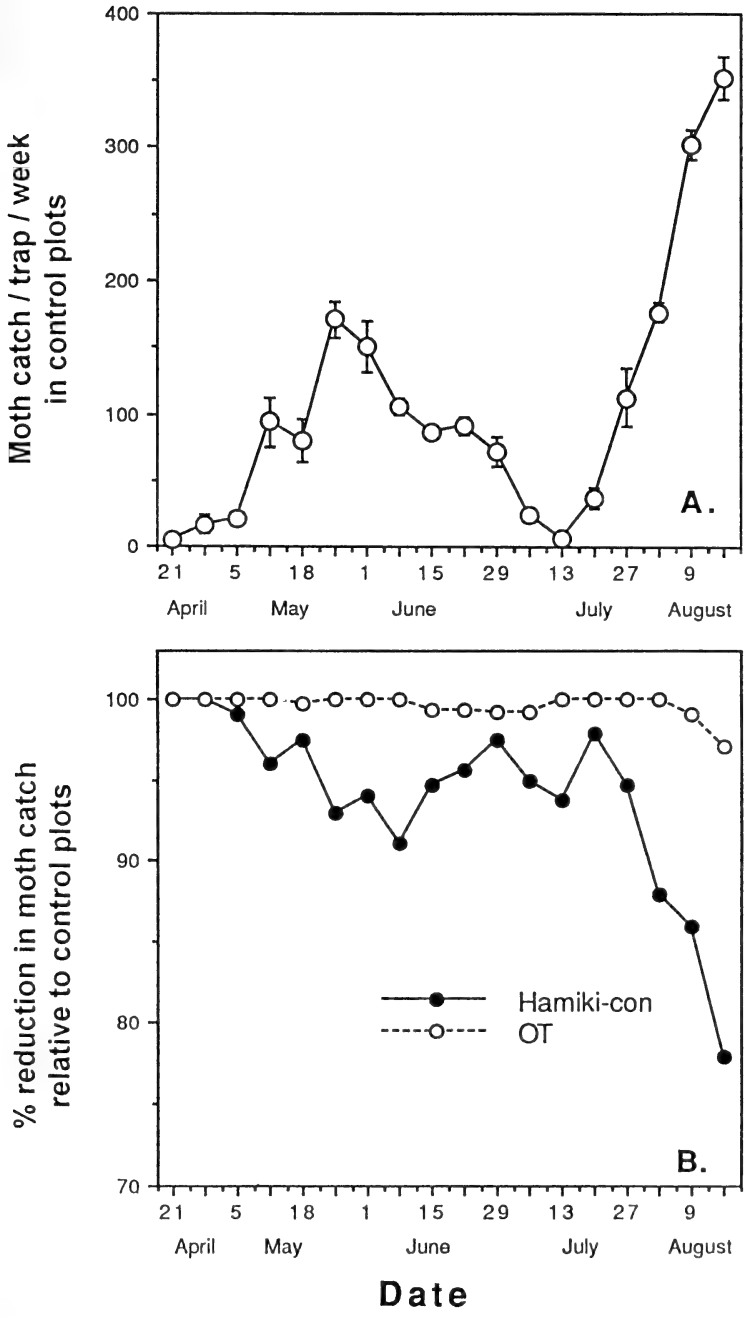

Figure 2. Sex-pheromone-based disruption of *A. citrana* using polyethylene tube dispensers applied at 1,000 / ha releasing either (Z)-11 tetradecenyl acetate (Z11-14:OAc) Hamaki-con dispenser; or a 15:1 blend of Z11-14;OAc and (Z)-11-tetradecenal - OT dispenser, from 14 April to 17 Aug. in a commercial marionberry field, Schols, OR. (A) Weekly catch of males in a lure-baitd trap in the control plot; and (B) Percentage reduction of weekly trap catch in the Hamaki-con and OT pheromone treatments compared with control

mating (F = 4.9; df = 4, 140; p = 0.001), and then increased, and remained unchanged during the next four nights (Fig. 1B). Frequency of calling by mated females was significantly lower than for virgin moths (F = 58.2; df = 1,375; $P < 0.0001$), but a significant interaction with age occurred (F = 3.2; df = 1,375; P = 0.01). All linear contrasts for mating status by age were significant except for 3-day-old moths, P = 0.23. Timing of peak calling by mated females was more restricted than for virgin moths and was shifted 1-2 h later into scotophase (Fig. 1A, B).

Mating. Mating on average (± SE) began 4.8 ± 0.2 h into scotophase and lasted 63 ± 4 min. Eighty-seven percent of females were mated when paired with a male in cups. Only 4% of these females mated more than once per evening and this occurred only when the first mating event lasted < 30 min. Dissection of these females found only one spermatophore. Thirty-eight percent of the females mated more than once during the six nights and had a mean refractory period of 2.1 ± 0.2 d. Twenty-seven percent of males mated more than once and no male mated more than three times per evening. Males mated an average of 2.9 ± 0.3 times during the six nights of the test.

