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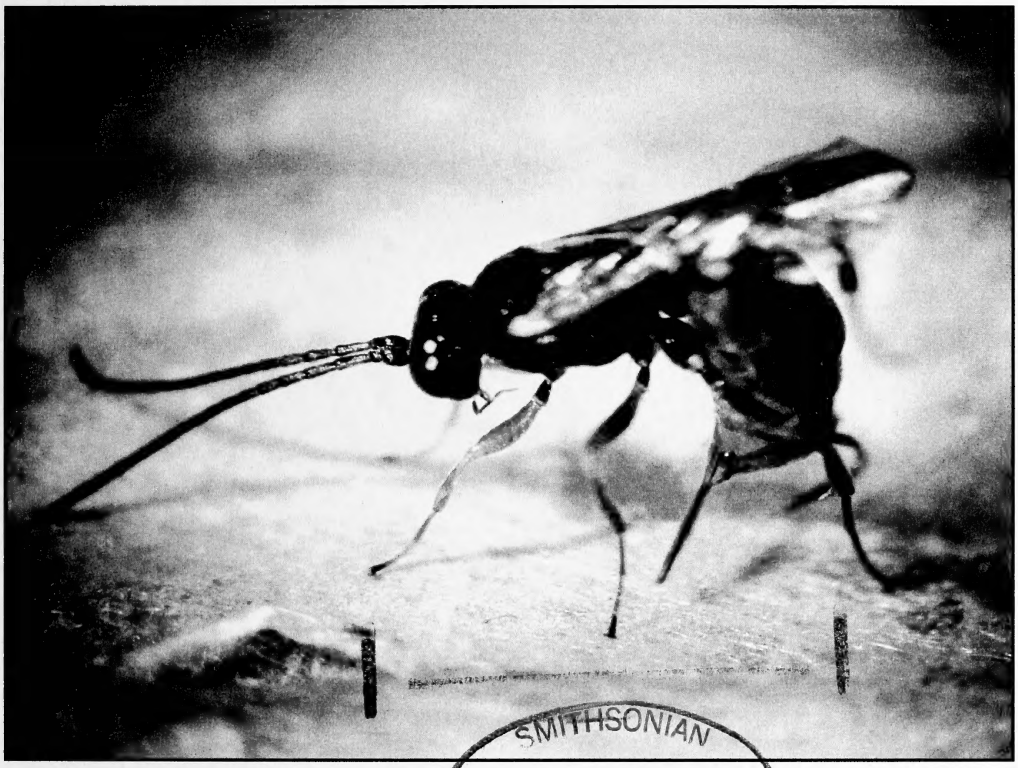

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COVER: *Mastrus ridibundus* (Gravenhorst) (Hymenoptera: Ichneumonidae)

Mastrus ridibundus was introduced into the United States from its native Kazakhstan for classical biological control of codling moth. This gregarious ectoparasitoid specializes on cocooned codling moth larvae, homing in on semiochemical cues from the silk of newly spun cocoons. Females paralyze the host and deposit between 1-7 eggs within the host cocoon. Parasitoid larvae consume the host before spinning their own cocoons within their host's empty cocoon.

Photograph details:
Female *Mastrus ridibundus*, ovipositing in a cocoon of its host, *Cydia pomonella*. Photo taken with a digital camera through a dissecting microscope (16 ×) by Zaid Jumean, Department of Biological Sciences, Simon Fraser University.

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Almond volatiles attract neonate larvae of *Anarsia lineatella* (Zeller) (Lepidoptera: Gelechiidae)

MARK SIDNEY[1], REGINE GRIES[1], ADELA DANCI[1], GARY J.R. JUDD[2] and GERHARD GRIES[1,3]

ABSTRACT

Post-diapause overwintered larvae and neonates of any generation of the peach twig borer, *Anarsia lineatella* (Zeller), seek suitable sites to bore into and mine tissue of their host plants, including almond and peach. We tested the hypothesis that larvae are attracted to the same almond volatiles that elicit antennal responses from adult moths. Of five candidate almond semiochemicals [β-bourbonene, (*E,E*)-α-farnesene, (*E*)-β-ocimene, nonanal, decenal] tested singly or in binary combination (nonanal, decenal) in laboratory Y-tube olfactometers, only β-bourbonene attracted neonate larvae. β-Bourbonene in combination with (*E,E*)-α-farnesene was as attractive as the complete almond volatile blend, indicating that they are key semiochemicals for foraging larvae.

Key Words: Semiochemicals, β-bourbonene, (*E,E*)-α-farnesene, (*E*)-β-ocimene, nonanal, decanal, olfactometer bioassay

INTRODUCTION

The peach twig borer, *Anarsia lineatella* (Zeller) (Lepidoptera: Gelechiidae), is a worldwide pest of almond and stone fruits (Marlatt 1898, Jones 1935, Bailey 1948, Ahmad 1988, Ponomarenko 1990). Almond and peach are the principle crop host plants, but apricot, nectarine, plum and prune (Summers 1955), and even sweet and sour cherry, apple and persimmon are attacked (Ponomarenko 1990).

There are three generations of *A. lineatella* in the Okanagan Valley of British Columbia (BC) (Sarai 1966) and two generations and a partial third in the Similkameen Valley of BC. Larvae predominantly enter buds and terminal shoots, boring a path toward the centre, and then downward, often until they reach the previous year's wood (Ponomarenko 1990). In peach orchards, most economic damage is caused when larvae burrow into fruits. Larvae typically mine cavities just beneath the skin, discolouring the fruit and causing exudation of gum mixed with frass. Even when only minor damage is inflicted, cosmetic alterations reduce the fruit's value and increase picking and culling costs. Fruit damage also increases putrefaction and susceptibility to other pests (Curtis 1983). In both peach and almond orchards, severe shoot damage can stunt and kill small trees (Summers 1955).

Host-foraging and selection by *A. lineatella* is likely achieved by both female moths and larvae. Five almond-derived volatiles [β-bourbonene, (*E,E*)-α-farnesene, (*E*)-β-ocimene, nonanal, decanal] elicit antennal responses from female *A. lineatella* moths (Sidney 2005), and thus may be behaviourally active semiochemicals to foraging adults. When females lay eggs on sites other than a new shoot or fruit, larvae must search for a site to enter host plant tissue. Overwintered larvae emerging from hiber-

[1] Department of Biological Sciences, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada
[2] Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, Summerland, British Columbia V0H 1Z0, Canada
[3] To whom correspondence should be addressed; E-mail: gries@sfu.ca

nacula may need to move considerable distances to locate new growth in spring (Bailey 1948).

Larval foraging behaviour may be mediated in part by airborne semiochemicals, as shown for codling moth, *Cydia pomonella* L. (Bradley and Suckling 1995, Landolt *et al.* 1998, Knight and Light 2001), and parsnip webworm, *Depressaria pastinacella* (Duponchel) (Carroll and Berenbaum 2002). Lepidopteran larvae can detect semiochemicals from host plants (Dethier 1980, Landolt *et al.* 1998, 2000, Singh and Mullick 2002) with semiochemical receptors residing on rudimentary antennae or maxillae (Dethier and Schoonhoven 1969, Dethier and Kuch 1971, Dethier 1980). However, such antennae are difficult to prepare for electrophysiological screening of potential host plant semiochemicals. Thus, we used adult moth antennae instead (Sidney 2005), working under the assumption that olfactory receptors are conserved across life stages, and that larval and adult antennae respond to the same semiochemicals.

Our objectives were (1) to determine whether neonate *A. lineatella* larvae orient chemo-anemotactically toward Porapak Q extracts of almond and peach shoot volatiles; and (2) if so, to determine the semiochemical(s) responsible for attraction of larvae. In this paper, we focus on bioassays with almond volatiles because β-bourbonene, the most abundant component, was present only in almonds, rendering it potentially useful for attraction of *A. lineatella* in peach orchards having no naturally occurring competing sources of the compound.

MATERIALS AND METHODS

Experimental Insects. Insects were collected from peach orchards in Keremeos, BC, and reared according to protocols developed and modified, respectively, by McElfresh and Millar (1993) and Sidney (2005).

Acquisition of Fruit and Shoot Volatiles. Freshly collected early season fruits and shoots of almond and peach were aerated separately for 3-7 d in a cylindrical Pyrex® glass chamber (15.5 × 20 cm). Charcoal-filtered air was drawn at 2 L/min with a water aspirator through the chamber and a glass column (14 × 0.40 cm ID) containing 3 cm of 50-80 mesh Porapak Q (Waters Associates Inc., Milford, MA). Volatiles were eluted from the Porapak Q with 3 ml of redistilled pentane and refrigerated (4 °C) until use.

Olfactometer Bioassays. Anemotactic responses of neonate larvae to test stimuli were assessed in a vertical Y-shaped Pyrex® glass olfactometer (Fig. 1) at 20 ± 3 °C and 35% ± 5% relative humidity. The olfactometer was placed vertically and illuminated from above with tubes of fluorescent "daylight" and "wide spectrum grow light" (Osram Sylvania Ltd., Mississauga, Ontario) because *A. lineatella* larvae are both negatively geotactic and positively phototactic. Two pieces of 20-gauge steel wire were suspended inside Y-tubes to facilitate movement of larvae (Landolt *et al.* 1998), with one piece connecting the opening of each side arm, and a linear piece suspended therefrom (Fig. 1). Visual cues were standardized by enclosing the olfactometer on three sides with black poster board.

Treatment and control test stimuli were micropipetted onto Whatman No. 2 filter paper discs (1.27 cm diameter) inserted 1 cm into the orifice of each side arm. All pipetting was done in a separate room to avoid contamination. For each replicate, a freshly-cleaned and oven-dried Y-tube with new steel wire, insect and filter paper were used, with test stimuli randomly assigned to side arms. Air drawn through the apparatus at 0.1-0.2 L/min with a water aspirator was humidified before entering the side arms. Nalgene® tubes running from the humidifiers to the side arms were dedicated as treatment or control tubes to avoid contamination. Thirty seconds after placement of stimuli, a neonate was introduced into the Y-tube on the linear piece of wire. All neo-

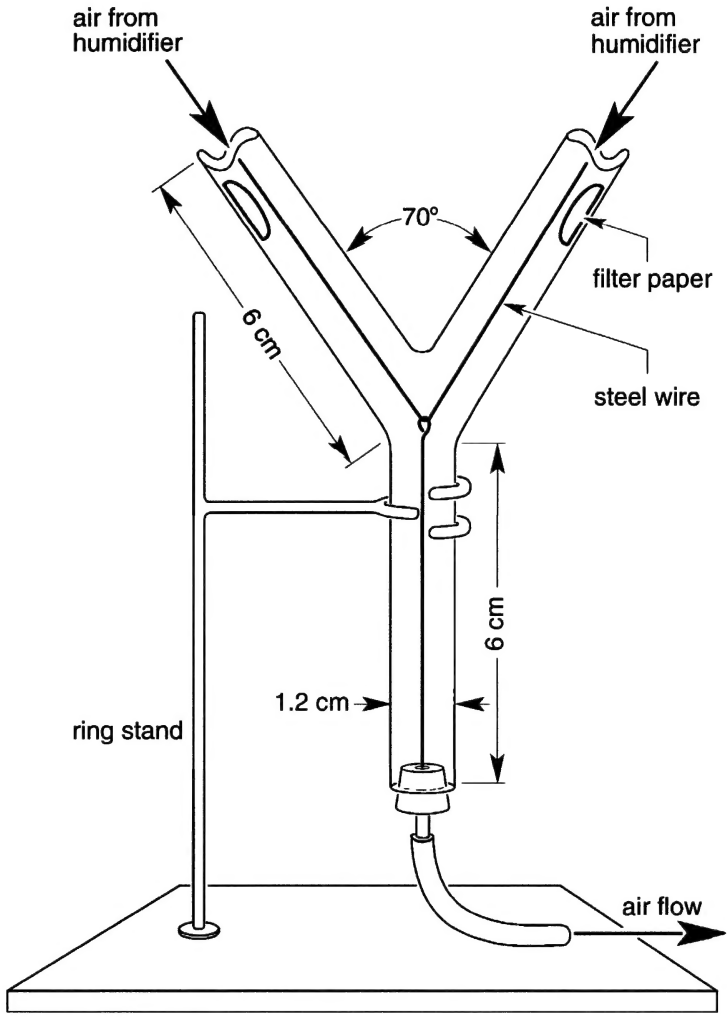

Figure 1. Vertical Y-tube olfactometer used for testing chemoanemotactic responses of neonate *Anarsia lineatella* larvae to test stimuli in experiments 1–11. Neonates were placed on the steel wire and classed as responders when they crawled > 2 cm up a side arm within 10 min; all others were classed as non-responders and were not included in statistical analyses.

nates were less than 5 h old at the time of bioassay. Neonates that travelled more than 2 cm up a side arm within 10 min were classed as responders; all others were classed as non-responders and were not included in statistical analyses.

Stimuli tested in experiments 1-11 are listed in Tables 1 and 2. Experiments 1 and 2 tested Porapak Q extract of peach and almond shoots, respectively, and experiments 3-11 tested five synthetic or plant-derived almond volatiles that elicited responses from adult moth antennae (Sidney 2005). Experiments 3-6 tested three of those five components singly, and nonanal and decanal in combination. To determine whether β-bourbonene, as the most attractive of the five components, was solely responsible for attraction of neonates to Porapak Q almond extract, experiment 7 tested β-bourbonene versus Porapak Q almond extract. Because Porapak Q extract was more attractive than β-bourbonene, experiments 8-10 tested β-bourbonene singly versus binary combinations of β-bourbonene with (*E,E*)-α-farnesene (Exp. 8), (*E*)-β-ocimene (Exp. 9), or with nonanal plus decanal (Exp. 10). Experiment 11 tested β-

Table 1.

Name, amount, chemical purity, and source of stimuli tested in experiments 1-11.

Stimuli	Amount (ng / lure)	Chemical purity (%)	Source
Porapak Q peach twig extract[1]	85.0		
Porapak Q almond twig + fruit extract[2]	39.4		
β-Bourbonene	12.0	99	Saje[3,4,5]
(*E*,*E*)-α-Farnesene	3.0	99	TCI[5,6]
(*E*)-β-Ocimene	3.0	99	IFF[5,7]
Nonanal	3.2[8]	95	Aldrich
Decanal	3.2[8]	95	Aldrich

[1] Amount is the sum of all antennally active compounds present in 5 µL of Porapak Q extract
[2] Amounts of almond volatiles used were equivalent to the amounts present in 5 µL of Porapak Q almond twig and fruit extracts.
[3] Saje, Delta, BC (geranium essential oil); absolute configuration of β-bourbonene unknown
[4] Purified by high-performance liquid chromatography
[5] Purified to 99% by preparative gas chromatography
[6] TCI = Tokyo Chemical Industry, Portland
[7] IFF = International Flavours and Fragrances, New York, NY
[8] 3.2 ng of nonanal were combined with 3.2 ng of decanal

Table 2.

Stimuli tested in Y-shaped Pyrex® glass olfactometer experiments and number of neonate larvae responding.

Experiment no.	Test stimuli		Larvae tested (n)[1]
	Treatment	Control	
1	Porapak Q peach twig extract	Pentane	175 (106)
2	Porapak Q almond twig/fruit extract	Pentane	170 (105)
3	β-bourbonene	Pentane	260 (155)
4	(*E*,*E*)-α-Farnesene	Pentane	60 (37)
5	(*E*)-β-Ocimene	Pentane	60 (38)
6	nonanal + decanal	Pentane	90 (59)
7	β-Bourbonene	Porapak Q extract[2]	60 (34)
8	β-Bourbonene + (*E*,*E*)-α-farnesene	β-Bourbonene	80 (58)
9	β-Bourbonene + (*E*)-β-ocimene	β-Bourbonene	60 (45)
10	β-Bourbonene + nonanal + decanal	β-Bourbonene	60 (37)
11	β-Bourbonene + (*E*,*E*)-α-farnesene	Porapak Q extract[2]	150 (115)

[1] Number of responding insects given in parenthesis
[2] Porapak Q almond twig/fruit extract

bourbonene plus (*E,E*)-α-farnesene (the only binary combination more attractive than β-bourbonene alone) versus Porapak Q almond extract.

Data Analysis. Data were analyzed with the χ^2 goodness-of-fit test using Yates correction for continuity to determine whether observed frequencies deviated significantly from expected frequencies, under the null hypothesis that *A. lineatella* neonate larvae did not prefer either treatment or control stimuli (Zar 1996).

RESULTS AND DISCUSSION

In Y-tube olfactometer bioassay experiments, more larvae responded to Porapak Q extracts of peach shoots ($\chi^2 = 8.2$, $P < 0.005$; Fig. 2, Exp. 1) or almond shoots and fruits ($\chi^2 = 18.9$, $P < 0.001$; Fig. 2, Exp. 2) than to solvent controls, demonstrating that *A. lineatella* neonate larvae orient chemoanemotactically to host volatiles.

Of the five almond volatiles [β-bourbonene, (*E,E*)-α-farnesene, (*E*)-β-ocimene, nonanal, decanal] that were bioassayed in experiments 3-6, only β-bourbonene was attractive to neonate larvae ($\chi^2 = 22.1$, $P < 0.001$; Fig. 2, Exp. 3). How-

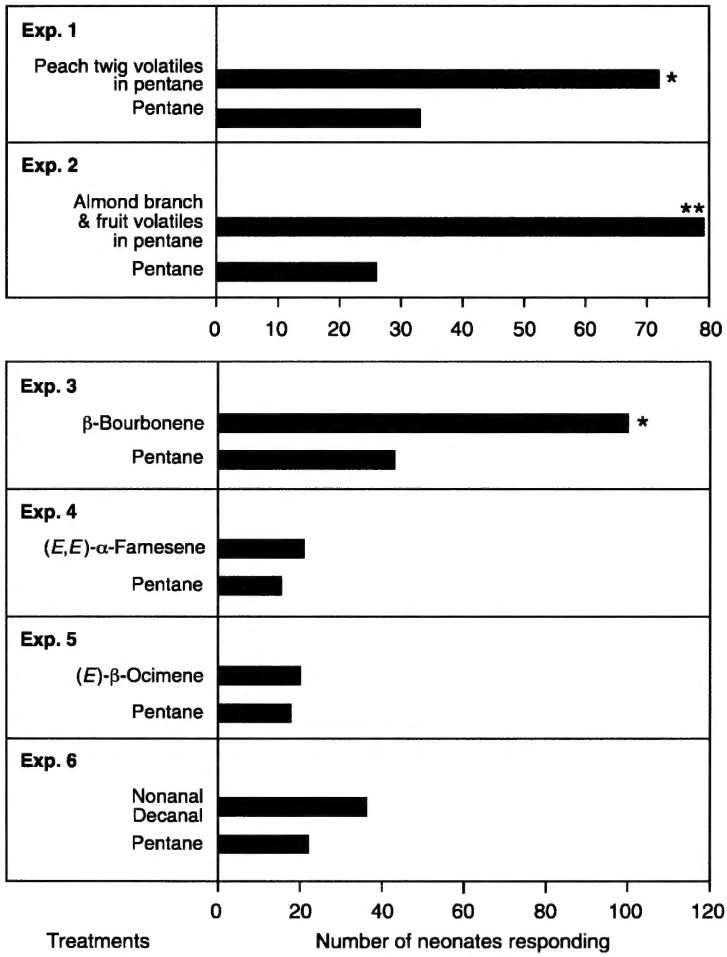

Figure 2. Anemotactic responses of neonate *Anarsia lineatella* larvae in Y-tube olfactometer experiments to Porapak Q extracts of peach twigs (Exp. 1), almond twigs and fruits (Exp. 2), or to specific candidate semiochemicals (Exps. 3-6). For each experiment, bars with asterisks (*) indicate a significant preference for a particular treatment; χ^2 test with Yates correction for continuity, treatment versus control; * $P < 0.005$; ** $P < 0.001$.

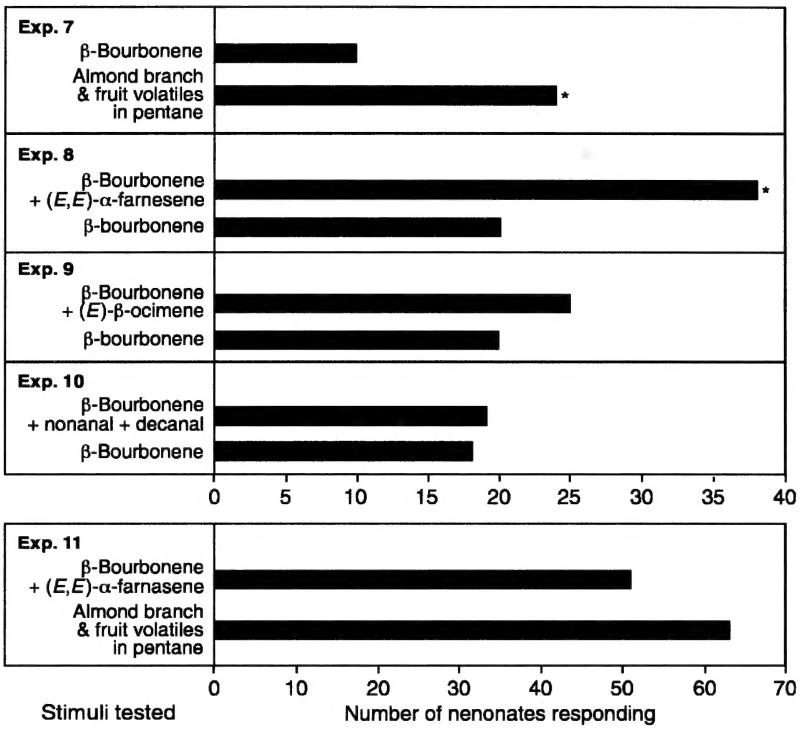

Figure 3.
Anemotactic responses of neonate *Anarsia lineatella* larvae in Y-tube olfactometer experiments 7-11 to Porapak Q extracts of almond twigs and fruits (Exp. 7), or to specific candidate semiochemicals (Exps. 8-11). For each experiment, bars with asterisks (*) indicate a significant preference for a particular treatment; χ^2 test with Yates correction for continuity, treatment

ever, β-bourbonene was not as attractive as Porapak Q extracts of almond shoots and fruits ($\chi^2 = 5.4$, $P < 0.05$; Fig. 3, Exp. 7), suggesting that the almond volatiles contained at least one additional semiochemical. Of the potential synergistic components [(*E*,*E*)-α-farnesene, (*E*)-β-ocimene, or nonanal plus decanal] that were bioassayed in experiments 8-10, only (*E*,*E*)-α-farnesene enhanced attractiveness of β-bourbonene ($\chi^2 = 5.3$, $P < 0.05$; Fig. 3, Exp. 8). No difference in attractiveness between almond Porapak Q extract and β-bourbonene plus (*E*,*E*)-α-farnesene (Fig. 3, Exp. 11) indicated that the latter two components mediate attraction of neonate larvae to almond extract.

(*E*,*E*)-α-Farnesene is also a component of 'Granny Smith' apples, and attracted *C. pomonella* larvae in Petri dish bioassays (Bradley and Suckling 1995). The (*E*,*E*)-isomer in 'Granny Smith' apples accounts for 99.5% of the total α-farnesene content (Bradley and Suckling 1995) and it is also the predominant isomer in Porapak Q extracts of almond volatiles.

Neonate *A. lineatella* larvae seeking a feeding site are probably susceptible to predation and poor weather, as are neonate *C. pomonella* larvae under similar circumstances (Jackson and Harwood 1980). Through oriented movement toward β-bourbonene and (*E*,*E*)-α-farnesene, *A. lineatella* larvae would likely increase the chances of successful almond shoot or fruit location, host penetration, and survival. In integrated pest management programs for peaches, neonate *A. lineatella* could possibly be controlled by depositing bait droplets impregnated with attractive β-bourbonene and (*E*,*E*)-α-farnesene and laced with insecticide on tree twigs. However, this "attract and kill" tactic would be effective only if larvae were attracted over a considerable distance, and if both sesquiterpenes became commercially available.

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Management and within-tree spatial distribution of the small red-belted clearwing borer, *Synanthedon myopaeformis* (Borkhausen) (Lepidoptera: Sesiidae), infesting dwarfing apple orchards in southern Jordan

MAZEN A. ATEYYAT[1,3] and TAWFIQ M. AL-ANTARY[2]

ABSTRACT

Experiments were conducted in the Ash-Shoubak apple-growing region of southern Jordan to determine the impact of four management practices on reducing populations of the small red-belted clearwing borer, *Synanthedon myopaeformis* (Borkhausen) infesting apple cultivars grafted on M26, M109, and M106 rootstocks. Results revealed that use of a flexible wire to mechanically kill insect larvae, mounding soil over the graft-union area, wrapping tree trunks with cheesecloth from the soil surface to a height of 80 cm, and use of an insecticidal paint composed of water, copper sulfate, petroleum oil, and Durusban®, all reduced the insect populations compared with untreated control trees. The insecticidal paint treatment caused the greatest population reduction. More *S. myopaeformis* larvae were recovered from the main trunk of the trees than from main and sub-main lateral branches.

Key Words: Sessiidae, pome fruits, burr knots, clonal rootstocks, cultural control, chemical control, Mondial Gala

INTRODUCTION

Since the late 1980s, the small red-belted clearwing borer (RBB), *Synanthedon myopaeformis* (Borkhausen) (Lepidoptera: Sesiidae), also known as apple clearwing moth, has become an increasingly important indirect pest of apple, *Malus domestica* Borkhausen (Rosaceae), in Jordan (Al-Antary *et al.* 2004). In Europe before the 1960's, the RBB was considered a secondary pest, which usually attacked apple trees weakened by other factors. However, since the 1960's, the RBB has been considered a serious pest of commercial European apple and pear orchards (Maini and Pasqualini 1980) where a RBB infestation of apples in Germany resulted in a 22.1% decline in yield over a two-year period (Dickler 1976). The RBB was reported as a new pest of apple trees in British Columbia Canada in 2006 (Philip 2006).

