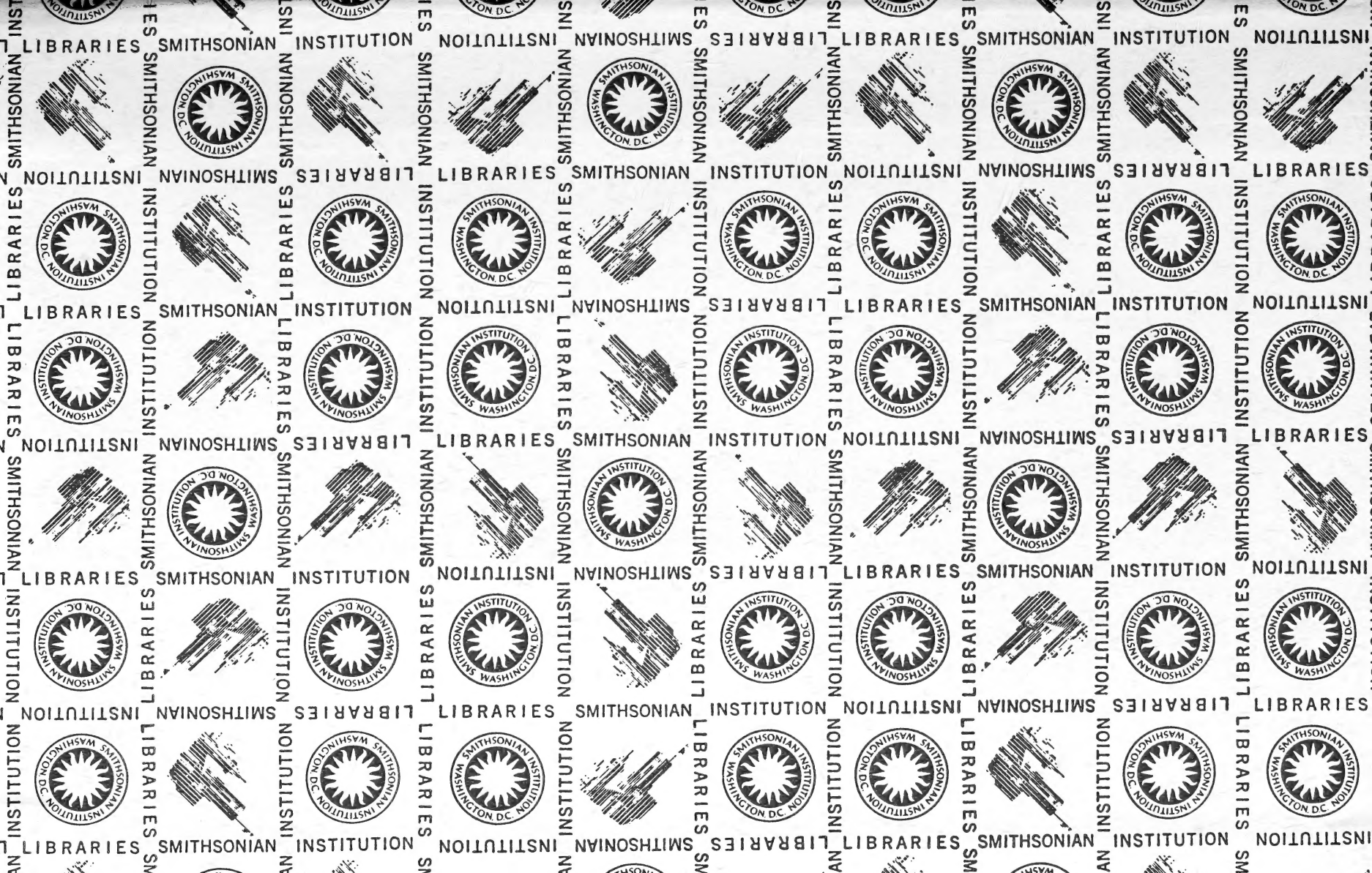
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A COMPARISON OF HONEY BEE (*Apis mellifera* L.) COLONIES ESTABLISHED FROM PACKAGES OR NUCLEI IN TWO AREAS OF BRITISH COLUMBIA, CANADA

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SUMMARY

A comparison of the biological performance and economic returns from honey bee colonies established in April from either 0.9 kg packages or four-frame nuclei was made in both the Lower Fraser Valley and Peace River areas of British Columbia. In the Lower Fraser Valley, nuclei were superior to packages both biologically and economically, while in the Peace River, no biological differences were found between the two, and packages provided higher economic returns. Either packages or nuclei would be viable in commercial beekeeping operations, depending on individual circumstances.

INTRODUCTION

A new honey bee (*Apis mellifera* L.) colony may be established in the spring from either a package or a nucleus. A package consists of 0.9-1.8 kg of bees (7,500-17,000 bees) plus a queen. The bees are transported in a wooden box covered on each side with wire screen to provide ventilation, with a metal can containing sugar syrup hung inside the box to feed the bees during transit. A nucleus consists of three to five frames of bees, brood, honey and pollen plus a queen, and is commonly transported in a cardboard box with a screened lid to allow for ventilation. Before the First World War, nuclei were widely used in the U.S. and Canada for establishing colonies. Fear of disease transmission reduced the demand, however, and the package bee business developed, so that packages purchased from shippers in the southern states replaced the nuclei used earlier (Johansson and Johansson 1970). Recently, a renewed interest in nuclei has been shown by beekeepers (Winston 1983). However, research on the comparative biological performance and economic returns to the purchaser from use of packages and nuclei is needed if nuclei are to be accepted commercially.

Nuclei are more expensive to purchase than packages; $35.00 for a four-frame nucleus versus $29.70 for a 0.9 kg package (McCutcheon 1984). In addition, nuclei must be inspected to ensure they are disease free, and standards for nuclei are not as precise as for packages. The bee population and brood, honey or pollen areas may vary greatly among producers of nuclei. However, nuclei have one principal advantage over packages. A nucleus contains drawn comb, stored honey and pollen, and, most importantly, brood, all of which should enhance early population growth. This may be a critical factor in regions with short growing seasons, as in most of Canada.

The objective of this research was to compare the biological performance and economic returns from 0.9 kg packages and four-frame nuclei established in April in both the Lower Fraser Valley and Peace River areas of B.C.

MATERIALS AND METHODS

A. Lower Fraser Valley

This study was conducted from April to August 1984 at a single apiary site in Langley, in the Lower Fraser Valley area of southwestern British Columbia. A total of 20 colonies were established on 17 April, each in a single super (drawn comb) of standard Langstroth equipment (497 mm x 420 mm x 241 mm deep). Ten colonies were established from 0.9 kg packages and 10 colonies from four-frame nuclei. All colonies were headed by Italian (*Apis mellifera ligustica* L.) queens imported from Florida.

Colonies were managed throughout the season for honey production using standard techniques. A second brood super and either one or two honey supers were added as required (standard Langstroth equipment). Sixteen and a half liters of sugar syrup were fed to all

colonies between 17 April and 26 May to facilitate colony growth. Oxytetracycline hydrochloride mixed in icing sugar also was fed to all colonies from 22 April to 12 July for brood disease prevention.

Five colony characteristics (sealed brood, honey and pollen areas, colony weight, and frames of bees) were measured approximately every 21 days from 10 May to 1 August. Sealed brood, honey and pollen areas were measured using a plexiglass grid to estimate the area on each frame. All colonies were weighed with a tripod scale. Colony weight was determined by subtracting the weight of empty equipment from the tripod scale reading. The number of frames of adult workers was estimated by looking through the super from above and below to determine how many frames were covered by workers. Extracted honey was determined in August by weighing supers before and after frames of honey were extracted. All colonies were left with six full frames of honey after the honey removal in August. For economic analyses, honey was valued at $1.12 per kg, the average sale price of bulk honey in B.C. in 1984 (McCutcheon 1984). The purchase prices of 0.9 kg packages and four-frame nuclei were valued at $29.70 and $35.00 respectively (McCutcheon 1984).

Student's t-test was used to test for significant differences between experimental treatments ($P \leq 0.05$).

B. Peace River

On 17 April, 1984 ten 0.9 kg packages and ten four-frame nuclei were transported by truck to a 1500-colony commercial beekeeping operation in the Peace River region of British Columbia, and maintained throughout the season by the cooperating beekeeper, Dale Hansen. The packages and nuclei were established in a single super (drawn comb) of standard Langstroth equipment and managed throughout the season for honey production using standard techniques. All colonies were headed by Italian queens imported from Florida. Colonies were weighed twice during the season; 5 June and 3 July. Extracted honey was determined in August by weighing supers before and after frames of honey were extracted. The same figures listed in part A were used for economic analyses.

Student's t-test was used to test for significant differences between experimental treatments ($P \leq 0.05$).

RESULTS

A. Lower Fraser Valley

By 1 August the biological characteristics did not differ significantly between packages and nuclei ($P > 0.05$) except for colony weight, where the nuclei weighed significantly more than the packages ($P = 0.02$) (Fig. 1). Significant differences in biological characteristics occurred on various earlier measurement dates, with nuclei always recording higher measurements than packages. The nuclei produced significantly more honey than did the packages ($P = 0.03$) (Fig. 1). Both nuclei and packages recorded deficits of $12.94 (Canadian) and $18.28 (Canadian) respectively (Table I).

B. Peace River

Colony weight on both measurement dates and extracted honey did not differ significantly between packages and nuclei ($P > 0.05$) (Fig. 2 and 3). Packages provided higher incomes than nuclei, $57.77 (Canadian) and $52.36 (Canadian) respectively (Table II).

DISCUSSION

The results of this study suggest that both packages and nuclei are commercially viable in B.C., and which is used will depend on area and compatability with an individual's beekeeping operation. By 1 August the packages and nuclei in the Lower Fraser Valley differed significantly only in colony weight and extracted honey (Fig. 1). The packages produced significantly less extracted honey than the nuclei, possibly due to a smaller foraging force during the nectar flow. In the Langley area the major nectar flow is in July (McCutcheon 1982); on 20 June (approximately one week before the beginning of the nectar flow) and 12 July (during the nectar flow) the packages had a significantly smaller worker population than

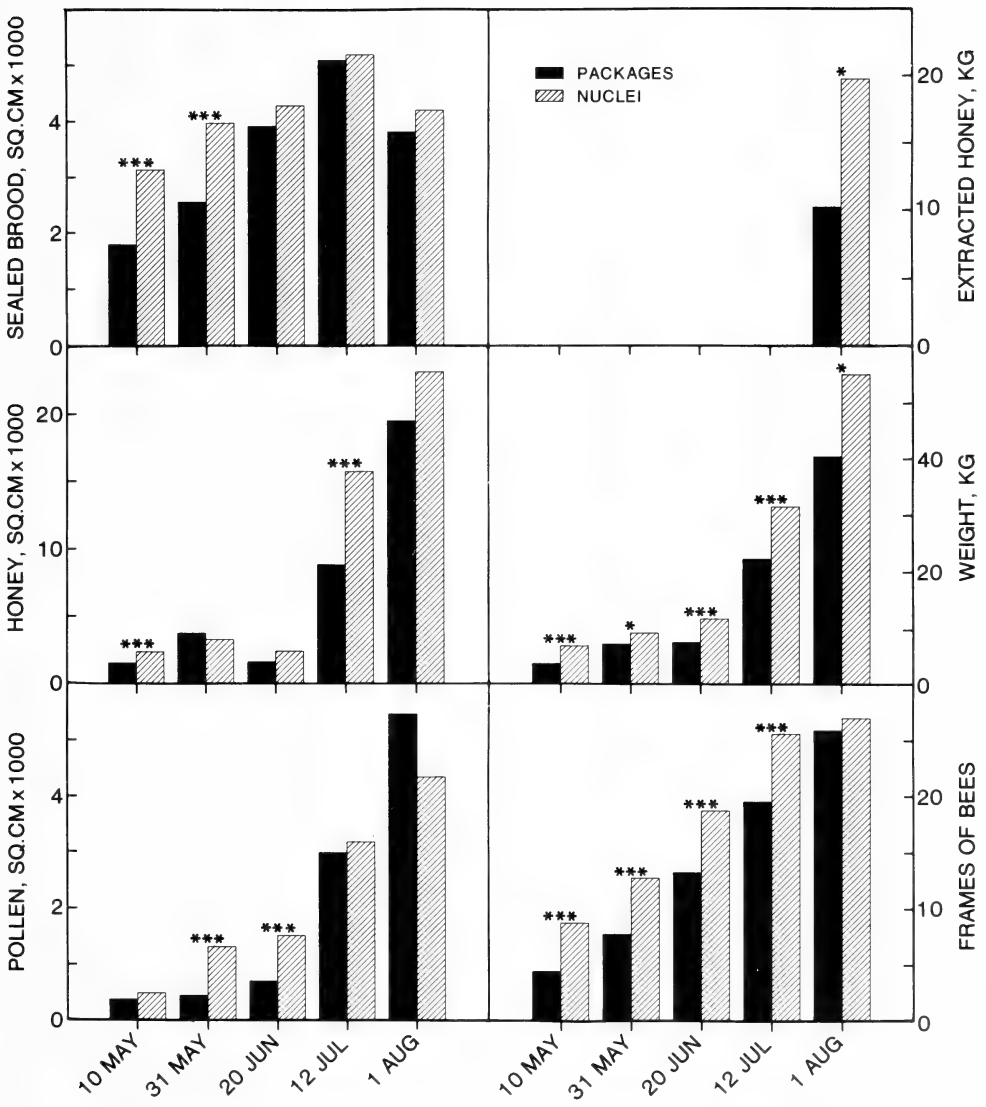

Figure 1: Biological (sealed brood, honey and pollen areas, frames of bees and colony weight) and economic (extracted honey) characteristics on five measurement dates for colonies established from 0.9 kg packages and four-frame nuclei in the Lower Fraser Valley. Standard errors are represented by bars above each histogram. (*=P≤0.05, **=P≤0.01, ***=P≤0.005).

TABLE I

Incomes from colonies established from 0.9 kg packages and four-frame nuclei in the Fraser Valley.

Treatment	Purchase Price ($)	Extracted Honey (kg)	Honey Income ($)	Total Income ($)
Package	29.70	10.2	11.42	-18.28
Nucleus	35.00	19.7	22.06	-12.94

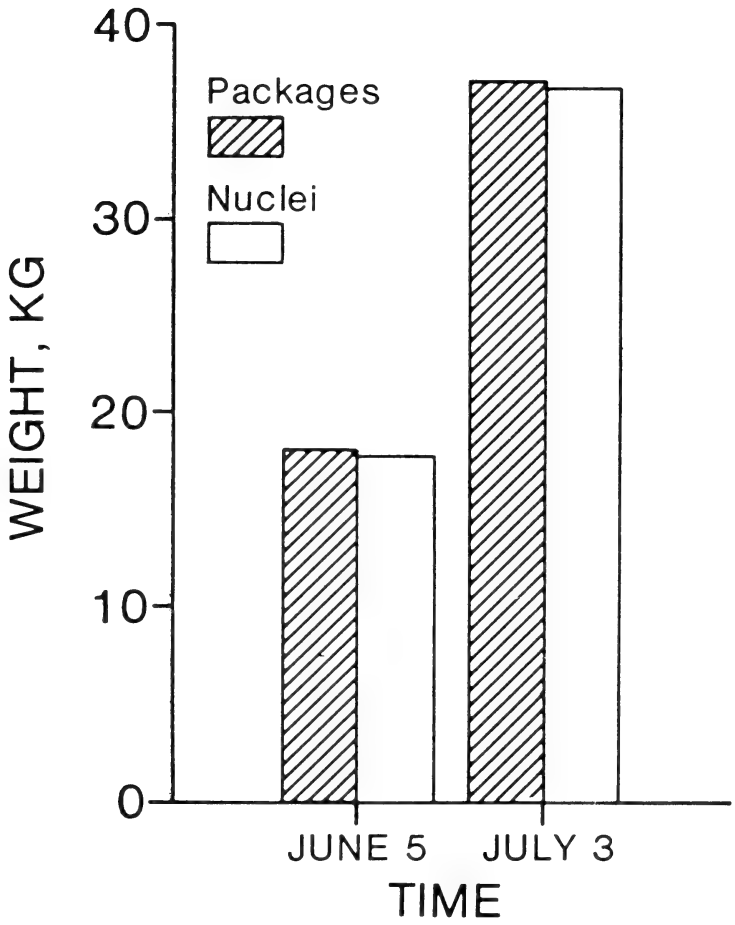

Figure 2: Colony weight on two measurement dates for colonies established from 0.9 kg packages and four-frame nuclei in the Peace River. (P>0.05 on both dates).

the nuclei, but both treatments were maintaining equivalent brood areas (Fig. 1). This meant that the packages had a greater proportion of their worker population involved in brood rearing, resulting in a smaller foraging force. Previous research has reported the tendency of small colonies to allocate a high proportion of available resources to brood rearing, resulting in low honey production (Farrar 1968). The worker population in colonies started from packages peaked after the nectar flow (1 August) (Fig. 1), resulting in a significantly lower honey yield than the nuclei.