Oviposition. Eggs were laid 1-3 d after females mated. Females laid an average of 4.8 ± 0.3 egg masses in cups. The first egg mass averaged 60.1 ± 6.9 eggs and was significantly larger than subsequent egg masses (F = 4.61; df = 6, 263; p = 0.003). The mean number of eggs laid per female was 218.2 ± 9.4. Females laid an average of 5.1 ± 0.8 egg masses on the oviposition apparatus. Eggs were laid between 1700 and 0700 hours, however, oviposition was highly concentrated at the beginning of scotophase (lights off at 2200 h), mean= 2311 ± 0.09 h.

Analysis of dispensers. Hamaki-con dispensers exhibited a linear decline in their residual pheromone content over 110 d , r^2 = 0.97 , mean release rate = 0.87 mg/d during the experiment (Table 1). A new dispenser contained an average of 5.7% E11-14:OAc and this increased to 9.3% after 110 d in the field. Nearly 70 mg of pheromone remained in the dispenser after 110 d.

Table 1

Analysis of field-aged polyethylene tube dispensers. The Hamaki-con dispensers contained an average of 165.4 mg of 11-tetradecenyl acetate (11-14:OAc) and the OT dispenser contained an average of 180.5 mg of a 15:1 ratio of 11-14:OAc and 11-tetradecenal (11-14:ALD). Dispensers were placed in the field on 21 April, 1992 and collected every two weeks.

	Hamaki-con Dispenser		OT Dispenser		
Field age (D)	Pheromone loss mg/day[a]	Isomeric purity (Z:E) ratio 11-14:OAc	Pheromone loss mg/day[a]	Isomeric purity (Z:E) ratio 11-14:OAc	Isomeric purity (Z:E) ratio 11-14:ALD
New	-	94.3:5.7	-	94.3:5.7	92.8:7.2
0-14	1.40	94.0:6.0	1.01	94.1:5.9	93.3:6.7
15-28	0.55	93.5:6.5	0.98	94.2:5.8	92.4:7.6
29-41	1.19	93.5:6.5	1.44	94.2:5.8	90.0:10.0
42-55	0.88	92.9:7.1	0.89	94.2:5.8	92.0:8.0
56-69	0.58	92.3:7.7	0.68	94.2:5.8	92.6:7.4
70-83	0.85	91.8:7.9	0.43	94.2:5.8	92.4:7.6
84-96	0.51	91.2:8.8	1.39	94.2:5.8	90.2:9.8
97-110	1.00	90.7:9.3	1.32	94.2:5.8	86.7:13.3

[a] Change in residual content of 4 dispensers sampled on each date expressed as loss (mg) per d.

Pheromone loss from the OT dispenser declined linearly, $r^2 = 0.99$, mean release rate = 1.01 mg/d (Table 1). This dispenser contained 6.2% 11-14:ALD initially with ca. 92.8% Z-isomer. After 110 d, the pheromone blend left in the dispenser contained 3.2% 11-14:ALD with a 86.7% Z-isomer. The percentage of E11-14:OAc was stable during the season (Table 1). Nearly 70 mg of pheromone remained in the dispenser after 110 d.

Field tests. In the 1992 experiment there were significant differences in moth catches between treatments in both lure-baited ($F = 85.4$; df=2,12; $p = 0.0001$) and female-baited traps (average number of males caught: $F = 7.5$; df = 2,12; $p = 0.001$; and the proportion of traps catching ≥ 1 moth: $F = 174.4$; df = 2,12; $p = 0.001$). No significant differences in cumulative moth catches occurred between the two pheromone treatments (Table 2).

Table 2.

Sex pheromone-based disruption of *Argyrotaenia citrana* using polyethylene tube dispensers at 1,000 per ha releasing either (Z)-11-tetradecenyl acetate (Z11-14:OAc) or a 15:1 blend of Z11-14:OAc and (Z)-11-tetradecenal (Z11-14:ALD). Tests were conducted from 10-21 August, 1992 in mixed marionberry / boysenberry field, Woodburn, OR

	Mean (±SE) catch per trap				Proportion female-baited	
Treatment	Lure-baited	% reduc.[1]	Female-baited	% reduc.[1]	traps catching > 1 moth	% reduc.[1]
Z11-14:OAc	2.4 ± 0.7b	98	0.5 ± 0.2b	90	0.08 ± 0.03b	96
Z11-14:OAc + Z11-14:ALD	0.0 ± 0.0b	100	0.0 ± 0.0b	100	0.00 ± 0.00b	100
Control	144.2 ± 15.4a	-	24.7 ± 6.5a	-	0.76 ± 0.05a	-

[1] Percent reduction relative to the control plot.

Column means followed by different letters are significantly different, LSD, $p < 0.05$.