The RBB was first discovered in the Ash-Shoubak area of Jordan in the late 1980's (Al-Antary *et al.* 2004), the country's most important area of commercial apple production. RBB has been observed attacking apple trees in neighboring Egypt (Abd Elkader and Zaklama 1971) but its presence in Jordan is the first record of this species in Asia. In 2003, all sixteen commercial Jordanian apple orchards screened for the RBB were found to have at least one cultivar of apple trees infested (Ateyyat *et al.* 2005). The RBB is not found in apple orchards in northern Jordan and this difference may be attributed to the increasing use of clonal, size-controlling rootstocks in high-density orchards in the Ash-Shoubak region (Balazs *et al.* 1996). A similar situation was recorded in eastern North America where the dogwood borer, *Synanthedon*

[1] Department of Agricultural Sciences, Ash-Shoubak University College, Al-Balqa' Applied University, Al-Salt 19117, Jordan
[2] Department of Plant Protection, Faculty of Agriculture, The University of Jordan, Amman, Jordan
[3] To whom correspondence should be addressed: e-mail: ateyyat@bau.edu.jo

scitula (Harris), has become increasingly important as it infests burr knots on the rootstock of trees planted in high-density orchards (Riedl *et al.* 1985, Warner and Hay 1985, Weires 1986, Pfeiffer and Killan 1999, Kain and Straub 2001). Burr knots are the result of many partially developed initials that form just below the graft union on some dwarfing and semi-dwarfing rootstocks (Rom 1970, 1973). These burr knots appear to be preferred ovipostion sites for female sesiid moths including the RBB (Dickler 1976, Riedl *et al.* 1985, Warner and Hay 1985, Kain and Straub 2001). Generally, sesiid borers cause a slow decline and reduced yields over several years of infestation due to girdling resulting from larvae feeding in the cambial layer (Weires 1986, Bergh and Leskey 2003)

There is little documented research on control measures for RBB. Sontgen and Sengonca (1988) recorded a low level of larval parasitism in Germany, and Deseo and Miller (1985) achieved control of RBB larvae using entomopathogenic nematodes, *Steinernema* spp. in apple orchards trials in Northern Italy.

The main objective of this work was to study the effect of four management practices on populations of RBB. These practices included: (1) destruction of larvae using a flexible wire, (2) painting lower tree trunks with a mixture of water, copper sulfate, petroleum oil, and Durusban® (chlorpyriphos), (3) covering the graft-union area with soil, and (4) wrapping the trunk of trees from the soil surface up to 80 cm of height with a cloth veil. These methods could be helpful in establishing an integrated management program for this destructive insect. The spatial distribution of the RBB within individual trees was also studied.

MATERIALS AND METHODS

Management practices. The influence of four management practices on numbers of RBB larvae was studied on 10-year old apple trees, *Malus domestica cv.* Mondial Gala grafted on M26 rootstock, in Al-Hashlamoun apple orchards (about 120,000 apple trees) in the Ash-Shoubak area 220 km south of Amman, Jordan (elevation ca. 1300 m above sea level). These practices were: (1) use of a flexible wire (40 cm long, 2 mm thick) to mechanically kill, by either twisting or probing the wire, all available larvae of the insect that could be seen on infested wounds or in holes that showed signs of infestation; (2) painting the trunk of trees with a mixture of water, copper sulfate, petroleum oil, and Durusban® (chlorpyriphos) (4 L, 2 kg, 2 L and 40 cc, respectively) from its base up to a height of about 80 cm to poison larvae; (3) a cheese cloth (0.25 mm^2 mesh) veil wrapped once around the main tree trunk from its base up to a height of 80 cm and secured with two thick threads at the base and top; and (4) mounding soil to cover the graft union area. Control trees were not subjected to any practice.

Orchardists were requested not to interfere with any practice so as to keep the selected trees as comparable as possible. All treatments were applied once in July 2003, except the wire treatment that was used monthly. Numbers of larvae were recorded monthly from July 2003 to June 2004. The orchard was subdivided into eight plots. Each plot contained a mixture of apple cultivars grafted on various rootstocks. Treatments were distributed according to a randomized complete block design. Each plot was considered as a block and one tree was selected in each block for each treatment. All treated and control trees were pruned in February 2003 and 2004. Some RBB larvae could be seen directly on the wounds. Parts of the bark that showed signs of infestation were cut, the larvae counted and the wound resealed. Field lenses were used to count early larval instars.

Spatial distribution of larvae within trees. This experiment was conducted on 10-year old apple trees, *M. domestica cv.* Mondial Gala grafted on M26, MM106 and

M9, in Al-Hashlamoun apple orchards. Three plots from the orchard were chosen for conducting the experiment. Each plot was considered as a block. Three trees were chosen randomly from each rootstock. One tree was considered as an experimental unit. Experimental trees were subdivided into three parts, trunk, main lateral and sub-main lateral branches. Also, the trunk was subdivided into three parts that were, 0-25 cm above soil, 26-50 cm above soil, and 51-75 cm above soil. The numbers of RBB larvae were recorded using protocol previously described for management trials, on each tree section in July, August and September 2004.

Statistical analysis. An analysis of variance was used to evaluate data (SAS 2001) after data were exposed to the univariate test of normality. Repeated measures ANOVA was used to analyze the main effects of treatments. Mean separation was made by using Least Significant Differences test (LSD).

The diameter of trunk, main laterals and sub-main laterals of the studied trees was measured using a measuring tape and the Table Curve 2D version 4 Program (Jandel Scientific 1992) was used to find the most suitable equation that describes the relationship between distribution of insect larvae and the diameter of trunk, main laterals and sub-main laterals.

RESULTS

Management practices. Mean numbers of RBB larvae found during monthly examinations from July 2003 through June 2004 on a Mondial Gala apple cultivar grafted on M26 rootstock are presented in Figure 1. During the July 2003 pre-treatment examination there were no significant differences in the numbers of RBB larvae found on treated and control trees. All the tested treatments caused a signifi-

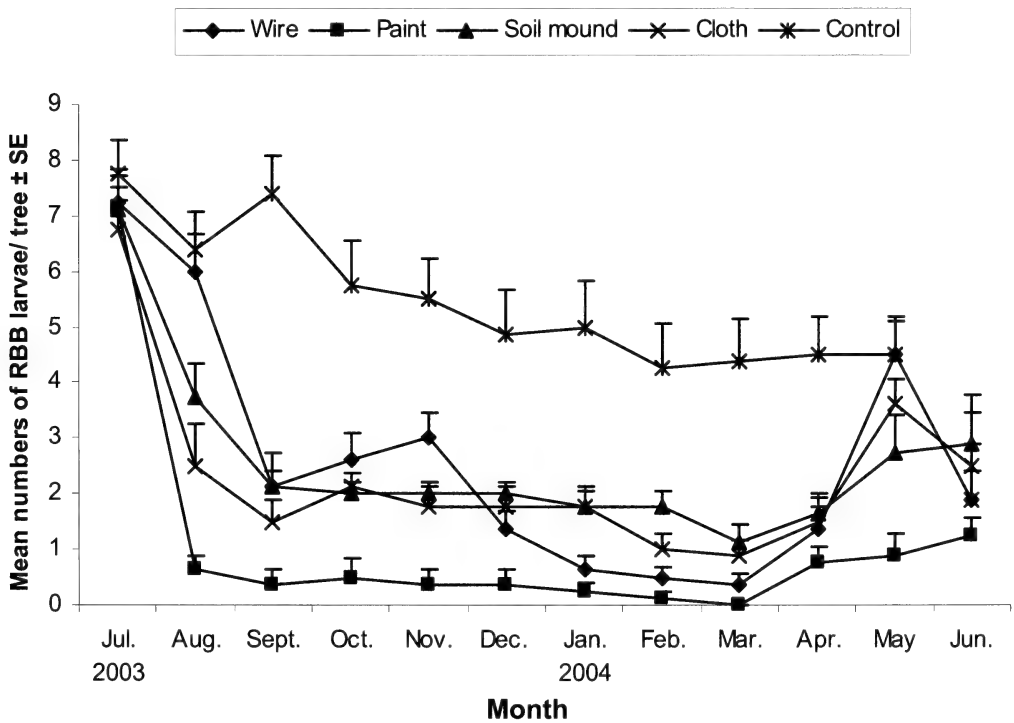

Figure 1. Mean numbers of RBB larvae found during monthly examinations from July 2003 through June 2004 and the effect of the management treatments on a Mondial Gala apple cultivar grafted on M26 rootstock.

Table 1.

Impact of management practices on the mean numbers of small red-belted clearwing borer, *S. myopaeformis* larvae from July 2003 to June 2004 on a Mondial Gala apple cultivar grafted on M26 rootstock. Treatments included (1) using a flexible wire to mechanically kill the larvae, (2) painting the trunk of trees with a mixture of water, copper sulfate, petroleum oil, and Durusban® (chlorpyriphos), (3) mounding soil to cover the graft union area and (4) a cloth veil wrapped around the main tree trunk from its base up to a height of 80 cm. Replicated 8 times, n=1.

Treatment	Mean number of larvae from July 2003 through June 2004	
	July 2003 (Pre-treatment)	Overall efficacy (Post-treatment)
Wire	7.25 a[1] ± 0.59	2.21 b ± 0.23
Paint	7.13 a ± 0.40	0.64 c ± 0.14
Soil mound	7.13 a ± 0.58	2.16 b ± 0.22
Cloth	6.75 a ± 0.53	1.89 b ± 0.28
Control	7.75 a ± 0.59	4.76 a ± 0.37

[1] Means within the same column that have the same letters are not significantly different using Least Significant Differences LSD

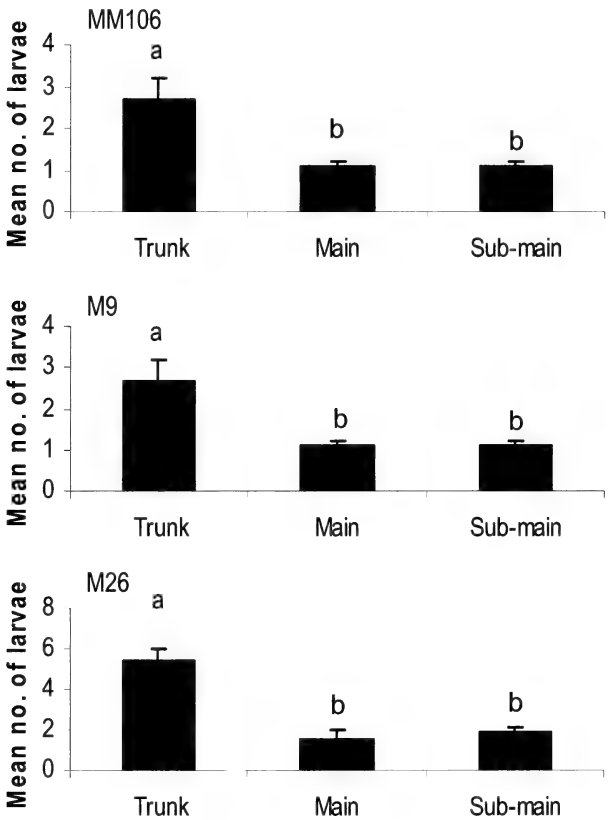

Figure 2. Within-tree spatial distribution of the small red-belted clearwing borer, *S. myopaeformis* larvae infesting the trunk, main and sub-main laterals of Mondial Gala apple cultivar grafted on MM106, M9 and M26 apple rootstocks. Means with the same letters are not significantly different using LSD.

cant reduction in the populations of this insect in subsequent samples (F = 19.63; df = 4, 35; P = 0.0001) (Fig. 1, Table 1) and the insecticidal paint treatment caused the greatest reduction (Table 1).

Within-tree spatial distribution of larvae. The numbers of larvae recovered in samples of the trunk, main and sub-main lateral branches of Mondial Gala apple cultivar grafted on MM106, M9 and M26 apple rootstocks are presented in Figure 2. RBB larvae were most often recovered from the trunks of trees compared with numbers found on the main and sub-main lateral branches (MM106: F = 8.60; df = 2,6; P = 0.0173; M9: F = 25.13; df = 2,6; P = 0.0012; M26: F = 15.10, df = 2,6; P = 0.0046) (Fig. 2). Within these trunk samples however, there were no significant differences in the numbers of larvae recovered from different subsections (0-25, 26-50 and 51-75 cm above soil surface) of the trunks on trees grafted onto MM106 rootstocks (Fig. 3), but on trees grafted onto M26 rootstocks the upper sample of the trunk contained significantly fewer larvae than the middle and lower portions of the trunk (F = 5.61; df = 2,6; P = 0.0423) (Fig. 3). No significant relationship was found between the number of larvae recovered and the diameter of the trunk, main or sub-main lateral limb they were recovered from.

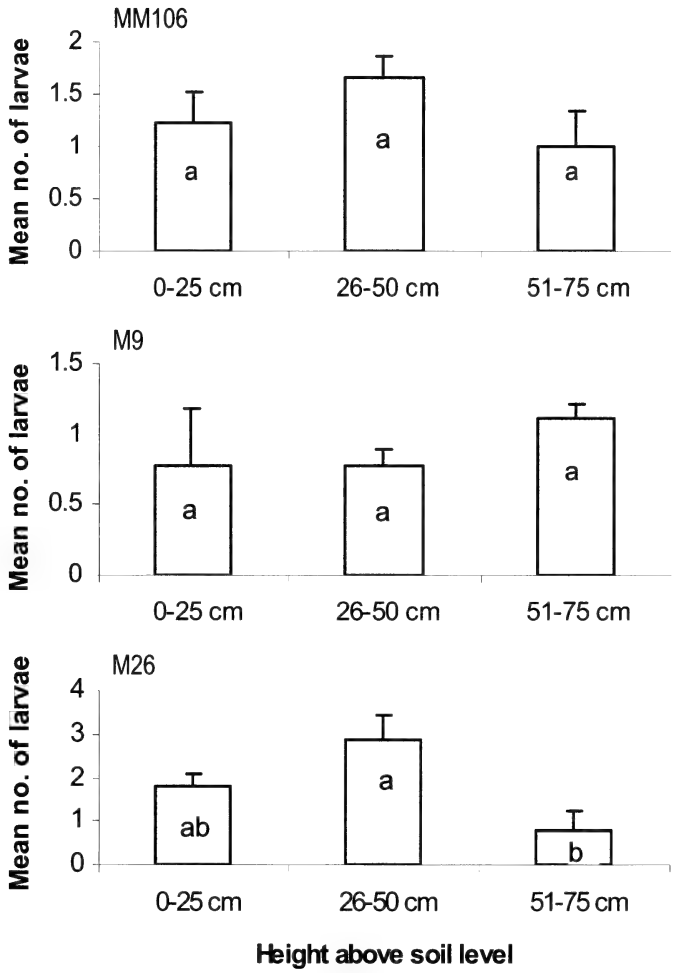

Figure 3. Within-tree spatial distribution of the small red-belted clearwing borer, *S. myopaeformis* larvae infesting the trunk of Mondial Gala apple cultivar grafted on MM106, M9 and M26 apple rootstocks at three different heights above soil. Means with the same letters are not significantly different using LSD.

DISCUSSION

In the present study, one application of an insecticidal paint composed of a mixture of Durusban (organophosphate insecticide), petroleum oil and hydrous copper sulfate caused a significant reduction in this insect for at least one-year. The other management practices had significant, but less impact on larval numbers. There are also disadvantages to their use. Using wire to mechanically control larvae is laborious and it is difficult to remove all larvae that can infest not only the trunk, but also main and sub-main lateral branches. Mounding soil and wrapping a veil of cloth around the exposed rootstocks will probably not prevent oviposition on main and sub-main branches. Young and Tyler (1983) showed that mounding soil around the exposed rootstock promoted the development of roots from burr knots. Riedl *et al.* (1985) reported that burying rootstocks with infested burr knots prevented the emergence of dogwood borer adults and further infestation of them. In the present study, it was found that some rootstocks such as M26 harbored more larvae of *S. myopaeformis* on portions of the trunk that were above the graft union (26-50 cm). This semi-dwarfing rootstock was noticed to have more burr knots at this portion of the trunk. Young and Tyler (1983) recommended that apple trees propagated on clonal rootstocks should be grafted no higher than 20-25 cm above the nursery roots, or that the new trees be planted deep in the soil to control dogwood borer. This would not entirely resolve the problem of *S. myopaeformis* infestation of burr knots as some cultivars of apple propagated on clonal rootstocks (such as MM106, M9 and M26 in the present study) tend to produce burr knots on the trunk and scaffold limbs, and these are also subject to infestation by the RBB. Earth and cloth guards to prevent the insect from ovipositing on the trunk may prevent already present RBB from emerging as adults but may also protect already present eggs and larvae from predation and parasitism and create optimal conditions for their development.

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Temperature, irradiation and delivery as factors affecting spring-time flight activity and recapture of mass-reared male codling moths released by the Okanagan-Kootenay sterile insect programme

GARY J.R. JUDD[1,2] and MARK G.T. GARDINER[1]

ABSTRACT

Laboratory flight-tunnel and field mark-release-recapture experiments were conducted to compare pheromone response, flight activity and recapture of wild codling moths, *Cydia pomonella* (L.), with codling moths mass-reared by the Okanagan-Kootenay Sterile Insect Release Programme. These experiments were designed to identify factors that may contribute to poor pheromone trap catches of sterile moths in the spring. Irradiation (250 Gy) had no influence on catches of mass-reared moths in pheromone traps at spring (16 °C) or summer temperatures (25 °C) in flight-tunnel assays. In field experiments however, recapture of mass-reared and wild moths in pheromone traps was significantly reduced after irradiation, suggesting effects of irradiation were modified by additional factors acting in the field. Catches of mass-reared moths in flight-tunnel assays showed a nonlinear increase with increasing temperature. There was no evidence that mass-reared moths were less responsive to pheromone at low temperatures than wild moths. Based on *x*-intercepts of linear regressions of percent catch *vs.* temperature (15 – 25 °C), flight-temperature thresholds for mass-reared (14.7 °C) and wild moths (15.4 °C) were similar in flight-tunnel assays. Irradiated moths carried for 4 h on all-terrain vehicles used for delivering sterile moths were less responsive to pheromone lures in subsequent flight-tunnel assays than moths that spent no time on these vehicles, but only when flown at spring-like temperatures (16 °C). In field tests, moths released on the ground were caught significantly less often than moths released within the tree canopy and negative effects of ground release appeared greater when made in spring compared with autumn.

Key Words: Codling moth, sterile insect technique, sterile:wild ratios, flight-temperature thresholds, flight tunnel tests, mark-recapture tests

INTRODUCTION

The Okanagan-Kootenay Sterile Insect Release (SIR) Programme was initiated in 1992 to eradicate codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), from montane fruit-growing regions in British Columbia (BC). Dyck *et al.* (1993) designed this SIR Programme with three phases: (1) pre-release sanitation (two years), (2) sterile moth release (three years), and (3) surveillance monitoring and protection (open-ended). The objective of phase 2 was to deliver sufficient sterile moths each week to maintain ratios of ca. 40 sterile (S) to 1 wild (W) male moth in pheromone trap catches for the entire season. This 40:1 ratio was deemed necessary if sterile moths were going to reduce wild populations to near extinction in three years (Proverbs *et al.* 1982, Dyck *et al.* 1993).

Following a pre-release sanitation pro-

[1] Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, 4200 Hwy 97, Summerland, British Columbia, Canada, V0H 1Z0
[2] Author to whom correspondence should be sent (email: juddg@agr.gc.ca)

gramme that extended from Osoyoos to Summerland and included the Creston and Similkameen Valleys (49° 34′ N Latitude - 119° 39′ W Longitude), sterile moths were released area-wide in May 1994. SIR Programme trapping data (1994 - 2004) indicates that since 1994, S:W ratios have rarely reached 40:1 in the spring, often failing to reach 10:1, whereas target ratios were usually achieved in the summer (Thistlewood *et al.* 2004). Consistently low S:W ratios in the spring have delayed population suppression, made supplementary controls necessary and increased programme costs (Thistlewood and Judd 2003, Judd *et al.* 2004, Judd and Gardiner 2005). In recent years the focus of the programme has changed from eradication to management, but because sterile moths continue to be the primary control tactic in spring, improvements in programme delivery are needed to make it economically sustainable (Dendy *et al.* 2001). Understanding the factors that contribute to inactivity of sterile moths in the spring may lead to corrective action and improve the economics of the programme.

Bloem and Bloem (1996) hypothesized that cool weather was largely responsible for suboptimal S:W ratios in the spring, implying mass-reared moths fly poorly at low temperatures. Although normal seasonal increases in temperature and recapture rates of sterile males are correlated, a clear cause and effect relationship between temperature and flight activity of sterile moths has never been demonstrated (Judd *et al.* 2004). In nearly all studies where the activity of sterile moths in relation to temperature has been discussed, catches in pheromone traps have been used to measure this activity (Hutt 1979, Rogers and Winks 1993, Bloem *et al.* 1998, 1999, 2004, Judd *et al.* 2004). Interpreting these data is difficult because several factors are confounded. For example, mass-reared codling moths may fly poorly at cool temperatures, but it is equally plausible that mass-reared moths have undergone behavioural changes related to pheromone communication that are only expressed under cool spring temperatures. Also, as none of the above studies measured the relative effects of irradiation or ground release on trap catches, or included similarly-treated wild moths, any adverse effects of mass-rearing can not be separated from interacting effects of irradiation, handling and release techniques.

Our objective was to identify factors that might contribute to poor activity of sterile moths in the spring in an effort to take corrective action to improve S:W ratios in the operational SIR Programme. We undertook studies to specifically examine the effect of air temperature on pheromone response of mass-reared codling moths relative to wild moths and to determine if temperature modified any effects of irradiation and handling. In this study we use field mark-release-recapture tests to assess activity of codling moths (Bloem *et al.* 1998), but also use a laboratory flight tunnel because we wanted to isolate effects of temperature on activity and pheromone response without the confounding effects that field experiments impose.

MATERIALS AND METHODS

Test insects. Wild codling moths used in these experiments were collected as diapausing larvae from several organic apple orchards in the Similkameen Valley. Corrugated cardboard bands were wrapped and stapled to trunks of apple trees in July to capture overwintering, diapausing fifth instar larvae (Judd *et al.* 1997). Bands were removed from orchards in early October and transferred to an outdoor screen house at the Pacific Agri-Food Research Centre (PARC) in Summerland. They were held there in plastic garbage bags until March of the following year, when they were placed in a 0.5 °C growth chamber in total darkness. Wild larvae were brought out of cold storage as needed for experiments and set up in emergence cages held in environmental chambers at 27 °C under a 16:8 h Light:Dark (L:D) photoregime.

All mass-reared codling moths used in these experiments were produced by the Okanagan-Kootenay rearing facility in Osoyoos, BC as described by Bloem and Bloem (2000). For experiments requiring non-irradiated moths, trays of artificial diet (Brinton *et al.* 1969) containing mature larvae were provided by the Osoyoos rearing facility as needed and transferred to an environmental chamber at PARC where they were held at 27 °C under a 16:8 h L:D photoregime. Mature pupae were removed from the diet, sexed and placed individually in 30 ml plastic cups provided with wet cotton wicks until moths eclosed. Male and female moths from all sources were isolated in separate environmental chambers maintained at 27 °C and 65% relative humidity with 16:8 h L:D photoregime before testing.

Irradiated, mass-reared moths were obtained from the SIR Programme's Osoyoos rearing facility. Moths were collected in adult emergence rooms (27 °C) after flying out of diet trays towards UV lights located on the ceiling. Vacuum hoods adjacent to UV lights drew moths through pipes into a collection room maintained at 2 °C. Chilled moths were then packaged by weight into plastic petri dishes in which they were irradiated. Moths were sterilized by exposure to 250 Gy (11.5 - 13.2 Gy min^{-1}) of gamma radiation from a $Cobalt^{60}$ source (Gammacell 220, Nordion, Canada). After irradiation petri dishes were loaded into a refrigerated trailer (4 °C) and trucked to area drop-off points. There they were placed either in temporary storage facilities (4 °C) awaiting pickup by delivery drivers, or directly into coolers (6 - 8 °C) on the back of all-terrain vehicles (ATVs) outfitted with moth-dispensing units (McMechan and Proverbs 1972). Irradiated moths destined for release were moved from ATV coolers and placed in a small hopper on the front of the ATV, where a small fan unit dispensed moths by gently blowing them onto the ground beneath trees. In some cases sterile moths spent up to 4 h in the release-vehicle cooler before being dispensed at the end of a delivery route. Moths used in this study were collected after delivery to field cold-storage units, or after being carried by drivers on moth-release vehicles for 4 h.

Flight-tunnel procedures. A pushing-type flight tunnel described in detail by Judd *et al.* (2005) was used to assess behavioural responsiveness of male codling moths to sex pheromone sources in clean air. An air conditioning unit attached to the air intake vent at the upwind end of the tunnel allowed us to achieve flight temperatures of ca. 10 - 25 °C in the tunnel. Detailed description of moth handling procedures and experimental protocols for flight-tunnel assays are described by Judd *et al.* (2005). Pheromone lures used in flight-tunnel experiments were made from red rubber septa (Aldrich Chemical Company Inc., Milwaukee, Wisconsin) loaded with 200 µl of dichloromethane containing 10 µg of the codling moth sex pheromone (*E*,*E*)-8,10-dodecadien-1-ol, known as codlemone (99% isomeric and chemical purity, Shin-etsu, Fine Chemicals Division, Tokyo). Septa were air dried for ca. 18 h at 23 °C in a fume hood and stored in sealed jars at 0 °C until used.