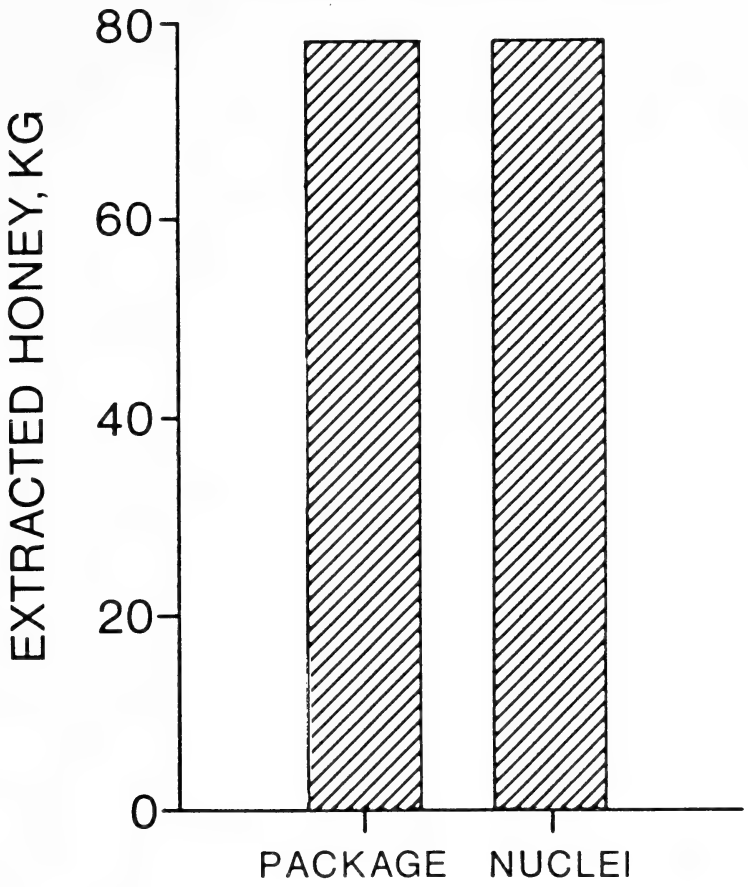

Figure 3: Extracted honey for colonies established from 0.9 kg packages and four-frame nuclei in the Peace River. (P>0.05).

TABLE II

Incomes from colonies established from 0.9 kg packages and four-frame nuclei in the Peace River.

Treatment	Purchase Price ($)	Extracted Honey (kg)	Honey Income ($)	Total Income ($)
Package	29.70	78.1	87.47	57.77
Nucleus	35.00	78.0	87.36	52.36

The packages and nuclei in the Peace River were not monitored as closely as those in the Lower Fraser Valley. The colonies in the Peace River had only colony weight measured on two dates, and extracted honey determined at the end of the season. Packages and nuclei in the Peace River produced equivalent amounts of extracted honey (Fig. 3), whereas in the Lower Fraser Valley, nuclei produced significantly more extracted honey than packages (Fig. 1). This difference was probably due to the later honey flow in the Peace River, which begins in mid-July, two weeks later than in the Lower Fraser Valley. This allows packages to "catch up" to nuclei before the honey flow, thereby producing equivalent amounts of extracted honey. In the

Lower Fraser Valley, the honey flow began before the packages were as populous as the nuclei, and they did not produce as much extracted honey. The suitability of packages and nuclei for honey production would appear to be at least partially dependent on the timing of the honeyflow in an area. Had 1983 been a severe spring rather than mild in the Peace River, the nuclei may have performed better than the packages due to their initial advantage of brood and a slightly larger worker population (D. Hansen, personal communication).

Economically, the results from the Lower Fraser Valley and the Peace River also differed. In the Lower Fraser Valley, neither nuclei or packages provided an income (Table I), whereas both packages and nuclei provided incomes in the Peace River (Table II). In the Lower Fraser Valley in 1984, a relatively poor year, nuclei and packages produced deficits of $12.94 and $18.28 respectively. In seasons with both a good nectar flow and good weather, both nuclei and packages may provide an income in the Lower Fraser Valley. Under such conditions nuclei would likely provide the greater income, since they have a larger foraging force available during the early honeyflow characteristic of the Lower Fraser Valley. In the Peace River, both packages and nuclei yielded incomes, but packages provided a higher income ($57.77) than nuclei ($52.36) due to their lower purchase price (Table II).

The beekeeping operation in the Peace River to which the packages and nuclei were sent has traditionally been based on spring package management. The cooperating beekeeper found the nuclei more labor-intensive from the standpoint of transportation and installation (D. Hansen, personal communication), partly because his operation was set up to accommodate packages, not nuclei. In the Lower Fraser Valley study no difference was noted in ease of transportation of packages and nuclei, and the nuclei were considered to be easier to install than the packages.

Numerous researchers have made biological and economic comparisons between packages of different sizes established on different dates (reviewed in Nelson and Jay 1972). However, comparisons between packages and nuclei have been lacking. To our knowledge, this experiment represents the only comparison made between packages and nuclei. If Canadian beekeepers are to become self-sufficient, both packages and nuclei will have to be incorporated into beekeeping operations. This preliminary research indicates that either packages or nuclei would be viable in commercial beekeeping operations, depending on individual circumstances. In the Lower Fraser Valley nuclei are superior to packages both biologically and economically, while in the Peace River, no biological differences were found between the two, and packages provided greater economic returns than nuclei. However, research for more than one season and in various beekeeping areas of the province is needed to establish the suitability of packages versus nuclei for honey production.

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We are grateful to Linda Fergusson and Stephen Mitchell for field assistance; and to Dale Hansen for his cooperation and assistance in this project. Financial support was provided by British Columbia Science Council and Natural Sciences and Engineering Research Council grants (M.L. Winston, principal investigator) and a Natural Sciences and Engineering Research Council Postgraduate Scholarship (to E.N. Punnett).

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METHOMYL INSECTICIDE AND DOMESTICATED POLLINATORS[1]

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ABSTRACT

Susceptibility to methomyl sprays was greatest for the alfalfa leafcutting bee, *Megachile rotundata* (F.); least for the honey bee, *Apis mellifera* L.; and intermediate for the alkali bee, *Nomia melanderi* Cockerell. Methomyl at 1.12 kg (AI)/ha had low residual hazard to honey bees, and at 0.6 kg (AI)/ha it had low residual hazard to leafcutting and aklaki bees after one day. Field tests of methomyl on pollen-shedding corn, blooming red raspberry, and blooming blueberry resulted in reduced bee visitation and low adult bee mortality.

Insecta, Bees, Pollinators, methomyl

INTRODUCTION

Methomyl is a carbamate insecticide available in wettable powder, dust, and liquid formulations. It kills as a contact or stomach poison and is registered for insect control on a large number of agricultural crops.

Bee poisoning or the killing of beneficial bees from pesticides is a serious problem for beekeepers in most parts of the world (Johansen and Mayer, 1989). For 35 years we have evaluated pesticides for their effects on bees and developed information to reduce bee poisoning (Mayer and Johansen, 1988).

This paper reports the results of research concerning the effects of methomyl on the honey bee, *Apis mellifera* L., alkali bee, *Nomia melanderia* Cockerell, and alfalfa leafcutting bee, *Megachile rotundata* (F.). Also reported are the insecticide's effects on honey bees when applied to pollen-shedding corn, blooming red raspberry, and blooming blueberry.

MATERIALS AND METHODS

Small-scale Bioassays. Tests were conducted with different formulations and rates of methomyl on honey bees, alkali bees, and alfalfa leafcutting bees, from 1968 through 1987. Methomyl was applied to 0.004-ha plots of alfalfa with a Solo® backpack boom sprayer, using 1758 g/cm^2 pressure and 234 liters of water/ha. Treatments of field-weathered methomyl residues were replicated four times with four foliage samples per treatment and time interval. Samples consisting of about 500 cm^2 of foliage taken from the upper 15-cm portions of plants were placed in each plastic petri dish (15 cm diameter) whose tops and bottoms were separated by a wire screen (6.7 meshes/ cm) insert (45 cm long and 5 cm wide). The same procedure was used in the following tests: residual toxicity of methomyl combined with the stickers Adhere® and Plyac (both United Agr. Products, P. O. Box 1286, Greeley, CO 80632).

The residual toxicity of methomyl combined with the formamidine insecticide chlordimeform also was tested. Residual toxicity of repeated applications (4 times) of methomyl also was evaluated as was the effect of methomyl on alfalfa leafcutting bees of different ages. In one test, treated foliage was held in the lab in the dark at 18 or 29°C, or outdoors in 18-35°C variable day-night temperatures and daily sunlight. In still another test, 50 honey bees were placed in each of 4 cages as described above and methomyl was applied directly onto the bees.

FOOTNOTES

[1] Washington State University, College of Agriculture and Home Economics Research Center. Work done under Projects 0742 and 1957.

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[4] Wash. State Univ., Western Wash. Research and Extension Center, Puyallup, WA 98371.

Worker honey bees were obtained from colonies and anesthetized with CO_2. Prepupae of leafcutting bees and alkali bees, in leaf piece cells and soil cores, respectively, were incubated at 29-31°C and 60% RH. Emergent adults were trapped in canisters fitted with screen funnels and chilled to facilitate handling. Residue test exposures were replicated four times by caging 60 - 75 worker honey bees, 25 - 40 leafcutting bees, or 15 - 20 alkali bees with each of four foliage samples per treatment and time interval. Bees were maintained in cages at 29°C, 60%, RH and fed 50% sucrose solution (1:1) in a cotton wad (5 by 5 cm). Bee mortality was determined after 24 h. Abbott's formula (Abbott 1925) was used to correct for mortality occurring in the untreated check. Data were analyzed using analysis of variance (ANOVA) techniques with mean separation by Duncan's Multiple Range Test (Duncan, 1951).

Field Tests -- Corn. In 1973 methomyl was tested for bee toxicity on pollen-shedding 'Jubilee' sweet corn in a 4.5-ha field and in 1983 in a 55-ha field near Prosser, WA. In 1973, methomyl 90% soluble powder (SP) was applied by airplane before 0700 h on 3 Sept, using 0.5 kg (AI)/ha in 45 liters of water. A 9-ha field 1 km away served as the untreated check. In 1983, methomyl 90% wettable powder (WP) was applied by helicopter before 0700 h on 2, 6, 10 and 14 Sept, using 0.5 kg (AI)/ha in 20 liters of water. A 55-ha field 1 km away served as the untreated check.

Honey bee colonies with Todd dead bee traps (2 in 1973; 6 in 1983) were located adjacent to the fields 3 days before the first application. In 1973 and 1983, the number of dead honey bees was recorded daily before and after the applications. In 1983, 25 dead bees from each colony were examined during each sample for tongues fully extended, and the data were recorded. Also in 1983, data on the number of corn pollen collectors per 25 foragers per colony for a total of 150 bees per sample were recorded. Colony conditions were evaluated before and after each application and at the conclusion of each test.

Field Tests -- Raspberries. In 1983, methomyl was tested for bee toxicity on blooming red raspberry near Vancouver, WA. Methomyl 90 SP was applied at 0.5 kg (AI)/ha and at 1.0 kg (AI)/ha to separate 0.02-ha plots of 'Meeker' red raspberry, and a separate 0.02-ha plot was left untreated. Applications were made on 26 July at 2000 h by ground equipment with a hooded-boom sprayer. Two weeks before the application, four honey bee colonies were placed near the center of the field. Bee numbers and foraging behavior were assessed in the plots during mid-afternoon of the first day after application and on days 2, 3, and 6 following application. The number of honey bees foraging on 14 meters (5 replications) of row were counted in each plot on each date.

On 27 July, at 0600 h, 200 blooms in each plot were covered with white paper bags, to exclude bees so that nectar samples could be taken. Three kinds of samples were taken from each plot: (1) 200 flowers that were rinsed in 200 ml of distilled water, (2) the rinse water drained from the flowers, and (3) 20 l of floral nectar collected from each of 20 flowers. Samples were taken at 0800 h and 1200 h, frozen, and sent to E. I. DuPont de Nemours and Company chemists for analysis of methomyl residues. We consistently obtained 15-20 µliters of nectar per flower (av. 17) with 50% sugar content. Data were analyzed using ANOVA techniques with mean separation by Duncan's Multiple Range Test (Duncan, 1951).

Field Tests -- Blueberry. Methomyl 1.8 soluble liquid (LS) (1.0 kg (AI)/ha) was applied in 936 liters of mixed spray per ha at 1000 h on 16 April 1987. Biofilm wetting agent at the rate of 473 ml per 379 liters was added. The plots consisted of 9 x 8 m of 'Berkeley' blueberry in full bloom adjacent to six honey bee colonies. The weather was cool and overcast at 13°C with a light northwest wind at 11-13 kph. A few bumble bees were working in the blueberries, but no honey bees. Twenty white paper bags were placed on blooming tips in the treated plots and on tips in the check plots (33 m west and 33 m east) at 1230 h. The temperature increased to 14°C by 1600 h, but light rains started at 1630 h.

April 17 was cool and rainy and no honey bees were working. Nectar samples were extracted from the bagged blooms using a micropipet. There was an average of 10.2 µliters of nectar per flower with an average 24% sugar content. On 18 April the weather was still cloudy with occasional light rains, but was suitable at times to observe honey bee activity. The number of honey bees foraging on 15 meters of row was determined for each plot.

RESULTS

Small-scale Bioassays. Table 1 presents the means of bioassay tests done from 1968 through 1973. The mortality sequence for the three species was typical in that alfalfa leafcutting bees were most susceptible, alkali bees were intermediate in susceptibility, and honey bees least susceptible to methomyl. Bee susceptibility to an insecticide is a function of size or surface/volume ratio which is related to chance adherence of residues to the body of a forager (Johansen et al., 1983). The mortality of bees in 24 h continuous contact with treated foliage samples decreased as the age of residues increased. The 2% dust formulation was more hazardous than other formulations, causing 46 - 98% mortality one day after application. For the other formulations, the rates of 0.6 kg(AI)/ha or lower caused less than 25% mortality of honey bees 3 h after application. The rate of 1.12 kg(AI)/ha caused 27% or lower mortality after 8 h. Methomyl 1.8 LS (0.3 kg/ha) and methomyl 90 WP (0.6 and 1.12 kg/ha) applied directly to honey bees caused 100% mortality.

Adding the sticker Adhere® significantly reduced mortality for all three bee species. Adding Plyac® did not always reduce bee mortality. Mayer *et al.* (1987) showed that adding the sticker Bond® to methomyl and Johansen (1972) showed that adding Evanol to methomyl resulted in reduced bee mortality.

Repeated applications of methomyl at 5-day intervals caused increasing mortality with successive treatments (Table 3). For example, with honey bees, mortality for each application was 19, 28, 41, and 63%.

Adding chlordimeform 97% soluble powder (SP), a material essentially non-hazardous to bees (Mayer & Johansen, 1988), at 0.3 kg/ha to methomyl 1.8 LS at 0.3 kg/ha, resulted in a synergistic effect that increased honey bee mortality from 2 h residues by 72%.

Methomyl 1.8 LS (0.3 kg/ha) caused 51% mortality in 4-wk-old leafcutting bees but only 8% in 1-2-day-old bees. In general, older leafcutting bees that have been nesting for 3 or more weeks have increased susceptibility to poisoning by most insecticides (Mayer & Johansen, 1988).

Table 1.

Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to different age residues of methomyl applied to field plots of alfalfa. Pullman, WA, 1968-1973.

Rate Methomyl Treatment[a]	(kg(AI) /ha)	24-h mortality (%) of bees caged with treated foliage at indicated age of residues										
		AB				LB				HB		
		3 h	8 h	24 h	72 h	3 h	8 h	24 h	72 h	3 h	8 h	24 h
1.8 LS	0.3	3	0	-	-	13	5	0	-	2	0	0
1.8 LS	0.6	24	0	-	-	23	6	2	-	23	0	0
1.8 LS	1.12	61	38	19	-	86	59	65	-	43	10	3
25 WP	0.6	-	-	-	-	-	-	-	-	20	5	1
90 WP	0.6	47	8	-	-	48	13	4	-	18	5	2
90 WP	1.12	96	64	40	16	83	73	60	13	92	27	1
90 SP	0.3	0	2	-	-	11	3	4	-	4	3	0
90 SP	0.5	-	-	-	-	-	-	-	-	26	0	0
90 SP	0.6	-	-	-	-	-	-	-	-	18	7	0
90 SP	1.12	-	-	-	-	-	-	-	-	44	21	0
2% dust	0.6	-	-	-	-	100	100	100	-	100	75	46
2% dust	1.12	100	90	84	-	100	100	88	-	100	98	98

[a]LS, liquid; WP, wettable powder; SP, soluble powder

Table 2.
Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to different age residues of methomyl applied to field plots of alfalfa. Prosser, WA, 1987.

Treatment	Rate (kg (AI)/ha)	24-h mortality (%) of bees caged with treated foliage at indicated time after treatment						
		AB		LB		HB		
		2h	8h	2h	8h	2h	4h	8h
Methomyl 90 WP	1.0	83a	78a	86a	50a	69a	-	36a
Methomyl 90 WP + Adhere	1.0 + 118 ml	34b	26b	60b	31b	18b	-	13b
Methomyl 90 WP + Plyac	1.0 + 118 ml	43b	39b	60b	63a	21b	-	31a

Means within a column and year followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Table 3.
Mortality of alkali bees (AB), alfalfa leafcutting bees (LB), and honey bees (HB), exposed to residues of methomyl 1.8 LS (0.5 kg (AI)/ha) from successive applications to plots of alfalfa. Pullman, WA, 1976.

Treatment[a/]	24-h mortality (%) of bees caged with treated foliage at indicated time after treatment			
	AB	LB	HB	
	2 h	2 h	2 h	8 h
1st application	9 a	36 a	19 a	4 a
2nd application	22 b	52 b	28 a	11 b
3rd application	42 c	54 b	41 b	16 b
4th application	89 d	55 b	62 c	62 c

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).
[a/] Application dates: 12, 17, 22, 27 June.

The effects of temperature and sunlight on methomyl activity against honey bees are shown in Table 4. Two- and 8-h residues held at 18°C and 29°C in constant dark caused significantly less mortality than the residues held in variable day-night temperatures and exposed to sunlight. This is the reverse of expected results (Johansen *et al.*, 1983). Perhaps sunlight and heat caused the methomyl to break down to a more toxic product.