In 1993 the first moths were caught in the check plots during the week of 21 April and the first adult flight continued until 13 July (Fig. 2A). In comparison, the first moths were caught in the Hamaki-con and OT-treated plots on 5 May and 18 May, respectively. Moth flight during the second generation began the week of 20 July and moth catch increased sharply each week until the study was terminated on 17 Aug (Fig. 2A). Moth catch varied significantly among treatments during both generations (first generation: $F = 142.5$; df = 2, 12; $p < 0.0001$; second generation: $F = 370.0$; df = 2, 12; $P < 0.0001$ [Table 3]).

Table 3.

Sex pheromone-based disruption of *Argyrotaenia citrana* using polyethylene tube dispensers at 1,000 per ha releasing either (Z)-11-tetradecenyl acetate (Z11-14:OAc) or a 15:1 blend of Z11-14:OAc and (Z)-11-tetradecenal (Z11-14:ALD) from 14 April to 17 August, 1993, in a marionberry field, Scholls, OR.

	Mean catch (+SE) per trap			
	14 April - 13 July		14 July - 17 August	
Treatment	Lure-baited	% reduc.[1]	Lure-baited	% reduc.[1]
Z11-14 acetate	49.6 ± 7.3b	95	148.4 ± 18.6b	85
Z11-14 acetate + Z11-14 aldehyde	2.4 ± 1.1b	>99	14.6 ± 3.7c	99
Control	21.4 ± 74.7a	-	980.8 ± 41.8a	-

[1] Percent reduction relative to the control.

Column means followed by different letters are significantly different, LSD, $p < 0.05$.

Weekly moth catch in the OT dispenser treatment was reduced by > 99% compared to traps in the control and then declined to 96% the last week of the study (Fig. 2B). Moth counts in the Hamaki-con treatment compared with the control were reduced 95% during the first flight, but were only reduced 85% during the second flight. Disruption declined sharply during the last three weeks of the study (Fig. 2B). During the second moth flight, the percentage reduction in trap catch was significantly different between the two pheromone treatments, $P < 0.05$ (Table 3)

Cage experiments. Thirty-five percent of the tethered females were mated in the untreated cages. This was significantly higher ($F = 10.0$, df = 2, 12; $p = 0.01$) than the level of mating under either pheromone treatment, OT = 0.0% and Hamaki-con = 1.9%. The level of mating in the two pheromone treatments did not differ, $p > 0.05$.

DISCUSSION

Successful incorporation of mating disruption technology into pest management programs first requires a basic knowledge of the insect's biology and behavior and then depends on a reliable dispenser system and reasonable cost. This study provides more information on the temporal aspects of female calling, mating, and oviposition of *A. citrana*. Further insights into the myriad attributes of this species' mating behavior are needed, including a female's pheromone emission rate, moth behavior within a pheromone-flooded field, and the effects of canopy structure on the pheromone plume (Cardé and Minks 1995).

A preliminary test of mating disruption with an acetate:aldehyde blend was done at the same time as mine by R. LaLone (Smuckers Inc., Woodburn, OR) in commercial fields,but the role of population density and immigration on its results was not clear. Capture of males was suppressed, but in some cases, larval populations were high and supplemental sprays were needed. At present, growers control *A. citrana* in caneberry fields with 1-2 applications of conventional insecticides (Knight *et al.* 1988). Adoption of mating disruption for control of *A. citrana* is hampered by its expected higher cost and the need to treat fields with pesticides to avoid the presence of arthropods in processed fruit (Martin and Lawrence 1976). Market forces that demand no pesticide residues may be needed for the registration and grower adoption of this technology (Ott *et al.* 1991).

Both dispensers appeared to provide relatively stable pheromone emissions for 110 d in the field. The percentage of E11-14:OAc in the Hamaki-con increased continuously with field aging similarly to that reported by Deland (1992) but at a low rate, 0.03% per d. This isomerization did not occur in the OT dispenser. The formulation in the OT also appeared to stabilize the isomer ratio of the aldehyde for 80 d. Over the last 30 d of the study, however, the percentage of the E11-14:ALD nearly doubled (Table 1). The ratio of acetate/aldehyde remaining in the dispenser dropped from 6.2% to <4.0%; this may have been due to a higher emission rate of the aldehyde during the season or to degradation. Aldehydes can be oxidized and trimerized (Dunkelblum *et al.* 1984), but I did not measure these byproducts. The stabilizers in these dispensers are proprietary and not known to me.

The effect of these changes in the blend and isomer ratios of pheromones in these dispensers for disruption of *A. citrana* or for other species is unknown. Studies are needed to assess the level of disruption caused by dispensers of various ages. The second flight of *A. citrana* can extend into late Sept and disruption of both flights requires dispensers to last up to 150 d. Further analyses of these dispenser's performance after 110 d are needed.