Mark-release-recapture techniques. Before each field release and some laboratory assays, moths were chilled for 10 min in a cold room (0.5 °C) and dusted lightly with Day-Glo® Daylight Fluorescent Powders (Switzer Brothers Inc., Cleveland, Ohio, USA). Different coloured powders were used to distinguish groups of moths treated, handled or released differently. Marked moths were placed in plastic petri dishes or 60 ml plastic cups and transported to field sites in ice chests. Dishes or cups were opened in the field and moths took flight under their own capacity. Pherocon 1-CP style, sticky, wing traps (Phero Tech Inc., Delta, BC), baited with similar 10 µg lures as used in flight-tunnel experiments, were used to recapture moths. The 10 µg lure load was chosen because it releases codlemone at a rate similar to an individual female codling moth (Bäckman 1997) and has the advantage of being both attractive in the field, at least for short periods of time, and the flight tunnel, the latter of which is

not true of standard 1 mg field monitoring lures. When experiments were completed traps were returned to PARC where exposure to UV light revealed the fluorescent dusts and moths were counted.

Flight Tunnel Tests

Experiment 1: effects of irradiation on pheromone response. Responses of irradiated (250 Gy) and non-irradiated, mass-reared codling moths to pheromone lures in flight-tunnel experiments were assessed at 16 and 25 °C, temperatures typical of dusk in the spring and summer respectively. On each of seven flight days, uniquely-marked (as above) groups of 9 - 10 irradiated or non-irradiated moths were flown in random order at one of the two randomly assigned temperatures. The percentage of moths caught in a pheromone-baited trap within a 30 min period was recorded, then the other group was flown, after which the temperature was changed and the process repeated. Moth catches were expressed as proportions (p) and transformed using arcsine $\sqrt{p}$. Mean recapture rates for each treatment combination were calculated and compared using a two-way (flight temperature, radiation treatment) analysis of variance (ANOVA) with a temperature × irradiation interaction term in the model. Significance of each factor in the model was tested using an F-test. All statistical analyses were performed with an α value of 0.05 using SigmaStat® (Version 3.0, SYSTAT Software Inc., Richmond, CA).

Experiment 2: effects of air temperature on pheromone response. Pheromone responses of non-irradiated, mass-reared moths and apple-reared wild moths emerging from diapause, were compared in the flight tunnel at 15.5, 17.5, 19 and 25 °C following a randomized block design. On each of 5 flight days (blocks), uniquely-marked groups of 11 - 15 mass-reared and 11 - 15 wild males were flown simultaneously from the same release cage described by Judd *et al.* (2005) at one randomly assigned temperature. The percentages of each moth type caught in a pheromone-baited trap within a 30 min test period were recorded. Temperature was adjusted and the procedure repeated until catch at all four temperatures was evaluated on a given day. Percentage catch for each moth type was plotted against temperature. Linear regression (SigmaStat®) was used to estimate the lower threshold temperatures for pheromone-mediated flight based on the x-intercepts of these lines. A t-test was used to compare slopes of regression lines (Zar 1984).

To verify the lower-temperature flight threshold for mass-reared moths we conducted a set of six additional flights with groups of 17 - 45 mass-reared moths at 13, 14, 14.5, and 15 °C. A one-way ANOVA and Student-Newman-Keuls' multiple comparisons test were used to compare mean (n = 6) percentage capture at each of these temperatures (SigmaStat®).

Experiment 3: effects of handling time in moth release vehicles. Irradiated codling moths were collected at two different points in the moth distribution process used by the SIR Programme. Moths were obtained at noon on each of 10 days after they were delivered by a refrigerated truck and placed in a storage refrigerator at a drop-off depot in Summerland. One petri dish of irradiated moths was removed from the storage fridge and labelled ATV - 0 - h. A second petri dish labelled ATV - 4 - h was removed from a cooler on the back of an ATV which had just returned after four hours of field deliveries. Labelled petri dishes were returned to PARC where moths were sexed and counted in a 0.5 °C cold room. Fifty males were placed in each of several 11.4 L plastic buckets and held overnight at 27 °C in an environmental chamber under a 16:8 L:D photoregime. The following day moths were chilled for 10 min at 0.5 °C, placed individually into release cages described by Judd *et al.* (2005) and transferred to the flight-tunnel room 15 min before scotophase. Following a randomized block design, on each of 10 flight days (blocks), moths from each treatment group (ATV- 0 h and ATV- 4 h) were flown individually in random order at one of two randomly assigned temperatures

typical of spring (16 °C) and summer (25 °C); one moth from each of the two handling times was flown in every two flights. Each moth was placed downwind from a 10 µg pheromone lure and given 2 min to fly upwind and make contact with the lure. After flying 7 - 18 moths from each treatment group the temperature was reset and the process repeated.

On a given test day the percentages of each moth type making contact with the pheromone lure at each temperature were calculated. Percentage data were transformed by arcsine $\sqrt{p}$ and mean rates of source contact at each temperature, for each handling treatment, were compared using a two-way (flight temperature, moth handling treatment) ANOVA with a temperature × handling interaction term in the model. Significance of each factor in the model was tested using an F-test.

Field Tests

Experiment 4: effects of irradiation on pheromone trap catches of mass-reared and wild moths in the field. A mark-release-recapture field experiment was conducted in September to assess the effects of irradiation on rates of moth recapture in pheromone traps. Mass-reared codling moths (from trays of diet provided by the Osoyoos facility) and diapausing wild moths emerged in our laboratory as described in the test insect section above. Two- to three-day-old moths were transported to the Osoyoos rearing facility, where one half of each moth type was irradiated with 250 Gy and the other half remained non-irradiated to serve as a control group. This procedure provided four moth treatment groups: irradiated and non-irradiated, mass-reared and wild moths, respectively. After irradiation, moths were returned to PARC, chilled (0.5 °C) and each of the four moth treatment groups was uniquely marked as before. One moth release device, as described by Judd et al. (2006a), and containing 24 moths of one treatment was hung within the canopy of each of the four corner trees in a 32 × 32 m square release area located near the centre of a mixed-variety apple orchard having a 3 m tree × 4.6 m row spacing and an average tree height of 3 m. Four wing traps, each loaded with 10 µg of codlemone, were hung ca. 1.5 - 2 m above ground in the central tree of this release area. One trap was placed in each cardinal sector of the central tree. After one week, traps were returned to PARC and marked moths caught were identified under UV light. Catches of each moth treatment group in all four traps within a given orchard (replicate) were summed and used to calculate the percentage recapture. This entire procedure was repeated in four independently replicated releases in different orchards. Percentage recapture data were transformed by arcsine $\sqrt{p}$ and analyzed using a two-way (moth type, irradiation treatment) ANOVA model containing a moth type × irradiation treatment interaction term. Significance of each factor in the model was tested using an F-test.

Experiments 5 - 7: effects of ground release on moth recapture. Experiments 5 and 6 were preliminary tests designed to compare the rates of recapture of moths released within the tree canopy with those released on the ground beneath the same trees. Within-canopy release was used to simulate the location that recently-emerged wild moths might likely be found, and ground release was used to simulate the location that sterile moths were delivered by the SIR Programme. Uniquely-marked, irradiated, mass-reared moths were used for these experiments. Paired independent releases were conducted during September in two separate orchards and each orchard release was analyzed as a separate non-replicated experiment (5 and 6). Moths were released and recaptured in 32 × 32 m square release areas exactly as described in experiment 4, with the exception that an additional set of adult moth release devices was placed on bare soil at the base of the four corner trees in each release area. Any effects of moisture in these experiments were minimal because both releases were made during September in an absence of any irrigation and moths were released in early afternoon when dew had evaporated. Direct moth contact with the ground was

minimized by moths flying from release devices under their own power. Within each orchard (experiment), the paired proportions of ground- (p_{GROUND}) or canopy-released moths (p_{CANOPY}) recaptured out of the 128 moths released at each of these locations within each orchard, were compared using *z*-tests on two binomial proportions (Zar 1984).

In experiment 7 the effect of release location on recapture of moths was examined again but under spring temperature conditions in a series of replicated tests. Four independent but simultaneous moth releases (replicates) were made in four similar release areas and moths were recaptured in each area as described in experiments 5 and 6. The experimental sequence was to release moths during afternoons of days 1 - 3 and trap during nights 3 and 4. Traps were removed the morning of day 5 and returned to the laboratory to identify and count moths. The above mark-release-recapture procedure was repeated on four different occasions: (I) 12 - 16 May, (II) 19 - 23 May, (III) 26 - 30 May, and (IV) 2 - 6 June. In total 16 independent releases and recaptures were made. Within each five-day release-recapture test period (I - IV), 128 - 200 uniquely-marked moths were released from within the canopy of four trees and on bare dry soil beneath each of these trees in each orchard. Percentage recapture of moths from each release location (canopy *vs.* ground), within each orchard and time interval was transformed by arcsine $\sqrt{p}$. Recapture data for each time period (I - IV) were analysed separately because each time period represented an independent set of releases rather than a repeated measure on one set of releases. Within each time period mean recaptures from each release location (canopy *vs.* ground) across the four release orchards (replicates) were calculated and compared using a paired *t*-test.

RESULTS

Flight-Tunnel Tests

Experiment 1: effects of irradiation on pheromone response. Irradiation (250 Gy) of mass-reared moths had no influence ($F_{1,24} = 0.13$, $P = 0.72$) on their response to pheromone lures in flight-tunnel assays (Fig. 1). There was no interaction between temperature and irradiation treatment ($F_{1,24} = 0.10$, $P = 0.754$) indicating the effects of irradiation were the same at temperatures typical of spring (16 °C) and summer (25 °C) (Fig. 1). Temperature had a highly significant effect ($F_{1,24} = 102.69$, $P < 0.001$) on catches of mass-reared moths in this experiment (Fig. 1) and its effects were studied in more detail in subsequent experiments.

Experiment 2: effects of air temperature on pheromone response. For illustrative purposes the percentages of mass-reared moths caught in two separate tests were plotted against the complete range of temperatures evaluated in these tests (Fig. 2A). This plot suggests that the pheromone response × temperature function of mass-reared moths between 13 and 25 °C is nonlinear, but within the range of 15.5 and 19 °C it appears linear. Nonlinearity at higher temperatures is probably an experimental artifact because catches can not be greater than 100% and maximum response appears to have been reached near 19 °C (Fig. 2A). Nonlinearity at lower temperatures is an indication of a lower-temperature threshold for pheromone-mediated flight. This lower-temperature threshold seems most relevant within the context of comparing pheromone-mediated flight of mass-reared and wild codling moths and S:W trap-catch ratios.

Catches of wild codling moths in flight-tunnel assays were lower than mass-reared moths at every temperature tested (Fig. 2B). No wild moths were caught at 15 °C and only 58% were caught at 25 °C (Fig. 2B), compared with 85% catch of mass-reared moths (Fig. 2A). Linear regression was used to compare the temperature response function of the two populations of moths in flight-tunnel assays (Fig. 2B). The slopes (20.3 SIR *vs.* 5.6 Wild) of these regression lines were significantly different (*t*-test, t =

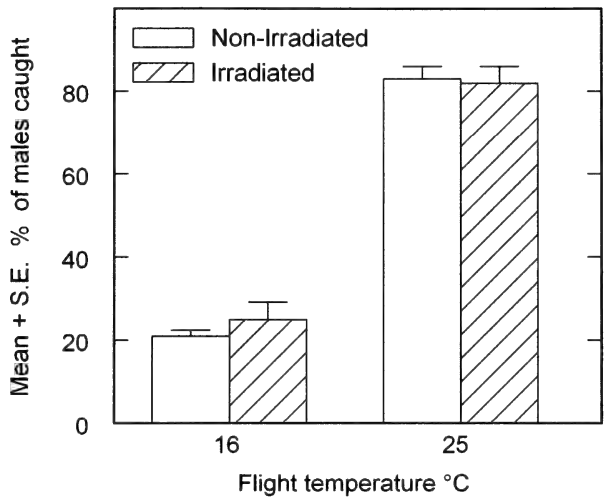

Figure 1. Mean + S.E. percentages of irradiated (250 Gy) and non-irradiated, mass-reared male codling moths caught in a synthetic pheromone-baited trap (red septum with 10 µg load) in 30-min flight-tunnel tests conducted at temperatures typical of spring (16 °C) and summer (25 °C). Two-way ANOVA indicates a significant temperature effect ($F_{1, 24}$ = 102.69, $P < 0.001$) but no significant radiation effect ($F_{1, 24}$ = 0.13, P = 0.72).

7.05, df = 26, $P < 0.001$). Similar x-intercepts suggest the lower-temperature thresholds for pheromone-mediated flight of wild (15.4 °C) and mass-reared males (14.7 °C) are similar (Fig. 2B) but no statistical test was made. The lower threshold for mass-reared moths was substantiated by our separate comparison of the percentages of mass-reared moths caught at 13, 14, 14.5 and 15 °C. In this experiment there was a significant difference in catches at 15 °C (16.3 ± 3.7%) and all other temperatures ($F_{3, 18}$ = 9.87, $P < 0.001$), but not between 14.5 °C (5.7 ± 1.5%) and all lower temperatures (SNK test, $P < 0.05$).

Experiment 3: effects of handling time in moth release vehicles. Tests examining the pheromone response of mass-reared moths at different temperatures after being carried on an ATV delivery vehicle revealed a significant temperature effect ($F_{1, 36}$ = 87.44, $P < 0.001$), but no significant handling time effects ($F_{1, 36}$ = 0.33, P = 0.57) and no significant interaction between temperature and handling times ($F_{1, 36}$ = 0.98, P = 0.33). However, when flown at 16 °C, the percentage of moths making contact with a pheromone lure after experiencing 4 h on an ATV was clearly depressed relative to contacts made by moths that spent no time on the ATV (Fig. 3). A statistical comparison isolating these two treatments found a significant reduction (two sample t-test, t = 2.62, df = 18, P = 0.022) as a result of being carried on the ATV that was not detected in moths flown at 25 °C (t = 0.67, df = 18, P = 0.95) (Fig. 3).

Field Tests

Experiment 4: effects of irradiation on pheromone trap catches of mass-reared and wild moths in the field. Irradiation significantly ($F_{1, 8}$ = 15.53, P = 0.004) reduced recapture of both mass-reared and wild codling moths relative to non-irradiated moths in a field test conducted in late September (Fig. 4). Overall catches of mass-reared and wild moths in pheromone traps were not significantly different ($F_{1, 8}$ = 0.46, P = 0.517). The effects of irradiation were independent of moth type ($F_{1, 8}$ = 0.02, P = 0.88). Irradiated, mass-reared moths were about 1.5× less responsive to pheromone traps in this field test than were the non-irradiated wild moths they compete with in a sterile insect programme (Fig. 4).

Experiments 5 - 7: effects of moth release location on recapture. In two separate non-replicated releases conducted in mid September, irradiated, mass-reared

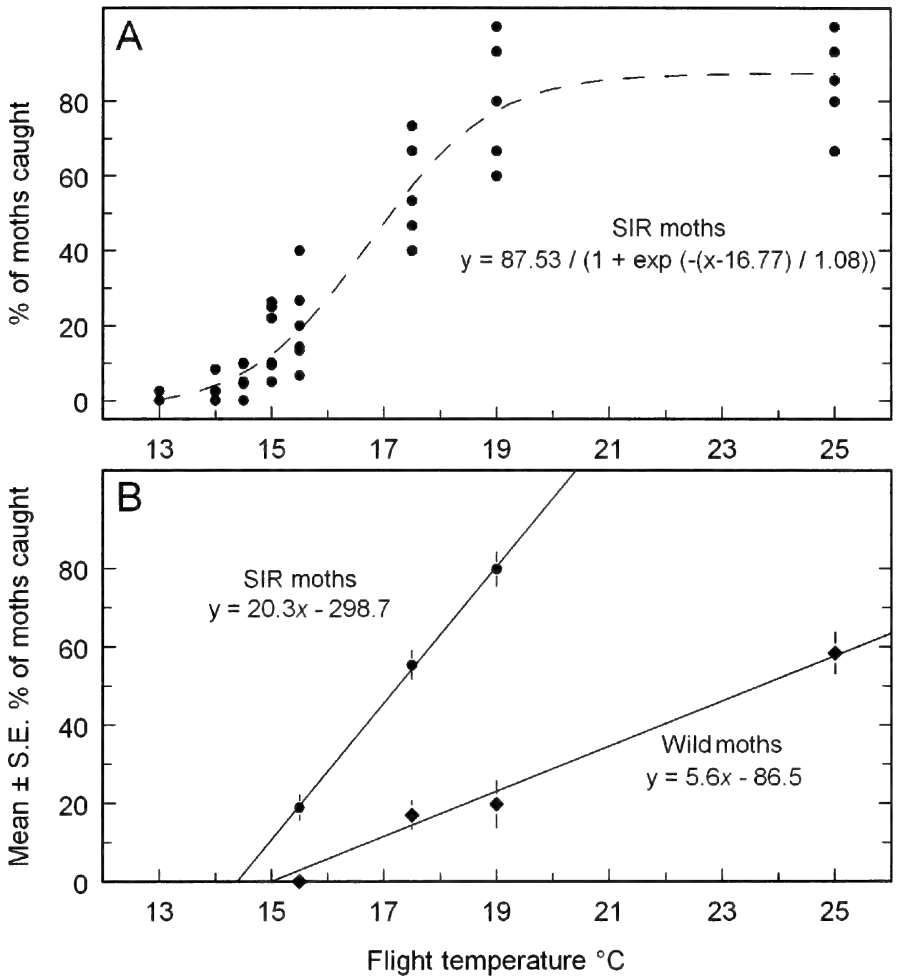

Figure 2. (A) Composite scatter plot of percentages of non-irradiated, mass-reared male codling moths (SIR moths) caught in a synthetic pheromone-baited trap (red septum with 10 µg load) in separate 30-min flight-tunnel tests conducted at different temperatures (13 - 25 °C). Dotted curve represents best-fit nonlinear regression line. (B) Plot of mean ± S.E. percentages of non-irradiated, mass-reared (SIR moths) and wild codling moths caught over temperature ranges of 15.5 - 19 °C for SIR moths and 15.5 - 25 °C for wild moths. Solid lines are best-fit least-squares linear regression lines for relationship between percentage catch and temperature (ANOVA n = 15; df =1, 13; $P < 0.001$ for each line). Slopes of regression lines are significantly different (*t*-test, t = 7.05, df = 26, $P < 0.001$).

moths released on the ground were recaptured (p_{GROUND}) significantly less often than canopy-released moths (Expt. 5: $p_{GROUND} = 0.227$ *vs.* $p_{CANOPY} = 0.435$; n = 128 moths released on ground and in canopy; $z = 3.2$, $P < 0.001$; Expt. 6: $p_{GROUND} = 0.422$ *vs.* $p_{CANOPY} = 0.601$; n = 128 moths released on ground and in canopy, $z = 2.5$, $P = 0.012$).

In replicated paired canopy and ground releases made during four weekly test periods (Fig. 5), moths released in the canopy were caught significantly more often than those released on the ground in weeks two, three and four, respectively ($t_1 = 4.19$, df = 3, $P = 0.025$; $t_2 = 15.57$, df = 3, $P = 0.001$; $t_3 = 4.81$, df = 3, $P = 0.017$). The four-week grand mean recapture rates for canopy- and ground-released moths in spring were 15.7 ± 2.4 and 4.9 ± 1%, respectively (Fig. 5).

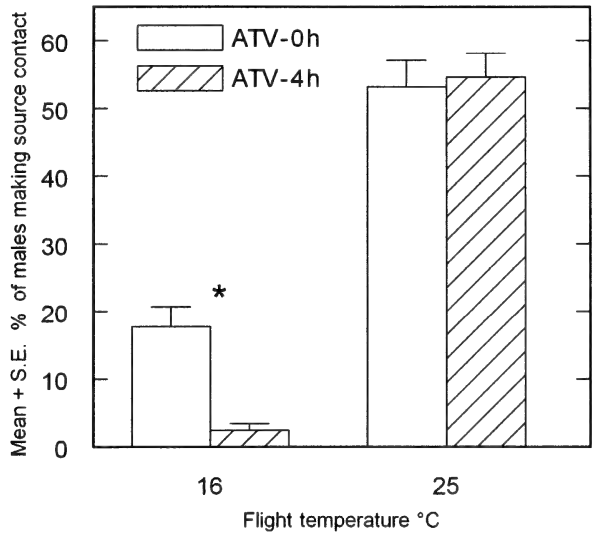

Figure 3. Mean + S.E. percentages of irradiated (250 Gy), mass-reared male codling moths contacting a synthetic pheromone lure (red septum with 10 µg load) in 2-min flight-tunnel tests conducted at temperatures typical of spring (16 °C) and summer (25 °C) after being carried for different times (0 *vs.* 4 h) on an all-terrain moth delivery vehicle (ATV). Two-way ANOVA indicates a significant temperature effect ($F_{1, 36} = 87.44$, $P < 0.001$) but no significant effect of time on an ATV ($F_{1, 36} = 0.33$, $P = 0.57$). Paired bars within a temperature grouping having an asterisk superscript are significantly different (t-tests, $P < 0.05$).

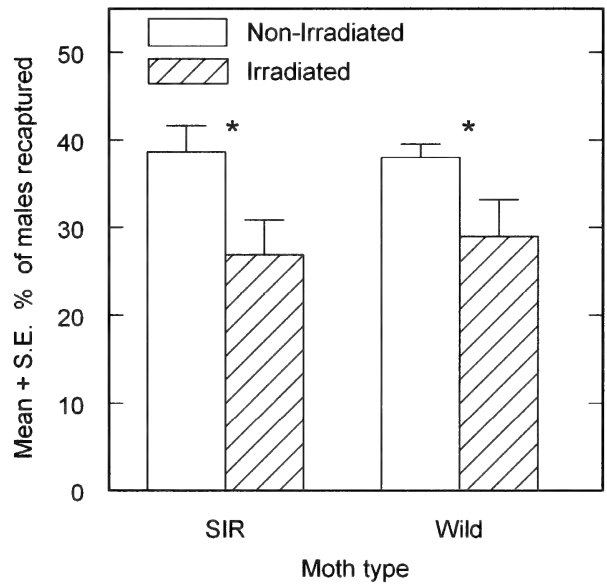

Figure 4. Mean + S.E. percentages of irradiated (250 Gy) and non-irradiated, mass-reared (SIR moths) and wild male codling moths recaptured in pheromone-baited (red septum with 10 µg load) Pherocon 1-CP wing traps after release in four apple orchards, Summerland, BC. Two-way ANOVA indicates a significant radiation effect ($F_{1, 8} = 15.53$, $P = 0.004$) but no significant moth effect ($F_{1, 8} = 0.46$, $P = 0.517$). Paired bars within a moth type having an asterisk superscript are significantly different (t-tests, $P < 0.05$).

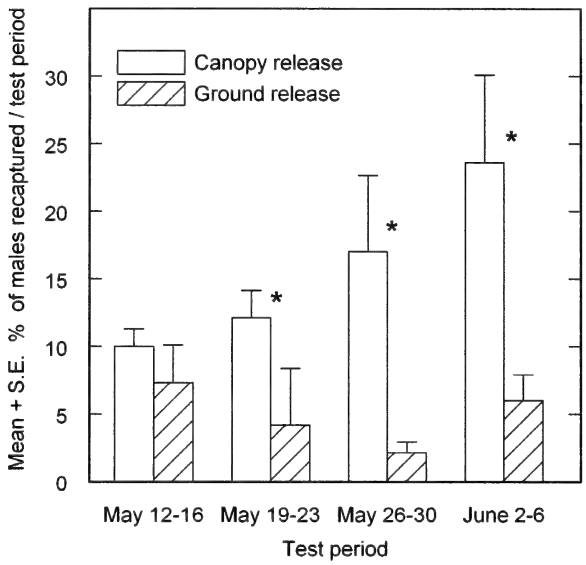

Figure 5. Mean + S.E. percentages of irradiated (250 Gy), mass-reared male codling moths recaptured in synthetic pheromone-baited traps (red septum with 10 μg load) after release on the ground or within the canopy of apple orchards, Summerland, BC. Paired bars within each weekly test period having an asterisk superscript are significantly different (t-tests, $P < 0.05$).

DISCUSSION

Our examination of flight activity and recapture of sterile, mass-reared moths released by the Okanagan-Kootenay SIR Programme has helped identify factors that contribute to low activity of sterile moths in spring (Judd *et al.* 2004). Determining the impact of various factors in a complex operational SIR Programme is challenging because many factors interact and vary irregularly across orchards and seasons. Even in controlled studies like those conducted here interpretation requires careful consideration.

Irradiation with 250 Gy did not appear to impair pheromone perception and behavioural response when moths were assayed under controlled laboratory conditions. In flight-tunnel assays, equal proportions of irradiated and non-irradiated mass-reared moths were caught in traps baited with 10 μg pheromone lures (Fig. 1). Although catches with pheromone lures were lower at 16 than at 25 °C, there was no significant difference in the proportions of irradiated and non-irradiated moths caught at each of these temperatures, respectively (Fig. 1). This lack of a significant irradiation effect on catches with pheromone traps in laboratory assays is both supported and contradicted by field studies. Bloem *et al.* (1999) made several field releases in late June, July and August and found that mass-reared moths irradiated with 250 Gy were recaptured in female-baited traps at the same rate as non-irradiated moths. Likewise, Judd *et al.* (2006a) conducted mark-release-recapture experiments in May and August and found that mass-reared moths irradiated with 250 Gy were recaptured in standard monitoring traps loaded with 1-mg codlemone lures as often as non-irradiated mass-reared moths. However, in the September study reported here (Fig. 4), we found that irradiation did cause a reduction in recapture of both mass-reared and wild codling moths in traps baited with 10 μg lures.