Field Tests -- Corn. In 1973, the Todd trap catches for the first 24 h after application averaged 13 bees next to the treated field and 20 in check colonies 1 km distant. Methomyl applied to pollen-shedding corn in 1983 resulted in no abnormal loss or perhaps a low kill (Table 5). Use of Todd dead bee traps on honey bee colonies has shown that up to 100 dead bees per day is a normal die-off, 200-400 is a low kill, 500-900 is a moderate kill, and 1000 or more is a high kill (Mayer & Johansen, 1983). Bees dying with tongues extended is often a sign

Table 4.

Mortality of honey bees exposed to different age residues of methomyl 90 SP applied to field plots of alfalfa at the rate of 1.0 kg (AI)/ha. Residues were held under different environmental conditions before bee exposure. Prosser, WA, 1987.

Treatment	24-h mortality (%) of bees caged with treated foliage collected at indicated times after treatment		
	2 h	8 h	24 h
18°C - constant dark	28a	9a	0a
29°C - constant dark	49a	6a	1a
18-35°C - outdoors, daily sunlight	77b	36b	1a

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Table 5.

Effect of methomyl applied to sweet corn at 0.5 kg (AI)/ha on honey bee foragers returning to the hive with corn pollen and on honey bee mortality, based on Todd dead bee traps, in colonies placed adjacent to treated sweet corn fields. Prosser, WA, 1983.

Date		Mean No. dead bees/colony/day (% with tongues fully extended)		% bees bringing in corn pollen**
Aug.	29	25	(41)	73
	30	12	(44)	74
	31	28	(42)	71
Sept.	1	10	(43)	65
	2*	74	(65)	22
	3	170	(61)	37
	4	137	(64)	50
	5	100	(62)	79
	6*	104	(54)	36
	7	66	(55)	51
	8	260	(52)	--
	9	77	(44)	55
	10*	38	(42)	40
	11	250	(50)	41
	12	109	(57)	32
	13	53	(38)	51
	14*	83	(36)	45
	15	214	(42)	31
	16	27		25
	17	42		21

* Applied by aircraft at 0600 h on these dates.

**Sample size-150 bees on each date.

of bee poisoning, especially with organophosphates (Johansen, 1984), but with methomyl there was no difference in the number of dead bees with tongues extended. Bees collecting corn pollen were reduced by about 30% for one day after application. There were no reductions in bee populations or brood in the colonies at the end of the test.

Field Tests -- Raspberry. As soon as bees began foraging raspberry blooms the day after application their behavior changed. They removed nectar, backed away, and soon were avoiding treated blooms. Sometimes they would move onto a leaf to groom themselves.

Table 6.
Effect of methomyl applied on 26 July at 2000 h on honey bees foraging in blooming red raspberries. Vancouver, WA, 1983.

	Mean Number foraging bees/14 m of row			
Kg (AI)/ha	27 July	28 July	29 July	1 August
0.5	9 *	6 *	21 *	64 ns
1.0	4 *	1 *	15 *	78 ns
Untreated check	56	61	69	68 ns

*Values are Significantly different (P = 0.05) from untreated check value in respective column. Pooled t test.

Within a short time, most bees drifted along the rows to the check block. Methomyl was strongly repellent to the bees for 2 days but less so on the third day. Bees resumed normal activity by the 6th day (Table 6).

Most methomyl residues detected from flower surfaces (water wash), flower interiors (homogenized flowers), and nectar showed some degradation between the 0800 h and 1200 h samplings. However, only surface residues were reduced greatly during the 4-h period. The minimal amounts of residue detect-ed in the untreated check plot samples were a true reflection of the spray application. The hooded boom sprayer was driven through all three adjacent plot rows during each pass because of space limitations. No doubt there was a minimal contamination of the check plot during this process (Table 7).

Table 7.
Residues of methomyl detected in red raspberry flower and nectar samples 27 July. Vancouver, WA, 1983.

	Methomyl residues (ppm)					
	0800 h			1200 h		
Kg (AI)/ha	Flower surface	Homogenized flowers	Nectar	Flower surface	Homogenized flowers	Nectar
0.5	2.0 a	8.1 a	3.4 a	0.27 a	2.1 a	2.8 a
1.0	2.6 a	9.0 a	6.9 b	0.91 b	9.3 b	5.3 b
Untreated check	0.05b	0.29b	<0.02c	0.04 c	0.28c	<0.02c

Means within a column and followed by the same letter are not significantly different (P = 0.05; Duncan's [1951] multiple range test).

Field Tests -- Blueberry. Honey bees started to enter the blueberry field by 0930 h, but there were too few to make useful counts in the plots. After 2 days of inactivity, bees started foraging in fair numbers by 1100 h, even though the temperature was only 12°C. The same kind of response, which was first observed with methomyl in red raspberry investigations in

Table 8.
Effect of methomyl applied at 2000 h on 16 April (1.0 kg[AI]/ha) on honey bee behavior in blooming blueberries. Cornelius, OR, 1987.

		Mean number foraging bees/15 m of row on 18 April	
Time	Temp		
1100	12°C	treated	0(8)[a/]
		check	20(0)
1200	10°C	treated	0(1)
		check	17(0)
1400	11°C	treated	0(2)
		check	18(0)

[a/]Figures in parentheses are counts of bees that alighted on flowers or probed around the bases, but never inserted their heads into the flower cups.

1983, was again recorded (Table 8). In this case, the honey bees probed around the base of the flowers externally and then flew off to untreated portions of the field without again landing on a treated bloom. Apparently they were able to detect the chemical and avoid it after the initial approach. In contrast, bees foraging the untreated check blooms inserted their heads into the flower cups in normal foraging fashion.

DISCUSSION

It is evident from these studies that methomyl is toxic in varying degrees to the bee species studied, and that methomyl applications affect bee behavior. In laboratory tests of direct toxicity, both 0.01 and 1% concentrations of methomyl caused 100% mortality of honey bees (Harris and Svec, 1969). The topical LD_{50} for honey bees is reported as 1.29 µg per bee (10.1 ppm) (Atkins *et al.*, 1981) or 0.068 µg per bee (Mansour & Al-Jalili, 1985).

Anderson & Wojtas (1986) found methomyl residues, along with other insecticides, in dead bees obtained from beekeepers but were not able to determine if it was methomyl that killed the bees. Flaherty et al. (1977) observed that early morning and night applications of methomyl to citrus bloom caused little harm to honey bees. Atkins *et al.* (1981) reported that methomyl was highly toxic to honey bees present in the field during applications, though the field hazard was low with evening applications. In our studies, the residual degradation time (RT) in hours required to bring bee mortality down to 25% (RT 25) in cage test exposures to field-weathered spray deposits applied at 0.3 kg (AI)/ha was < 2 h. At 0.5 kg (AI) ha the RT 25 was 2 h, and at 1.0 kg (AI)/ha it was 6 h. However, with the dust formulation the RT 25 was > 1 day. Materials with an RT 25 of 8 h or less are useful in terms of bee safety if applied during the late evening or at night.

ACKNOWLEDGMENT

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THE ROBBER FLIES (DIPTERA: ASILIDAE) OF A *FESTUCA* GRASSLAND IN THE OKANAGAN VALLEY, BRITISH COLUMBIA[1]

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ABSTRACT

The robber flies of a small area of grassland at Penticton, B.C. were studied; information on 21 species in 17 genera was gathered during ten years of sporadic collecting. The habitat, dominated by the bunchgrass, *Festuca scabrella* and the shrub, *Chrysothamnus nauseosus*, is briefly described. Flight periods, data on prey, and zoogeographic notes are included.

INTRODUCTION

Except for a few scattered locality records in the literature, no information on the robber flies (Diptera: Asilidae) of British Columbia has been published. Because these flies are a significant component of the predatory insect fauna of the province's grasslands, I undertook a simple study of the species present in a small area adjacent to my parents' property near Penticton. I was interested in examining the temporal distribution of the species, in addition to documenting their occurrence. Such basic natural history studies are important, because robber fly assemblages in B.C. grasslands vary considerably depending on habitat details, and these habitats are rapidly disappearing in the Okanagan Valley.

THE STUDY SITE

Robber flies were collected in a small area of native grassland at 430 m elevation on the Penticton Indian Reserve at the southern boundary of the West Bench Irrigation District (49° 29.5' N x 119° 37.5'W) (Figs. 1, 2). The area is approximately 200 m x 300 m, bordered on the north by irrigated gardens and orchards, and with a dirt track running east and west near the southern edge of the rectangle.

The site is an undulating, kettle-holed terrace overlooking Penticton to the east. Penticton has a mean July temperature of 20.1° C., a mean January temperature of -2.9° C, and 235 frost-free days. The mean annual precipitation is 290 mm and the mean annual snowfall is 0.56 m (Cannings *et al.* 1987). The soil is characterized as Osoyoos Sandy Loam (Kelley and Spilsbury 1949); it is brown, fine to medium-textured soil with 3% gravel and 1.8% organics by volume. It has good moisture holding capacity, and three samples gave a mean pH of 6.7 and a salinity of 0.28 dS/m (B. Maxwell *in litt.*).

The vegetation is dominated by *Festuca scabrella* (Rough Fescue) and *Chrysothamnus nauseosus* (Rabbit-brush). The shrub layer is scattered and sparse, composed of *Chrysothamnus nauseosus* (Pall.) Britt. and a few individuals of *Artemisia tridentata* Nutt. The herb layer is dominated by *Festuca scabrella* Torr., with secondary grasses such as *Festuca octoflora* Walt., *Bromus tectorum* L., *Sporobolus cryptandrus* (Torr.) Gray, and *Poa sandbergii* Vasey. Other herbs include *Phlox longifolia* Nutt., *Lewisia rediviva* Pursh, *Fritillaria pudica* (Pursh) Spreng., *Calochortus macrocarpus* Dougl., *Zygadenus venenosus* Wats., *Geum triflorum* Pursh, *Arabis holboelli* Hornem., and *Ranunculus glaberrimus* Hook. The introduced pest *Centaurea diffusa* Lam. (Diffuse Knapweed) is abundant in disturbed areas. The bryophyte and lichen layer, however, is well developed in much of the site, and consists primarily of *Cladonia, Peltigera,* and *Pohlia* species.

[1] This study is a contribution to the work of the Biological Survey of Canada (Terrestrial Arthropods) and its Grasslands Subcommittee.

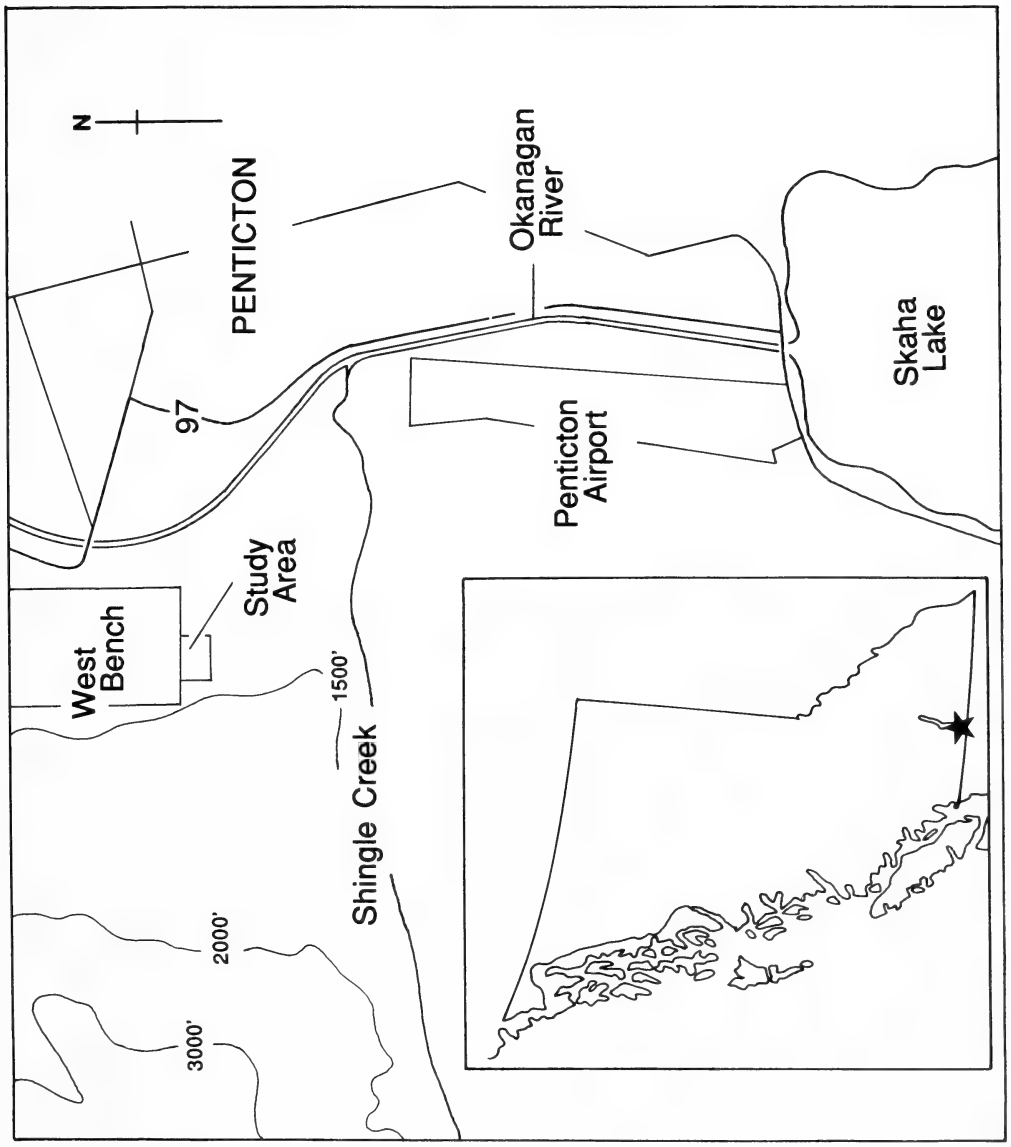

Figure 1. Location of the study area. The inset shows the position of Penticton at the south end of Okanagan Lake in southern British Columbia.

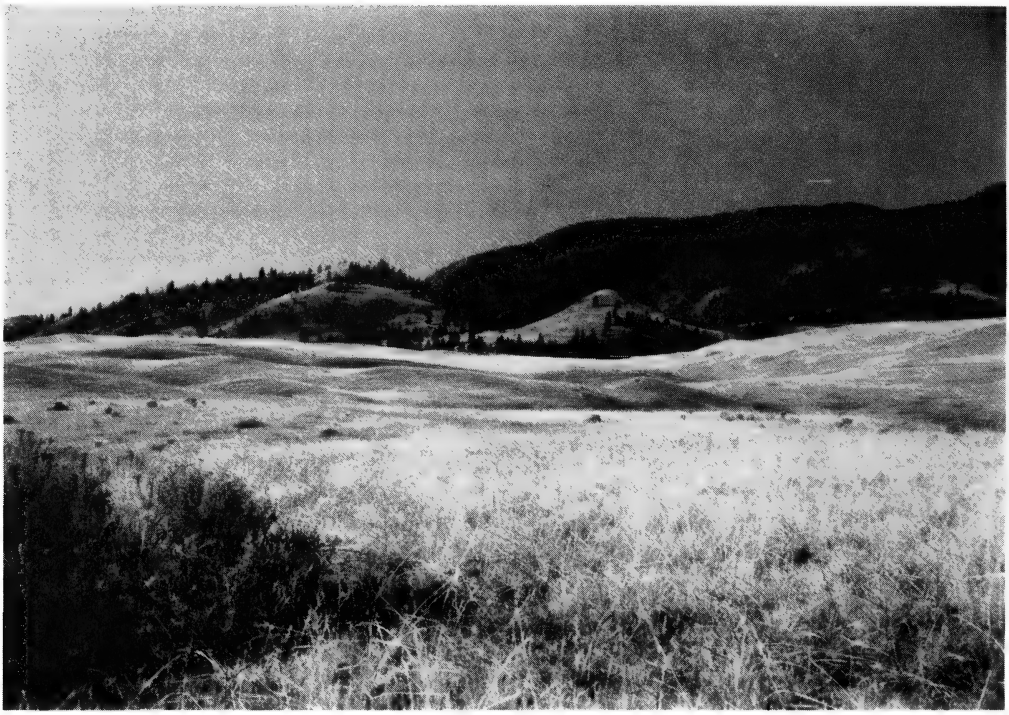

Figure 2. The study area: View south across the Rough Fescue grasslands of Penticton Indian Reserve, West Bench, Penticton.

METHODS

From 1980 to 1988, and in early 1989, robber flies were collected sporadically during the months that they were active (March-October) at the site. The flies were mostly caught individually in aerial nets, but beginning in 1986 a Malaise trap was also used. This was placed, with the collecting head facing south, along the fenceline at the northern edge of the site. In 1988 a second trap was located at the bottom of a hollow adjacent to a dense stand of *Rosa woodsii* Lindl.

The nomenclature used here follows Stone *et al.* (1965) for the most part; exceptions are the splitting of *Stenopogon* and *Scleropogon*, and the use of the names *Dicropaltum mesae* (Tucker) and *Neomochtherus willistoni* (Hine). These are changes included in a draft chapter (Asilidae) by Fisher and Wilcox for the updated Nearctic Diptera catalogue (E.M. Fisher, *in litt.*). In Stone *et al.* (1965) *D. mesae* and *N. willistoni* are placed in *Asilus*.

Described ranges are compiled from my own records and published statements in Stone *et al.* (1965), Adisoemarto (1967), and Adisoemarto and Wood (1975).