The Hamaki-con dispenser has been used by several researchers to test a generic blend for mating disruption of tortricid pest species (two species in tea in Asia [Nagata 1989], and several on apple in Japan [Oku 1993], and North America [Deland *et al.* 1994, Agnello *et al.* 1996]). However, the Hamaki-con dispenser used in their trials had less pheromone (80 mg A.I.) and a lower emission rate (ca. 0.48 mg/d [Deland *et al.* 1994, Agnello *et al.* 1996]). A generic dispenser containing only a partial pheromone blend was used in these trials because the pheromone of all these species contains Z11-14:OAc as a major component (Arn *et al.* 1992). Its performance has been inconsistent; Deland *et al.* (1994) obtained > 99% reduction of male catch of *Archips argyrospila* (Walker) in lure-baited traps with plots treated with Hamaki-con, but only 90% for *Archips rosana* (L.) and *Choristoneura rosaceana* (Harris). The poorer performance of the Hamaki-con dispenser for the last two species was probably because its binary blend was not different enough from the female's complete blend to cause a significant imbalance in sensory input nor was it similar enough to cause false trail following (Deland *et al.* 1994). Agnello *et al.* (1996) obtained 94% reduction in catch of *C. rosaceana* in plots treated with Hamaki-con dispensers, however, using the complete three-component pheromone blend that included 5% Z11-14:OH, they improved trap catch shut-down to 99%.

These findings are consistent with my results with *A. citrana*. Hill *et al.* (1975) showed that Z11-14:OAc is not attractive to male moths and that attraction of the natural blend was not affected by up to 10% of the E-isomer. Thus sensory imbalance is not likely to be an important mechanism due to the similarity in the percentage of Z11-14:OAc in the natural blend and the dispenser. The high level of disruption provided by the natural blend suggests that false trail following could be a major mechanism of disruption of *A. citrana* with the OT dispenser.

I suggest that the OT dispenser's blend should be investigated as a generic blend for some species of leafrollers in the western U.S. For instance, the sex pheromone of *C. rosaceana* in western North America contains Z11-14:ALD (Thomson *et al.* 1991). Lures loaded with the natural blend of *A. citrana* are 7-10× more attractive than lures loaded with the three-component blend (Hill and Roelofs 1979) of *C. rosaceana* from the eastern U.S. (unpublished data). Yet, small-plot trials conducted in Washington with the OT and Hamaki-con dispensers for *C. rosaceana* have not shown any significant difference in the activity of these two dispensers (unpublished data). The effect of Z11-14:ALD on the other horticultural tortricid pests in the western U.S. is unknown.

The major limitation in the development of mating disruption to control leafrollers may be economics. Leafrollers have been a secondary pest in most crops and have only become a problem after the development of resistance or softer conventional programs. Companies have not been interested in developing many specific pheromone products for the various species of leafrollers. In apple, dual dispensers containing the sex pheromone of both codling moth, *Cydia pomonella* L. and leafrollers have been tested (reviewed by Cardé and Minks 1995). These dispensers have always contained Z11-14:OAc for generic disruption of leafrollers and their performance has been mixed. My results with *A. citrana* support the use of the natural pheromone blend but more research is needed on other leafroller species and to show how this approach can best be developed and used in IPM.

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A Teflon®-walled mating table for assessing pheromone-based mating disruption

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ABSTRACT

A Teflon®-walled mating table to assess pheromone-based mating disruption of lepidoptera was constructed and field-tested using the eyespotted bud moth, *Spilonota ocellana* (Denis and Schiffermüller) (Lepidoptera: Tortricidae), in an apple orchard in the Okanagan Valley of British Columbia. Sentinel females were placed individually on mating tables on eight different nights during July 1996. The percentage of mated females ranged from 20-100%, with an average of 55.8% (n = 47). One female died and only three escaped. Females of the obliquebanded leafroller, *Choristoneura rosaceana* (Harris), also mated when placed on the tables in the field, suggesting that the table may have potential for use with many species, particularly those that are too small to be tethered.

Key words: mating table, pheromone-based mating disruption, sentinel female, *Spilonota ocellana*, *Choristoneura rosaceana*