The conclusion we draw from these various data sets is that small spring-time catches of sterile moths in pheromone traps is not caused by radiation-induced impairment of the olfactory system. If it was, this

very direct effect should show up consistently across laboratory and field tests, since the radiation treatment is the one factor that remains consistent across studies. It seems more likely that irradiation has an indirect effect on pheromone response, probably by reducing general flight activity and dispersal, which might reduce the frequency with which sterile moths encounter pheromone plumes in the field. When placed directly in pheromone plumes the irradiated moths appear as responsive to pheromone sources as do non-irradiated moths. If the effects of irradiation are mainly to reduce moth activity, then variable environmental test conditions that also affect activity, could easily explain the varied impact of irradiation in different field studies. The other factor that could come into play in different studies is the quality of the non-irradiated moths used in comparison with irradiated moths. Judd *et al.* (2006a) found that non-irradiated mass-reared moths were recaptured ca. 4× less often than non-irradiated wild moths released under identical conditions, and S:W trap-catch ratios were as low as those observed by the SIR Programme in the spring. The recapture of non-irradiated moths was so poor in that study that irradiation contributed little effect. The effects of irradiation on the activity of sterile moths in the spring are obviously complicated by external interactions not yet fully understood.

Temperature had a significant effect on the response of codling moths to pheromone lures in all flight-tunnel assays (Figs. 1, 2 & 3), however, the hypothesis that mass-reared moths fly less frequently at low temperatures than wild moths was not supported by our data (Fig. 2). Our estimated lower-temperature threshold for pheromone response of mass-reared codling moths was 14.7 °C, while the established lower-temperature threshold for pheromone trap catches of wild codling moths in the field is 15.6 °C (Reidl *et al.* 1986) and for wild codling moths in flight-tunnel assays it was 15.4 °C (Fig. 2). Therefore, an inability of sterile moths to engage in pheromone-mediated flight at low temperatures is probably not responsible for their low catches in pheromone traps during spring.

While we were unable to demonstrate any effect of mass-rearing on temperature thresholds for pheromone-mediated flight, our assays would not necessarily detect differences in the response of wild and mass-reared moths to temperature transitions that are common in the field. In spring, temperatures often decline very quickly before the normal dusk flight period (Judd *et al.* 2006a,b). These temperature transitions stimulate an earlier release of pheromone by female codling moth (Castrovillo and Cardé 1979) and an earlier male response to pheromone (Batiste *et al.* 1973, Song and Reidl, 1985). Judd *et al.* (2006a) demonstrated that during temperature transitions wild male codling moths mated significantly earlier than mass-reared moths, suggesting wild moths have an earlier or quicker response to pheromone while temperatures are declining.

Even if mass-rearing has no affect on temperature thresholds for pheromone-mediated flight, it could be affecting temperature thresholds for general activity or dispersal from release locations. While the mass-rearing system currently used by the SIR Programme incorporates flight of moths as part of its collection and rearing process, this flight occurs in response to UV light at 27 °C (Bloem and Bloem 2000). Moths that do not respond well to UV light or are inactive at 27 °C are excluded from the rearing system because they never get collected. This collection system could inadvertently select for different activity thresholds. It would be interesting to compare the response of wild and mass-reared moths to UV lights at temperatures closer to the pheromone-mediated flight threshold in order to determine whether mass-reared moths have undergone more general changes in activity. Differences of this type between wild and mass-reared moths could be an important factor causing low S:W ratios and deserves examination.

While there may not be an obvious difference in the flight-temperature threshold for wild and mass-reared moths, the tem-

perature profiles to which they are both exposed in the field is likely quite different. Many wild moths emerge on the bark within the canopy of host trees, and ambient temperatures on the bark are often greater than air or ground temperatures (unpublished data). Unlike wild moths which warm naturally as part of a temperature-regulated emergence process, sterile moths are chilled, up to 48 h in some cases, before being dispensed onto cold ground. Some moths spend an additional 4 h in a cooler on an ATV before being dispensed. Moths that were carried on an ATV for 4 h were somewhat less responsive to pheromone in flight-tunnel assays conducted at spring temperatures than were moths not carried on the ATV (Fig. 3). In field experiments conducted in the spring, ground-released moths were recaptured ca. 3× less often than canopy-released moths (Fig. 5). It seems plausible therefore that ground delivery of chilled moths in combination with cool soil temperatures is contributing significantly to reduced flight activity of sterile moths in spring. If sterile moths released in the spring spend a greater period of time on the ground than those in summer, they may be more susceptible to predation. Predation could significantly reduce the effective number of sterile moths flying up into the orchard canopy. The degree to which sterile moths are preyed upon and seasonal differences in predation rates have not been studied but probably should be.

Producing good quality insects is obviously one of the most important components of a robust sterile insect programme (Huettel 1976). Over time the Okanagan-Kootenay SIR Programme has made a number of improvements in moth quality by shortening the time moths spend in cold storage before being shipped to the field and decreasing the time moths spend on ATVs. The programme has also reduced radiation doses from the original 350 to 250 Gy (Dyck *et al.* 1993, Bloem and Bloem 2000). Nevertheless, spring S:W ratios in this operational programme have remained far below the 40:1 target ratio even though the numbers of sterile moths being released has increased over time. Because of increasing costs, inadequate S:W ratios and slower than expected population declines, the use of sterile moths as a management tool for area-wide control of codling moth in BC is subject to continuing discussion (Dendy *et al.* 2001, Thistlewood and Judd 2003). Based on current technology we recently concluded that the most effective use of sterile moths in an area-wide codling moth control programme was to restrict delivery to summer and augment control by applying other tactics in spring (Judd and Gardiner 2005). Results presented here suggest that significant improvements in the quality of sterile moths and increases in S:W ratios might be gained by changing the delivery system. Aerial release seems a logical alternative but has its own difficulties in a highly-urbanized mountainous valley system. Development of a ground delivery process which limits time in cold storage, minimizes moth damage (such as loss of wing scales) while being carried on ATVs, and dispenses moths into the canopy rather than onto the ground, should probably be considered. If the effects of a ground-delivery system are not considered and addressed, then expected improvements in the quality of mass-reared moths gained by modifying the rearing system (Judd *et al.* 2006b) might never be realized.

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Mass rearing codling moths: improvements and modifications

J.D. HANSEN[1,2] and P.A. ANDERSON[1]

ABSTRACT

Current diet, oviposition cages, rearing containers, diapause induction and adult handling are described for a rearing colony of codling moth, *Cydia pomonella* (L.), maintained at the USDA-ARS facility in Wapato, WA , USA, for over 40 years for use in field, laboratory and postharvest research. Previous studies have found codling moth production to approach maximum efficiency at a density of one larva per 4.8 ml of diet. Since 2002, the current YARL rearing program has produced an average of 1 adult per 4.5 ml diet.

Key Words: *Cydia pomonella*, reproduction

INTRODUCTION

The USDA-ARS Yakima Agricultural Research Laboratory (YARL) in Wapato, Washington, USA, has maintained a colony of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), for about 40 years, comprising more than 480 generations. This colony has primarily been used to provide immature stages for postharvest treatments and distribution to other research facilities. Many improvements and modifications have been made since Toba and Howell (1991) described the rearing procedures at YARL and the purpose of this paper is to describe the current methods used for large-scale rearing of codling moth at the same facility.

EGG COLLECTION AND HANDLING

The plywood oviposition cages described by Toba and Howell (1991) have been replaced by wax paper-covered drums (Muchkhof Manufacturing, Oliver, BC) that rotate on rollers within a Plexiglas compartment, which forces moths to evenly distribute their eggs. To help control moth scales, air is circulated within the enclosure with a 1 hp 20 amp electric model (Model No. 4C447, Dayton Electric Manufacturing, Co., Niles, IL) and passes through a HEPA filter (Kenmore Model No. U28337, Sears, Roebuck & Co., Hoffman Estates, IL).

Adult codling moths are collected from emergence chambers in a cold room set with continuous lighting and held at 1.1 °C. Numbers of moths are estimated by weight (38.5 moths/g), with a maximum of 1,425 ± 75 moths put in a single oviposition cage. Moths are placed into the oviposition cage through a slit cut in the wax paper. The paper is then pulled tight and the slit moved through the rollers so that the chamber is thoroughly enclosed by the wax paper.

Oviposition cages are held in an environmentally controlled room at 25 ± 0.5 °C, 77% RH, and a photoperiod of 16:8 h, L:D. Each female adult can produce 80 eggs (Howell 1971). The paper is cut into strips of (2.5 x 10 cm) to facilitate handling before the sheets are dipped into a 32 °C solution of 0.06% sodium hypochlorite for two min, rinsed in 32 °C water for 4 min, and allowed to dry.

[1] USDA-ARS Yakima Agricultural Research Laboratory, 5230 Konnowac Pass Road; Wapato, WA 98951 USA

[2] To whom correspondence should be addressed: Tel.: +1-509-454-6573; Fax: 509-454-5646; e-mail: jimbob@yarl.ars.usda.gov

FORMULATED DIET AND REARING CONDITIONS

The YARL diet has been continually improved over three decades (Howell 1970, 1971, 1972). Diet ingredients are pre-measured before mixing (Table 1). The soybean meal is soaked for 1 h in 1000 ml of hot water (52 ± 3 °C) and then placed in a blender containing 1900 ml of hot water (52 ± 3 °C). Next, wheat germ, sucrose, wheat starch, agar, and mineral salts are added. The vitamins and aureomycin are mixed separately then, together with methyl p-hydroxy benzoate and sorbic acid, are dissolved in a sufficient amount (ca. 50 ml) of ethanol. In a third container, 30 ml of propylene glycol are dispensed into 600 ml of hot water (52 ± 3 °C), then the fungicide (Benlate ® SP Fungicide, E. I. du Pont de Nemours and Co., Wilmington, DE.), ascorbic acid and propionic acid are added. Finally, all the ingredients are mixed with the soybean meal in the blender, whose speed is gradually increased to high and then maintained for 1 min. After blending, 4.3 litres of the mixture (density = 1,080 g/ litre is poured in an aluminum pan (31.8 w x 50.8 l x 8.3 d cm). Pans filled with diet are sterilized in 121 °C for 22 min in an autoclave (Castle® M/C3522 Laboratory Sterilizer, Rochester, NY).

A wax film over the top surface of the diet prevents dehydration (Howell 1967). Following autoclaving, the pans of diet are allowed to cool overnight before they are waxed using a Dynamini Adhesive Supply Unit (ITW Dynatec, Henderson, TN). The 5 sec application spreads a thin coat (ca. 1 mm thick) of paraffin wax (2391 Wax, Dussek-Campbell Applied Wax Technology, San Francisco, CA) on the top surface of the diet. After hardening, holes (2 mm diam) are made in the wax using an edge of folded hardware cloth with 1.3 x 1.3 cm wire squares, which facilitate entry of neonate larvae into the diet.

Typically, codling moth production declines during the winter (Howell 1971). In the non-winter months (March to September), eight egg strips (nine strips during winter) are evenly spread out on top each of pan of diet, then placed on racks in incubation rooms set at 24 to 26 °C, 35 to 50% RH, and a 16:8 h L:D photoperiod to allow for egg hatch and larval development.

After 28 d, the eggs hatch and larvae develop through five instars. Larvae normally feed vertically into the rearing diet. When larvae reach mature fifth instar, they exit the rearing diet in search of pupation sites. Strips (14 per pan) of double-sided corrugated card board (2 x 40 cm) are placed vertical to the diet surface to facilitate cocoon formation. The average monthly number of pupae produced per pan is estimated from three pans (biweekly before 2005, weekly after 2005) by examining the pupal strips. In 2005, the average (± SEM) monthly pupal production was 952.8 (± 34.5) and increasing the number of egg strips in the winter allowed for stable production of pupae year round. The lowest production was in late summer-early fall when research activities slowed. Since 2003 the monthly production of pupae has increased by 19%.

Howell (1971) reported that a codling moth larva needed at least 1.3 ml of diet to complete development, but did not mention the effects on size and reproductive potential. Siegal *et al.* (2001) reared disease-free codling moth larvae on 1.8 ml of diet in individual tubes, one larva per tube. Howell (1971) found that the best initial larval density to obtain maximum adult yield per pan was 1 larva per 4.8 ml. Since 2002, the current YARL rearing program produces an average of 1 adult per 4.5 ml diet.

Because codling moth larvae are cannibalistic and intolerant of crowding, production efficacy decreases with increased larval density. Also, crowding increases the likelihood of pathogen transmission. A compromise must be made to produce the maximum number of insects with a limited amount of resources, yet avoid high densities that increase the likelihood of disease.

Table 1.

Ingredients for one pan of rearing media.

Item	Amount
Soybean meal	600.0 ml
Wheat germ	180.0 g
Sucrose	87.0 g
Wheat starch	81.0 g
Agar	18.0 g
Mineral salts	5.4 g
Benlate	0.45 g
Methyl p-hydroxy benzoate	3.0 g
Sorbic acid	2.7 g
Vitamins	33.0 g
Aureomycin	3.2 g
Ethanol	50.0 ml
Ascorbic acid	12.6 g
Priopionic acid	8.1 ml
Propylene glycol	30.0 ml
Heated water for mixing propylene glycol	600.0 ml
Water for meal soaking	1000.0 ml
Water for mixing	1900.0 ml

DIAPAUSE INDUCTION

Eggs strips are placed on pans of diet and held for five d in the rearing room (24 to 27 °C, 16:8 h L:D , 40% RH) to allow for eclosion. Then the pans are transferred to the diapause room (16 to 17 °C, 8:16 h L:D , 50 to 70% RH). This differs from Bloem *et al.* (1997) who described diapause induction at 25 °C, 12:12 h L:D, 55% RH. Three wk later, the corrugated cardboard strips are placed on the diet as described above and diapausing larvae are collected in the strips the following four wk. Diapausing larvae differ from non-diapausing late fifth instars by becoming more inactive, having lower respiration rates and thicker-walled cocoons, and assuming a paler cuticular color (Hansen and Harwood 1968). Diapausing larvae are only used for experimental purposes at YARL, are rarely allowed to develop to adulthood and are not intended for maintaining the colony.

ADULT COLLECTION AND HANDLING

After pupation, the strips are removed and the diet pans are placed in a 50 °C room for 24 h to destroy any remaining larvae and then disposed in commercial garbage. In the laboratory, the strips containing pupae are placed in a cardboard box (25 x 50 x 50 cm) sealed except for an exit hole to allow for adult emergence (the interior is dark except for the exit hole). The room containing the boxes is held at 24 - 25 °C. The exit hole in each box is connected by a PVC tube to a vertical clear Plexiglas shaft with continuous air flow (222.5 m/min and 1.1 °C) in the adjoining eclosion room. Adult moths in the boxes are attracted to the light in the next room, move through the connecting tube, then become inactive when they reach the cold air and drop to the

bottom of each shaft where they are collected on a sieve (Hutt *et al.* 1972). This system replaces the adult moth collection apparatus described by Hutt *et al.* (1972) and the version modified by Toba and Howell (1991).

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Quantitative relationship between potato tuber damage and counts of Pacific coast wireworm (Coleoptera: Elateridae) in baits: seasonal effects

DAVID R. HORTON[1]

ABSTRACT

Experimental plots of potatoes were baited with rolled oats in spring to assess the relationship between counts of Pacific coast wireworm, *Limonius canus* (Coleoptera: Elateridae), and end-of-the-season damage to potato tubers. Baiting was done at seven intervals beginning before planting of potatoes and ending following plant emergence. Injury (percentage of tubers damaged or number of holes per tuber) showed a curvilinear relationship with increasing wireworm counts in baits. Damage increased rapidly with increasing wireworm numbers at lower densities, eventually flattening out at very high counts. Wireworm counts in baits fluctuated seasonally, increasing from lows obtained during pre-planting samples to a peak just before plant emergence, followed thereafter by declines in counts. Thus, baiting efficiency varied seasonally. Low counts in baits during the pre-planting interval may have been due primarily to low soil temperatures, while declining counts following plant emergence may have been due to the presence of competing food sources (i.e., the seed piece and developing potato plant). I also assessed depth of wireworms in the soil profile between late-March and mid-May, and found that a relatively large percentage (approaching 25% on two dates) of wireworms occurred very deep in the soil (61-91 cm) until soil temperatures at 31 cm approached 17 °C in early- to mid-May. Thus, low counts in baits during the pre-planting samples may also have occurred in part because a proportion of the population was deep in the soil during this time interval. Seasonal variation in baiting efficiency led to date-to-date differences in predicted damage for a given wireworm count. Low efficiency during the pre-planting interval would complicate efforts to use pre-planting baiting as a means to predict end-of-the-season tuber damage.

Key Words: *Limonius canus*, potato, sampling, damage prediction, spatial distribution

INTRODUCTION

The Pacific coast wireworm, *Limonius canus* LeConte (Coleoptera: Elateridae) is an important pest of potatoes in the major potato growing regions of central Washington State. Problems caused by wireworms in potatoes and other crops appear to be increasing in severity (Jansson and Seal 1994, Parker and Howard 2001, Alvarez 2004), for unknown reasons. Several factors complicate efforts to manage these pests, including incomplete understanding of adult and larval field biology, multi-year development times, and a paucity of effective chemicals (Parker and Howard 2001, Alvarez 2004).

A lack of efficient tools with which to estimate wireworm densities has also complicated efforts to manage these pests in potatoes (Jansson and Seal 1994, Parker 1996, Parker and Howard 2001, Alvarez 2004), to the extent that most potato growers who apply insecticides for controlling wireworms likely do so without having first sampled for these pests. Wireworms are monitored either by taking soil cores or by burying some type of bait. Unfortu-

[1] USDA-ARS, 5230 Konnowac Pass Road, Wapato, WA 98951 USA, (509) 454-5639, horton@yarl.ars.usda.gov

nately, these pests have a number of characteristics that have limited the use of either sampling method in potatoes. Those characteristics include patchy spatial distributions (Onsager 1969, Williams *et al.* 1992), a tendency to cause damage even at very low and often undetectable densities (Parker and Howard 2001), and their seasonal movement vertically through the soil profile (Jones and Shirck 1942). Additional complications arise because it is not known what levels of damage can be expected for a given absolute density of wireworms in a potato field (Parker and Howard 2001).

A number of studies have shown that food baits (e.g., germinating grain seed, rolled oats, seedling grains) can be used to attract or sample wireworms (Apablaza *et al.* 1977, Toba and Turner 1983, Jansson and Lecrone 1989, Parker and Howard 2001, Horton and Landolt 2002, Vernon *et al.* 2003). However, attempts to use baiting for estimating damage potential or for predicting damage to harvested tubers have shown inconsistent success (Parker 1996, Parker and Howard 2001). One factor that might affect whether baiting in spring can be used to predict end-of-season damage to tubers is timing of baiting relative to seasonal phenology of the pest. Specifically, wireworms move down the soil profile in autumn in preparation for overwintering, returning towards the soil surface in early spring as soil temperatures warm (Jones and Shirck 1942, Lafrance 1968). Baiting trials that are done once most wireworms have moved near the soil surface would seemingly provide a better index of wireworm density and have higher predictive value than trials done earlier in the year when the insects are deeper in the soil and potentially too far away from the baits to respond to the attractants. Soil treatments for wireworms in potatoes are done before or at planting, thus if baits are to be used for determining whether treatment is necessary, baiting in spring must be done very early in the season. At that time of year, an unknown (but potentially significant) proportion of the population could be relatively deep in the soil. If this is true, baiting in spring could provide changing estimates of damage potential through time even within one field, just due to movement by wireworms towards the soil surface as the season progresses.

Objectives of this study were to examine the relationship between pre- and post-planting counts of *L. canus* in baits and end-of-year tuber damage, and to assess whether the relationship between counts and damage changes through time. I also examined the depth of *L. canus* in the soil profile between March and May, to assess whether any seasonal variation in baiting efficiency might be explained partially by phenology of wireworm movement upwards into the baiting area from overwintering quarters deeper in the soil.

MATERIALS AND METHODS

Study site. The studies were done in a field at the USDA-ARS experimental farm located near Moxee, Washington. The soil type is a sandy loam. The field has been used exclusively for small plot trials with potatoes for at least the five years preceding this study. Soil insecticides were not used in the current trials or in previous years. The field has a history of infestation by Pacific coast wireworm, based upon examination of adults and larvae collected from the field during the study and in previous years. Wireworm species other than *L. canus* are only rarely collected in the study field. Vouchers of larvae collected from the study site are in the collection of the author.

Baiting trial (2004). Thirty plots were established on 12 April 2004, two weeks preceding planting of potatoes. Each plot was 10 rows wide by 10 m in length, separated from adjacent plots by 10 m of bare soil. Baiting began on 16 April, before planting. Potatoes (Russet Burbank) were planted on 26 April at 0.3 m spacing within rows. Irrigation was done using

overhead sprinklers. Arthropod pests were not controlled, other than an application of a pyrethroid insecticide (Asana) in summer to control Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Coleoptera: Chrysomelidae). Weeds were controlled using a pre-planting application of trifluralin (Treflan) and an application of metribuzin (Sencor) at layby. Temperature of the soil at 31 cm was monitored using two Hobo temperature recorders (Onset Computer Corporation, Bourne, MA), buried in two of the plots.

Baits composed of uncooked rolled oats (Quick Oats; Western Family, Portland, Oregon) were used to sample wireworms (Horton and Landolt 2002). Bait ingredients were a 2:1 (by volume) mix of potting soil and rolled oats. The potting soil was a 1:1:1 (by volume) mix of sand, peat, and vermiculite. This particular mix was used because it was readily available from the plant-rearing operations at our laboratory. An individual bait was composed of ca. 120 ml of the soil and rolled oats mixture, wrapped in a 25 x 25 cm section of 3 x 3 mm bridal veil mesh. Mesh size was large enough to allow wireworms to enter the bait, but was small enough to contain the bait. A section of bright colored twine was attached to each bait, to allow easy retrieval from the field. Baits were thoroughly saturated with water just before they were buried in the plots. Baits were buried between the potato rows, 20-25 cm in depth.

Plots were baited weekly for six consecutive weeks beginning on 16 April; a seventh sample was taken 22 June, well after plant emergence. The first two samples (20 and 26 April) were collected before planting. In every sampling week, baits were left in the ground for four days. After the four-day interval, baits were retrieved and examined in the field. Wireworms were counted, categorized to size ($\leq$ 1 cm or > 1 cm), and then returned immediately to the hole from which the bait was retrieved. Wireworms were returned to the soil to ensure that the baiting itself did not substantially affect absolute population densities in the plots. By examining the baits in the field, it is possible that some very small wireworms were missed and not counted. However, examination of baits in the field allowed me to process a large number of baits and to return wireworms immediately to the plots from which they had been collected, so this method of sampling was used.

A very high density of baits (9 per plot) was used, to maximize chances of obtaining good regressions relating wireworm counts and tuber damage. Bait density is too high to be used realistically by growers, but objectives of the study are to understand phenological aspects of the baiting process, and not to develop here a grower-friendly monitoring tool. The density of nine baits per plot was used in 25 of the 30 plots. The remaining five plots each contained a single bait, to provide a few preliminary data about whether bait density might affect prediction. The data from the five plots having the low bait density are not used in the following analyses, but are shown in the figures. The nine baits in the 25 plots that had the high bait densities were set out in 3 x 3 grids, with approximately three m spacing between baits, and two m between plot edges and baits. In the five plots having one bait per plot, the bait was placed near the center of the plot. Bait positions were shifted laterally 0.3-1.0 m between sample weeks, either within the same row or to an adjacent row. By shifting location, I avoided damaging just-released wireworms (collected in the newly recovered baits) as I excavated the holes into which the new baits were to be placed.

Tubers were harvested in late September from rows 3, 5, 6, and 8 (of the 10 rows) in each plot. Harvest excluded the two plants at either end of each row. I randomly selected 400 tubers per plot from the four harvested rows. The samples included all tuber sizes. Tubers were washed, and then examined for wireworm damage. Tuber damage was expressed as percentage of tubers having wireworm injury and as number of wireworm holes per tuber.

Linear and non-linear regression was used to assess the relationship between wireworm counts in baits and tuber damage. Only data from the plots that were baited with nine baits per plot are used in the regressions (N = 25 observations per regression). The models were fitted in the graphics package SigmaPlot (Systat Software, Richmond, CA).

Depth in the soil profile (2005). Phenological trends in the baiting data from 2004 (see Results) suggested that it would be worthwhile to examine how vertical distribution of wireworms in the soil changed through time during the March-May baiting period. In spring 2005, distribution of wireworms at three depths was examined: 0-31 cm, 31-61 cm, and 61-91 cm. The samples were taken in the same field used in the 2004 baiting study. The field was left fallow during the 2005 study.

I extracted 31 cm long cores of soil using a soil auger (91 cm long x 15 cm in diameter) attached to a tractor. A 61 x 61 cm square of plywood having a 20 cm diameter hole cut in the center was used as a guide for the auger. The guide was placed flat on the soil surface at a randomly located spot in an area of the field known to have wireworms. The auger was then lowered through the 20 cm hole until it reached a depth of 31 cm. As the auger was extracted, the excavated soil fell onto the plywood square. Loose soil falling back into the hole was scooped out by hand. The plywood guide was removed from the cored area, and a second guide was placed over the newly drilled hole. The auger was then lowered to the 61 cm depth, and the soil was again excavated and deposited on the plywood guide. The process was repeated a third time to obtain the 61-91 cm depth sample. Excavated soil on the guides was examined in the field for wireworms. Wireworm size was not recorded. Thirty to sixty cores per sampling date were examined. With this volume of soil examined, it is likely that some very small wireworms were missed and not counted. A Hobo data logger was used to monitor soil temperature at 31 cm.

RESULTS

Baiting trial (2004). Counts in baits indicated that wireworms were distributed non-uniformly among the 30 plots (Fig. 1A). Numbers of wireworms summed over the seven sampling dates varied among plots between 0 and 54.1 per bait. In four plots, baiting failed to collect a single wireworm over the duration of the sampling study (Fig. 1A: plots lacking black squares). Wireworm numbers in baits changed seasonally (Fig. 2). Counts averaged 1.0 wireworms per bait on the first sample date, increasing to a peak of 3.3 per bait just before plant emergence (17 May), and dropping thereafter (Fig. 2). A maximum of 17.4 wireworms per bait was obtained in one plot on the 17 May sampling date. Percentage of wireworms that were 1 cm or less in length varied among the seven sampling dates between 34% and 66%, with the highest percentage value occurring in the 22 June sample.