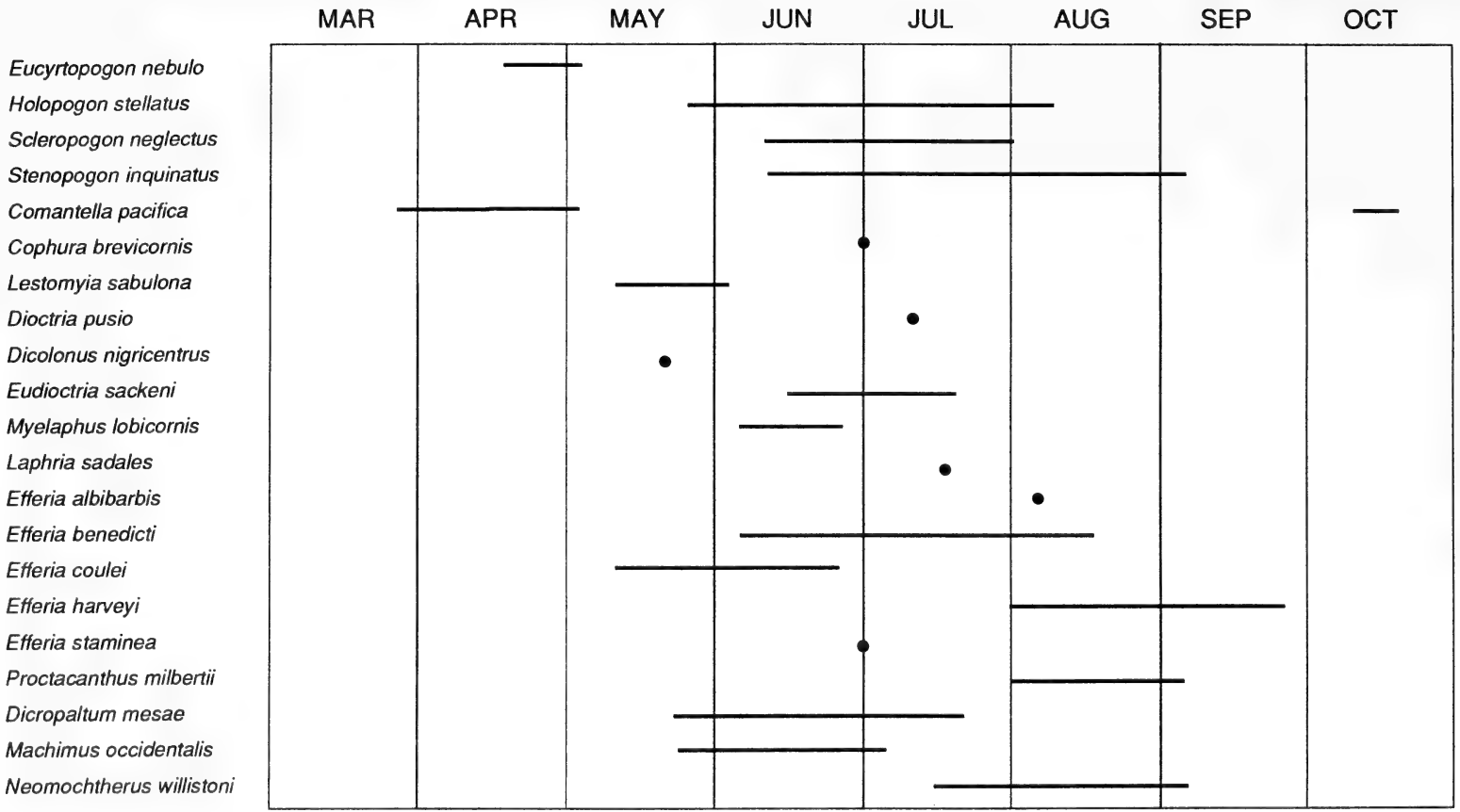

Figure 3. Phenology of West Bench robber flies. Horizontal bars represent the range of dates over which each species was collected; those represented by a single specimen are indicated by dots.

RESULTS AND DISCUSSION

Annotated List

Twenty-one species in 17 genera were collected. Collection dates and the duration of the flight periods of each species are illustrated in Fig. 3. Collection data are listed below. Collectors and repositories for specimens are as follows:

CNC - Specimens donated to the Canadian National Collection, Agriculture Canada, Ottawa, Ontario.
LV - Lynn Vasington (all specimens in UBC).
MBC - M. Brent Cooke (all specimens in RBCM unless otherwise designated).
RAC - Robert A. Cannings (all specimens in RBCM unless otherwise designated).
RBCM - Royal British Columbia Museum, Victoria, B.C.
RJC - Richard J. Cannings (all specimens in UBC unless otherwise designated).
RJH - Richard J. Hebda (all specimens in RBCM).
SGC - Sydney G. Cannings (all specimens in UBC unless otherwise designated).
UBC - Spencer Entomological Museum, University of B.C., Vancouver, B.C.

Subfamily Dasypogoninae

Tribe Stenopogonini

Eucyrtopogon nebulo (Osten Sacken). 19.iv.1988, 1f (RAC); 20.iv.1988, 2f (RAC); 21.iv.1988, 1m (RAC); 30.iv.1989, 1m (RAC); 1.v.1989, 1f (RAC); 3.v.1989, 1m (RAC).

The genus *Eucyrtopogon* needs revision because there appear to be a number of undescribed species in western North America. The identity of the West Bench specimens is uncertain, but they resemble *E. nebulo* more than any other described species. This fly lives mainly in open, dry woods from the Yukon south to California. The few West Bench specimens were caught perched on grass as well as in the fenceline Malaise trap from 19 April to 3 May. In B.C. the species has been captured as late as 1 September (1960, Langford [CNC]).

Holopogon stellatus Martin. 25.v.1987, 1m (RAC); 14.vi.1983, 1f (RJC); 24.vi.1988, 3m2f (SGC); 25.vi.1988, 2m (SGC); 10.vii.1988, 3m3f (RAC); 11.vii.1986, 3m (RAC); 15.vii.1988, 3m 2f (RAC); 16.vii.1988, 3m5f (RAC); 19.vii.1986, 1m (RAC); 11.viii.1988, 2m1f (SGC).

A tiny black asilid of open woods and grasslands from southern B.C. south to California and Nevada, *H. stellatus* hunts mainly from the branch tips of shrubs, as do many members of the genus (Dennis and Lavigne 1975). This habitat preference is reflected in the fact that all specimens were captured in the two Malaise traps set at the shrub-grassland boundary. Specimens were recorded from 25 May to 11 August.

Scleropogon neglectus (Bromley). 10.v.1982, 1m (RAC); 12.vi.1982, 1m1f (RAC); 13.vi.1983, 3m1f (RJC); 13.vi.1987, 1m (SGC); 22.vi.1983, 1f (RJC); 30.vi.1982, 1m1f (RAC); 15.vii.1986. 1m2f (RAC); 17.vii.1988, 2m3f [1m with *Formica subpolita* Mayr (Hymenoptera:Formicidae) as prey] (RAC); 1.viii.1987, 1m (RAC,RJH).

This is a large, elongate, mainly grey species occurring in grasslands from southern B.C. and Alberta south to California and New Mexico. It tolerates a wide range of different conditions, and in southern B.C. reaches its greatest densities in the *Artemisia tridentata* stands in the hot, dry lowlands around Chopaka in the Similkameen Valley. It prefers to forage from bare ground; on the study site most were captured along the dirt track. An ant, a male *Formica subpolita*, is the only prey recorded.

Stenopogon inquinatus Loew. 10.vi.1982, 1f (RAC); 13.vi.1983, 1f (RJC); 13.vi.1987, 1f (SGC)[RBCM]; 21.vi.1983, 1f (RJC); 22.vi.1983, 1f (RJC); 30.vi.1982, 2f (RAC); 5.ix.1983, 2f (RAC).

Along with *Machimus occidentalis*, *S. inquinatus* is perhaps the most common and widespread of the large robber flies in the dry forests and grasslands of southern B.C. This heavy-bodied, reddish species ranges from northeastern B.C. south to California and east to Manitoba and New Mexico. It is much less common on the West Bench grasslands than in the adjacent open woods of *Pinus ponderosa* Dougl. (Ponderosa Pine) and *Pseudotsuga menziesii* (Mirbel) Franco (Douglas-fir). The few specimens recorded were all females; dates range from 10 June to 5 September, with all but the latter in June. One was seen attacking the asilid *Machimus occidentalis* on 9 June 1982, but was not collected.

Tribe Dasypogonini

Comantella pacifica Curran. 26.iii.1988, 2m (SGC); 28.iii.1987, 1f (SGC); 28.iii.1987, 1f (SGC)[RBCM]; 2.iv.1984, 6m2f (RAC); 19.iv.1988, 4m7f [1f with *Platycheirus coerulescens* (Will.) (Diptera: Syrphidae) as prey] (RAC); 20.iv.1988, 9m (RAC); 21.iv.1988, 4m1f (RAC); 22 iv.1988, 1m1f (RAC); 28.iv.1989, 1m (RAC); 29.iv.1989, 1m (RAC); 30.iv.1989, 2m1f (RAC); 1.v.1989, 1m (RAC); 3.v.1989, 1m (RAC); 8.x.1984, 2f (SGC); 8.x.1984, 1f (SGC) [RBCM]; 13.x.1986, 2f (SGC), 1f (SGC)[RBCM]; 22.x.1983, 2m (SGC), 6m3f (RAC).

Known in Canada only from the Okanagan Valley, *C. pacifica* ranges south into the grasslands of Washington. Penticton is the type locality (4 April 1919, E.R. Buckell [CNC]). The species perches both vertically on grass and horizontally on the ground while hunting. The known flight period on the West Bench is divided into an early segment (26 March to 3 May) and a later one (8 to 22 October). The only prey recorded is the hover fly *Platycheirus coerulescens*, which is common along the dirt track in April.

Cophura brevicornis (Williston). 30.vi.1982, 1f (RAC)

This species ranges from the Chilcotin region of central B.C. south to California, Colorado, and Nebraska. In B.C., *C. brevicornis* is predominantly a denizen of open, dry woods; it is probably a wanderer to the study area. The single specimen was collected on 30 June 1982. It is rather common in the Ponderosa Pine and Douglas-fir woods on the surrounding hills in July; the latest B.C. date is 24 August (1964, Princeton [CNC]).

Lestomyia sabulona (Osten Sacken). 11.v.1983, 1m1f *in copula* (SGC); 17.v.1985, 3m (RJC); 20.v.1984, 4m (RAC); 21.v.1984, 3m2f (RAC); 22.v.1987, 1f (RAC); 29.v.1984, 2m1f (RJC), 1m1f (RJC)[RBCM]; 30.v.1984, 1m (RJC); 3.vi.1986, 1m (RJC).

L. sabulona is a small, pale robber fly ranging from the grasslands of Alberta and the southern Okanagan Valley of B.C. south to California and Wyoming. The recorded flight period is early and short, from 11 May to 3 June; a single mating was noted on 11 May.

Tribe Dioctrini

Dioctria pusio Osten Sacken. 10.vii.1988, 1f (RAC).

In B.C. *Dioctria pusio* is generally found in dry woodlands; it ranges from the southern fringes of the province south to California and Colorado. The single specimen was caught on 10 June 1988 in the fenceline Malaise trap. At Robson, in the Kootenay district, where the largest series of the species in B.C. was captured, records range from 13 June to 23 August [CNC].

Dicolonus nigricentrus Adisoemarto and Wood. 18.v.1987, 1f (SGC).

A rather rare grassland species known in B.C. from the Chilcotin region south into the Okanagan and Similkameen valleys, *D. nigricentrus* ranges into Washington and northern Idaho. The single specimen is from the fenceline Malaise trap on 18 May 1987; other B.C. records range from 3 May (1987, Osoyoos, C.S. Guppy [RBCM]) to 29 June (1923, Keremeos, C.B. Garrett [CNC]).

Eudioctria sackeni (Williston). 14.vi.1987, 2f (SGC); 24.vi.1988, 1m2f (SGC); 10.vii.1988, 1m (RAC); 11.vii.1986, 2m (RAC); 14.vii.1986, 2m2f (RAC); 19.vii.1986, 2m (RAC).

This is a common species of forests and open areas in the lowlands of southern B.C. from Vancouver Island to the Rocky Mountains; it ranges south through Idaho and western Montana to California. All specimens are from Malaise traps between 14 June and 19

July. Two colour morphs are represented, designated sackeni and rivalis by Adisoemarto and Wood (1975). The character differences are most pronounced in males. The sackeni morph has a yellow-white face, yellow facial bristles, extensive orange markings on the legs, and in the male, the wings are orange basally, and grey apically. The rivalis morph has a silver face in the male, brassy in the female. The facial bristles are black, the wings are grey, and the legs are black with only the bases of the tibiae and apices of femora yellow. Sackeni is the more common morph, outnumbering rivalis 2 to 1 in the West Bench collections.

Myelaphus lobicornis (Osten Sacken). 4.vi.1983, 4m (SGC), 2m1f (RAC); 7.vii.1983, 1f (RAC); 10.vi.1982, 2m (SGC), 2m (SGC)[RBCM], 1f (SGC)[CNC], 1m2f [1 pr *in copula*] (RAC), 1m (RAC)[CNC] 3m1f (MBC), 1m (MBC)[CNC]; 12.vi.1982, 1m (RAC); 13.vi.1987, 1f (SGC); 14.vi.1983, 1m (RJC); 17.vi.1987, 1m (SGC); 22.vi.1983, 1m (RJC); 25.vi.1984, 5m (RAC).

All Canadian specimens but one (Dutch Creek, Columbia Lake, 16 July 1967 [RBCM]) are from Penticton. The species ranges south to California, Nevada and Utah. Records in the study area are from 4 to 25 June; since the periods before and after these dates were well-collected in several years, the flight period is likely restricted to June. *M. lobicornis* was collected only in open stands of rabbit-brush, where it looks and behaves much like an ichneumonid wasp. It lacks extensive bristles or body hairs, has a black head and thorax, and has unusually long antennae. The wings are blackish, the abdomen red, and the legs yellow. It flies slowly, with the abdomen and long legs dangling.

Subfamily Laphriinae

Tribe Laphriini

Laphria sadales Walker. 16.vii.1988, 1f (RAC)

Laphria species are characteristic of forests, and *L. sadales* is no exception. It shows a typical Boreal distribution across the northern forests of North America, with a southerly extension along the western mountains as far as California and Wyoming. The single specimen captured in the fenceline Malaise trap on 16 July 1988 was undoubtedly a wanderer from the Ponderosa Pine woodlands 1 km to the west.

Subfamily Asilinae

Tribe Apocleini

Efferia albibarbis (Macquart). 4.viii.1986, 1m (RAC)

This species is one of the most widespread of North American asilids, ranging across the continent and south to Guatemala. In Canada, however, it occurs only in the southern Okanagan Valley and on the beach dunes along Lake Erie in southern Ontario. The lone specimen caught (4 August 1986) was clearly out of the species' usual Okanagan habitat, which is the sandy benchlands around Oliver and Osoyoos. There is suitable habitat near the study area, however, that has yet to be investigated; it may support a small population. Records from the southern Okanagan Valley range from 9 June (1958, Osoyoos, H.& A. Howden [CNC] to 27 July (1953, Osoyoos, J.R. McGillis [CNC]).

Efferia benedicti (Bromley). 4.vi.1983, 2f (SGC); 9.vi.1982, 1m [with *Formica subpolita* Mayr (Hymenoptera: Formicidae) as prey] (RAC); 10.vi.1982, 3f (RAC); 12.vi.1982, 1m 1f (RAC); 16.vi.1983, 1m (RJC); 30.vi.1982, 1m [with *Astata bakeri* Parker (Hymenoptera:Astatidae) as prey] (RAC); 9.vii.1988, 1m (RAC); 17.vii.1988, 1m 1f (RAC); 3.viii.1986, 1f (RAC); 17.viii.1988, 1f (RAC).

Ranging from southern B.C. south to California and Arizona, *E. benedicti* is one of the most abundant robber flies of the cordilleran grasslands. In the study area it has been collected from 4 June to 17 August. Two prey species, both Hymenoptera, are recorded from these collections - the sphecoid wasp *Astata bakeri*, and a queen of the common grassland ant *Formica subpolita*. Mating was recorded on 13 May.

Efferia coulei Wilcox. 11.v.1983, 2f (SGC); 13.v.1983, 4m6f [1 pr *in copula*] (SGC); 16.v.1984, 1m (SGC); 17.v.1985, 2m (RJC); 21.v.1984, 2m (RAC); 22.v.1987, 3m3f (RAC); 26.v.1987, 1f (RAC): 28.v.1984, 1m (RJC); 3.vi.1986, 3m1f (RJC); 4.vi.1983, 3m6f (RAC); 1m1f (RAC)[CNC], 1m1f [1f with *Serica* sp. (Coleoptera: Scarabaeidae) as prey] (SGC); 5.vi.1983, 1m (SGC); 9.vi.1982, 1m2f [1f with *Salda buenoi* (McD.) (Hemiptera: Saldidae) as prey] (RAC); 10.vi.1982, 1m6f (RAC), 3f (RAC)[CNC]; 12.vi.1982, 2m3f (RAC); 13.vi.1983, 1m (RJC); 13.vi.1987, 1f (SGC); 24.vi.1984, 5f (RAC): 25.vi.1984, 2m (RAC), 2f (MBC).

E. coulei is one of the more common species of the northern mesic intermontane grasslands, ranging from the Chilcotin region of central B.C. south to central Washington. It is strictly a spring species; records on the West Bench are from 11 May to 25 June. Recorded prey species are the shore bug *Salda buenoi* and a species of the scarab beetle genus *Serica*.