INTRODUCTION

Several methods have been used to assess pheromone-based mating disruption of lepidoptera (Roelofs and Novak 1981, Rothschild 1981, Lingren *et al.* 1981), including mating cages (Fitzpatrick and Troubridge 1993), tethered sentinel or decoy virgin females that mate with wild or released males (Alford and Silk 1983, Cardé *et al.* 1977, Suckling and Shaw 1992, Rothschild 1981), and clipped-wing sentinel females placed on mating tables (Brooks *et al.* 1979, Lingren *et al.* 1981, Flint and Merkle 1983; 1984a; b, Niwa *et al.* 1988, Jenkins *et al.* 1990, Shaver and Brown 1993). During our study on pheromone-based mating disruption of eyespotted bud moth (ESBM), *Spilonota ocellana* (Denis and Schiffermüller) (Lepidoptera: Tortricidae), we focused on the use of mating tables to assess the mating status of sentinel females. This insect is a pest of apples and cherries in the Okanagan Valley of British Columbia and other fruit-growing areas in the northern hemisphere (Weires and Riedl 1991). Tethering is difficult with this small moth (length = 8 mm) and entry into a trap may interfere with mating. Escape of clipped-wing females from mating tables can be impeded by application of metal strips (Snow *et al.* 1976, Shaver and Brown 1993), talcum powder (Snow *et al.* 1976, Niwa *et al.* 1988) or petroleum jelly (Curtis *et al.* 1985) to the inner rim of the mating station. However, none of these techniques was effective for ESBM. We report the design and field-testing of a Teflon®-walled mating table for assessing the mating success of virgin sentinel female ESBM in apple orchards. The suitability of this table for the obliquebanded leafroller (OBLR), *Choristoneura rosaceana* (Harris) (Lepidoptera: Tortricidae), was also examined as part of our effort to control this pest with pheromone.

MATERIALS AND METHODS

Mating table design. Each mating table (Fig. 1) was designed to hold an individual sentinel female but more could be accommodated. A roof (14 x 17 cm) and base (18.5 x 9 cm) with a 2.5 cm high rim were cut from tops of wing traps (Phero Tech Inc., Delta, B.C.). A 28 cm length of Teflon® insect barrier tape (Consep®, Inc., Bend OR) was formed into a cylinder (8 cm diam. x 5 cm high) with the Teflon® side in. The ends were secured by duct tape, and a cylinder was glued to the base of each table using a glue gun. Backing on the barrier tape was not removed. Two circular drainage holes (1 cm diam.) were punched in the base outside the cylinder of Teflon® tape. Two 40-cm long pieces of stiff wire (1.5 mm diam.) attached the base to the roof, and were twisted together above the roof for attachment to a tree branch. To prevent horizontal movement in the wind, the base of each table was secured to surrounding branches using string or wire.

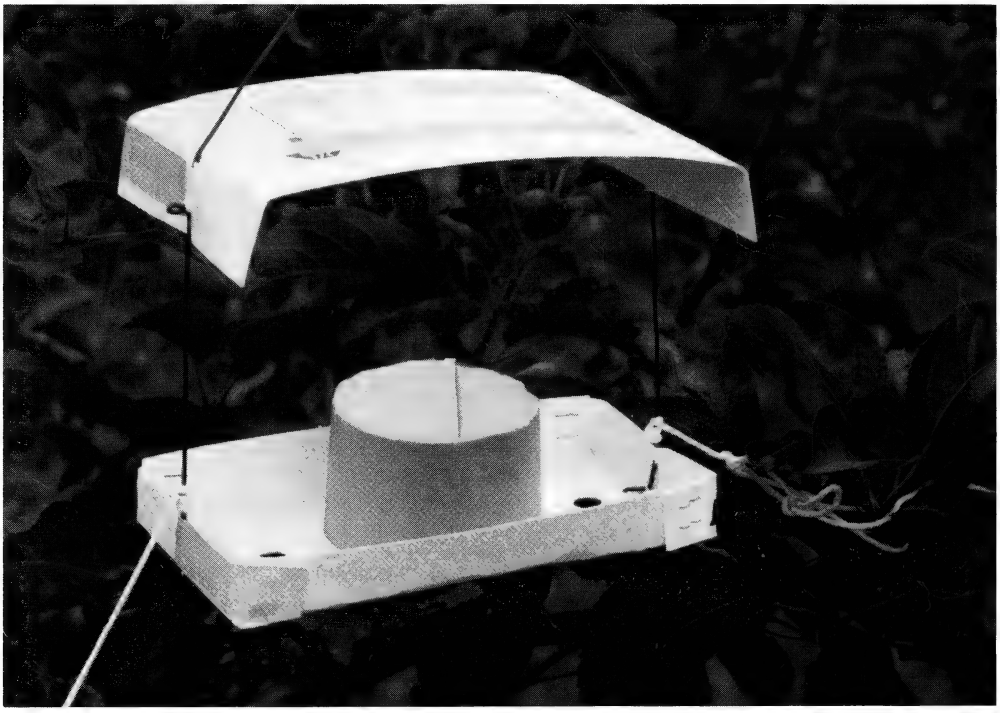

Figure 1. Mating table hanging in an orchard. Inner cylinder is 5 cm high.

Sentinel females. In May 1996, ESBM larvae were collected from an unsprayed apple orchard at the Pacific Agri-Food Research Centre (PARC) in Summerland, B.C. Larvae were reared on a diet of apple leaves in 59.1 ml plastic cups (two larvae per cup) in the laboratory at 20°C (± 0.5°C) and a light regime of 16:8 (L:D). Female pupae were isolated individually in 150 ml clear plastic cups and adults were provided with water. One- to 4-d-old females were used in field trials. Sentinel female OBLR were obtained from a laboratory colony reared on a pinto bean-based artificial diet at 24°C (± 0.5°C) and a light regime of 16:8 (L:D). Female pupae and adults were treated as described for ESBM.