Tuber damage was highly variable among plots (Figs. 1B-C). Percentage of tubers damaged varied between 3% and 89% (Fig. 1B), whereas number of holes per tuber varied between 0.05 and 6.4 (Fig. 1C). Damage was seen in all plots, including in those four plots from which no wireworms were collected during the seven baiting intervals.

The relationship between percent of tubers damaged and counts in baits was curvilinear (Fig. 3). An asymptotic model was fitted:

% damage = Intercept + a*(1-exp(-b*wireworms per bait)).

The b-term describes how rapidly the asymptote is approached; the asymptote is the sum of the a-term and the intercept term. Based upon r^2 values, models of this form consistently fit the data better than linear, quadratic, or power models. The regressions were fitted to data from the 25

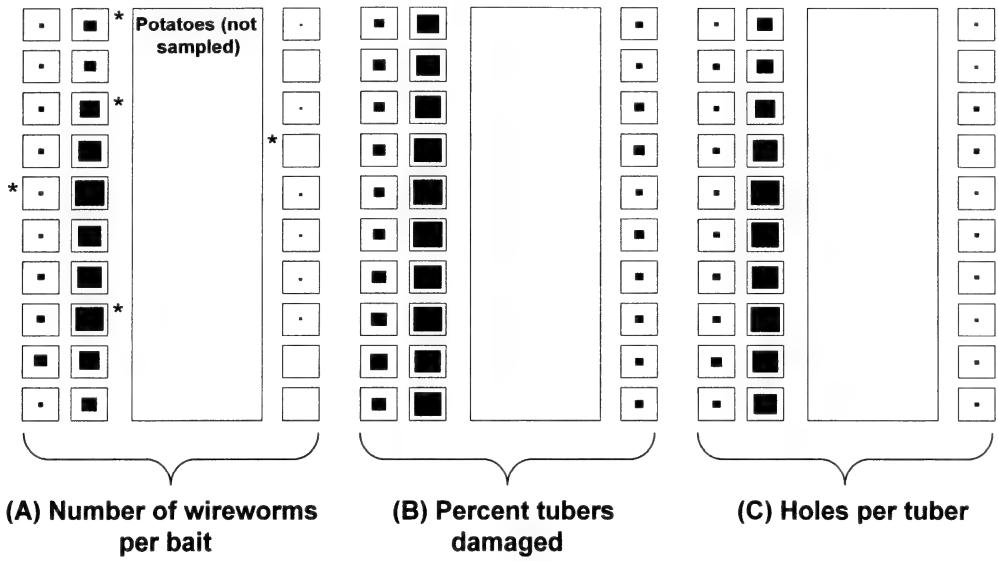

Figure 1. Arrangement of the 30 study plots (each 10 rows wide x 10 m long) on two sides of an unsampled potato field. Area of the black square within any plot is proportional to number of wireworms per bait summed over the seven sampling dates (Figure A: range 0 to 54.1 wireworms per bait), percentage of tubers damaged (Figure B: range 3% to 89% tubers damaged), or number of holes per tuber (Figure C: range 0.05 to 6.4 holes per tuber). The four plots in which no wireworms were collected in baits lack black squares (Figure A). Asterisks in Figure A show location of the five plots that received one bait per plot.

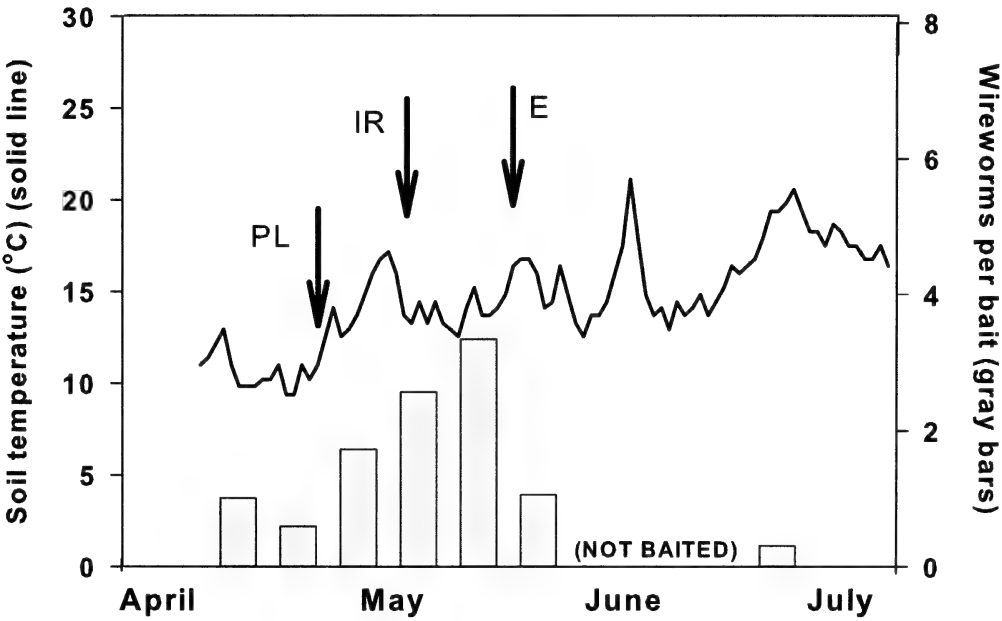

Figure 2. Soil temperature at 31 cm (solid line) and wireworm counts per bait (gray bars) over the duration of the baiting study. Collection dates for baits: 20 April, 26 April, 3 May, 10 May, 17 May, 24 May, and 22 June. Arrows show date of planting (PL), first irrigation (IR), and plant emergence (E).

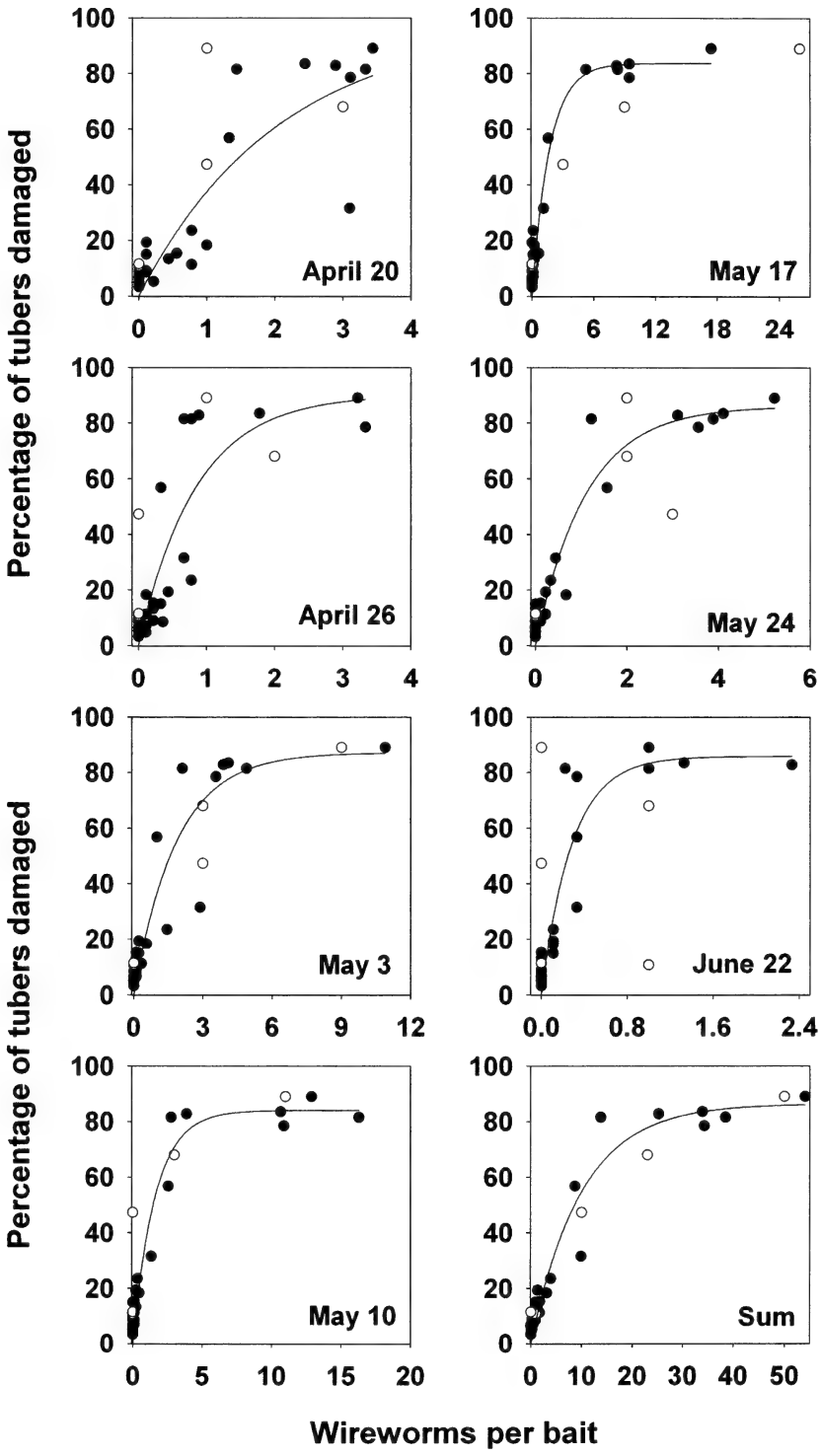

Figure 3. Scatter plots and regression lines showing relationship between number of wireworms per bait and percentage of tubers damaged. Solid circles: nine baits per plot (N = 25 plots); open circles: one bait per plot (N = 5 plots). Regressions fitted excluding the open symbols. "Sum": wireworm numbers per bait were summed over the seven sample weeks.

plots having nine baits per plot (filled symbols in Fig. 3), although data for the five plots having one bait per plot are shown (as open symbols in Fig. 3). Except for the 20 April sample, predicted damage approached an asymptote at 85-92% of tubers, irrespective of sampling date (Fig. 3; regression coefficients are reported in Table 1). The r^2 values were lowest for the two pre-planting sample dates (Table 1).

Both linear and curvilinear models were fitted to describe the relationship between number of holes per tuber and wireworm counts (Fig. 4). An asymptote model of the same form used to describe percentage damage again fit the data better than a linear model (Fig. 4; see Table 2 for r^2 values), and also fit the data better than a quadratic or power model (data not shown). Data for the five plots having a single bait per plot (open symbols in Fig. 4) often fell well away from the scatter of points for the data obtained in the other 25 plots (filled symbols in Fig. 4), suggesting that bait density may affect fit of models quite substantially. For the asymptote model, r^2 values were again lowest for the two pre-planting sampling dates (Table 2).

Predictions of percent damage (from the asymptote models in Figure 3) for a given density of wireworms depended upon when the sampling was done (Table 3). For example, at a count of 1.0 wireworms per bait, damage was predicted to be 62% of tubers for the 26 April sampling date, dropping to 35-38% for the early- and mid-May samples, and then increasing to 49% in late May and 83% in June (Table 3). Predictions of damage generally were higher (for a given bait count) during those weeks when overall counts in baits were lowest.

Depth in the soil profile (2005). Numbers of wireworms collected in the soil cores varied from 37 to 51, depending upon sample date (Table 4). The results suggest that movement up the soil profile in spring occurred over a relatively long time period (Table 4). On two dates, almost a quarter of wireworms collected were obtained at the 61-91 cm depth. Only on the final sample taken 13 May did I fail to collect wireworms at the lowest depth. On that date, soil temperatures at 31 cm had reached 17 °C.

DISCUSSION

Baiting trials showed that wireworm densities (as reflected by counts in baits) and tuber damage were highly variable among plots (Fig. 1), suggesting that wireworms had a non-uniform distribution in the field (Onsager 1969). Environmental or biological factors leading to these non-uniform distributions of *L. canus* and dam-

Table 1.
Regression statistics from asymptote models relating wireworm counts per bait and percentage of tubers damaged. N = 25 observations per date.

Sample date	Intercept	*a*	*b*	r^2
20 April	4.7[1]	104.5	0.37	0.80
26 April	1.6[1]	89.1	1.13	0.75
3 May	6.1[1]	85.7	0.43	0.87
10 May	6.8	78.2	0.51	0.97
17 May	7.9	77.3	0.43	0.97
24 May	6.8	81.9	0.73	0.94
22 June	7.0	79.6	3.07	0.87
Sum	4.7	83.6	0.09	0.96

[1] Intercept not significantly different from zero.

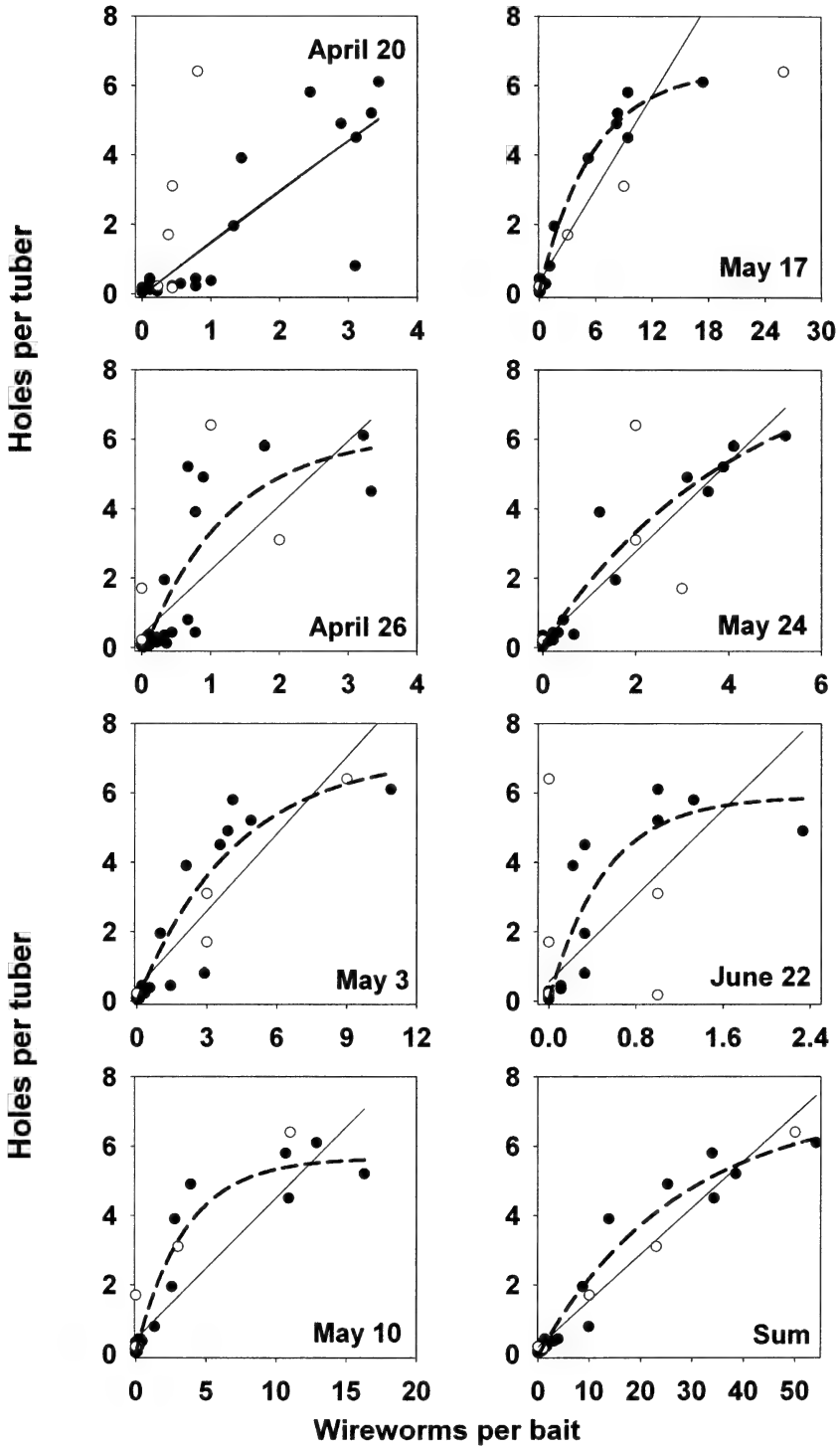

Figure 4. Scatter plots and regression lines showing relationship between number of wireworms per bait and number of holes per tuber. Solid circles: nine baits per plot (N = 25 plots); open circles: one bait per plot (N = 5 plots). Regressions fitted excluding the open symbols. Both linear and asymptote models are shown (regression lines overlap for the 20 April sample). "Sum": wireworm numbers per bait were summed over the seven sample weeks.

Table 2.
Regression statistics from linear and asymptote models relating wireworm counts per bait to number of holes per tuber. N = 25 observations per date.

	Linear model			Asymptote model			
	Intercept[1]	Slope	r^2	Intercept[1]	*a*	*b*	r^2
20 April	-0.04	1.48	0.75	-0.06	44.5	0.04	0.75
26 April	0.37	1.86	0.62	-0.29	6.4	0.82	0.73
3 May	0.37	0.74	0.75	-0.04	7.1	0.24	0.87
10 May	0.44	0.41	0.81	0.03	5.6	0.29	0.95
17 May	0.35	0.45	0.90	0.10	6.4	0.17	0.98
24 May	0.18	1.29	0.94	0.06	8.7	0.24	0.95
22 June	0.56	3.10	0.66	0.02	5.9	1.93	0.86
Sum	0.20	0.13	0.91	-0.05	7.3	0.04	0.96

[1] Intercepts significantly different from zero only for the 10 May and 17 May linear models

Table 3.
Predicted percentage of tubers damaged (from asymptote models in Figure 3 and Table 1) for different wireworm counts per bait provided for each sampling date. The shaded area encompasses predictions within the range of wireworm counts observed in the samples.

Wireworms per bait	Pre-planting		Post-planting				
	20 April	26 April	3 May	10 May	17 May	24 May	22 June
0	5	2	6	7	8	7	7
0.25	14	24	15	16	16	20	50
0.5	22	40	23	24	23	32	69
1.0	37	62	36	38	35	49	83
1.5	49	74	47	49	45	61	86
2.0	59	81	56	57	52	70	86
2.5	68	85	63	63	59	75	87
3.0	75	88	68	68	65	80	87
4.0	85	90	76	75	72	84	87
5.0	93	90	81	79	77	87	86
10.0	>100	91	91	85	84	89	86
15.0	>100	91	92	85	85	89	86

age are not known, but could include characteristics of the soil (soil type, moisture, organic matter) and availability of preferred host plants in previous growing seasons (Gui 1935, Lefko *et al.* 1998, Parker and Howard 2001). The row of plots having the highest densities of wireworms (Fig. 1A) occurred in an area of the field that had been planted to potatoes in each of the previous five years. The row of plots which had the lowest densities occurred in an area of the field that had in some preceding years been left fallow.

Tuber damage, expressed either as percent of tubers damaged or as number of holes per tuber, showed a curvilinear relationship with wireworm counts (Figs. 3-4). Curves exhibited a rapid increase in damage levels with increasing numbers of wireworms at lower wireworm numbers, while showing slower increases in damage with increasing wireworm numbers as

Table 4.

Sample date, soil temperature at 31 cm, number of soil cores sampled (n), total number of wireworms collected, and number of wireworms per soil core collected at each of three depths. Numbers in parentheses indicate percentage of total obtained at that depth. Data for the earliest dates have been combined due to difficulties finding wireworms.

Sample date	Soil temperature at 31 cm (°C)	n	Total wireworms collected	Number of wireworms per soil core (% of total)		
				0-31 cm	31-61 cm	61-91 cm
March 15 and 23	8.3	90	37	0.17 (41%)	0.14 (34%)	0.10 (24%)
March 31 and April 7	9.4	70	44	0.40 (64%)	0.17 (27%)	0.06 (9%)
April 15	9.4	30	42	0.70 (50%)	0.43 (31%)	0.27 (19%)
April 22	13.9	30	48	0.97 (61%)	0.50 (31%)	0.13 (8%)
April 28	15.0	30	51	0.90 (53%)	0.40 (24%)	0.40 (24%)
May 13	17.2	30	40	1.17 (88%)	0.17 (13%)	0.00 (0%)

wireworm counts became high. These results suggest that low densities of wireworms caused disproportionate levels of damage relative to levels of damage caused by high densities of the pest. It may be that tubers or feeding sites previously damaged by wireworms were attractive to other wireworms, and that wireworms at high densities tended to feed on the same tubers and in the same sites on those tubers that had been previously damaged by other wireworms. Gibson (1939), who used soil sifting rather than baiting to estimate densities of *Limonius* spp., also concluded that levels of damage caused by wireworms were disproportionately high at low densities of the pests.

Use of soil sampling to predict tuber damage has suffered from the occurrence of false negatives in the sampling results (Parker and Howard 2001). That is, wireworm densities below the level of detection may nonetheless cause economic damage to tubers (Parker and Howard 2001). The present study suggests that baiting may suffer from the same criticism. Three of the plots having the high density of baits failed to collect a single wireworm over the duration of the seven sample weeks. Tuber damage occurred in all three of these plots (3.3-6.8% of tubers were damaged in those plots). The presence of zero counts was observed despite use of an impractically (for growers) high density of baits. Regression models describing percentage tuber damage (Fig. 3, Table 1) often exhibited significant intercept terms, indicating that predicted damage was non-zero at wireworm counts of 0 per bait.

Counts of wireworms in baits were low in the pre-planting samples, increased to a peak just before plant emergence, and declined thereafter. The early season counts in baits may have been low in part because cool temperatures led to lowered rates of wireworm movement or feeding, or slowed spread of bait volatiles through the soil. The drop in wireworm counts between the first and second sample dates accompanied a period of cooling soil temperatures (Fig. 2). The drop in numbers following peak count may have been due in part to wireworms feeding on seed pieces and the developing potato plants, rather than on the baits. Toba and Turner (1981) demonstrated that counts of wireworms in seed pieces following planting could be used to predict end-of-the-season wireworm damage to potatoes, suggesting that wireworms feed readily on seed pieces.

Another factor possibly contributing to seasonal patterns in counts (Fig. 2) is that movement by wireworms into the baiting area, from overwintering quarters deeper in the soil, appears to occur over a fairly long time interval. Thus, in April, the low counts

in baits may have been caused in part by the fact that a proportion of the population was relatively deep in the soil. The depth study in 2005 showed that 8-24% of wireworms collected between March and late-April were obtained at the 61-91 cm depth. Only as soil temperatures at 31 cm approached 17 °C (in the mid-May sample), did I fail to collect wireworms at the 61-91 cm depth. That soil temperature was not reached in the baiting study of the previous year until early May (Fig. 2), which was about two weeks after planting. The depth study was done in a fallow field. It is not known whether movement up the soil profile by wireworms in spring would have occurred more rapidly had there been a food source available (e.g., newly planted potato seed pieces).

One consequence of the week-to-week differences in wireworm counts is that predicted damage for a given count varied week-to-week. Three of the sampling dates on which overall counts were low (26 April, 24 May, and 22 June) produced damage predictions for a given bait count that were substantially higher than predictions obtained on those dates for which baiting efficiency was better (Table 3; for a given bait count, contrast predictions for the May 3, 10, and 17 dates with predictions from 26 April, 24 May, and 22 June). That is, because baiting efficiency varied seasonally (being comparatively inefficient during pre-planting and post-emergence samples relative to the May 3-17 samples; Fig. 2), a given wireworm count did not provide a constant estimate of damage potential among sample weeks. Consequently, regression models indicated that a given level of damage would be associated with lower bait counts during the pre-planting and post-emergence periods than during those three weeks in May when baiting was more efficient (Table 3). Thus, factors that cause reduced bait efficiency (e.g., wireworms deep in soil, low soil temperatures, or presence of competing food sources), would lead to overestimates of damage potential relative to estimates obtained for the same bait count when baiting was more efficient.

In summary, results suggest that using baits before planting potatoes to predict end-of-the-season damage to tubers would be difficult to implement with a great deal of confidence. First, the bait densities which were used in this study were much too high to be used feasibly by growers. Moreover, as baiting density was lowered, scatter of points around the regression lines appeared to increase (Figs. 3-4). Thus, use of a logistically more feasible bait density would result in a sacrifice of model fit. Second, predicted levels of damage for a given absolute density of wireworms depended on time of year and sampling efficiency (Table 3), thus it is not possible to develop a single, general regression model that would allow growers to predict damage from counts of wireworms in baits without taking into account factors (e.g., soil temperature, wireworm depth in the soil) that are likely to affect baiting efficiency. Finally, on the two pre-planting sampling dates, baits failed to collect even a single wireworm in over 25% of the plots. All of those plots nonetheless experienced end-of-the-season damage. Thus, potato growers who might use these baits to predict damage potential would have to accept the possibility that fields in which baits failed to detect wireworms could nonetheless experience some level of damage.

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Movement of *Ericaphis fimbriata* (Hemiptera: Aphididae) apterae on blueberry

W.G. VAN HERK[1,2], D.A. RAWORTH[2] and S.L. GILLIES[3]

ABSTRACT

Blueberry scorch virus is a new and important pathogen of blueberry in British Columbia, Canada of which the blueberry-infesting aphid *Ericaphis fimbriata* is a known vector. In a study of the movement of apterous *E. fimbriata*, significantly more aphids fell when one ladybird beetle was added to *E. fimbriata* infested blueberry branches than when zero, two, or four were added. Similar numbers of aphids fell in the presence or absence of beetles at low aphid density (10-30 aphids per terminal), but more fell in the presence of beetles at high aphid density (50-70 aphids per terminal). The time taken for aphids to move a minimum distance of 60 cm off infested plants onto uninfested plants decreased with increasing aphid density which has important implications for the spread of the virus.