Efferia harveyi (Hine). 1.viii.1987, 2m3f (RAC, RJH); 13.viii.1986, 3m3f (SGC), 2m (SGC)[RBCM]; 22.viii.1987, 6m1f (RAC); 23.viii.1987, 3m2f (RAC); 24.viii.1983, 4m2f (RAC), 1f (RAC)[UBC]; 30.viii.1983, 9m4f [1f with *Lasius pallitarsus* (Provancher) (Hymenoptera: Formicidae) as prey] (RAC), 3m (RAC)[CNC]; 31.viii.1983, 4m1f (RAC), 1m (RAC)[UBC]; 1.ix.1983, 2m4f (RAC); 2.ix.1983, 4m1f (RAC); 3.ix.1983, 2m4f (RAC), 2m2f (RAC)[UBC]; 5.ix.1983, 12m2f [1m with *Villa* sp. (Diptera: Bombyliidae) as prey, 1m with *Platymyia confusionis* (Sellers) (Diptera: Tachinidae) as prey] (RAC); 2m (RAC)[CNC], 2m (RAC)[UBC]; 6.ix.1983, 3f (RAC)[CNC]; 6.ix.1980, 1f (SGC); 26.ix.1987, 1f (RAC).

A common late summer and autumn species, *E. harveyi* ranges from the Chilcotin grasslands south through the Nicola and Okanagan valleys to California. It is at home in a variety of habitats - lowland sandy habitats dominated by *Purshia tridentata* and *Aristida longiseta, Agropyron spicatum* grasslands with *Artemisia tridentata*, and mesic *Festuca* grasslands.

Efferia staminea (Williston). 30.vi.1982, 1m (RAC)

This species is more or less restricted to the cooler, more mesic grassland sites in southern B.C. and is nowhere common. It ranges south to Colorado, and also occurs in southern Alberta, but is rare there. A single specimen was captured on the West Bench on 30 June 1982. Records from other parts of the valley range from 12 June (1919, Vaseux Lake, E.R. Buckell [CNC]) to 4 August (1915, Okanagan [RBCM]). Lavigne and Holland (1969) state that although the species is euryphagic, it has a preference for dipterous prey.

Proctacanthus milbertii Macquart. 1.viii.1987, 1m1f (RAC, RJH); 3.viii.1986, 2m1f (RAC); 4.viii.1986, 1f [with *Paratiphia nevadensis* Cam. or *claripennis* Cam. (Hymenoptera: Tiphiidae) as prey] (RAC); 10.viii.1982, 2m (SGC); 13.viii.1986, 2m [1m with *Vespula arenaria* (Fab.) (Hymenoptera: Vespidae) as prey] (SGC); 17.viii.1988, 1m (RAC); 18.viii.1986, 1m (SGC); 22.viii.1987, 2m (RAC); 24.viii.1983, 1m (RAC); 30.viii.1983, 1m, 2f (RAC); 31.viii.1983, 1m [with *Melissodes* sp. (Hymenoptera: Anthophoridae) as prey] (RAC); 1.ix.1983, 1m2f (RAC); 2.ix.1983, 1m (RAC); 3.ix.1983, 1m1f (RAC); 5.ix.1983, 2m1f (RAC).

A very large, grey asilid with a wide geographical range, *P. milbertii* occurs from coast to coast in the U.S.; in Canada it is restricted to the southern limits of B.C., Ontario, and Quebec. In B.C. it is strictly a grassland species. In the study area it flies mainly in August (1 August - 5 September). Identified prey here are a yellow jacket wasp (*Vespula arenaria*), an anthophorid bee, (*Melissodes* sp.), and a tiphiid wasp, (either *Paratiphia nevadensis* or *P. claripennis*).

Tribe Asilini

Dicropaltum mesae (Tucker). 21.v.1987, 1f (RAC); 22.v.1987, 1m (RAC); 26.v.1987, 2f (RAC); 3.vi.1986, 1f (RJC); 4.vi.1983, 1f (RAC); 9.vi.1982, 1m1f [*in copula*] (RAC); 10.vi.1982, 1m2f (RAC); 12.vi.1982, 1m2f (RAC); 13.vi.1987, 1f (SGC); 14.vi.1987, 1m1f (SGC); 26.vi.1981, 1f (SGC); 1.vii.1980, 1m (SGC), 11.vii.1986, 1m1f (RAC); 15.vii.1986, 2m2f (RAC); 16.vii.1988, 1m (RAC); 17.vii.1988, 1f (RAC); 19.vii.1986, 1f (RAC).

A common little golden species inhabiting B.C. grasslands from the Chilcotin region southward to the Okanagan Valley, *D. mesae* also ranges east into Alberta and south to Utah and Kansas. The recorded flight dates in the study area are from 21 May to 19 July, which is probably a good estimate of the extremes of the flight period in the study area. Mating was recorded on 9 June.

Machimus occidentalis (Hine). 22.v.1987, 1m (RAC); 4.vi.1983, 7m3f (RAC), 2f (SGC); 6.vi.1981, 1m (SGC); 9.vi.1982, 1m (RAC); 10.vi.1982, 4m2f (RAC); 12.vi.1982, 1f (RAC); 14.vi.1987, 1m (SGC); 16.vi.1983, 2m (RJC); 25.vi.1984, 3m1f (RAC); 25.vi.1988, 1f (SGC); 30.vi.1982, 1m (RAC); 3.vii.1981, 1f (SGC).

This is one of the most common robber flies of open, dry forest and associated grassland in the western cordillera. In B.C. it is common throughout the south from the Rocky Mountains to southern Vancouver Island at low and middle elevations. It ranges south to California and Nevada. It is a spring and early summer species; the majority of West Bench records are from June (22 May - 3 July).

Neomochtherus willistoni (Hine). 16.vii.1988, 1m (RAC); 17.vii.1988, 1m (RAC); 18.vii.1986, 3m (RAC); 19.vii.1986, 1m1f (RAC); 1.viii.1987, 2m1f (RAC, RJH); 2.viii.1987, 2m1f (SGC); 3.viii.1987, 3m (SGC); 16.viii.1988, 1f (RAC); 17.viii.1988, 1m (SGC); 22.viii.1987, 4m2f (RAC); 23.viii.1987, 1f (RAC), 1f (SGC); 24.viii.1987, 1m1f (RAC); 27.viii.1980, 1m (RJC); 31.viii.1983, 1m1f (RAC); 3.ix.1983, 1f (RAC); 6.ix. 1982, 1f (LV).

Similar in general appearance and behaviour to *Machimus occidentalis*, *N. willistoni* has an almost identical distribution in B.C. However, it occurs only as far south as Washington. Unlike *M. occidentalis*, it is a late summer species; records on the West Bench range from 16 July to 6 September.

Zoogeography

1. Faunal Elements

Grouping the twenty-one robber fly species into faunal elements based on their geographical distribution patterns produces a generalized picture of the assemblage's geographic origins. These faunal elements are derived from range patterns observed in this study, but follow similar treatments in Cannings and Cannings (1987) and Cannings *et al.* (1987). The species composition of the assemblage reflects a distinct western origin of the fauna (Fig. 4).

Cordilleran (28.5%). Species of mountain forests of western North America. Six of the 21 species inhabit open forests in the valleys and plateaus of the western mountains, typically from B.C. south to California. These species also occur in adjacent grasslands to some extent, some more abundantly than others. Included here are *Dioctria pusio, Eucyrtopogon nebulo, Eudioctria sackeni, Holopogon stellatus, Machimus occidentalis*, and *Neomochtherus willistoni*.

Intermontane (28.5%). Species of plateau and valley grasslands in the western mountains. Six species, *Comantella pacifica, Dicolonus nigricentrus, Efferia benedicti, E. coulei, E. harveyi*, and *Myelaphus lobicornis* are restricted to these grasslands. *C. pacifica, D. nigricentrus*, and *E. coulei* have rather restricted distributions in the northern grasslands of the Cordillera, from Washington north into the Chilcotin region of B.C. This Northern Intermontane element can be considered a subset of the Intermontane element, because it is distinct in its northern character. It is not treated separately in Fig. 4.

Western (28.5%). Species of the western mountains, associated lowlands and, to varying degrees, adjacent areas of the Great Plains. *Cophura brevicornis, Dicropaltum mesae, Efferia staminea, Lestomyia sabulona, Scleropogon neglectus*, and *Stenopogon inquinatus* are western species whose ranges extend east of the Rocky Mountains. Some reach only the western parts of the Great Plains, but others, such as *C. brevicornis* (Nebraska), *D. mesae* (Kansas), and *S. inquinatus* (Minnesota) range further east. Were it not for an extensive Great Plains component in their ranges, these species would be considered part of the Cordilleran or Intermontane elements. Only *C. brevicornis* and *S. inquinatus* are predominantly open forest species in the west.

Southern (9.5%). Species ranging transcontinentally south of the Boreal Forest, at least in the U.S.; in Canada only in extreme southern areas. *Proctacanthus milbertii* and *Efferia albibarbis*, in B.C. at least, are strictly grassland species. Both enter Canada only in southern B.C. and Ontario.

Boreal (5%). Species ranging transcontinentally in the Boreal Forest and southward in the western mountains to varying degrees. *Laphria sadales* is the sole Boreal species recorded; it ranges in the northern forests from B.C. east to Quebec . The presence of *L. sadales* in the study area is probably accidental; it is undoubtedly a visitor from nearby woodland. The Boreal faunal element cannot be expected to contribute to the origin of the western grassland fauna.

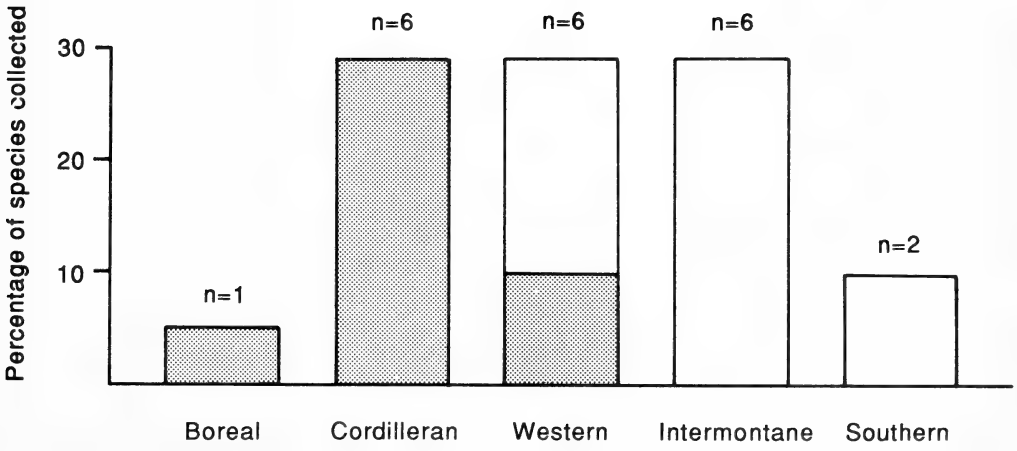

Figure 4. Origins of the fauna: percentage of species from different faunal elements, based on distribution patterns. The bars representing each element are further divided to show the general habitat preferences of the species included.
(stippled = grassland and woodland; clear = grassland only)

2. Habitat

If *Laphria sadales* is eliminated from the list (its presence likely is accidental), 18 of the 20 remaining species are restricted to the grasslands and open, dry forests of western North America. The other two, *Proctacanthus milbertii* and *Efferia albibarbis*, are Southern elements and, in B.C. at least, are inhabitants of grasslands only. In the East and South, however, they may be found in regions where true grasslands do not exist, especially in open, sandy areas.

Forty-three per cent (9 species) of the assemblage lives in both open woodland and grassland (Fig. 4). Indeed, these species may be more common in the former habitat than in the latter; *Stenopogon inquinatus*, *Cophura brevicornis*, and *Eudioctria sackeni* are examples.

Microhabitat clearly plays an important role in the local distribution of many robber flies. Local differences in climate, soil type, and vegetation determine the presence of species in any small area of grassland. For example, the moister, darker soils associated with the cooler climatic regimes of grasslands above about 500 m in the southern B.C. Interior often are characterized by forbs such as *Balsamorhiza sagittata* (Pursh) Nutt. (Balsamroot) and *Lupinus sericeus* Pursh (Silky Lupine) and support several abundant species of asilids not found on the West Bench. *Cyrtopogon willistoni* Curran and *Stenopogon rufibarbis* Bromley are good examples. Several other species, common elsewhere, are absent from the study area. *Proctacanthus occidentalis* Hine is the dominant member of the genus in the grasslands of the Oliver-Osoyoos area; the soil there is usually coarse and sandy, and plants predominating include *Purshia tridentata* (Pursh) DC. (Antelope-brush) and *Aristida longiseta* Steud. (Red Three-awn Grass). *P. milbertii*, the West Bench species, occurs there as well, but in much lower numbers. The two species are more or less temporally separate, with *P. occidentalis* active in June and July and *P. milbertii* in August and September. No *Leptogaster* species have been recorded from the West Bench, although at least one species (near *L. fornicata* Martin) is present in the grasslands growing on the coarser, better drained soils further south. *Leptogaster* is a genus of small, elongate, rather fragile asilids (Asilidae: Leptogastrinae) that, in British Columbia, at least, perch on, and hunt from, grasses. *Efferia albibarbis* prefers sandy soils, and is common around Osoyoos Lake; the single specimen from the study area was not in its typical habitat. An undescribed species of *Efferia* common in the drier soils of Vaseux Lake to the south and Kalamalka Lake to the north is not present on the West Bench site. This species evidently is closely related to *E. coulei*, and like *E. coulei* is a spring species; its requirement for a different microhabitat is likely one of the barriers that separates them. *Efferia staminea* is rare in the study area; it is more common in the drier habitats dominated by *Agropyron* and *Stipa* grasses where the undescribed *Efferia* is found. *E. benedicti* is more common on the West Bench than its close relative *E. staminea*, but not as abundant as *E. coulei*. The preferred habitat of *E. benedicti* in the southern Okanagan is the dry, silty soil favoured by *Artemisia tridentata*. *E. harveyi* is common in both types of habitat.

Within the study area a few species show particular preferences for certain sites. *Myelaphus lobicornis* is restricted to the large clusters of *Chrysothamnus nauseosus* on the northeastern border of the area. It uses these shrubs as perching sites, but also lands on grass stems. Its particular relationship to the shrub is unclear, but the only other known locality for the species in B.C. and Canada is Dutch Creek near Columbia Lake where Rabbit-brush is also the dominant grassland shrub. *Eudioctria sackeni*, an example of a species mainly associated with shrubs and trees in open woodland (where it uses these larger plants for perching sites), was captured only in the two Malaise traps, both set adjacent to the shrub/grassland interface.

3. Phenology

Figure 3 illustrates that although June and July are the months with most species present, some flies have flight periods temporally separate from those of other species. Particularly striking is the observation that several closely related species, or species of similar size and habits (and thus perhaps potential competitors), fly at different times during the season. Thus,

Machimus occidentalis is active mainly in June and the related *Neomochtherus willistoni* flies mostly in August; their flight periods do not overlap. The two appear to fill very similar niches. Likewise, the three most common species of *Efferia* - *E. coulei*, *E. benedicti*, and *E. harveyi* - follow each other from spring to autumn, evidently doing similar things in the same place. All three species hunt from the ground, or from very low on grass stems. Presumably the separation of their flight periods allows the three species to live in the same habitat without much competition. Other behavioural differences may also be important. Lavigne and Dennis (1985) studied three sympatric *Efferia* species in Mexico and found that each foraged at different heights in the vegetation, predominantly at different times of day, and that the type of prey taken by each species exhibited very little overlap. They speculated that these factors allowed the three species to coexist. On the West Bench, prey selection was not observed often enough to be of use in this context. *Comantella pacifica* hunts in a similar manner to these *Efferia* species, and takes prey of a similar size to at least that of *E. coulei*. *Comantella's* flight period is very early and very late, bracketting all species of *Efferia*. The spring specimens appear fresh, suggesting to some students that *Comantella* species emerge in both the late fall and early spring. In Colorado, James (1937) felt that there was a partial emergence of *C. fallei* Back in the fall, with a continuation of the emergence the following spring. Dennis and Lavigne (1975), however, state that in Wyoming adults have been collected from beneath rocks in early March, indicating that they may overwinter in that stage. Whatever the mechanism, the very early and late flight periods enable *C. pacifica* to be active when no other robber flies can compete with them. *Lestomyia sabulona* and *Dicropaltum mesae*, although not closely related, are similar in size and hunting behaviour. The former is almost completely restricted to a May flight period; the latter, although first seen in May, is predominantly active in June and July.

As in many insects, there is a tendency in some species for males to emerge earlier in the season than females, although the data is too spotty to make significant analyses of this phenomenon. It is most noticeable in *Neomochtherus willistoni*, *Myelaphus lobicornis* and *Lestomyia sabulona*, and to a lesser degree in *Proctacanthus milbertii* and *Holopogon stellatus*. Females appear more common early in the flight period in *Dicropaltum mesae* and *Efferia benedicti*. Females seem to fly later in the season than males in some species; this is especially evident in the genus *Efferia*. Most species do not show major peaks in flight times, but *L. sabulona* evidently is most abundant at the end of the third week of May, *M. lobicornis* in the second week of June, *E. coulei* in the first two weeks of June, *Efferia harveyi* in the last week of August and the first week of September, and *Machimus occidentalis* in the first two weeks of June.

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BIOLOGY OF *Erythroneura elegantula* AND *E. ziczac* (HOMOPTERA: CICADELLIDAE) ON *Vitis vinifera* IN SOUTHCENTRAL WASHINGTON

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ABSTRACT

The western grape leafhopper, *Erythroneura elegantula* Osborn, and the Virginia creeper leafhopper, *Erythroneura ziczac* Walsh, were the only species of leafhoppers found colonizing grapevines, *Vitis vinifera* (L.), in southcentral Washington. Other Cicadellids collected did not colonize. Where the mymarid parasitoid, *Anagrus epos,* was found, the predominant leafhopper was *E. elegantula.* In the absence of *A. epos, E. ziczac* seemed to be the more abundant. *E. ziczac* quickly dominated a mixed population of both species in a greenhouse. On heavily damaged grape leaves, *E. ziczac* eggs remained surrounded by green tissue whereas *E. elegantula* eggs were not. This suggests the presence of a repellent or anti-feedant with *E. ziczac* eggs. Development time for *E. elegantula* averaged 402.6 D° which is much shorter than previously published times, and for *E. ziczac* averaged 390.5 D°.