One third of one forewing of each moth was removed using fine scissors to prevent flight. Moths were chilled at 0°C (± 0.5°C) for 30 min before and during wing clipping, and transported to the field in refrigerated containers.

Field trials. Trials were run in July 1995 and 1996 in three unsprayed blocks of semi-dwarf apple trees at the PARC entomology orchard in Summerland. Mating tables were hung about 2 m above ground. Clipped-wing females were placed on tables shortly before dusk, removed by 09:00 PDT the following day, and dissected in the laboratory to check for the presence of spermatophores in the bursa copulatrix. One moth was placed on each table. Three to eight female ESBM were placed on mating tables on eight different nights in July 1996 for a total of 47 insects, and five OBLR females were tested on 24 July 1995.

Hourly air temperatures in the orchard were recorded using a DP-212 Datapod (Omnidata International, Logan, UT) housed in a standard Stevenson screen. The average hourly temperature at dusk (18:00 to 22:00 PDT) was calculated for each trial.

RESULTS AND DISCUSSION

Each of the five OBLR females placed on mating tables was mated and none escaped. The mean hourly air temperature at dusk during the trial was 22.6°C. Mating of ESBM over the eight nights in July 1996 ranged from 20 to 100%, and there was no clear relationship between dusk temperature and their mating success (Table 1). Catches of male ESBM in pheromone-baited traps in an adjacent unsprayed orchard (H.L. McBrien, unpublished data) showed that 10, 50, and 90% of total trap catch during the 1996 flight occurred on 29 June, 15 July, and 1 August, respectively. Thus, low population densities of wild male ESBM during the last week of the field trials probably contributed to the low percentage of mated sentinel females. The proportion of mated sentinel females may be improved by placing host vegetation on tables to provide shelter and a perch for calling (Snow *et al.* 1976, Brooks *et al.* 1979, Flint and Merkle 1983; 1984a; b, Niwa *et al.* 1988, Jenkins *et al.* 1990, Shaver and Brown 1993). This was not done here because contact of materials with the surface of Teflon® tape decreases its effectiveness.

Table 1.

Numbers of female *Spilonota ocellana* deployed, recovered, mated, escaped, and dead in Teflon®-walled mating tables hung in apple orchards. Mean hourly air temperatures (T) at dusk (18:00-22:00 PDT) during July 1996, Summerland, B.C.

Date	T (°C)	Females tested	Recovered alive	Number mated	% mated	Number escaped	Number dead
4 July	16.6	6	6	2	30	0	0
9 July	20.8	3	3	3	100	0	0
16 July	21.9	6	5	4	80	0	1
17 July	11.6	6	5	5	100	1	0
22 July	21.2	5	5	3	60	0	0
25 July	23.2	5	4	2	50	1	0
26 July	23.3	5	5	1	20	0	0
31 July	20.4	11	10	4	40	1	0
Total		47	43	24	55.8	3	1

One female ESBM died during the field trials (Table 1). When removed, it had no signs of attack by a predator, and may have died because of injury during handling. On one occasion, a spider was found attacking a female ESBM, but dissection to check for spermatophores was still possible. If the spider had crawled into the Teflon® cylinder, this might have been prevented by having a Teflon® surface on the outside of the cylinder, as well as on the inside. Only three ESBM females escaped during the trials (Table 1). These were probably either blown out by the wind, or they crawled up the seam in the cylinder of Teflon® barrier tape, although inspection of the tables determined the latter to be unlikely.

The range in the percentage of female ESBM mated each night during our study (Table 1) is comparable to that obtained for pink bollworm, *Pectinophora gossypiella* (Saunders) (Lepidoptera: Gelechiidae) (Flint and Merkle 1983; 1984a; b) and tomato pinworm, *Keiferia lycopersicella* (Walsingham) (Lepidoptera: Gelechiidae) (Jenkins *et al.* 1990) on mating tables in nontreated control plots during studies on pheromone-based mating disruption. The overall recovery of female ESBM from our study was 91.5% (Table 1). This falls within the range reported for other studies, which varied from 52% (Flint and Merkle 1983; 1984b) to almost complete recovery (Niwa *et al.* 1988, Shaver and Brown 1993).

If the Teflon®-walled mating tables are handled so that the surface of the tape is not damaged and the duration of exposure to field conditions, particularly rain, is kept to a minimum, they can be used several times. The base and roof of the tables last longer than the insect barrier tape, but the latter can be quickly replaced if necessary. Mating tables made of materials such as ice cream cartons attached to stakes (Lingren *et al.* 1981) or plywood and galvanized flashing (Shaver and Brown 1993) may be easier to handle and probably last longer under field conditions. However, clipped-wing ESBM crawled out of tables made from these materials. Teflon®-walled mating tables do not require the addition of substances such as talcum powder (Snow *et al.* 1976, Niwa *et al.* 1988) or petroleum jelly (Curtis *et al.* 1985), making them easy to handle.