Key Words: *Ericaphis fimbriata*, Blueberry scorch virus, highbush blueberry, apterous aphids, coccinellids

INTRODUCTION

Highbush blueberry, *Vaccinium corymbosum* L. (Ericaceae) is one of the most important agricultural crops in British Columbia (BC). With approximately 4800 ha in production in 2004, BC ranks as the second-highest blueberry producing region in the world (British Columbia Blueberry Council 2006). Blueberry scorch virus (BlScV) was first reported in the Fraser Valley in June 2000 (Martin 2003) and is a serious threat to the BC blueberry industry. As of 2003, over 76 fields were infected with BlScV (Wegener *et al.* 2003). Plants infected with BlScV often do not show symptoms for 1-2 years, but do not recover once symptoms appear (Bristow *et al.* 2000).

Transmission of BlScV by *Ericaphis fimbriata* (Richards) (= *Fimbriaphis fimbriata*) (Hemiptera: Aphididae) (Remaudière and Remaudière 1997), occurs predominantly between mid-April and mid-August, and when aphids are not controlled the number of infected plants in a field can double annually (Bristow *et al.* 2000). While alate *E. fimbriata* can move rapidly from one row to another and potentially spread BlScV through a blueberry field, little is known about the movement of the apterous form of *E. fimbriata*, which predominates in blueberry fields in spring and summer (Raworth 2004). The rate of apterous aphid movement may significantly affect how rapidly a plant virus is transmitted in the field (Bailey *et al.* 1995).

The presence of predators can have a strong influence on the dispersal of aphids and hence on the spread of a virus (Smyrnioudis *et al.* 2001). Predators (e.g. coccinellids) and parasitoids are known to increase aphid movement in the laboratory and the field (Tamaki *et al.* 1970, Niku 1972, Roitberg and Myers 1978, Gowling and van Emden 1994) and have been dem-

[1] To whom correspondence should be addressed
[2] Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre, P.O. Box 1000, Agassiz, British Columbia, Canada V0M 1A0 (ph: 604 796-2221 ext. 234; fax: 604 796-0359; e-mail: vanherkw@agr.gc.ca).
[3] Department of Biology, University College of the Fraser Valley, 33844 King Rd, Abbotsford, British Columbia, Canada V2S 7M8

onstrated to increase the spread of plant viruses by aphids (Roitberg and Myers 1978, Sewell *et al.* 1990, Bailey *et al.* 1995). In this study, we investigated whether the number of both red and green apterous *E. fimbriata* that fall off blueberry plants increased in the presence of ladybird beetles and if apterous *E. fimbriata* moved quickly from one plant to another in the field.

MATERIALS AND METHODS

Aphids falling in the presence of ladybird beetles. *Vaccinium corymbosum* 'Duke' plants (approx. 1 year old) purchased from a commercial nursery were used for aphid rearing and movement experiments during May-August 2002. Plants were cultivated in 8 L pots in a vented greenhouse (18-28 °C), pruned to remove flowers and fertilized with 20-20-20 N-P-K to ensure fresh leaf growth. *Ericaphis fimbriata*, obtained from field samples in 2001 and 2002, were raised on blueberry plants in a 60 x 60 x 60 cm screen-covered cage in the greenhouse. Multi-coloured Asian ladybird beetles, *Harmonia axyridis* L. (Coleoptera: Coccinellidae) were obtained from a commercial insectary (Applied Bionomics Ltd, Sidney, British Columbia) and maintained on pea aphid, *Acyrthosiphon pisum* (Harris), reared on bean *Vicia faba* L. (Fabaceae). One branch from each of 48 'Duke' plants was bent to a 30-45° angle and secured in this position with wire so that it extended beyond the edge of the pot. The branch was cleared of most leaves so that only eight to ten fresh young leaves remained, and the base was coated with StickemSpecial® (Seabright Enterprises, Emeryville, California) to prevent walking insects from moving onto or off the branch. Five randomly selected apterous adult *E. fimbriata*, either of the red or green morph, were placed on one of the leaves on each plant following methods described by Bristow *et al.* (2000). Plants were left in the greenhouse for one, two or four weeks to allow aphids to establish and reproduce for different durations. They were then moved to a table covered with white paper in an observation room (75% RH, 23 ± 1 °C, light intensity 10.1 mE $m^{-2}s^{-1}$) and left undisturbed for 1 h before experimental observations. Zero (control), one, two, or four *H. axyridis* were released on each of 32 plants (eight replicates of each beetle treatment), on or near the leaf that was initially inoculated with aphids one to two weeks previously (without disturbing aphids). Within each beetle treatment, four plants had been previously inoculated with the red morph *E. fimbriata*, and four with the green morph. Among each group of four plants with the respective color morph, two plants had been infested for one week and two for two weeks. In addition, zero or two *H. axyridis* were released on each of 16 plants infested with the green morph for four weeks. Different beetles were used on each plant, and treatments were completely randomized in time. Beetle behaviour was monitored for 20 min and the number of aphids that fell recorded. All observations were conducted within a six week period, and up to four observations were conducted per day. Observations were conducted between 0800 and 1100 h to reduce potential variation in aphid or beetle behaviour resulting from circadian rhythms. After each observation, all aphids were removed from the inoculated branch and placed in 70% ethanol for subsequent counting.

The numbers of aphids fallen were transformed using square-root (x + 0.5) before analysis to stabilize the variance (Southwood 1966). For plants infested for one and two weeks ANOVA (SAS Institute Inc. 1990) was used to determine the effect of the number of weeks aphids were on the plants, the number of ladybird beetles, the color morph of the aphid and the first-order interactions between these terms, on aphid density and the number of aphids fallen. Plants infested for four weeks were not included in this analysis as only green color morphs were used. The analysis was then repeated, pooling color morph data, and

including data from plants infested for four weeks. When effects were significant at $P < 0.05$, Fisher's least-significant-difference test was used to separate means. Finally, SAS REG (SAS Institute Inc. 1990) was used to regress aphids fallen on aphid density, ladybird beetles, and the interaction, where ladybird beetles were either present or absent. Data from three plants that were accidentally disturbed during the observations were not included in the analyses.

Aphid movement in the field. Fifteen potted blueberry plants were pruned (45 cm tall and 60 cm wide) and fertilized (as above) to ensure fresh growth. Each plant was inoculated with five aphids and set in screen-covered cages in the greenhouse (as above) for 14 days to prevent predation and parasitism. They were then planted in a row in a freshly tilled field with 1.5 m between plants. On either side of the row of inoculated plants, a row of uninfested plants was planted so that the main stems of the plants were 45 cm apart and there was a 7.5 to 10 cm overlap between one branch of the inoculated plant with one branch of each uninfested plant. Care was taken to ensure that the aphids on the central plant were not disturbed and that the branches of the central plant that touched those of the two uninfested plants had no aphids on them. The minimum combined walking distance for two aphids between an infested and two uninfested plants was 60 cm. The uninfested plants were monitored at 0800 h and 1600 h every day to determine if aphids had moved onto them, and whether they were alate or apterous morphs. There were no other blueberry plants within a 100 m radius. The aphids on the inoculated plants were removed and counted after aphids were observed on both adjacent uninfested plants. The average time for the first aphids to move off the central plant onto the two adjacent plants was regressed against aphid density on the infested terminal using SAS REG (SAS Institute Inc. 1990).

RESULTS AND DISCUSSION

Aphids falling in the presence of ladybird beetles. Aphid density did not differ significantly ($P > 0.05$) between color morphs, the number of weeks plants were infested, or for the interaction between color morph and week, for plants infested for one and two weeks. Similarly, the number of fallen aphids did not differ significantly ($P > 0.05$) between color morphs, the number of weeks plants were infested, or for the interaction between color morph and week, for plants infested for one and two weeks. This suggests that the variation in aphid density was large enough to mask an extra week's reproduction by the aphids on plants infested for two weeks. It also suggests that reproduction by red and green color morphs was similar and confirms that allocation of beetle treatments to plants infested for one and two weeks was random. An effect of ladybird beetles on the number of aphids falling was almost detectable ($F = 2.97$; $df = 3,19$; $P = 0.058$) at the aphid densities utilized (mean density = 30.6 ± 2.9 (SE) aphids per terminal, n = 32).

When the data for red and green color morphs were pooled and data from the plants infested for 4 weeks included in the analysis, aphid density was significantly different between plants infested for different numbers of weeks ($F = 5.28$; $df = 2,45$; $P < 0.01$; mean number of aphids per terminal for one, two, and four weeks of infestation were: 30.4 ± 4.1; 30.7 ± 4.1; and 50.7 ± 4.6, respectively). Aphid density was not significantly affected by the number of ladybird beetles or by the interaction between beetles and weeks of infestation ($P > 0.05$). This shows that maintaining aphids on the plants for different lengths of time was eventually effective in creating different aphid densities and that beetle treatments were allocated at random to plants infested for different numbers of weeks.

For the combined data (plants infested for one, two, and four weeks, pooling red and green forms), zero to four aphids fell per plant in each 20 minute replication. There was a significant effect of ladybird

beetles on the number of aphids falling ($F = 3.95$; df = 3,35; $P < 0.05$). Significantly ($P < 0.05$) more aphids fell when one ladybird beetle was added to the branches (2.13 ± 0.44, n = 8) than when zero, two, or four were added (0.47 ± 0.17, n = 15; 1.14 ± 0.36, n = 14; 0.75 ± 0.37, n = 8, respectively). The analysis of variance indicated no significant effect of the number of weeks plants were infested or of the interaction between the number of beetles and the weeks of infestation ($P > 0.05$). Regression of the number of aphids falling against aphid density in the absence of ladybird beetles indicated that significantly more aphids fell as density increased ($t = 2.86$, $P < 0.01$). When beetle presence or absence was added to the regression, the interaction between aphid density and ladybird beetles was significant ($t = 4.12$, $P < 0.001$). Similar numbers of aphids fell in the presence or absence of beetles at low aphid density (10-30 aphids per terminal), but more fell in the presence of beetles at high aphid density (50-70 aphids per terminal); $y = 1.01 - 0.0104\ x - 0.118\ z + 0.0116\ xz$; where y = the number of apterous *E. fimbriata* falling; x = aphid density; and z = absence (0) or presence (1) of *H. axyridis*; $P < 0.01$, $R^2 = 0.30$, df = 41; $SE_{(slopes)} = 0.0122$, 0.276, and 0.00692 respectively. While neither main effect was significant when combined with the interaction, both were retained for completeness of the regression.

Hodgson (1991) reported that apterous forms of the green peach aphid, *Myzus persicae* (Sulzer), the cabbage aphid, *Brevicoryne brassicae* (L.) and the vetch aphid, *Megoura viciae* Buckton, move off acceptable host plants in the absence of crowding and argued that the dispersal of apterous aphids may be common. Apterous aphids usually move off plants either to escape predators or to search for new host plants (Robert 1987), and this behaviour would likely evolve if new host plants are easy to find (Hodgson 1991) and if there is little probability of mortality when aphids have left a plant (e.g. desiccation). Movement of individual apterous aphids off plants may maximize the overall fitness of the aphid clone by distributing the clone over different resource units (Roitberg *et al.* 1979). Aphids do this by producing alate forms when the quality of the resource plant decreases, but movement by apterous aphids eliminates the one-generation lag time required to produce alates (Roitberg *et al.* 1979). The mortality of apterous *E. fimbriata* that fall in a blueberry field may be low as the aphids are likely to fall onto other blueberry plants or find new host plants quickly. While little is known about the survival of *E. fimbriata* on the soil, Alyokhin and Sewell (2003) demonstrated that *M. persicae*, the potato aphid *Macrosiphum euphorbiae* (Thomas), and the buckthorn aphid *Aphis nasturtii* Kaltenbach, can all survive at least 24 h off host plants and move at least 180 cm on the soil surface.

The increase in apterous aphid movement in the presence of predators has been reported for other aphid species (Niku 1972). Aphid falling in response to predators is an integral part of aphid escape behaviour for some (McAllister and Roitberg 1987; Bailey *et al.* 1995) but not all aphid species. Roitberg *et al.* (1979) found that the black bean aphid *Aphis fabae* does not drop in response to predators. The increase in apterous *E. fimbriata* movement in the presence of adult coccinellids would increase their dispersal and hence likely increase the local spread of BlScV through a field. This suggests that biological control of *E. fimbriata* via the introduction of adult coccinellids may increase the spread of BlScV.

Aphid movement in the field. Apterous *E. fimbriata* moved quickly from infested blueberry plants onto adjacent uninfested plants in the field (Fig.1). The first apterous aphids were detected on the uninfested plants after 24 h and aphids had moved onto all of the uninfested plants after 120 h. The time taken for aphids to move a minimum distance of 60 cm off infested plants onto the uninfested plants decreased with increasing aphid density ($t = 6.09$, $P < 0.0001$) (Fig. 1).

Raworth (2004) showed that peak aphid density varied between 300 and 9000 per

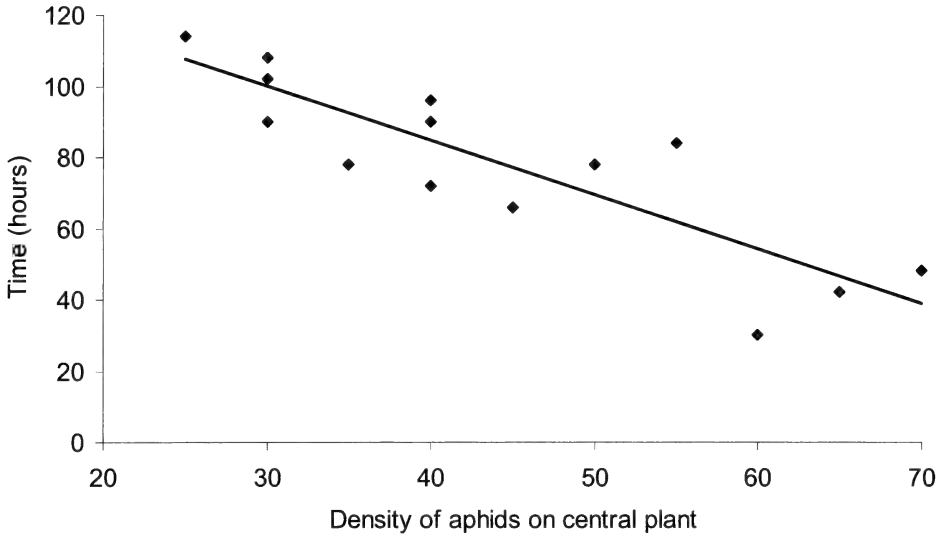

Figure 1. Average time required for apterous *Ericaphis fimbriata* to move a minimum of 60 cm onto branches of adjacent plants in the field versus aphid density on the central plant. $y = -1.52x + 145.7$; $P < 0.0001$, $R^2 = 0.74$, df = 13, $SE_{(slope)} = 0.25$.

blueberry plant in commercial fields. Given that branches overlap between plants within a row, the results of our current work suggest that there is probably significant movement of apterous *E. fimbriata* from one plant to another in the field. Bristow *et al.* (2000) showed that *E. fimbriata* is not an efficient vector of BlScV, but given that high aphid densities can occur, there is significant potential for plant-to-plant, within-row transmission of the virus by apterae. Although coccinellids are generally considered beneficial, they may exacerbate the problem by increasing aphid movement. Further work is needed to determine the effect of various aphid controls and removal of BlScV-infected plants on the local spread of the virus.

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A review of the distribution and natural history of *Apiocera barri* and *Nemomydas pantherinus* (Diptera: Apioceridae and Mydidae), two rare asiloid flies from the southern Interior of British Columbia

ROBERT A. CANNINGS[1]

ABSTRACT

Canada's only apiocerid fly, *Apiocera barri* Cazier, and sole western mydid fly, *Nemomydas pantherinus* (Gerstäcker), (Diptera: Apioceridae and Mydidae) are rare species practically restricted to the antelope-brush, *Purshia tridentata* (Pursh) de Candolle (Rosaceae), steppe of the southern Okanagan Valley of British Columbia. Some aspects of their natural history are outlined. The distributional records of the species are recorded and mapped in the context of antelope-brush steppe in the Okanagan Valley. This ecosystem has been reduced to one-third of the area occupied in the 1860s. Because these two flies are conspicuous, rare, and dependent to a large extent on antelope-brush steppe, they are good candidates for further study in the federal and provincial efforts to conserve this threatened ecosystem and its many rare species.

INTRODUCTION

The families Apioceridae and Mydidae are sister clades in the dipteran superfamily Asiloidea (Yeates and Irwin 1996). In western North America, the two families are associated with arid or semiarid habitats. Canada's only apiocerid, *Apiocera barri* Cazier, and sole western mydid, *Nemomydas pantherinus* (Gerstäcker), (Diptera: Apioceridae and Mydidae) are rare species practically restricted to the grasslands of British Columbia (BC) in the southern Okanagan Valley. The only other mydid in Canada is *Mydas clavatus* (Drury), a very large fly living mostly on beaches of the Great Lakes in southern Ontario (Marshall 2006).

These two families have similar biogeographical histories. Both ranged widely in western and southern Pangaea before its breakup in the late Jurassic (180 to 160 million years ago) and the distribution of the apiocerids and the plesiomorphic mydid subfamilies (Raphiomidinae and Megascelinae) is congruent with the known geological sequence of the separation of the Gondwanian continents (Yeates and Irwin 1996).

The antelope-brush steppe of BC's southern Okanagan Valley (Figs. 1-3) is one of the most endangered ecosystems in Canada and contains many nationally rare species of plants and animals (Schluter *et al.* 1995). This ecosystem is dominated by the antelope-brush/needle-and-thread grass plant community (*Purshia tridentata* (Pursh) de Candolle (Rosaceae) and *Hesperostipa comata* (Trinius & Ruprecht) Barkworth (Poaceae)) (Dyer and Lea 2003). Although *Purshia* is most commonly found in this plant community, peripheral communities, including ponderosa pine woodland, also may contain this shrub. The antelope-brush / needle-and-thread grass community is red-listed in BC and is globally imperiled owing to limited world distribution and substantial decreases in area related to agricultural development and urbanization. One hundred four rare invertebrates including 33 provincially listed species at risk occur there (Dyer and Lea 2003). Some of these species are also listed federally by the fed-

[1] Royal British Columbia Museum, 675 Belleville Street, Victoria, BC V8W 9W2, (250) 356-8242, RCannings@royalbcmuseum.bc.ca

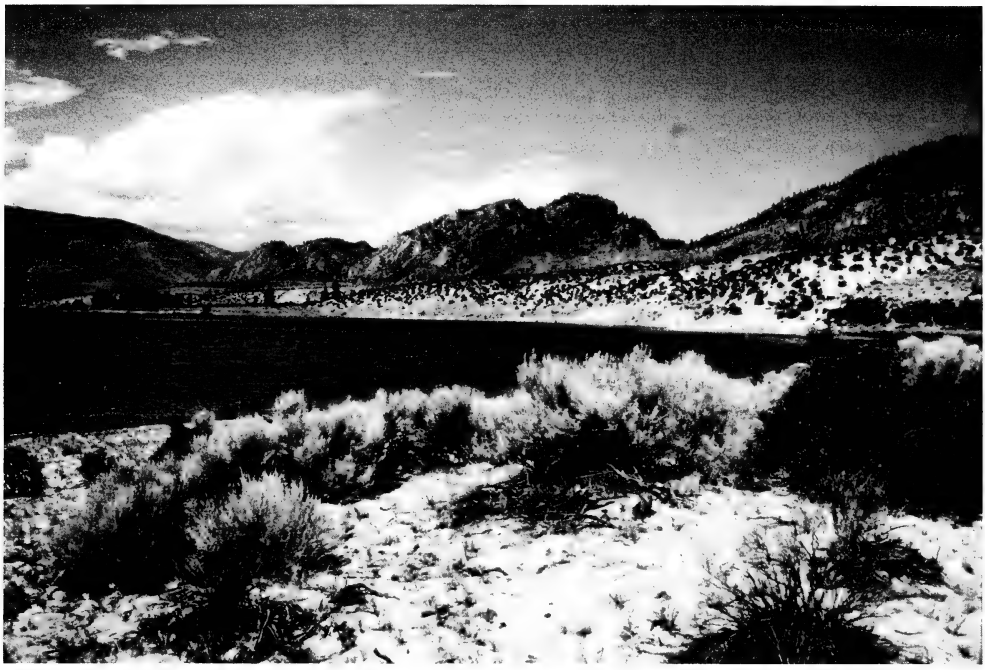

Figure 1. Antelope-brush steppe on the east side of Osoyoos Lake north of Osoyoos, British Columbia; view to north. The darker shrubs, especially prevalent in the background, are antelope-brush, *Purshia tridentata*; the paler ones are big sagebrush, *Artemisia tridentata* Nuttall (Asteraceae). Photo: Robert A. Cannings, 1981.

Figure 2. Antelope-brush steppe north of Oliver, British Columbia; view to north. McIntyre Bluff, on the left, is near the south end of Vaseux Lake. The pale shrubs in the foreground are common rabbit-brush, *Ericameria nauseosus* (Pallas) Nesom & Baird (Asteraceae). Photo: Stephen R. Cannings, 1979.

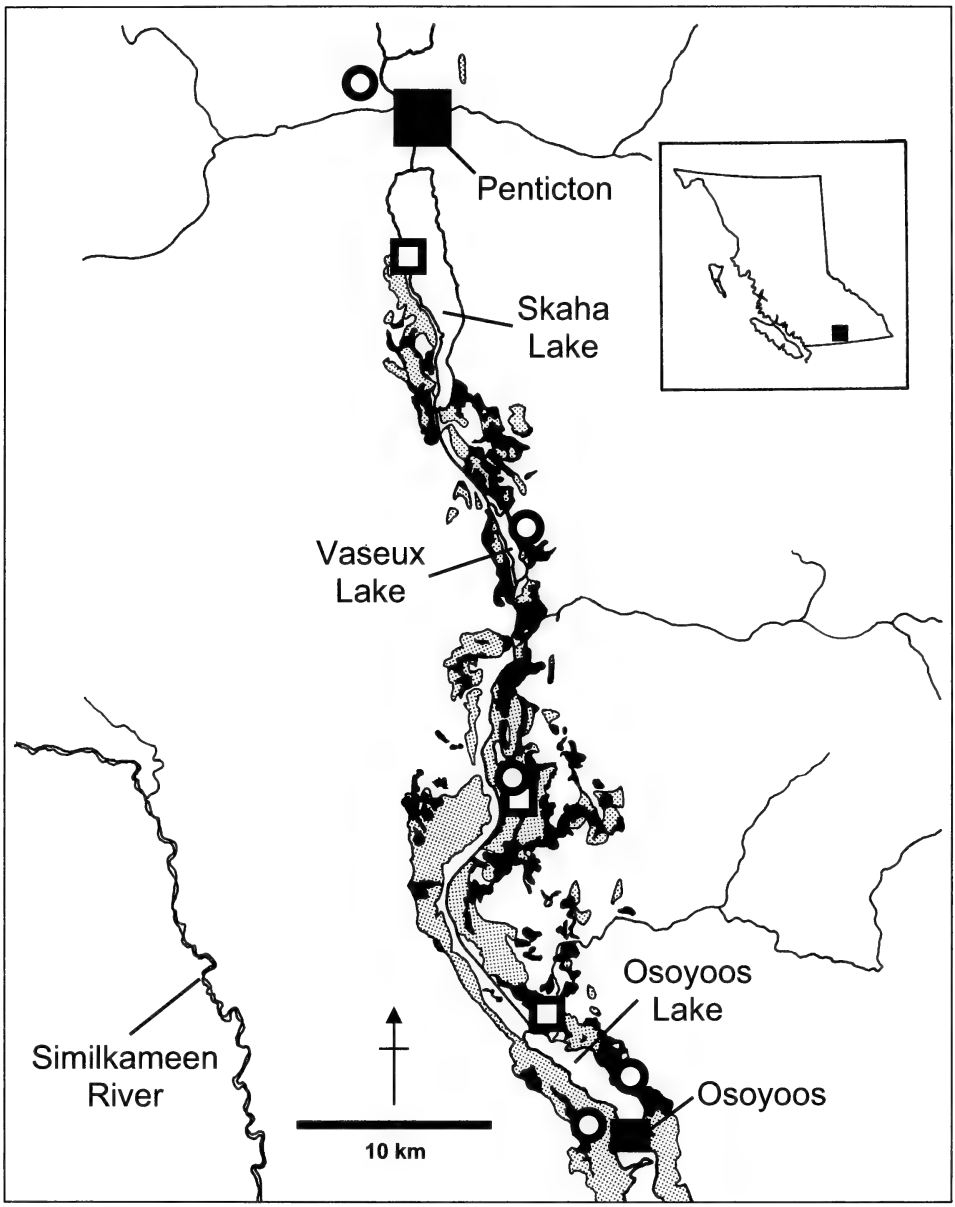

Figure 3. Distribution of *Apiocera barri* (○) and *Nemomydas pantherinus* (□) in British Columbia. Some symbols represent several records at approximately the same locality. *Nemomydas pantherinus* has been collected in two locations outside the range of this map: at Vernon to the north (119°15'N x 50°15'N) and near Grand Forks to the east (49°01'N x 118°32'W). Insert shows location of the South Okanagan in British Columbia. The original (1860) range of the antelope-brush / needle-and-thread grass community is shown in grey; the recent distribution (2001) is in black.

eral Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

COSEWIC and the BC Ministry of Environment's Ecosystems Branch (MOE) are involved in the documentation of species at risk in BC. The former (COSEWIC 2006) develops lists and status reports of species of national relevance and, in conjunction with the BC Invertebrate Recovery Team (MOE 2006), adopts recovery plans for nationally endangered invertebrate species occurring in BC. In addition, the BC Con-

servation Data Centre (CDC) (MOE 2006) maintains data on species and habitats at risk within the province and develops conservation ranks for them. For the sake of practicality and efficiency, COSEWIC and MOE are focusing attention on a few rare arthropod species in the antelope-brush ecosystem that are reasonably well-known and amenable for inventory and other study. Behr's hairstreak (*Satyrium behrii* (W.H. Edwards)) and the ground mantid, (*Litaneutria minor* (Scudder)) are obvious choices that are currently being studied. *Apiocera barri* and *N. pantherinus* are large (2 cm long) and conspicuous flies that apparently are truly rare and largely restricted to the threatened antelope-brush steppe ecosystem. As such, they are excellent candidates for official conservation listing. The information outlined below is the first overview of the available distributional data on these two species.