Keywords: *Erythroneura elegantula, Erythroneura ziczac, Vitis vinifera,* wine grapes, leafhopper biology

INTRODUCTION

Doutt and Nakata (1973) believed that *Erythroneura elegantula,* the western grape leafhopper (WGLH) infested *Vitis californica* Bentham in California before the cultivation of *V. vinifera.* It was probably introduced into the Pacific Northwest on cultivated grapevines. Wolfe (1955) described WGLH as the leading insect pest of grape in Washington; it has the same distinction in California (Jensen and Flaherty, 1981).

Erythroneura ziczac, the Virginia creeper leafhopper (VCLH) was described by Walsh from a single specimen collected in Illinois (Beamer, 1936). It was recognized early as a minor pest of grape (Wirtner, 1904) and apple (DeLong, 1931), and as a principal insect pest of Virginia creeper and Boston ivy (Fairbairn, 1928; Pepper and Mills, 1936). VCLH occurs throughout the U.S. and southern Canada (Metcalf, 1968) but like WGLH is probably new to the Pacific Northwest,which has no native Vitaceae (Hitchcock and Cronquist, 1973). VCLH was recognized as the worst pest of *V. vinifera* grapes in British Columbia by McKenzie and Beirne in 1972.

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MATERIALS AND METHODS

Collection and identification.

Erythroneura adults and nymphs were collected in June and July of 1983 on *V. vinifera* in vineyards at the Irrigated Agriculture Research and Extension Center, Prosser, and also at Paterson, Grandview, and Cold Creek (Fig. 1). Fifty leaves were collected, placed in plastic bags, and examined in the laboratory. Sweep net samples, taken from at least 200 m along one side of vineyard rows during each of four visits to each site, were also placed in bags and examined in the laboratory. Identification was based on 150 males chosen randomly from about 10,000 *Erythroneura* adults taken, plus 83 males reared from nymphs. These were dissected for identification, using the method of Oman (1949) and the keys of Beamer (1936).

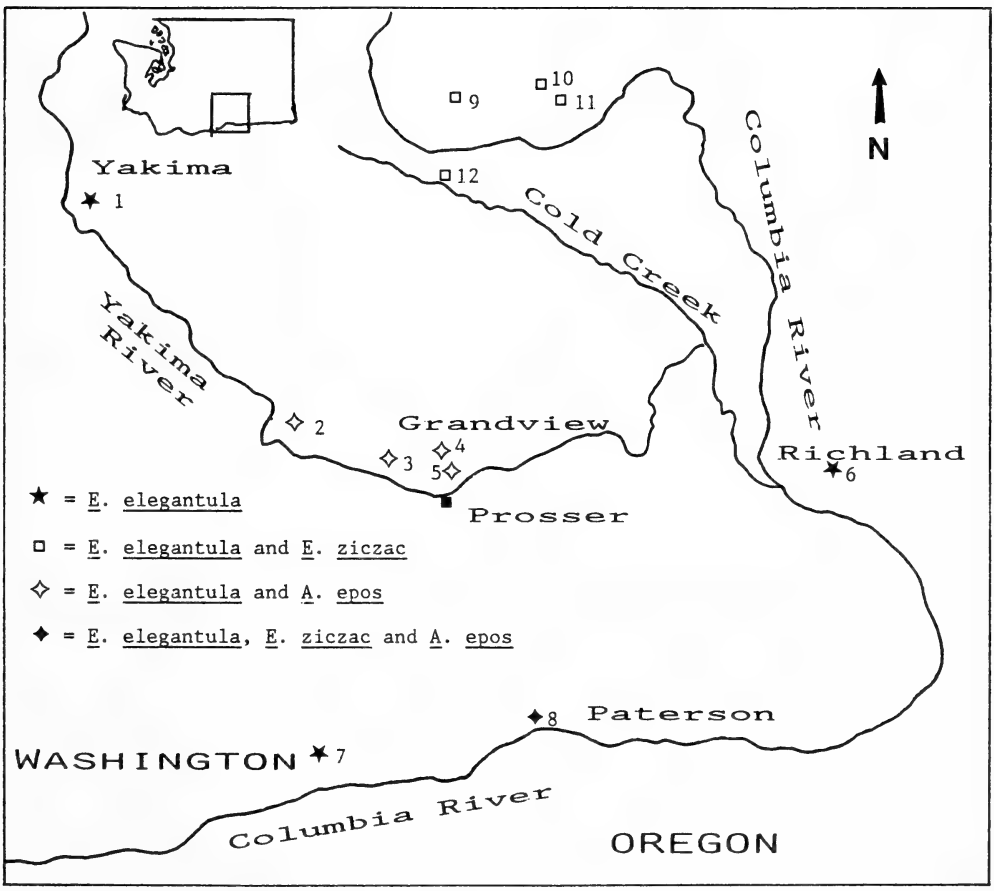

Figure 1.Known distribution of *E. elegantula, E. ziczac* and *A. epos* on southcentral Washington *V. vinifera*.

Temporary Food Plants.

Overwintering *Erythroneura* adults were collected in Tulgren funnel samples of vineyard debris, about 20 kg each, from Prosser, Grandview and Cold Creek on 28 Feb., 1983. *Erythroneura* spp. were not found in similar samples taken on 15 Apr., a date preceding *V. vinifera* bud break. At that time vegetation within and up to 200 m from the edges of vineyards plus a vineyard at Paterson, was sampled with a sweep net. Plants yielding *Erythroneura* spp. were identified using the keys of Hitchcock and Cronquist (1973).

Survey for *Erythroneura* spp., arthropod predators and parasitoids.

At least 50 m of each vineyard margin was sampled with a sweep net and 200 leaves taken during Sep. and early Oct. 1984 at 12 vineyards. The sites are shown in Fig. 1. Leaf and sweep net samples were also collected during the growing seasons of 1983 and 1984 at Prosser and Cold Creek. Vine leaves were examined for the presence of *Erythroneura* immatures and evidence of *A. epos*. Cicadellid species were determined using the keys of Oman (1949), Beirne (1956), and Beamer (1936). Other Arthropoda were sent to appropriate authorities for identification. Voucher specimens have been placed in the insect collection at Washington State University, Pullman.

Development and Mortality of Immature *Erythroneura* spp.

The development rate and mortality of immature WGLH and VCLH in the absence of natural predators and parasitoids were compared on vines at Prosser in Jul., 1985. Air temperature was recorded at a height of 1.5 m. The hourly values used were averages of field data measured every 10 sec. Using the developmental threshold of 10.3°C (50.5°F) determined for WGLH in California (Cate, 1975), physiologic time was calculated as the area under a temperature curve using a Fortran computer program.

Eggs of known age were obtained by confining 15-20 individuals of each species in leaf cages for 24 h. Mature, exposed leaves were selected free from *Erythroneura* spp. damage to avoid previously laid eggs. Upon selecting a mature leaf with no indication of leafhopper feeding injury, the shoot was cut leaving that leaf terminal. A single leaf cage similar to that used by Pickett *et al.* (1987) was tied on the shoot and leafhoppers added. Cage effect on leaf temperature was examined using an Omnidata® model DP212 2-channel temperature recorder (±0.2°C) to measure air temperature beneath a caged leaf and a neighboring leaf. Temperatures were recorded simultaneously every 0.5 h for 160 h.

Nymphs were counted when they reached instar V. Some were then placed individually on the underside of a leaf in a clip-on cage of 2.5 cm inner diam. modified from DeBach and Huffaker (1971). Data from leaf cages found later to contain arthropod predators were not used. The number of eggs deposited was determined by counting the unhatched eggs and empty chorions with a dissecting microscope (20X). The nymphs in the clip-on cages were examined daily. The date of death or imaginal molt, and the sex of emerged adults were recorded.

RESULTS AND DISCUSSION

The western grape leafhopper (WGLH), and the Virginia creeper leafhopper (VCLH), were the only *Erythroneura* pests of *Vitis vinifera* found. No immature cicadellids of other species were found on grapevines and 11 other species of adult leafhoppers identified, caused no noticeable damage. The characters distinguishing WGLH and VCLH in the field are shown in Fig. 2.

E. comes and *E. elegans*, both reported from *Vitis* spp. in Washington (Frick, 1952; Wolfe, 1955; Capizzi *et al.*, 1985) were not found. Some species of *Erythroneura* are difficult to distinguish from *E. comes*, and certain early workers considered them to be variations of that leafhopper (Robinson, 1926). We believe that difficulty in identifying *Erythroneura* spp. has

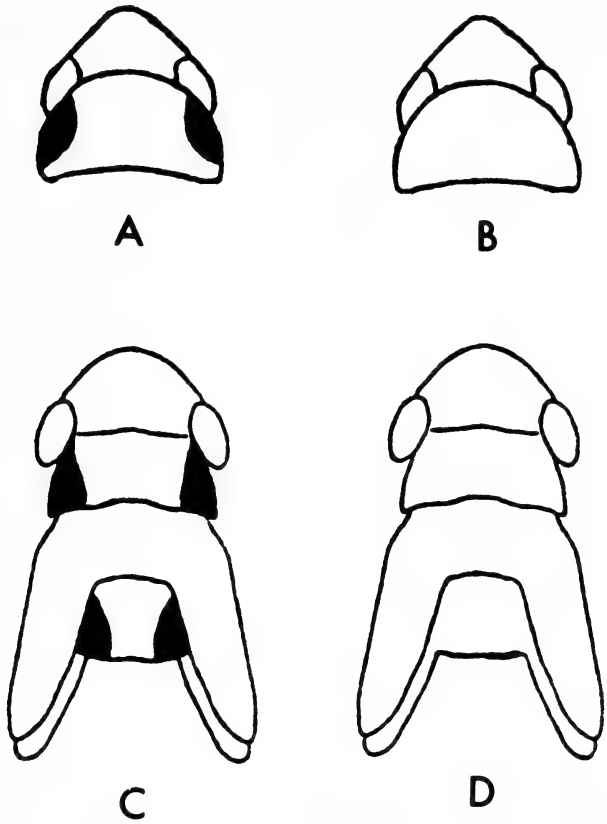

Figure 2.Characters for distinguishing *Erythroneura* spp. found in southcentral Washington vineyards are: *E. ziczac* adults (A) have dark lateral pronotal spots; nymphs III-V (B) have red spots on dorsum. *E. elegantula* adults (B) and nymphs (D) have no dark pigmentation on the dorsum.

resulted in incorrect reports of *E. comes* from west of the Rocky Mountains. *E. comes* has been reported from throughout the western U.S. and Canada (Gillette, 1898; Essig, 1926; Knowlton, 1933; Wolfe, 1955), but those authors did not describe distinguishing characters. Moreover, current workers in Washington, Oregon, and California have not seen *E. comes* (P.W. Oman and R. L. Doutt, 1985, pers. comm.), and no specimen labeled *E. comes* collected in the West was found in the collections of Washington State University or Oregon State University. The University of California at Berkeley, had a single specimen labeled *E. comes,* collected there in 1914 (J. Chemsak, 1985, pers. comm.). That specimen was found to be female and so could not be identified to species.

Temporary Food Plants.

In areas with cold winters, *Erythroneura* spp. overwinter as adults in plant debris, most often in the leaves of the host plant. Overwintering forms may become active during any brief warm period and move to temporary food plants. They are often found on temporary food plants just before and after their host plants growing season.

Cate (1975) conducted a spring survey and found that *Rubus* spp., *Prunus dulcis*, sagebrush and storksbill served as temporary food plants for WGLH. Adults were found on dandelion, pear, *Medicago* spp., willows, hops and in greatest density on balsam-root, *Balsamorhiza sagittata*. Immature forms were not found on these plants. WGLH's apparent preference for balsam-root as a temporary food plant suggests that it might serve as a trap crop. Clean culture in vineyards could increase WGLH movement to balsam-root in early spring.

VCLH was collected on dandelion only, which was also found to be a preferred temporary food plant by McKenzie and Beirne (1972). Since it occurred on *V. vinifera* in rather barren areas, it probably had other temporary food plants. VCLH adults that had escaped from colony cages were observed feeding on hops in a greenhouse. After WGLH was found in large numbers on balsam-root, an effort was made to sample balsam-root near vineyards with VCLH. However, no balsam-root was found within one km of vineyards containing VCLH.

Both leafhopper species had other host plants near Prosser. WGLH bred on Concord grapes, *Vitis labrusca* and VCLH on Virginia creeper, *Parthenocissus quinquefolia*.

Survey for *Erythroneura* spp. and the parasitoid, *Anagrus epos*.

The known distribution of *Erythroneura* spp. and *A. epos* on Washington grapevines in 1984 is shown in Fig. 1. WGLH is ubiquitous on grapevines in southcentral Washington. VCLH was not found on *Vitis* spp. in the Yakima Valley proper, although it was reported from a vineyard at Sunnyside, (Wolfe, 1955). *A. epos* was abundant on grapevines in the lower Yakima Valley and a single parasitized egg was found at Paterson, near the Columbia River. Most vineyards peripheral to the Yakima Valley are on recently reclaimed desert. The absence of *A. epos* from these still relatively barren areas may be explained by the lack of winter hosts.

Mortality.

The percent mortality of immature WGLH and VCLH is given in Table 1; 547 WGLH eggs produced 152 fifth instars, of which 71 produced 69 adults; 683 VCLH eggs produced 152 fifth instars, of which 84 produced 69 adults. The various factors responsible for mortality were not evaluated. Some eggs failed to develop and were considered by Cate (1975) to be infertile. He found that they darkened as they became infected with *Aerobacter* sp. and *Monila* sp. Our observations indicated that most nymphal mortality was associated with molting.

Table 1.

Percent mortality of immature WGLH and VCLH on *V. vinifera* var. Grenache at Prosser, Washington, 1985.

Species	Egg-instar IV	Instar V	Total
WGLH	53.2	6.1	56.1
VCLH	77.8	17.6	81.3

Developmental Rates of *E. elegantula* and *E. ziczac*.

Cate (1975) found that WGLH had two and a partial third, or three generations/year at various locations in California. He reported that development was completed in 844 D° during the proper limits of daylength (see below) while Jensen and Flaherty (1981) reported 980 D°. The generations became increasingly asynchronous during the growing season. Females caged at 21°C (70°F) deposited an average of 1.31 eggs/day for a mean total of 28.2.

WGLH adults entered reproductive diapause when exposed to daylength less than 13.6 h in late summer. Diapausing females were unmated, and the gonads of both sexes were undeveloped. Gonad development resumed when daylength increased to 11.6 h but was very slow until grape foliage became available. Laboratory studies showed a preoviposition period of 192 D° at 27°C (80°F) and 246 D° at 21°C (70°F).

A WGLH nymph destroyed a mean total of 43.6 mm^2 leaf surface to maturity at 21°C (70°F). At this temperature the adult consumed an average of 6.72 mm^2/day.

Pepper and Mills (1936) found that VCLH completed one and a partial second generation/year on Virginia creeper, *P. quinquefolia* (L.), in Bozeman, Montana. McKenzie and Beirne (1972) found that non-diapausing adult males were short-lived; two peaks in male density indicated that the species was bivoltine in British Columbia. Fairbairn (1928) believed at least three, probably four generations per year occurred on Virginia creeper in Kansas. He observed the developmental rates of VCLH but made no reference to temperature; the preoviposition period averaged 5.15 days, the egg stage averaged 8.1 days and nymphal stadia were 3 or 4 days.

McKenzie and Beirne (1972) found that a VCLH nymph destroyed about one cm^2 total leaf surface. Oviposition rates were lower on American varieties of *Vitis labrusca* than on *V. vinifera* and its hybrids. Younger nymphs were seen to be entangled in the leaf hairs of American grapes.

The mean physiological time between oviposition and imaginal molt for WGLH and VCLH is given in Table 2. Males of both species became adults before females (pooled t test, $P < 0.05$), a characteristic common in Cicadellidae (DeLong, 1971).

VCLH developed in less time that WGLH (pooled t test, $P < 0.05$). The occurrence of VCLH at higher latitudes than WGLH (Metcalf, 1968; McKenzie and Beirne, 1972) may partly reflect this.

Table 2.

Developmental time, in day-degrees above 10.3°C, of *Erythroneura* spp. on *V. vinifera* var. Grenache at Prosser, Washington, 1985.

	n	mean D°	s
WGLH males	31	398.2	15.0
WGLH females	36	406.3	14.5
WGLH total	67	402.6	15.2
VCLH males	33	386.2	12.6
VCLH females	36	394.4	10.2
VCLH total	69	390.5	11.8

WGLH developmental time was less than half of that reported by Cate (1975) who recorded development at constant temperatures. Development of an insect may take less physiological time under fluctuating temperatures (Siddiqui and Barlow, 1973), such as were used here. Shortened developmental time, perhaps resulting from a lowered developmental threshold, could be an adaptation to a shorter growing season, but such an extreme difference was unexpected. Precautions were taken so that cage interiors were not warmer than the surrounding air temperature. The average temperatures within the cage and beneath the adjacent leaf were 11.6 and 11.8°C. The difference was considered insignificant (paired t test, $t = 0.15$, $P < 0.1$, 319 df). A repetition of this experiment using WGLH from California and Washington might eliminate uncertainty in comparing populations.

Competition between *Erythroneura* spp.