Tethering a sentinel female to a branch using thread looped over the forewing or glued to the insect's body is a technique which is successful with OBLR and other species of lepidoptera (Cardé *et al.* 1977, Alford and Silk 1983, Suckling and Shaw 1992, Deland 1992, Delisle 1995). Losses of tethered females due to escape or predation are highly variable and depend on the site and environmental conditions. For example, losses of tethered female fruittree leafroller, *Archips argyrospilus* (Walker) (Lepidoptera: Tortricidae) was 6% (n = 281) in conventional apple orchards (Deland 1992) and 60% (n = 45) in the unsprayed apple orchard at PARC (H.L. McBrien, unpublished data). The use of the Teflon®-walled mating table may be preferred because of the low numbers of insects lost from escape or predation (Table 1) and a savings in labour during tethering, which limits the numbers of insects that can be set up at any one time.

This study shows that males of at least two species of lepidoptera enter the Teflon®-walled mating table and mate with sentinel females. It would be of interest to know what proportion of male moths approaching the table actually enter, and how this compares with mating cages (Fitzpatrick and Troubridge 1993). The Teflon®-walled mating table is probably suitable for many other species of lepidoptera, and possibly for insects in other orders.

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A northern range extension of *Tanypteryx hageni* (Odonata: Petaluridae)

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ABSTRACT

An adult female of the dragonfly *Tanypteryx hageni* (Selys) was collected near the Kowesas River in western British Columbia (53°18' N latitude) in August 1995. This collection increases its northern range and represents the most northerly collection of any member of the family Petaluridae. While no larvae were collected, it is likely that the muskegs that occur in the Kowesas River valley serve as the larval habitat. This distribution record supports the prediction that *Tanypteryx hageni* is not restricted to mountain habitats, but rather is a resident in low-elevation coastal forests in the northern part of its range.

Key words: Odonata, Petaluridae, *Tanypteryx hageni*, distribution, Kowesas River

DISCUSSION

The Family Petaluridae contains eight extant species that exhibit disjunct distributions in both the northern and southern hemispheres (Cannings and Stuart 1977). Only two species occur in North America. *Tanypteryx hageni* (Selys) occurs in western North America, ranging from California and Nevada into Oregon, Washington and British Columbia, while *Tachopteryx thoreyi* (Hagen) is limited to the eastern U.S. and southern Quebec (Smith and Pritchard 1956; Walker and Corbet 1975). Petalurids are well represented in the fossil record, suggesting that at one time they were a dominant component of the odonate fauna (Svihla 1959).

Tanypteryx hageni occurs in association with montane bogs and swamps, which serve as the larval habitat. Most collections in British Columbia were made in the Cascade Mountains and southern Coast Mountains (Cannings and Stuart 1977). Until recently this species was thought to be restricted to mountain habitats (> 1000 m) and collections made at lower elevations were considered accidental (Walker 1958; Cannings 1978). However, Cannings (1978) reported a distribution record from the mouth of the Ahnuhati River on Knight Inlet (lat. 50° 52') and suggested that *T. hageni* does occur naturally at lower elevations, particularly at the northern extent of its range. While Cannings (1978) suggested that the species probably has a wider distribution than previously thought, *T. hageni* is considered one of the rarest dragonflies in British Columbia and is formally listed as a potentially rare or threatened species in the province (Cannings and Stuart 1977; Scudder 1994).

In August 1995, an adult female of *T. hageni* was collected during a macroinvertebrate survey of the Kowesas River in western British Columbia. The

specimen was collected in the river valley near Cole Creek ca. 5 km from the mouth of the Kowesas River (lat. 53° 18', long. 128° 10'). This collection site is ca. 400 km north of the Ahnuhati River and thus represents a significant range extension for the species. The only other family member occurring in the northern hemisphere besides *Tachopteryx thoreyi*, is *Tanypteryx pryeri* from Japan (Svihla 1959). Consequently, the northern range extension of *T. hageni* reported here represents the northern-most occurrence of the Family Petaluridae. The specimen is deposited in the Systematic Entomology Laboratory at Oregon State University.

Only adult specimens of *T. hageni* have been collected in British Columbia. In other parts of its range, larvae inhabit burrows in the muck of mountain bogs, swamps, or seepage areas (Cannings and Stuart 1977; Smith and Pritchard 1956). Larvae appear to require permanent water where burrows are constructed, but may move away from water for extended periods, when they apparently breathe air (Svihla 1959). In Oregon and Washington, where life-history studies were conducted, *T. hageni* required 5-6 years for larval development (Svihla 1959; Corbet 1963). Muskegs in the Kowesas River valley near where the adult specimen was collected probably serve as the larval habitat.