MATERIALS AND METHODS

Data were collected from 22 and 18 specimens of *A. barri* and *N. pantherinus*, respectively, from the following institutions: Canadian National Collection of Insects, Agriculture and Agri-food Canada, Ottawa, ON (CNCI), Royal British Columbia Museum, Victoria, BC (RBCM), Spencer Entomological Museum, University of British Columbia, Vancouver, BC (UBCZ), and US National Museum of Natural History, Washington, DC (USNM).

In addition, 34 paratypes of *A. barri* collected at Osoyoos are deposited in a number of American collections, including the American Museum of Natural History (New York) and the California Academy of Sciences (San Francisco) (Cazier 1982).

RESULTS

Apiocera barri

Apiocerids, often mistakenly termed "flower-loving flies" (they seldom visit flowers) spend much of their time on open sand or soil in hot, dry areas where they imbibe water from soil and honeydew from beneath aphid-infested plants (Cazier 1982). Females lay eggs in sandy soil at the base of plants and the larvae apparently prey on soil invertebrates (McAlpine *et al.* 1981).

Apiocera, the only apiocerid genus, contains 137 described species in four subgenera. Each subgenus is restricted to one of four discrete geographical regions: western North America (including northern Mexico), southwestern South America, South Africa, and Australia. This disjunct distribution resulted from the break-up of Pangaea and Gondwanaland and the subsequent displacement of the continental plates (Yeates and Irwin 1996). The North American subgenus, the earliest lineage within the genus (Yeates and Irwin 1996), contains 58 named species (Cazier 1982). *Apiocera barri* occurs from the southern Okanagan Valley in BC south through eastern Washington, western Idaho and eastern Oregon to southern California (Cazier 1982). In BC it is most common in the sandy habitat dominated by *Purshia* on the east side of Osoyoos Lake (Fig. 1), but it occurs rarely at least as far north as the *Festuca* (Poaceae) grassland patches growing on sandy loam at Penticton. Adults have been collected only from 13 July to 17 August.

Canadian records (Fig. 3): Oliver, 13.vii.1923, C.B. Garrett (♀, CNCI); Oliver, 24.vii.1923, E.R. Buckell (♂, ♀, CNCI); Oliver, 24.vii.1923, P.N. Vroom (2♂, ♂♀ *in cop.*, CNCI; ♂, ♀ (RBCM); ♂, USNM); Osoyoos, 10.viii.1936, E.R. Buckell (♂♀ *in cop.*, CNCI, ♂, UBCZ); Osoyoos, 13.viii.1942, E.R. Buckell (4♀, CNCI); Osoyoos, Indian desert [east side Osoyoos Lake], 12.viii.1986, M.J. Sarell (♂, RBCM); same location, 13.viii.1986, M.J. Sarell (♀, RBCM); same location, 17.viii.1986, M.J. Sarell (♂, RBCM); Osoyoos Lake, east side, 14.viii.1969,

J.Bigelow, M. Mortenson and M. Cazier (24♂, 10♀, paratypes deposited in various US collections [Cazier 1982]); Penticton, West Bench, 3.viii.1986, R.A. Cannings (♂, RBCM); Vaseux Lake, 7.viii.1978, R.A. Cannings (♂, UBCZ).

Nemomydas pantherinus

Adult mydids, with their long antennae and colourful bodies, are probably wasp mimics. Adults may be predators but probably most feed at flowers and those with atrophied mouthparts (such as *Nemomydas*) may not feed at all (McAlpine *et al.* 1981). Little is known about the larvae; some species prey on beetle larvae in rotting wood and sandy soil (McAlpine *et al.* 1981).

Mydids are widely distributed, especially in dry tropical, subtropical and Mediterranean climates. The earliest lineages, Raphiomidinae and Megascelinae, were recently transferred from the Apioceridae to the Mydidae (Yeates and Irwin 1996). This old and widely scattered family contains about 355 species in 65 genera worldwide (Dikow 2006). There are 23 genera in the New World and at least 54 North American species (B.C. Kondratieff, pers. comm.). *Nemomydas* contains 21 species in North and Central America and eastern Asia (B.C. Kondratieff, pers. comm.).

Nemomydas pantherinus is distributed in intermontane grasslands and dry forests from southern British Columbia south to California (Stone *et al.* 1965). In Canada, this distinctive, yellow and black fly is evidently restricted to the dry, sandy grasslands of the southern Okanagan Valley and adjacent Boundary region to the east. Most Canadian records are from Oliver and Osoyoos in the extreme southern Okanagan where adults have been collected only from 5 July to 2 August.

Canadian records (Fig. 3): Grand Forks, 5.5km W on Hwy 3, 28.vii.1980, J.M. Cumming (♀, CNCI); Oliver, 19.vii.1923, E.R. Buckell (♀, CNCI); Oliver, 20.vii.1923, E.R. Buckell (♂, CNCI); Oliver, 24.vii.1923, E.R. Buckell (♀, CNCI); Oliver, 22.vii.1923, P.N. Vroom (2♂, ♀, CNCI); Oliver, 24.vii.1923, P.N. Vroom (♀, CNCI); Oliver, 20.vii.1953, J.E.H. Martin (♀, CNCI); Osoyoos, Haynes Lease Ecological Reserve, Throne area [north end Osoyoos Lake], 2.viii.1987, S.G. Cannings (♂, UBCZ); same locality, 27.vii.1988, C.S. Guppy (3♂, RBCM), G.E. Hutchings (2♂, RBCM); same locality, 8.vii.1979, R.A. Cannings (♂, UBCZ); Skaha Lake, Kaleden, 49°25'N x 119°36'W, 25.vii.1997, Russell Cannings (♂, RBCM); Vernon, 5.vii.1907, E.P. Venables (♀, UBCZ).

DISCUSSION

Apiocera barri and *N. pantherinus* are rare in Canada. All but two of the collection localities for both species are from lowland grasslands in the southern Okanagan Valley (two *Nemomydas* records are from just outside that area) – habitats that have been frequently examined by entomologists for almost a century. The Canadian ranges of both species are centred on the threatened antelope-brush steppe ecosystem from Penticton south to Osoyoos. Within this ecosystem, the dominant antelope-brush / needle-and-thread grass plant community has declined dramatically. In 1860, about the time of the first European settlement in the area, 10,053 ha were present but by 1938 only 7,425 ha (74%) remained. Most of this change was the result of fruit tree planting and the growth of towns between about 1900 and 1930. The reduction has continued at a rate of about 2% per year in recent times, decreasing from 4,438 ha (44%) in 1995 to 3,386 ha (33%) in 2001 (Dyer and Lea 2003). Figure 3 illustrates the decline from 1860 to 2001. The latest reductions are largely related to vineyard expansion. Only 18% of the extant plant community, representing 7% of the original 1860 area, is protected; 58% is on Indian Reserves and 29% is on private lands (Dyer and Lea 2003). Because of these pressures on the

extreme northern populations of these large and conspicuous flies, the two species are good candidates for further inventory and for conservation planning by COSEWIC and MOE.

ACKNOWLEDGEMENTS

I thank Jeff Cumming (Canadian National Collection of Insects, Agriculture and Agri-food Canada, Ottawa), Karen Needham (Spencer Entomological Museum, University of BC, Vancouver) and Norman Woodley (US National Museum of Natural History, Washington) for supplying specimens and data. Orville Dyer (BC Ministry of Environment, Penticton) provided the original map of *Purshia* habitat from which Fig. 3 was produced. Boris Kondratieff (Colorado State University, Fort Collins) furnished statistics on the Mydidae and gave permission to use personal communication. I also thank Robb Bennett, Art Borkent and an anonymous reviewer for valuable comments on the manuscript.

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A survey of the spiders (Arachnida, Araneae) of Chichagof Island, Alaska, USA

JOZEF SLOWIK[1]

ABSTRACT

A spider survey was conducted over the summer of 2003 on Chichagof Island, Alaska, USA. Based on this, as well as on data from a preliminary survey in 2002, and two subsequent visits, a preliminary list of 95 spider species is presented for the island. This survey resulted in 10 new species records for Alaska and 8 species not known to occur in British Columbia. The data were tested for completeness using Chao 1, Chao 2, bootstrap, and Michaelis-Menten species richness equations. The number of species observed fell within the variance for both Chao indicators but was below the other two estimators indicating that more species may still be found. Twenty-two micro and three macro habitats were defined in the survey. All data were submitted to the Nearctic Spider Database and cataloged on the Denver Museum of Nature & Science's website.

Key Words: Southeast Alaska, species richness estimators, species list, species diversity

INTRODUCTION

Spiders are a diverse but poorly understood animal group in the Pacific Northwest of North America (Bennett 2001). Little spider research has been completed in southeast Alaska (Mann & Gara 1980). Species lists are available for British Columbia (Thorn 1967; West *et al.* 1984, 1988; Bennett *et al.* 2006) and Yukon Territory (Dondale *et al.* 1997) but there are none for the southeast Alaskan archipelago.

Spider surveys may provide an effective means for measuring the impact of habitat degradation or land use change on biodiversity. Baseline studies involving spiders as biological indicators have been conducted elsewhere; e.g. Allred (1969) and Allred & Gertsch (1976) documented spider diversity in Arizona and Utah after new power plant installations and in Nevada at the Nevada Nuclear Test Site. The need for spider species lists for use in conservation decision making has also been expressed (Skerl 1999). In addition, spiders may play roles in the control of destructive insects (Jennings & Pase 1986; Maloney *et al.* 2003).

Southeast Alaska provides important resources for three major industries: logging, fishing, and tourism. Biodiversity surveys provide important baseline information to help land resource managers understand and monitor environments utilized by these industries. Spiders may provide a useful survey option because of the relative ease with which they can be collected, preserved, and identified.

The objective of this study was to document the spider fauna of northern Chichagof Island, Alaska in a manner that can be replicated on other islands in the southeast Alaskan archipelago in an attempt to assemble a comprehensive spider fauna list for the area. The preliminary spider species list and other information provided here are meant to be resources for future surveys in the area and relevant biogeographic and taxonomic studies.

[1] Department of Zoology, Denver Museum of Nature and Science, 2001 Colorado Blvd., Denver CO 80205, (303) 370-6354, jslowik@dmns.org

MATERIALS AND METHODS

Study Site. The study site is located at 58.10° N 135.42° W in southeast Alaska on the northeast corner of Chichagof Island, approximately 100 km west of Juneau (Fig. 1). The study area is located within the Tongass National Forest, Sealaska Corporation land, Huna Totem Corporation land and Alaska State lands. The study site consisted of an area of roughly 86,765 ha located around the town of Hoonah, Alaska (Fig. 1), and is characterized as northern temperate rainforest dominated by western hemlock (*Tsuga hetrophylla* (Raf.) Sarg.). The area around Hoonah and northward to Gustavus is in a slight rain shadow for southeast Alaska with an average annual rainfall of 130 cm (*versus* Juneau at 250 cm). The area is dominated by steep, abruptly ascending mountains and narrow valleys left by recent glacial activity with elevations from sea level to over 1,180 m.

In 2002 a preliminary survey was conducted and three general macro-habitats and 22 micro-habitats were defined (Table 1). The micro-habitats were used for comparing similar sites in the study area and for expanding search areas if few or only immature spiders were found at a given site. Each of the 22 micro-habitats is included in one of the three macro-habitats: shrubby skree or logged areas, open muskeg meadows, and densely treed old growth forests. The shrubby areas are dominated by several species of *Vaccinium* L. and *Rubus* L. and devil's club (*Oplopanax horridum* (Smith)) growing to over 2 m in height. The muskeg areas consist of low shrubs under 0.5 m tall (*Kalmia microphylla* (Hook.) Heller) and *Andromeda polifolia* L.) and grasses, with pools or slow moving streams. The old growth areas consist mainly of hemlocks (*Tsuga hetrophylla* and *T. mertensiana* (Bong.) Carr.) with some Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and yellow cedar (*Chamaecyparis nootkatensis* (D. Don) Spach) intermixed and usually have few shrubs in the understory and a closed canopy.

There are no protected areas within the study site and substantial clear-cut logging on blocks ranging from 0.08 to 40.00 ha occurred on the island from the early 1980's until 2004. During the survey period, the resulting second growth areas were relatively young and differed little in structure from the naturally occurring shrubby skree areas.

Data Collection. All specimens were collected by the author during the period 22 April to 24 August 2003 using one of six methods: beat sheeting, sweep netting, sifting moss, head-lamping, pitfall trapping and casual collection. Because of the density and thickness of the forests and clear-cut areas an alternative method of sweeping/beating was used in those areas. This method consisted of grabbing either branches or the top of a tree and stuffing it into the sweep net, then beating the branch or treetop in the net. This method was also used in shrubby areas where the vegetation was too dense to sweep or beat. The head-lamping method consisted of using a head-lamp or other light source and looking both up and down for eye shine and webs after dark. Specimens were deposited directly into 75% ethanol for preservation. Each collection occurrence consisted of one method and was conducted for one half hour, although multiple collection occurrences may have occurred in a day or at a site.

Pitfall traps were sets of 230 ml plastic cups placed in the ground with the lip of each cup level with the ground surface. Each set consisted of 10 cups placed 1 m apart in a line. The traps were filled with 30-60 ml of propylene glycol as a preservative. Traps were covered only if rain was imminent. Pitfall trap specimens were collected every two days to one week (dependant upon rainfall) then sorted, washed and stored in 75% alcohol.

Because of the difficulty of identifying juvenile spiders only adults were identified and used for the analyses. Linyphiidae

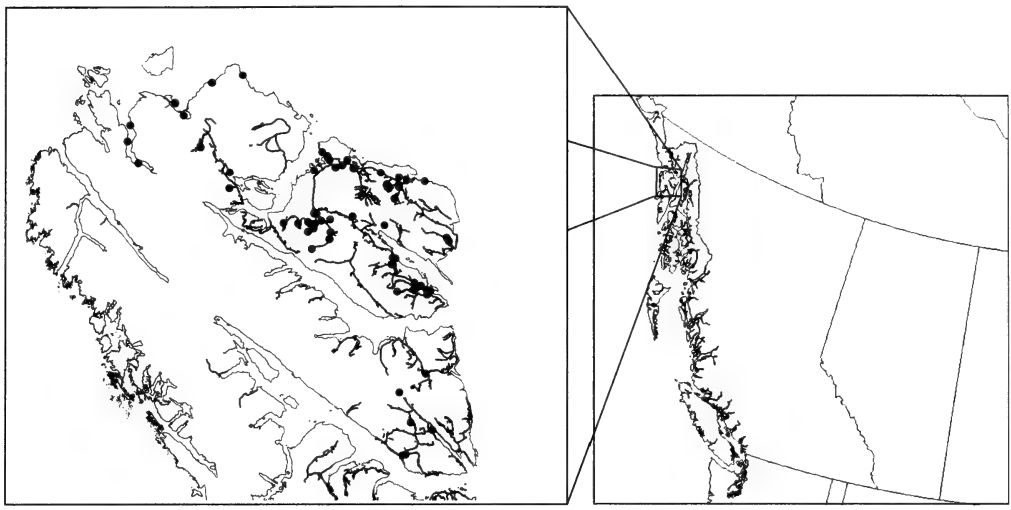

Figure 1. Spider collections sites on Chichagof Island, Alaska, USA, 2002-2005. Each point may represent more than one habitat or collection occurrence.

were identified by D. J. Buckle (Saskatoon, Saskatchewan), Philodromidae and Thomisidae were identified by F. X. Haas (Denver, Colorado). All other spiders were identified by the author using Roth (1993) or Ubick *et al.* (2005) and included references. Voucher specimens were deposited at the Denver Museum of Nature & Science. Nomenclature follows Platnick (2006). See discussions in Crawford (1988), Buckle *et al.* (2001) and Ubick *et al.* (2005) regarding linyphiid nomenclature.

Statistical analysis. Species richness was estimated using Chao 1 (Chao 1984), Chao 2 (Chao 1984, 1987), bootstrap (Smith & van Belle 1984), and Michaelis-Menten (Raaijmakers 1987) estimators following Coddington *et al.* (1996). The Chao 1 estimator is a non-parametric equation using relative abundance data; the Chao 2 estimator is also non-parametric but uses presence-absence data. The bootstrap estimator uses incidence data and the Michaelis-Menten model contrasts sampling effort data and number of species observed. See Magurran (2004) for discussion of the various usage and accuracy issues associated with these estimators. Species accumulation curves were plotted using EstimateS (Version 7.5, Colwell 2005).

Three of the richness equations, Chao 1, Chao 2, and bootstrapping require collection occurrence data, which is defined as each separate occurrence in which spiders were collected. For the sampling effort aspect of the Michaelis-Menten equation each collection occurrence (other than casual and pitfall trapping) consisted of one-half hour (as described above). Because the movements of spiders are not well understood, statistical analysis of each pitfall trap occurrence was arbitrarily attributed one hour of sampling effort following Coddington *et al.* (1996) (although Coddington used leaf litter samples and a Tullgren-funnel). Specimens collected with methods other than those described above were considered to be casual occurrences and were each attributed five minutes of time.

Specimen data were submitted to the Nearctic Spider Database (http://canadianarachnology.webhop.net) and catalogued on the Denver Museum of Nature & Science website (www.dmns.org/spiders/default.aspx).

Habitat and collection method were used to determine general species habitat associations: arboreal, ground-dwelling, or other. These determinations are speculative but may be helpful in locating species in similar environments.

Table 1.
Habitats sampled for spiders on Chichagof Island, Alaska, 2002-2005.

Microhabitat number	Macro-habitat	Physical description	Water	Canopy
1	Shrubby	Shot rock, buildings	None	Open
2	Shrubby	Sitka alder, snake grass	Pooled	Moderate
3	Open	Grass only	Running	Open
4	Open	Grass only	Pooled	Open
5	Open	Low shrubs and grass	Pooled or none	Open
6	Treed	Mossy, shrubby	None	Moderate
7	Treed	Mossy, few shrubs	None	Moderate
8	Treed	Mossy, few shrubs	None	Closed
9	Open	Shot rock, quarry	Temporary pools	Open
10	Shrubby	Shrubby	None	Moderate
11	Shrubby	Shrubby, no alder	None	Open
12	Shrubby	Shrubby, alder present	None	Open
13	Open	Muskeg, shrubs, various water, above 500m	Pooled, running	Open
14	Open	Grassy meadows, few shrubs, no water, above 500m	None	Open
15	Open	Rocky, shrubby, coastline debris	Tidal	Open
16	Open	Tall grass	Tidal	Open
17	Treed	Shrubby, treed	Running	Moderate to closed
18	Treed	Few shrubs, low grass	None	Closed
19	Shrubby	Tall grass, shot rock	Temporary pools	Open to moderate
20	Treed	Marshy, tall grass	Pooled	Moderate to closed
21	Shrubby	Shrubby, treed, mossy	None	Moderate
22	Open	Tall grass	Pooled	Open

RESULTS AND DISCUSSION

A total of 1,239 adult spiders representing 16 families, 68 genera and 95 species (Appendix 1) was collected and identified from 103 collection occurrences.

The 2003 survey consisted of 43 hours of collection time accumulated over 40 days during the period 22 April to 24 August and produced 93 of the 95 total species observed. *Agnyphantes arboreus* (Emerton) and *Tetragnatha extensa* (Linnaeus) were collected in 2002 but not subsequently. Total survey time including travel and sorting of pitfall traps was 150 hours. Additionally the site was surveyed casually in 2004 and 2005 but no further species were added to the list.

Based on the habitat and method of collection; 49 species were classified as ground-dwelling and 34 species as arboreal. Twelve species occurred in both general habitat types. Fifty-four species (56%) and 521 of all spiders (42%) collected

were linyphiids. Fifty-one of the linyphiid species were collected in pitfall traps, 13 were collected using others methods as well.

Expected number of species resulting from all species accumulation equations was higher than the observed number of 95 species, indicating that further sampling should result in more species (Figure 2). However, the observed number fell within the variance for both the Chao 1 and Chao 2 equations (97 ± 7.48 and 104.45 ± 11.58 respectively). The Michaelis-Menten model and the bootstrapping methods predicted 130.72 species and 106.35 ± 7.00 species respectively.

Species of interest. *Diplocephalus sphagnicola* Eskov 1988, a Siberian spider, was collected for only the third time in North America. Several specimens of a described but unnamed species of *Centromerus* Dahl, previously known only from one damaged male collected at Terrace, BC in 1920 (van Helsdingen 1973) were collected. This survey produced records of 10 species not previously reported from Alaska (D. J. Buckle, unpublished data) and eight species not known to occur in British Columbia (Bennett *et al.* 2006) (Appendix 1). Two of these records, *Maro amplus* Dondale & Buckle and *Walckenaeria redneri* Millidge, are the first for either area.

All of the 13 undetermined species are linyphiids, five are female erigonines (currently unidentifiable), two are known but undescribed species (*Porrhomma* sp. #1 and *Centromerus* sp. #1), five are in genera in need of revision (*Agyneta* Hull, *Eularia* Chamberlin and Ivie, *Oreonetides* Strand, *Pityohyphantes* Simon, *Tapinocyba* Simon) and could not be placed, and one species of *Walckenaeria* could not be determined. Several larger families were represented by surprisingly low numbers of species: only a single female philodromid, *Tibellus oblongus* (Walckenaer) and two females of a single salticid species, *Evarcha proszynskii* Marusik & Logunov, were collected.

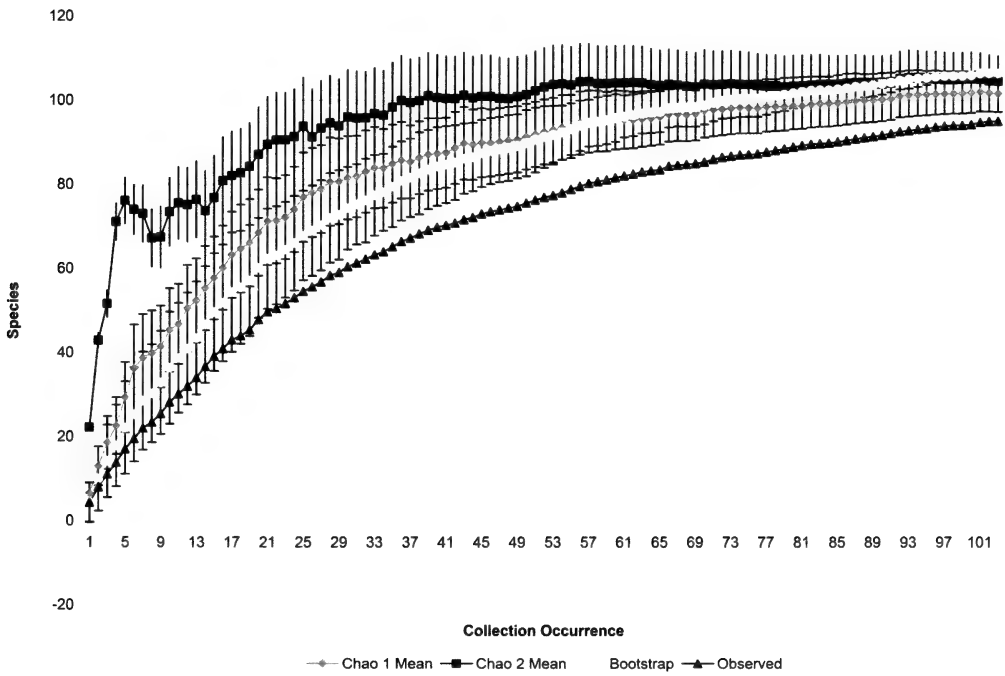

Figure 2. Species accumulation curve for spiders sampled using all methods described in text on Chichagof Island, Alaska, USA, 2002-2005 and estimates of Chao 1, Chao 2 and bootstrapping results from statistical analysis using EstimateS (Version 7.5, Colwell 2005). Vertical bars indicate computed variance. Michaelis-Menten analysis results are not displayed.

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APPENDIX 1

Spider species list and collection data for Chichagof Island, Alaska USA, sorted alphabetically by family, genus, and species. Habitat numbers refer to Table 1. "*" indicates a new record for Alaska; "**" indicates a species not listed for British Columbia. Detailed collection data for each species is accessible on the Nearctic Spider Database (http://canadianarachnology.webhop.net) and the Denver Museum of Nature & Science website (www.dmns.org/spiders/default.aspx).