Because WGLH and VCLH feed on *V.* vinifera in an apparently identical manner, and are seen on the vine at the same time of year, they may compete for grapevines in southcentral Washington. If this is the case, the distribution of *Erythroneura* spp. on grapevines (Fig. 1) indicates that WGLH is the more successful competitor. Although no experiments were conducted placing WGLH and VCLH in direct competition, certain observations suggest a mechanism for WGLH success.

VCLH occurs in vineyards where *A. epos* is rare or absent. The relative density of arthropod predator species was not measured but all predators collected on *V. vinifera* at Prosser, where only WGLH was found, were also collected at Cold Creek, where both leafhoppers were found. VCLH was not seen among the tens of thousands of WGLH collected on grapevines at Prosser, but was easily found on Virginia creeper nearby.

During this study, WGLH and VCLH were raised on caged *V. vinifera* in a greenhouse. Cultures were begun by introducing adults from the mixed population of WGLH and VCLH at Cold Creek. Each inoculum was first sorted in an effort to introduce only one species, but often included a small percentage of the other species. Eleven cages originally containing a large majority of WGLH, after several months with no additional input, contained a large majority of VCLH. The reverse never occurred.

Adults of both *Erythroneura* spp. escaped occasionally when the cages were opened, and flew to uncaged *V. vinifera* in the same greenhouse. These escaped leafhoppers multiplied until the uncaged vines were heavily damaged. At that time, the leafhoppers on the uncaged vines were almost exclusively VCLH. No evidence of *A. epos* was found in the greenhouse.

Competition between WGLH and VCLH in the greenhouse was not carefully controlled, but the outcome was so striking that we considered VCLH to have held a competitive advantage. When these observations are considered along with the known distributions of WGLH, VCLH and *A. epos* in the field, we concluded that VCLH is kept from grapevines in most of southcentral Washington by the wasp. Oviposition behavior varies between WGLH and VCLH. VCLH may lay eggs singly or in clusters, WCLH lays eggs only singly. A cluster of VCLH eggs may provide a more powerful chemical stimulus than a single egg for a searching *A. epos* female.

An Egg-associated Antifeedant.

When grape leaves supporting VCLH became chlorotic from feeding injury, the egg clusters were found to be surrounded by an undamaged area of leaf tissue. We suspected that the egg cluster exerted an antifeedant effect. The antifeedant theory was further investigated by confining nymphs and adults of both leafhoppers, separated by stage and species, on grape leaves with eggs of either spp. using the clip-on cages described earlier. After each caged leaf area had turned white with feeding damage it was examined under a dissecting microscope (20X) for undamaged tissue surrounding any eggs. Nymphs and adults of both spp. did not feed near the eggs of VCLH, but did feed near the eggs of WGLH. This antifeedant effect, perhaps chemical in nature, may disperse VCLH nymphs from crowded oviposition sites. If feeding by *Erythroneura* spp. can cause egg mortality by desiccation, then VCLH may have a reduced egg mortality when leafhopper density is high.

No efforts were made to isolate or characterize the anti-feedant, but the possibility exists for the development of a selective leafhopper control, based on repellency or other characteristics of an antifeedant.

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ERRATA

In the paper entitled "Semiochemicals..." by S.M. Salom & J.A. McLean (Vol. 85:34 - 39, 1988), some typesetting errors appeared on p. 37 under RESULTS. In **Experiment 1**, line two, Pkw 0.01 should read P >0.01. On the same line, P 0.05 should read P >0.05. The > sign is also missing from the same type of statistical presentation in **Experiment 2**, lines two, three, and fifteen (last line, p. 38).

EFFECT OF HOST PHENOLOGY ON OVIPOSITIONAL PREFERENCE OF WINTER FORM PEAR PSYLLA (HOMOPTERA: PSYLLIDAE)

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ABSTRACT

In free-choice assays using budwood at similar stages of leaf emergence, winter form (WF) pear psylla (*Cacopsylla pyricola* Foerster form *simulans*) showed no ovipositional preference for psylla-susceptible 'Bartlett' (*Pyrus communis* L.) over psylla-resistant W6 (*P. ussuriensis* Maxim.) or NY10353 (*P. ussuriensis* x *P. communis* hybrid). After budbreak, WF psylla oviposited on the host with foliage in the most advanced stage of leaf emergence.

Key Words: *Cacopsylla pyricola* Foerster, pear psylla, ovipositional cues, host plant resistance, behavior.

The pear psylla, *Cacopsylla pyricola* Foerster, exists in two distinct seasonal forms: form *typica*, or summer form, (SF) and form *simulans*, or winter form (WF). The WF psylla overwinter as adults in reproductive diapause, frequently outside the orchards (Burts, 1970; Fye, 1983). Oviposition begins on the reproductive host, pear (*Pyrus communis* L.), early in the spring in response to increasing daylength (McMullen and Jong, 1976). Release from diapause is coincident with tree phenology, beginning shortly before budbreak (Burts, 1970). Host plant location is an essential step in the repopulation of orchards.

Psylla-resistant genotypes of *Pyrus ussuriensis* Maxim. (Westigard et al., 1970) and *P. ussuriensis* x *P. communis* hybrid origin (Harris, 1973) have been identified in which ovipositional non-preference by SF is an important modality of host resistance. Harris (1973) also reported that differences in ovipositional preference exhibited by WF psylla between resistant and susceptible hosts were small, and suggested that differences in phenology may be involved. Vegetative budbreak and bloom of trees of this genetic lineage is three to ten days earlier than that on *P. communis* cultivars, which, as a group, are susceptible to the pear psylla. Oviposition by WF increases in response to budbreak and foliar expansion (Smith, 1965). On Asian, domesticated European, and local landrace cultivars of apple and pear, a European pear psyllid, *Cacopsylla pyri* L., and an apple psyllid, *Psylla melanoneura* Foerster form *taurica*, oviposited first on the genotypes which came out of dormancy earliest (Lazarev, 1974).

In these field studies, differences in host phenology were confounded with genotype, particularly when different host species were involved. Because terminal buds can influence the emergence of buds basal to them, a preliminary experiment was conducted to investigate this matter of technique. A subsequent experiment was then designed to investigate the contribution of host phenology to ovipositional performance by WF pear psylla through the early stages of leaf emergence.

MATERIALS AND METHODS

Experiment I. We tested the hypothesis that WF would oviposit preferentially on dormant budwood of a psylla-susceptible *P. communis* cultivar, 'Bartlett', over a resistant wild-type clone, *P. ussuriensis* W6 (W6) (Westigard et al., 1970). The experiment was designed as a free-choice paired comparison. Dormant budwood was collected from the Appalachian Fruit Research Station, Kearneysville, WV, orchard on 14 March 1985. Presence of a terminal bud may delay the opening of lateral buds and thereby influence psylla preference. Therefore, we used ten matched pairs of 'Bartlett' and W6 budsticks, five pairs with and five pairs without terminal buds. All budsticks had three lateral buds. The budsticks were placed in individual vials of water. Each pair ('Bartlett' and W6) was placed in a cylindrical plastic cage with four

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male and four female adult WF which had been field-collected the same day. Cages in this and subsequent experiments were placed in a rearing room at 25C, with a photoperiod of 16:8 (L:D). Egg counts were made on day six after insect removal. Data were analyzed using paired 2-tailed t-tests.

Experiment II. This experiment was designed as a set of six dual-choice comparisons: three between susceptible and resistant hosts at the same stages of bud development; two between stages that would occur naturally with the resistant host further developed than the susceptible host; and one between the resistant host in dormant condition and the susceptible host at budbreak, a situation not occurring naturally. The final comparison was made to ensure that choice was based on bud development and not host genotype.

The susceptible host was 'Bartlett' and the resistant was NY10353 (NY), a *P. ussuriensis* x *P. communis* hybrid shown to be resistant by greenhouse and field counts of nymphs (R.L.Bell, unpublished data; R.C. Lamb, personal communication). Budbreak of NY occurs about 5-7 days earlier than 'Bartlett' in the field. Fully-dormant budwood was collected from the orchard in mid-February 1987, and held in storage at 2C. Because budbreak proceeds more rapidly on NY than on 'Bartlett', bud stages were matched by removing 'Bartlett' budsticks from cold storage in advance of NY. Terminals buds were removed, because budbreak of lateral buds was observed to occur more uniformly in their absence. Adult WF were collected from the field by beating tray and aspirator on 14 April 1987, held in a refrigerator at 3C overnight and introduced to budsticks the following day.

Each choice test was replicated 10 times and consisted of a 'Bartlett' and a NY budstick, each with five buds. Budsticks were placed in individual vials of water, and each pair was enclosed in a plastic cylindrical cage with two male and two female WF. Eggs were counted after day five in the first five comparisons. In the final comparison, 'Bartlett' at budbreak vs. dormant NY, eggs were counted after three days to avoid the loss of uniform bud development, which had begun on about day three in previous comparisons. Square root transformation failed to improve normality and equality of variances in all comparisons, and, therefore, untransformed data were analyzed by paired 2-tailed t-tests.

Although we attempted to match each pair of budsticks as closely as possible in both size and the condition of the five buds, this uniformity could not be maintained. Within the five-day test period, leaf emergence progressed rapidly. Buds which had begun dormant had reached green tip, and buds which were initially at budbreak and green tip were at varying stages of leaf emergence and expansion, with NY buds developing faster than 'Bartlett' buds in most cases. Therefore, the data was also separated into three categories according to the relative stage of leaf emergence at the end of the experiment: NY equal to 'Bartlett', NY more advanced than 'Bartlett', and 'Bartlett' more advanced than NY.

RESULTS AND DISCUSSION

Experiment I. W6 buds, particularly the terminals, developed faster than 'Bartlett' buds. On intact budsticks, more eggs were oviposited on W6 terminal buds, which had ca. 1 cm of foliage, than on the lateral buds (Table 1; Prob. > /t/ = 0.07). More eggs were found on the most distal lateral buds. There was no significant difference between lateral and terminal buds of 'Bartlett' (Prob. > /t/ = 0.77). Eggs were deposited on the foliage or on tops of adjoining bud scales. On dormant buds, eggs were found on and around bud scales and in cracks near buds. The data shown for mean number of eggs on lateral buds represents the total eggs on all three lateral buds of each budstick. In no case were more eggs found on a single lateral bud than on the terminal.

Table 1.

Mean number of eggs ± standard error oviposited by winter form pear psylla on 'Bartlett' and *Pyrus ussuriensis* W6 (W6) budsticks with and without terminal buds.[1/]

	Budsticks with terminal buds			Budsticks without	
Host	3 Lateral buds	Terminal buds	Total	terminal buds	Overall
Bartlett	56.2 ± 13.2	53.0 ± 13.9	109.2 ± 24.9	79.4 ± 26.2	94.3 ± 31.5
W6	41.8 ± 10.8	139.6 ± 38.2	181.4 ± 40.3	198.2 ± 49.4	189.8 ± 91.1
Difference (Bartlett-W6)	14.4 ± 7.5	-86.6 ± 36.5	-72.2 ± 29.7	-118.8 ± 54.4	-95.5 ± 30.2
Prob. >/t/[2/]	.13	.08	.07	.09	.02

[1/] Two six-day free-choice tests, five replications each.
[2/] Null hypothesis, (H_o): 'Bartlett'-W6 = 0 at p = 0.05, 2-tailed paired t-test.

Where terminals were removed, W6 buds all opened rapidly. By day six, they showed ca. 2.5 cm of foliage, and new leaves were beginning to separate and expand, while 'Bartlett' buds were only slightly swollen with no foliar tissue showing. Slightly more eggs were deposited on W6, either directly on foliar tissue or on nearby bud scales, than on the still- dormant 'Bartlett' (prob. > /t/ = 0.09). However, one 'Bartlett' budstick developed faster than its paired W6 and showed foliage at all nodes. The 168 eggs deposited on that single budstick accounted for 42% of all eggs found on 'Bartlett'. The corresponding W6 had 113 eggs. There were no significant differences in oviposition between budsticks with or without terminals (Prob. > /t/ = 0.49). Therefore, the data were combined to test for preference between hosts.

WF did not prefer the budwood of the susceptible cultivar 'Bartlett' for oviposition. Instead, they chose oviposition sites on buds where foliage appeared, even if this was on the moderately-resistant W6. This could be interpreted to mean that W6 was more attractive for oviposition. However, the one replication in which eggs were concentrated on a 'Bartlett' budstick which was further advanced also leads to the hypothesis that attraction to foliage as an oviposition site was more important than other genotypic factors to WF psylla.

Experiment II. Ovipsition occurred on budwood of all stages, but was least when buds were dormant at the beginning of the assay (Table 2). Oviposition on both genotypes increased dramatically between the dormant stage and budbreak, and increased again, up to 3-fold between budbreak and green tip. In the 3-day test which began with dormant NY vs. 'Bartlett' at budbreak, only a single egg was found on NY.

Table 2.

Mean numbers of eggs deposited by winter form pear psylla on 'Bartlett' and NY10353 budsticks.[1/]

Bud stage[2/]		Mean number of eggs/budstick ± se			
Bartlett	NY10353	Bartlett	NY10353	Difference	Prob. > 1t[4/]
D	D	9.5 ± 3.9	3.7 ± 1.6	5.8 ± 3.1	.094
BB	BB	76.2 ± 21.1	77.9 ± 19.9	-1.7 ± 28.9	.954
GT	GT	113.7 ± 29.8	210.5 ± 38.0	-96.8 ± 56.8	.123
D	BB	50.5 ± 19.0	62.2 ± 19.9	-11.7 ± 29.1	.697
BB	GT	41.2 ± 10.0	184.0 ± 29.0	-142.8 ± 32.9	.002
BB[3/]	D[3/]	17.8 ± 6.5	0.1 ± 0.1	-17.7 ± 6.5	.024

[1/] In five-day free-choice test with 10 replications, analyzed by bud stage on day 0.
[2/] D = dormant, BB = budbreak, GT = 1/4" green tip.
[3/] Three-day test.
[4/] Null hypothesis (H_o): 'Bartlett' = NY10353; 2-tailed t-test.

When the data were analyzed on the basis of stage of emergence at the end of the experiment, the largest numbers of eggs were found on the host which had the most exposed foliar tissue (Table 3). No significant differences were found between NY10353 and 'Bartlett' where their buds had emerged to the same stage.

Adult pear psylla (WF and SF) show no preference for resistant or susceptible cultivars in either frequency or duration of visitation when foliar conditions are approximately equal (Harris, 1973; 1975). Our study indicated that, in addition, WF showed no ovipositional preference among phenologically similar hosts, from dormancy through early stages of leaf expansion. Instead, WF females were attracted to buds in the most advanced stage of foliar development. Similar observations of other psyllid species on pome fruit (Lazarev, 1974) tend to support the hypothesis that lack of host discrimination early in the season may be a widespread occurrence in psyllids.

Summer form pear psylla have shown ovipositional preferences among host genotypes with fully expanded leaves (Westigard *et al.*, 1970; Harris, 1973; Harris, 1975). This observation is also true when comparing orchard-grown trees of 'Bartlett' and NY (R.L. Bell, unpublished data). SF psylla will oviposit on dormant buds of 'Bartlett' (in laboratory) at a low frequency, and, hence, are behaviorally similar in this respect to WF psylla (Butt and Stuart, 1986).

Our data are consistent with observations that oviposition by WF females increases after budbreak (Smith, 1965). The cue(s) triggering host preference for oviposition may appear or

Table 3.

Mean number of eggs deposited by winter form pear psylla on 'Bartlett' (Bart) and NY10353 (NY) budsticks, analyzed by initial and final bud stage.[1/]

Initial Bud stage[2/]		Final bud stage: NY = Bart			NY > Bart			Bart > NY		
Bart	NY	N	Bart	NY	N	Bart	NY	N	Bart	NY
D	D	10	9.5	3.7	0	-	-	0	-	-
BB	BB	8	82.3	73.9	2	52.0	94.0	0	-	-
GT[3/]	GT[3/]	3	186.0	158.3	6	91.7	225.3	0	-	-
D[4/]	BB[4/]	2	38.0	30.0	4	10.3	107.5	3	128.3	42.0
BB	GT	0	-	-	10	41.2	184.0	0	-	-
BB[5/]	D[5/]	0	-	-	0	-	-	10	17.8	0.1
Final bud stage mean		23	60.3	50.6	22	50.3	173.2	13	43.3	9.7
Mean difference[6/] ± se		9.7 ± 12.4			-122.9 ± 27.1			33.6 ± 10.9		
Prob.> /t/		.4406			0.0002			0.0098		

1/ In five-day free-choice test, 10 replications per initial bud stage.
2/ D = dormant, BB = budbreak, GT = 1/4" green tip.
3/ One replication dropped due to death of one budstick.
4/ One replication dropped due to death of female psylla.
5/ Three-day test.
6/ Bartlett-NY.

be stronger when foliage develops, because the degree of oviposition is positively associated with the amount of foliar tissue available. The exact basis of this behavior is uncertain, considering the ovipositional preferences exhibited by SF psylla. The WF female psylla may not be capable of discriminating between host genotypes on the basis of the cues affecting SF females. Alternatively, if only fully expanded leaves express these cues, WF do not have the opportunity to discriminate among hosts because of phenological differences.

ACKNOWLEDGMENTS

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MORPHOLOGY, LIFE HISTORY AND IDENTIFICATION OF SEX PHEROMONE COMPONENTS OF AN UNDESCRIBED SPECIES OF CHORISTONEURA (LEPIDOPTERA: TORTRICIDAE) ON SCOTS PINE IN BRITISH COLUMBIA

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ABSTRACT

The morphology and life history of a probable new species of tortricid on Scots pine in British Columbia is described. It differs from other Canadian pine feeding *Choristoneura*. Abdominal tip extracts of unmated females contained *Z*-11- and *E*-11-tetradecenyl acetates and alcohols. An equal mixture of these materials was an effective attractant for capturing males in delta traps and is recommended for the detection and monitoring of this insect.