This distribution record for *T. hageni* supports the predictions made by Cannings (1978) that the species is a resident of coastal forests and enjoys a wider distribution than previously thought. However, *T. hageni* is rare throughout its known range and no doubt still merits its position on the list of potentially rare or threatened invertebrate species in British Columbia (Scudder 1994). Documenting the occurrence and habitat preferences of larvae of *T. hageni* in British Columbia would be a logical step in determining the status of this dragonfly.

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Effects of neem seed extract on the growth of fungal associates of the mountain pine beetle

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ABSTRACT

We investigated the fungicidal activity of neem seed extract, active ingredient azadirachtin, to *Ophiostoma clavigerum* (Robins. Jeff. & Davids) and *Ophiostoma ips* (Rumb.), the fungal associates of the mountain pine beetle, *Dendroctonus ponderosae* Hopk. When added to malt extract agar, concentrations of 100 ppm significantly reduced the growth of both fungal associates and concentrations above 250 ppm killed both fungi.

Key words: Azadirachtin, bluestain fungi, Coleoptera, Scolytidae

DISCUSSION

Mortality caused by the mountain pine beetle, *Dendroctonus ponderosae* Hopk., results in losses of millions of cubic metres of mature pines annually in British Columbia (Unger 1993). Present management techniques to reduce mountain pine beetle attack include sanitation logging of large infested areas, single-tree treatments, and the use of trap trees baited with pheromones (Unger 1993, Safranyik 1995). Single-tree treatments and baited-tree treatments usually consist of wintertime "fall and burn" or injection of a systemic pesticide, monosodium methane arsenate (MSMA). However, concern arises because this pesticide is potentially toxic to applicators and other organisms (MacLauchlin *et al.* 1988).

A potentially new control method for managing the mountain pine beetle is the use of neem seed extracts from the neem tree, *Azadirachta indica* A. Juss (Naumann *et al.* 1994). Neem seed extracts have several useful qualities for pest management including insecticidal and fungitoxic properties as well as low mammalian toxicity (Narasimhan *et al.* 1993, Koul *et al.* 1990, Schmutterer 1990).

The insecticidal activity of neem seed extracts on brood development of the mountain pine beetle have already been investigated (Naumann *et al.* 1994), but the question remained whether this compound was also active against *Ophiostoma clavigerum* (Robins. Jeff. & Davids) and *Ophiostoma ips* (Rumb.), the fungal associates of the mountain pine beetle (Robinson 1962, Reid *et al.* 1967, Whitney 1971).

Inoculation studies show these fungi can kill trees in the absence of their bark beetle vector (references in Owen *et al.* 1987) and these fungi also cause a reduction in the value of timber or timber products by discoloring sapwood (Behrendt *et al.* 1995). Therefore, fungicidal activity of neem seed extracts against bluestain fungi would provide an additional benefit while controling the mountain pine beetle.

To determine the fungicidal properties of neem seed extracts to *O. ips* and *O. clavigerum,* a proprietary emulsifiable concentrate of the extracts containing 5% active ingredient (azadirachtin) was obtained from Phero Tech Inc. (Delta, B.C., Canada). Dilutions were made with ethanol and added to malt extract agar (MEA) at rates expressed in terms of ppm of azadirachtin. *Ophiostoma clavigerum* and *O. ips* cultures were grown for 2 weeks on individual Petri plates of plain MEA. At this time 5 mm MEA

plugs colonized with either fungus were transferred to separate Petri dishes containing MEA with 0, 1, 10, 100, 250, and 500 ppm azadirachtin. Growth of the fungi across the plates was measured daily. Daily growth was determined for 3 replications of 3 Petri plates per concentration per fungus and observed over 28 days. Data were analyzed by a one-way ANOVA and by subsequent Student Neuman-Keuls tests (SAS 1989). Azadirachtin began showing significant fungicidal activity to *O. ips* at 10 ppm and growth of both fungi was significantly inhibited at 100 ppm (Table 1). No growth occurred at 250 or 500 ppm over the 28-day period and when the original plugs were transferred to new MEA without azadirachtin, no growth occurred.

Table 1.

Growth rate (mm/day) of *Ophiostoma ips* and *O. clavigerum* after 28 days on malt extract agar with different concentrations of neem seed extract, azadirachtin

	azadirachtin /ppm					
Fungus	Control	1	10	100	250	500
O.ips	7.80a[1]	7.75a	4.90b	0.63c	0.0d	0.0d
O.Clavigerum	4.87a	4.87a	4.74a	0.25b	0.0c	0.0c

[1] treatments in the same row followed by the same letter are not significantly different ($p \geq 0.05$, GLM procedure and Student Neuman-Keuls test).

Combined with its insecticidal properties, this compound may prove to be an effective control for both the mountain pine beetle and its fungal associates.

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