Family/Species	Months Adults Found	Collection Method	Habitat Number	Males	Females
Amaurobiidae					
Callobius pictus (Simon, 1884)	May-Sept.	casual, headlamp, pitfall	1, 6, 8	6	11
Cybaeopsis wabritaska (Leech, 1972)	April-June	headlamp, pitfall	2, 3, 4, 5, 13, 22	65	6
Araneidae					
Araneus saevus (L. Koch, 1872)	Aug.	casual	1	1	1
Araneus trifolium (Hentz, 1847)	July	casual, sweep	4, 5, 22		3
Araniella displicata (Hentz, 1847)	May-June	beat, sweep	4, 5, 20, 22	2	8
Cyclosa conica (Pallas, 1772)	May-June	headlamp, sweep	1, 4, 5, 21, 22	3	5
Larinioides patagiatus (Clerck, 1757)	April-May	headlamp, sweep	1, 4, 5		5
Parazygiella dispar (Kulczyn'ski, 1885)	May & Aug.	casual, headlamp	1	4	3
Clubionidae					
Clubiona pacifica Banks, 1896	April-Aug.	headlamp, sweep	1, 4, 5, 19, 22	8	6
Clubiona trivialis C. L. Koch, 1843	May-July	beat	4		6
Cybaeidae					
Cybaeus reticulatus Simon, 1886	April-May & Aug.-Oct.	casual, headlamp, pitfall	1, 2, 3, 5, 6, 7, 8, 10, 21	34	37
Dictynidae					
Dictyna brevitarsa Emerton, 1915	May-July	beat, sweep	4, 5, 13, 22		11
Dictyna major Menge, 1869	June-July	sweep	4, 5	10	7
Gnaphosidae					
Micaria pulicaria (Sundevall, 1831)	May-June	casual, sweep, pitfall	1, 4, 5		3
Sergiolus montanus (Emerton, 1890)	May	casual	1		1
Hahniidae					
*Antistea brunnea (Emerton, 1909)**	April-July	pitfall	3, 4, 5, 8, 22	1	34
Dirksia cinctipes (Banks, 1896)	May & Sept.	casual, sweep	8, 15	1	1

APPENDIX 1 *(continued)*

Family/Species	Months Adults Found	Collection Method	Habitat Number	Males	Females
Hahniidae *(continued)*					
Hahnia cinerea Emerton, 1890	May-June	pitfall	3, 4		3
Neoantistea magna (Keyserling, 1887)	April	pitfall	2		1
Linyphiidae					
Agnyphantes arboreus (Emerton, 1915)	July	casual, sweep	4, 5, 15	1	1
*Agyneta olivacea (Emerton, 1882)**	May-June	pitfall	3, 4, 5	15	
Agyneta sp #1	June	pitfall	4	2	2
Aphileta misera (O. Pickard-Cambridge, 1882)	June	pitfall	4, 5	1	
Bathyphantes brevipes (Emerton, 1917)	May & Sept.	beat, headlamp, pitfall	1, 6, 15, 18, 22	2	2
Bathyphantes pallidus (Banks, 1892)	May-June	pitfall, sweep	3, 21	1	2
*Centromerus sp #1**	April-May	pitfall, sift, sweep	3, 5, 15	2	2
Ceraticelus atriceps (O. Pickard-Cambridge, 1874)	May	pitfall	5		1
*Ceratinella acerea Chamberlin & Ivie, 1933**	April-May	pitfall, sift	8, 15		2
Ceratinella ornatula alaskana Chamberlin, 1948	May	pitfall	3	3	
Ceratinops inflatus (Emerton, 1923)	May	pitfall	7, 8	15	
Collinsia ksenius (Crosby & Bishop, 1928)	April-June	sweep	17		3
*Diplocephalus sphagnicola Eskov, 1988**	April	pitfall	3	1	1
Erigone aletris Crosby & Bishop, 1928	May-Aug.	sweep	4, 14, 16, 19	6	9
Erigonine sp #1	May	pitfall	7, 8		6
Erigonine sp #3	June-July	pitfall	4, 5, 22		3
Erigonine sp #4	June	pitfall	4, 5		2
Erigonine sp #7	May-June	pitfall	4, 8		2
Erigonine sp #8	May-June	sweep, pitfall	3, 4, 15		3
Eulaira sp #1	May	pitfall	5	1	
*Grammonota subarctica Dondale, 1959 **	April-July	pitfall	3, 4, 5, 22	3	129
*Hybauchenidium cymbadentatum (Crosby & Bishop, 1935)**	April-June	pitfall	3, 4, 5		8
Kaestneria pullata (O. Pickard-Cambridge, 1863)	April-July	casual, pitfall, sift, sweep	3, 4, 5, 11, 15, 21		8
Linyphantes pualla Chamberlin & Ivie, 1942	May	pitfall	8		1
Maro amplus Dondale & Buckle, 2001 & **	May	pitfall	4, 5	2	2
Meioneta simplex (Emerton, 1926)	June	pitfall	4, 5	3	
Microlinyphia dana (Chamberlin & Ivie, 1943)	May-June & Sept.	sweep	2, 4, 5, 15, 16, 19, 21, 22	13	37

APPENDIX 1 *(continued)*

Family/Species	Months Adults Found	Collection Method	Habitat Number	Males	Females
Linyphiidae *(continued)*					
Mythoplastoides erectus (Emerton, 1915)	April-July	pitfall, sift	7, 8	1	3
Neriene digna (Keyserling, 1886)	April-June	casual	1	4	5
Oedothorax alascensis (Banks, 1900) **	April-May	sweep, beat	6, 15, 17		2
Oedothorax trilobatus (Banks, 1896) **	April-May	pitfall	3	6	
Oreoneta brunnea (Emerton, 1882)	May-June	pitfall	3, 4, 5	24	8
*Oreonetides rectangulatus (Emerton, 1913)***	April-May	pitfall	3	3	
Oreonetides sp #1	May	pitfall	3	1	
Pelecopsis sculpta (Emerton, 1917)	May-July	pitfall	4, 5	9	4
Pityohyphantes sp #1	April-Aug.	casual, beat, head-lamp, sweep	1, 4, 5, 19, 21		10
Pocadicnemis pumila (Blackwall, 1841)	April-June	pitfall, sift	3, 4, 5, 11, 15, 21	12	5
Porrhomma sp #1	June	sweep	4, 5		1
*Satilatlas insolens Millidge, 1981***	May	pitfall	3	2	
Sciastes truncatus (Emerton, 1882)	April-May	pitfall	7	3	
Sisicotus nesides (Chamberlin, 1921)	April-June	pitfall, sift, sweep	1, 5, 6, 7, 8, 18, 22	18	20
Sisis rotundus (Emerton, 1925)	April-May	pitfall	3, 8	1	1
Symmigma minimum (Emerton, 1923)	May-June	pitfall	4, 5, 8	2	
Tachygyna ursina (Bishop & Crosby, 1938)	May-June	beat, sweep	4, 5, 18		4
Tapinocyba dietrichi Crosby & Bishop, 1933	May-July	pitfall, sift	6, 8	4	2
Tapinocyba sp #1	May-June	pitfall	4	4	1
Tenuiphantes zelatus (Zorsch, 1937)	April-June	casual, pitfall sift	6, 7, 8, 22	2	6
*Walckenaeria columbia Millidge, 1983**	April-June	pitfall, sift	7, 8, 13, 21	2	2
Walckenaeria cornuella (Chamberlin & Ivie, 1939)	April-May	sweep, pitfall	1, 7, 8, 9, 18	5	3
Walckenaeria directa (O. Pickard-Cambridge, 1874)	May-June	pitfall	3, 4, 5	7	3
*Walckenaeria exigua Millidge, 1983**	June	pitfall	4	4	
Walckenaeria redneri Millidge, 1983 & **	April-May	pitfall, sweep	3, 4, 5, 16	18	3
Walckenaeria spiralis (Emerton, 1882)	June	pitfall	4, 5	3	3
Walckenaeria sp #1	Oct.	pitfall	8		1
*Wubana pacifica (Banks, 1896)**	April-May	pitfall	7	2	
Lycosidae					
Alopecosa aculeata (Clerck, 1757)	May-June	pitfall	4	2	
Pardosa dorsuncata Lowrie & Dondale, 1981	April-June	headlamp, pitfall, sweep	1, 2, 3, 4, 5, 16, 18, 20, 21, 22	45	31

APPENDIX 1 *(continued)*

Family/Species	Months Adults Found	Collection Method	Habitat Number	Males	Females
Lycosidae *(continued)*					
Pardosa moesta Banks, 1892	May-July	sweep, pitfall	3, 4, 5, 18, 21	72	30
Pirata piraticus (Clerck, 1757)	June-July	casual, pitfall, sweep	4, 5, 21, 22	13	5
Trochosa terricola Thorell, 1856	April-June	casual, pitfall, sweep	3, 4, 5, 16	36	14
Philodromidae					
Tibellus oblongus (Walckenaer, 1802)	June	sweep	4, 5		1
Pimoidae					
Pimoa altioculata (Keyserling, 1886)	May & Aug.	casual, headlamp	1, 17	2	3
Salticidae					
Evarcha proszynskii Marusik & Logunov, 1998	June	sweep	4, 5		2
Tetragnathidae					
Tetragnatha extensa (Linnaeus, 1758)	July	sweep	4, 5	1	
Tetragnatha laboriosa Hentz, 1850	May-July	beat, sweep	4, 5, 11, 18, 19, 21, 22	37	46
Tetragnatha versicolor Walckenaer, 1842	May-Aug.	casual, sweep	4, 5, 19	7	5
Theridiidae					
Robertus vigerens (Chamberlin & Ivie, 1933)	April-June	pitfall, sweep	3, 4, 5, 18		9
Rugathodes sexpunctatus (Emerton, 1882)	April-July	beat, casual, sweep	2, 4, 5, 11, 15, 16, 18, 19, 20	9	30
*Theonoe stridula Crosby, 1906***	April-May	pitfall	3	2	
Theridion saanichum Chamberlin & Ivie, 1947	May-July	sweep	4, 5	3	
Thomisidae					
Bassaniana utahensis (Gertsch, 1932)	Aug.	headlamp	1		1
Misumena vatia (Clerck, 1757)	May-July	sweep	5, 21, 22	3	1
Ozyptila pacifica Banks, 1895	April	pitfall	3	4	
Xysticus luctuosus (Blackwall, 1836)	April-June	pitfall	4, 5, 21	12	
Xysticus pretiosus Gertsch, 1934	May & Sept.	casual, headlamp	1	3	
Uloboridae					
Hyptiotes gertschi Chamberlin & Ivie, 1935	Aug.-Sept.	casual, headlamp	1, 7		3

SCIENTIFIC NOTE

Exaireta spinigera (Diptera: Stratiomyidae): the first published North American records of an Australian soldier fly

J.E. SWANN[1], R.D. KENNER[1], R.A. CANNINGS[2] and C.R. COPLEY[2]

Specimens of a large and distinctive adult fly, recently collected in southwestern British Columbia, could not be identified to family using the available key in McAlpine (1981). However, we recognized it as probably belonging to the Stratiomyidae and finally identified it as *Exaireta spinigera* (Wiedemann), a species unknown in North America according to the published literature.

Exaireta spinigera is native to and widespread in Australia and has been introduced to New Zealand and Hawaii (Woodley 2001). It was common in Honolulu, Hawaii by 1900 although it was only first noticed in the late 1890s (Hardy 1960). Our material was identified, in part, by comparison to specimens in the Spencer Entomological Museum collected in Honolulu in 1904. In the National Museum of Natural History Collection, Smithsonian Institution, Woodley (pers. comm.) found a single North American specimen of *E. spinigera*, collected in 1985 from a greenhouse in Santa Barbara, California. However, he did not include the record in his world catalogue of Stratiomyidae (Woodley 2001) because he thought that this single record might not represent an established population. Recent unpublished data suggest it may now be established in California (Woodley, pers. comm.).

Material examined. Specimens are deposited in the Spencer Entomological Museum (UBCZ), the Royal BC Museum (RBCM) and the Canadian National Collection of Insects (CNC). CANADA: BC: Maple Ridge, dead on indoor windowsill, i-2006, J.R. Vockeroth, 1♀ CNC; Vancouver, 4244 West 15th Avenue, 22-vi-2002, G.S. Kenner, 1♀ UBCZ; same loc., in house, 14-ix-2005, R.D. & G.S. Kenner,1♀ UBCZ; Victoria, 657 Beaver Lake Road, in house, 23-ix-2005, C.R. Copley, 1♀ RBCM; same loc., potting shed near compost, 11-vi-2006, C.R. Copley, 1♀ RBCM; Victoria, Goldstream Prov. Park, at Visitor Centre, 16-vii-2006, D.R. Copley, 1♀ RBCM; same loc., at compost, 5-x-2006, D.R. Copley, 3♂ 1♀ RBCM; Victoria, 230 Goward Road, Malaise trap, 28-v-to 11-vi-2005, N.N. Winchester, 1♀ RBCM.

Unlike native species of Nearctic Stratiomyidae, *E. spinigera* has vein R_5 almost reaching the tip of the wing and cell d is roughly 2 to 2.5 times as long as broad. These characters are similar to those in the families Xylomyidae and Xylophagidae. However, these families have tibial spurs; *E. spinigera* lacks these on all legs. In order to include *E. spinigera* in McAlpine's (1981) key to Nearctic Diptera families, couplet 34 (p. 99) should be modified as follows:

34. C usually ending well before, rarely nearly at, wing apex; branches of R almost always more or less crowded anteriorly, and ending in margin well before wing apex; cell d (or dm) almost always short, usually little longer than wide (Fig. 30); if R_5 ending near wing apex and cell d at least 2 times as long as broad, then four marginal scutellar spines present (*Exaireta*). Tibial spurs usually absent .....**Stratiomyidae**

C extending beyond wing apex; branches of R not crowded anteriorly, with R_5 ending at or beyond wing apex; cell d at least two times as long as broad (Fig. 29);

[1] Spencer Entomological Museum, Department of Zoology, University of British Columbia, Vancouver, BC V6T 1Z4
[2] Royal British Columbia Museum, 675 Belleville Street, Victoria, BC V8W 9W2

scutellar margin bare or with at most 2 prominent spines. Tibial spurs present on at least mid and hind tibiae **35**

To include *Exaireta* in James' (1981) key to Nearctic stratiomyid genera, couplet 5 (p. 500) should be modified as follows:

5. Scutellum with six spines (Fig. 50) .....***Beris*** Latrielle

Scutellum with four spines **5a**

5a. Subscutellum at most with some tomentum; dorsum of the thorax metallic green/blue; specimens approximately 5 mm long .....***Actina*** Meigen

1 sp., *viridis* (Say); widespread

Subscutellum with tomentum and lateral pilose areas with fine, long white/translucent hairs; dorsum of thorax black; specimens over 10 mm long

.....***Exaireta*** Schiner

1 sp., *spinigera* (Wiedmann); introduced, BC, California.

Larvae of *E. spinigera* live in a wide variety of decaying organic material (Hudson 1950, Woodley 1995). Adults hover around rotting vegetation and have been collected by sweeping vegetation, from native flowers, in Malaise traps, and at lights (Woodley 1995). Because *E. spinigera* is so conspicuous, is readily collected, and has only been observed in southwestern British Columbia during the past five years, its introduction probably was not much earlier than 2002. The species likely was introduced to BC in association with potted plants or rotting vegetable matter from either California or Hawaii. *Exaireta spinigera* has been captured at the same location in Victoria in successive years implying that it has overwintered there. Even though it is only currently known from a few synanthropic localities, the behaviour and life history of this species suggest that it is likely to become (or already is) widespread in southwestern BC.

We thank N.E. Woodley for permission to use unpublished data.

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Marine forensic arthropodology: the use of a baited camera to study carrion decomposition in the Saanich Inlet

G. Anderson. *School of Criminology, Simon Fraser University, Burnaby, BC.*

Forensic entomology is traditionally applied to terrestrial homicide cases in order to estimate elapsed time since death. However, many human bodies are recovered from the marine environment and the effects of aquatic submergence and the faunal colonization of the remains are little studied. These experiments were conducted to examine the effects of marine submergence on pig carcasses (*Sus scrofa*) as human models.

In the first set of experiments, three pig carcasses were submerged and tethered at a depth of 7.5 m in Howe Sound, off the coast of the Lower Mainland of BC and a further three carcasses were submerged and tethered at a depth of 15m. The carcasses were examined by divers from immediate submergence until the remains stage. The first experiment was conducted in May and was repeated in October. The carcasses progressed through typical decomposition stages and were colonized by marine arthropods. Species and decomposition rates were impacted by depth and season but also by sediment type. Carcasses that came to rest on sand were consumed more rapidly than those on rocks.

The second set of experiments were conducted using a baited camera on the seabed of the Saanich Inlet at 94 m. A single pig carcass was placed under the camera and observed several times a day. The remains were rapidly consumed by a variety of arthropods, in particular, crabs, shrimp, and lobsters. Dogfish were probably responsible for the initial strike, but did not consume the carcass. The carcass was much more rapidly depleted at this site than at the previous site. This work is ongoing.

Waiter, there's a wasp in my water! A survey of the aquatic Hymenoptera of the world

A.M.R. Bennett. *Agriculture and Agri-Food Canada, Canadian National Collection of Insects, Ottawa, ON.*

A summary of the known species of aquatic Hymenoptera is presented. In total, 150 species from six superfamilies (11 families) are recognized as aquatic. This number is likely an underestimate because of lack of knowledge of host range and behaviour for most species. Exemplar aquatic species from the six superfamilies are discussed and compared as follows: *Caraphractus cinctus* (Chalcidoidea), *Psychopria hoguei* (Proctotrupoidea), *Tiphodytes gerriphagus* (Platygastroidea), *Agriotypus chaoi* (Ichneumonoidea), *Anoplius depressipes* (Vespoidea), and *Aspidogyrus strigosus* (Cynipoidea). Many aquatic species have relatively dense setae on the body and wings for holding a plastron of air, as well as elongate claws for clinging to the substrate, although these traits are not present in all aquatic species. Mapping of aquatic behaviour on a cladogram of the Hymenoptera superfamilies reveals that it is derived. It is estimated to have evolved independently at least fifty times within the order. Aquatic wasps occur in both lotic and lentic freshwater habitats, and four species of ants and one species of platygastroid are known to occur in marine intertidal zones. All freshwater species of Hymenoptera are parasitoids, parasitizing seven orders of insects as well as spiders. Aquatic parasitism likely evolved by transition from semi-aquatic parasitoids living around the water's surface.

Ten years after: history and current status of the 1992-1997 biological control releases of *Galerucella* beetles to control purple loosestrife, *Lythrum salicaria*, in Ontario

J. Corrigan. *BC Ministry of Forests and Range, Kalamalka Seed Orchards, Vernon, BC.*

In August 1992, the Biological Control Laboratory, University of Guelph, received shipments of three insect species imported to North America as classical biological control agents for the invasive wetland plant purple loosestrife, *Lythrum salicaria*. From 1992 to 1997, two species of Chrysomelid beetles, *Galerucella calmariensis* and *G. pusilla*, were released at 219 sites across Ontario. Approximately 320,000 individuals were released through this time period. In 2004 and 2005, monitoring tours were done to assess the results of these programs. Beetles were recovered at 90% of the original release sites and were providing some degree of control at 66% of these locations. Purple loosestrife was considered to be 'under control' at over 100 sites, with over 90% reductions in its coverage, biomass, and flowering, and with widespread replacement by other wetland species (e.g. cattails). Beetles have dispersed extensively from the original release sites and can now be found through all of the loosestrife-infested watersheds in southern Ontario. Although approximately equal numbers of each species of *Galerucella* beetles were released until 1996, *G. calmariensis* comprised over 90% of the 2,630 beetles collected in 2004, and were the only species found at many release sites originally initiated with *G. pusilla.*

Preparations for the arrival of West Nile virus - is BC ready?

M. Jackson. *Culex Environmental Ltd., Vancouver, BC, http://www.culex.ca.*

Since West Nile virus arrived in North America in 1999, it has spread to almost every continental US state as well as most provinces of Canada. WNv has yet to reach British Columbia and we can benefit from the experiences of affected jurisdictions. Are we ready for its imminent arrival? Highlights from preparations in the Lower mainland include:

On the plus side:

1. The main areas of WNv vector concern have been identified and mapped.
2. The GVRD has ensured that sampling protocols have been standardized.
3. Mosquito control treatments have been tested.
4. Communication and Response Plans have been drafted.

But against this:

1. Different municipalities have adopted different approaches and the level of response may be patchy.
2. Monitoring the effectiveness of mosquito control treatment is often neglected.
3. Private lands are generally not being treated.
4. Different Health Authorities are taking different stances.

Questions that remain are:

1. Will sufficient mosquito larval control be undertaken on private lands?
2. How significant are bird roosts and migration patterns of different birds?
3. Will the *Culex pipiens* complex turn out to include highly competent vectors?
4. How significant a WNv vector is *Aedes togoi*?
5. What will trigger an Official Order from the Health Authorities to treat with mosquito larvicide or adulticide?
6. How important are climatic factors – such as rainfall, snowpack, and temperature?
7. Does applying adulticides reduce the incidence of WNv?

In conclusion:

8. Experience from many other jurisdictions warns against complacency and underscores the need to respond preemptively to an outbreak.
9. Larval control from very early in the season is a key component of the most successful campaigns.
10. Keeping the public informed is essential.
11. Because of coordination between municipalities and three years' lead time, Brit-

ish Columbia is better placed to fight West Nile virus than most other previously affected jurisdictions.

A new species and genus of crawling water beetle (Coleoptera: Haliplidae) from China

R. Kenner and R. Roughley. *(R.K.) Department of Zoology, University of British Columbia, Vancouver, BC; (R.R.) Department of Entomology, University of Manitoba, Winnipeg, MB.*

A small dark dorsoventrally flattened haliplid collected in Sichuan Province, China, is described based on a single female specimen. It has a broad head (interocular separation four times eyewidth) with non-protruding eyes. The pronotum is broad and almost parallel-sided with the areas lateral to the longitudinal plicae raised relative to the medial area. The elytra are nearly flat and parallel-sided with blunt obtuse apices. The legs are typical for a haliplid but have extremely reduced swimming setae. The venter is black; the epipleura narrow gradually with no externally visible notch at the point of contact with the anterolateral corner of the metacoxal plates. Possible synapomorphies for the current genera of Haliplidae are presented and are used to show that this beetle cannot be a member of *Peltodytes* or the *Haliplus* clade (including *Algophilus* and *Apteraliplus*). Although this species appears closest to *Brychius*, it also cannot be placed in that genus as it does not share several of the suggested synapomorphies of that group of species.

Water beetles (Coleoptera: Dytiscidae) south to north in Manitoba

R. Roughley. *Department of Entomology, University of Manitoba, Winnipeg.*

Disturbance and change are common phenomena of all aquatic ecosystems. Over the last few years, my students and I have conducted extensive studies within the province. In southern Manitoba, the driving factors behind the differing dytiscid communities found in boreal vs. prairie ecozone ponds are principally associated with the impacts of agriculture. In northern Manitoba, at Churchill, the fauna has changed by >10% since 2000. Various reasons for this change are explored suggesting that many more opportunities exist for further study.

Waterbug ecology

G.G.E. Scudder. *Department of Zoology, University of British Columbia, Vancouver, BC V6T 1Z4.*

Waterbugs include the Belostomatidae (toebiters), Corixidae (waterboatmen), Nepidae (water scorpions), Notonectidae (backswimmers), and Pleidae (pygmy backswimmers). All are predators, and more or less opportunistic feeders with a broad feeding niche.

While the prairie *Trichocorixa verticalis interiores* Sailer overwinters as an egg, most species pass the winter as adults. Typically, dispersal of flying adults occurs in the spring and fall. The lentic bugs seem to be able to colonize virtually all aquatic habitats, being attracted to shiny surfaces by their UV reflection.

Saline lakes and ponds occur in the grasslands and parklands of British Columbia and the prairies. Many waterbugs occur in these waterbodies, but species differ in their salinity tolerance. In general, species richness decreases with increase in salinity, although abundance tends to increase in higher salinities.

Most freshwater species live in a wide variety of habitat types, including bogs, fens, marshes, ponds (temporary and permanent), and often lotic environments (at least overwinter). They are habitat generalists and widely distributed. As a result, they have been able to adapt to the loss of wetlands on the prairies and elsewhere, utilizing man-made dugouts and other artificial locations, provided these have sufficient food resources. This high adaptability implies that they are unlikely to become vulnerable, threatened, or endangered owing to habitat degradation and loss. They are not at risk and are not of conservation concern in Canada.

In contrast, there are a few species of lentic waterbug that occur in and are con-

fined to high salinity ponds and lakes. Laboratory experiments show that these can live, breed, and regulate their internal milieu in freshwater, even though most do not naturally breed in such habitats. Experiments with *Cenocorixa expleta* (Uhler) suggest that such saline species are confined to high salinities because these constitute enemy free space. They appear to be excluded from freshwater habitats by mite parasitism, but mites are absent in the most saline ponds and lakes.

Highly saline ponds and lakes are of limited occurrence in Canada, and are vulnerable to degradation and destruction. It is suggested that as a result, saline waterbugs and other saline insects could easily become at risk. Therefore such habitats are of conservation concern. Since they do not rank high in the vertebrate-dominated conservation agenda, entomologists should become proactive in this regard.

Entomology in environmental consulting: the role of aquatic invertebrates

L. Westcott. *Golder Associates Ltd., Castlegar, BC, lwestcott@golder.com.*

Entomology has applications in many areas of environmental consulting. Invertebrate studies may be components of Environmental Assessments for new projects, such as the development of hydroelectric facilities or coal and metals mines in BC.

Aquatic and terrestrial insects and other invertebrates are often useful indicators for monitoring environmental changes that may result from existing project operations (e.g., stream sedimentation related to industrial activities). Comparisons between invertebrate community data collected as part of baseline (pre-project) and operational studies are often important components of the on-going environmental effects monitoring programs for these projects.

Invertebrates are also useful in the ecological risk assessment process. Invertebrates are collected from an area of interest, in which chemicals of potential concern have been identified. Laboratory analysis provides the levels of chemicals in the samples and the resultant data are incorporated into food chain models, aiding in assessing the risks posed to receptor species (often birds and small mammals) that may ingest prey items from the area of interest.

In the consulting realm, entomologists employ their skills in study design and implementation, data analysis and interpretation, and invertebrate taxonomy, which is a skill that is currently in high demand in the field of aquatic environmental consulting.

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Dr. Ward Strong, Editor
Kalamalka Forestry Centre
3401 Reservoir Road
Vernon, BC V1B 2C7

ward.strong@gov.bc.ca
Phone (250) 260-4763
Fax (250) 542-2230

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Address inquiries to:

Dr. Lorraine Maclauchlan, Secretary
B.C. Ministry of Forests
515 Columbia St.
Kamloops, BC V2C 2T7

Lorraine.maclauchlan@gov.bc.ca
Phone (250) 828-4179
Fax (250) 828-4154

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