INTRODUCTION

The conifer-feeding *Choristoneura* in North America are composed of three complexes or series (Powell 1980): (1) the Fumiferana complex, associated with *Picea* spp. and *Abies* spp., (2) the Lambertiana complex, generally feeding on *Pinus* spp. and (3) the Carnana complex which feed on *Pseudotsugata* spp. Harvey (1985) contends that there are only two groups, one associated with spruces, Douglas-fir (*Pseudotsuga menziesii* Mirb. Franco) and true firs (Abietoideae) and the other feeding on pines (Pinoideae). He includes the Carnana group in the Fumiferana group. The species described in this paper would, by Powell's classification, be included in the Lambertiana complex. In western North America this complex consists of three subspecies: *Choristoneura lambertiana lambertiana* (Busck) in northern California and southern Oregon, *C. l. subretiniana* Obraztsov in eastern California and *C. l. ponderosana* Obraztsov in Colorado, Wyoming and North Dakota. In addition, there are populations in Wyoming, Montana, Idaho, southeast British Columbia (Silver and Ross 1964) and Oregon which are intermediate between the three subspecies and vary in a clinal fashion across the range (Powell 1980). In eastern North America another species, *Choristoneura pinus pinus* Freeman, occurs, with a subspecies *C. p. maritima* indicated in the southern part of its range. No pine-feeding species has been previously identified in southwestern British Columbia or Washington State.

The sex pheromone for *C. pinus pinus* was identified in 1985, (Silk *et al.* 1985) and found to consist of *E*-11- and *Z*-11-tetradecenyl acetate (85:15) and *E*-11- and *Z*-11-tetradecen-1-ol (85:15); the acetate and alcohol components occurred at a ratio of 9:1. The isolation and identification of the sex pheromone components of *C. lambertiana* (Busck) remain to be investigated, although good attraction occurs in traps using either a blend attractive to *C. orae* (Gray *et al.* 1984) or to the attractive blend proposed for *Choristoneura* n. sp. described in this paper.

In June 1979, T.G.G. noticed *Choristoneura* larvae feeding on Scots pine (*Pinus sylvestris* L.) and assumed from their general appearance that they were *C. occidentalis*, although this species is not commonly found on pine. Therefore, to confirm this assumption, six delta traps baited with *C. occidentalis* pheromone were set out on 23 July and collected on 18 September 1979. There were no *Choristoneura* adults present in any of the traps.

The biology of some of the *C. lambertiana* subspecies has been described by McGregor (1968, 1970), Stevens *et al.* (1977), and Stark and Borden (1965). This paper is based on observations made from 1979 to 1982 on the biology and life history of a previously undescribed species on naturally infested Scots pine trees near George Massey Tunnel, Richmond, B.C., on laboratory rearings with pine cuttings, and on synthetic diet (Robertson 1979). The isolation and identification of the pheromone components used to monitor the populations are also discussed.

MORPHOLOGY

Egg Convex and ovate, 1.13 mm long x 0.6 mm wide, light green, darkening as eclosion approaches; laid in overlapping, shingle-like rows on the needles.

Larva

First instar: pale yellow with light reddish brown head, thoracic shield lighter than head, 2.07 mm long x 0.33 mm wide.

Second instar: yellow with dark brown head, thoracic shield brown but lighter than head, anal plate same color as thoracic shield, 2.00 mm long x 0.33 mm wide.

Third instar: creamy-brown with two rows of whitish dots visible with x10 magnification, dark brown head and thoracic shield, the latter with a white median line; thoracic legs same color as shield; light brown anal plate. 3.33 mm long x 0.50 mm wide.

Fourth instar: light brown; dorsum with two rows of paired whitish spots with black centers around setae; gonads visible in males; head dark brown, thoracic shield black with white leading edge; thoracic claws black; clypeus and antennae basal segments whitish, antennae black. 4.33 mm long x 0.66 mm wide.

Fifth instar: reddish brown with lighter sides, dorsum with two rows of paired yellowish spots, male gonads visible in third abdominal segment; head red brown; thoracic shield darker than head. 22.5 mm long x 2.25 mm wide.

Pupa Appendages light brown; thoracic segments reddish brown; abdominal segments light brown and finely textured; intersegmental regions reddish brown with coarser texturing; eight cremastal setae, two on each side and four on basal segment; exuviae pink. Males 11.0 to 12.5 mm, females 13.0 to 13.5 mm in length.

Adult This *Choristoneura* species resembles the coastal form of *C. occidentalis* (Dr. A. Mutuura, Biosystematics Research Centre, Ottawa, ON, personal communication). The head and thorax are grey-brown to reddish brown; the hind wings are darker grey than those of *C.lambertiana* (Busck); forewings are a grey ground color with brown to brownish orange markings and numerous black strigulae; abdomen grey; aedeagus lacks spicules unlike *C. pinus* which displays many spicules (Dang 1985); Voucher specimens are available for study from the Canadian National Collection, Biosystematics Research Centre, Ottawa, ON K1A 0C6 and from the Regional Collection, Pacific Forestry Centre, Victoria, B.C. V8Z 1M5 wingspread: males 17 to 19 mm, females 20 to 22 mm.

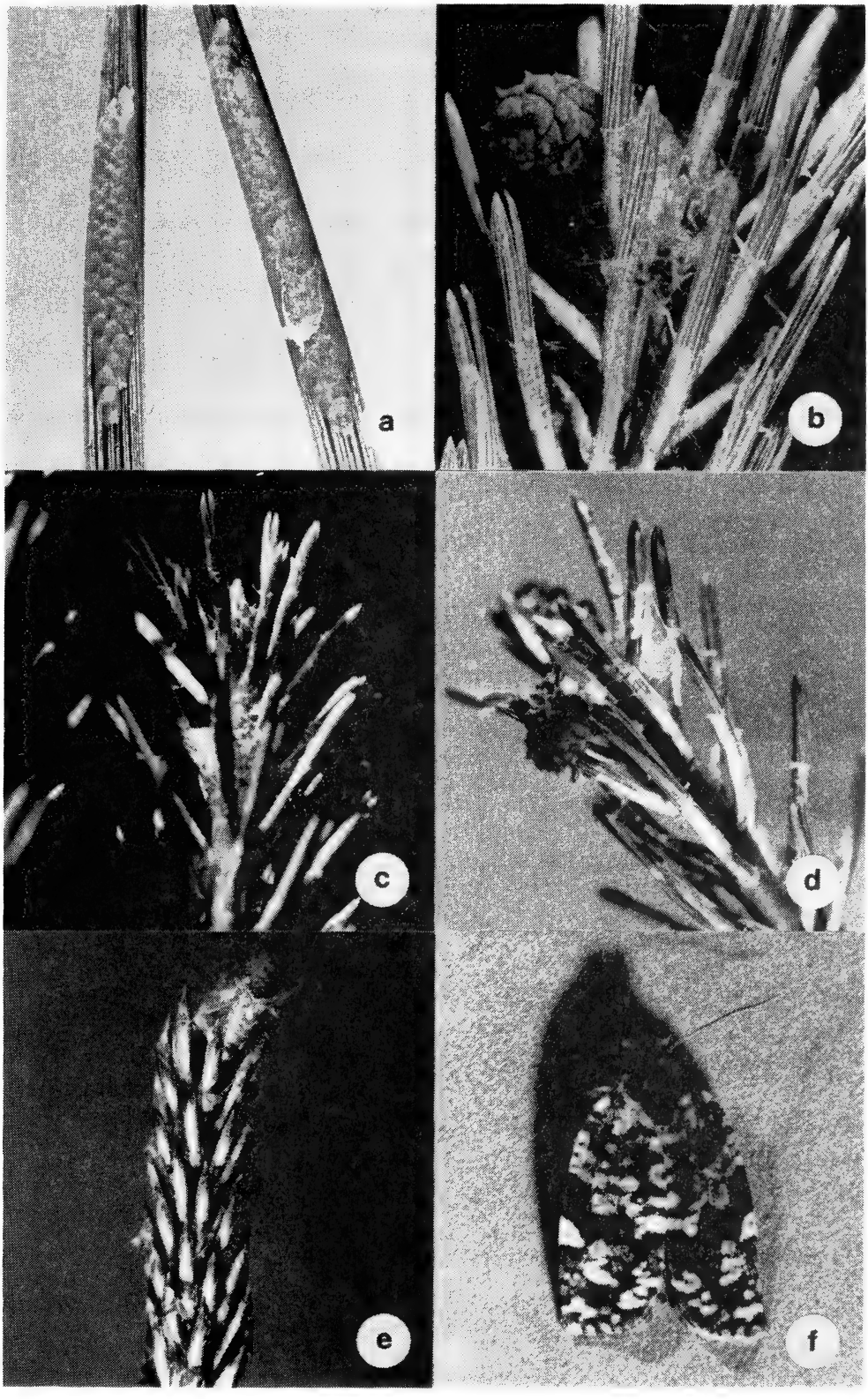

Fig. 3. Stages in the development of *Choristoneura* n. sp. on Scots pine at Richmond, B.C.: A. Egg masses on pine needles, B. Feeding site of second instar larva, C. Silk enclosure of third instar larva, D. Feeding site of fourth instar larva, E. Fifth instar, mature larva, F. Adult.

LIFE HISTORY

Clusters of eggs (Fig. 3A) were laid in a shingle-like fashion during the last week of July and the first week of August (Fig. 4) distally and on the top surface of pine needles, similar to other pine-feeding *Choristoneura*. In 1981, 32 egg masses were collected; of these 90% had two rows (mean number of eggs per mass was 23.5) and 10% had three rows (mean number of eggs per mass was 42.0). Field-collected egg masses hatched within 4 to 7 days at 20°C ± 2°C. The eggs slowly darkened and the black head capsules became visible through the chorions 48 h before eclosion.

The first instar larvae emerged from the eggs and dispersed to seek protected areas to spin overwintering hibernacula, often within the current year's pupal webbing on old foliage or old bud scales. They molted from first to second instar in the autumn and overwintered in the second instar. In 1982, 20 branches were cut from Scots pine and divided into three sections of current year's foliage, old foliage and bare twigs to determine the distribution of hibernacula. The sections were treated with hot NaOH solution, washed, filtered, and the larvae were counted (Miller *et al.* 1971). A total of 35 larvae were recovered of which 85% were found on the old foliage and bare branches. Even though two egg masses were found on the current foliage of two branches, only 12 larvae were recovered, indicating that larvae probably moved away from the light towards the bole of the tree to select an overwintering site. Terrell (1959) compared stem and branch samples for spruce budworm larvae on Douglas-fir and found, for an equivalent area, 2.9 larvae on the branches and 58 larvae on the bole.

In spring of 1981, young larvae first appeared on the tips of candles during the last week of May. Silk threads were visible between tips of needles, around candles and female cones (Fig. 3B) suggesting that larvae dispersed at this time. Larvae had spun silk enclosures at approximately 45° from the candle's main stem (Fig. 3C), but attached to it, about 25 mm from the tip. Feeding started at the base of needle sheaths of new growth. There was no evidence of needle mining, probably because the new needles were available when larvae emerged from their hibernacula. In 1982 larvae had spun silk enclosures by the second week of June and when feeding, only the top 1/4 to 1/3 of their bodies were exposed. Larvae fed with their heads outward and quickly retracted into their enclosures when disturbed.

Larvae feeding in the field molted from second to third and fourth instar and continued to feed at the needle bases (Fig. 3D). Those reared in the laboratory on artificial diet (Robertson 1979) stopped feeding at the end of the third instar and entered a second diapause (97%), even though rearing conditions simulated field conditions. Harvey (1967) similarly noted that *C.*

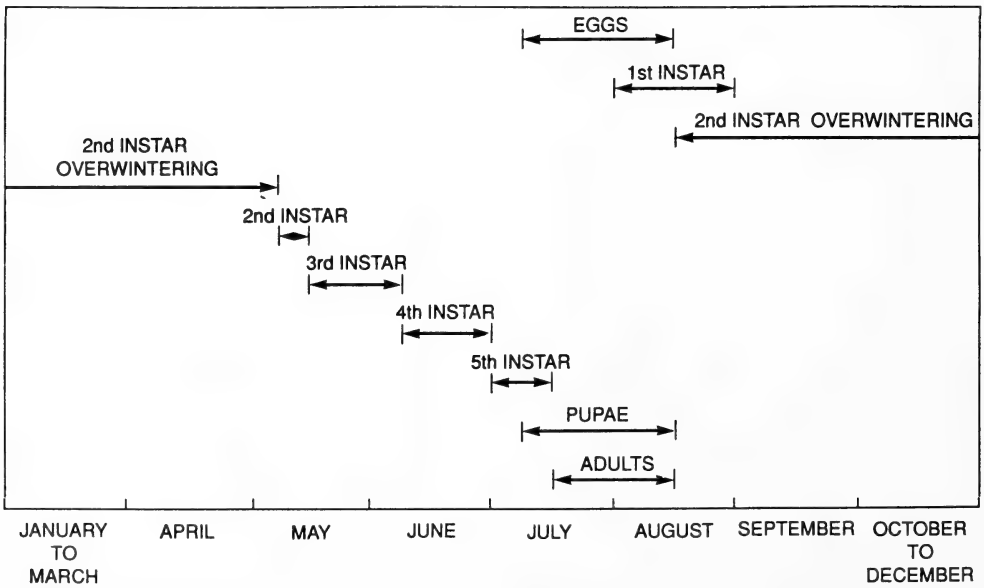

Fig. 4. Life cycle of *Choristoneura* n. sp. determined from field observations at Richmond, B.C.

orae, which we consider to be closely related to *Choristoneura* n. sp., tended to enter a second diapause (82%) when reared in the laboratory. When entering the second diapause, third instar larvae spun tight double silk enclosures and, once enclosed, shed the head capsule and integument at opposing ends of the hibernaculum. The larva reduced in size from 3.3 - 4.0 mm to 1.67 - 2.67 mm in length because they ceased feeding and used their food reserves to spin the hibernacula. There was no visible movement by the larvae unless subjected to high-intensity light or probing.

Fourth-instar larvae fed mostly on the south facing side of the host. Larvae did not attack the main stem or developing female cones but usually consumed one needle completely before chewing another. This behavior is unique to this species. Other *Choristoneura* species are wasteful feeders and often take one or two bites from a needle before moving to another; they thus cause very noticeable defoliation. Feeding sites had an average of 18 needles held to the developing candle with silk. Defoliation was therefore not detectable from a distance. Most larvae were in the fourth instar by the third week of June; there appeared to be more larvae present at that time than when observed as third instars, suggesting a second diapause in the field.

Fifth-instar larvae looked like those of *C. occidentalis*. They were more free roaming than previous instars (Fig. 3E), and they spun loose silk enclosures to secure developing side candles to the main candle.

Individual pupae were present on the foliage by the first week of July and were attached near the tips of candles by silk and dead needles. Often, pupae were found under curled immature cones. They were always oriented with the anterior end pointing distally along the axis of the candle. The pupal stage in the laboratory averaged 15 days at 19°C and the male/female ratio was close to 1.

The adults (Fig. 3F) were first evident in mid-July and were visible resting or laying eggs on the current year's foliage for approximately four weeks. The adults, which normally fly at dusk, flew only during daylight hours when branches were disturbed by the wind or physically moved.

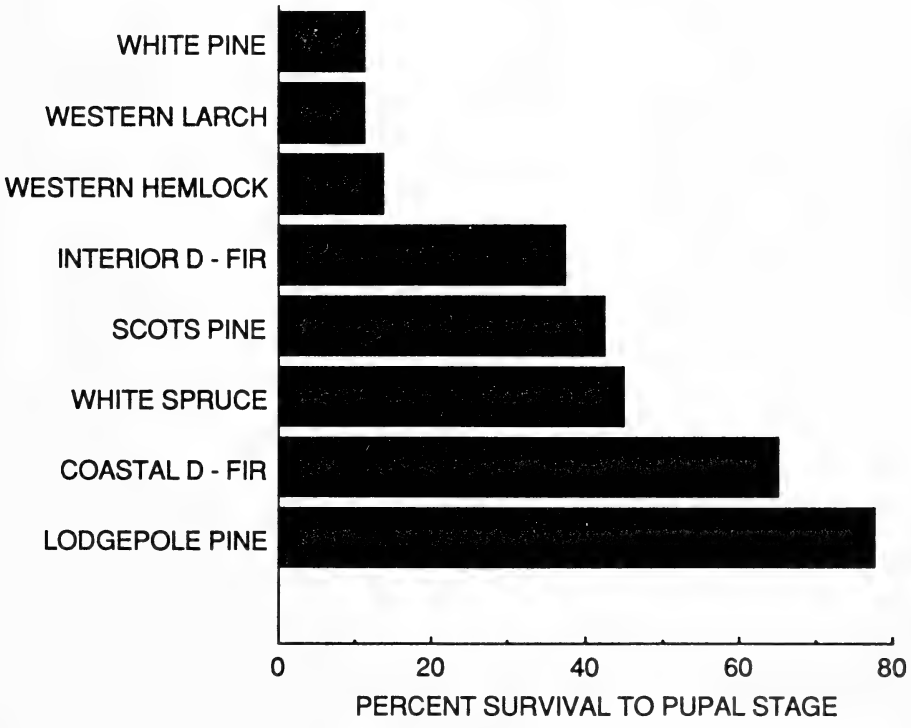

Fig. 1 Survival of *Choristoneura* n. sp. on different hosts maintained in an environmental chamber for 36 days. n=80

Host

Scots pine, *Pinus sylvestris* L. Laboratory rearings indicate that this insect can survive equally well on lodgepole pine (*Pinus contorta* Dougl.), coastal Douglas-fir and white spruce (*Picea glauca* (Moench) Voss), but it has not been found on these native species (Fig. 1). Scots pine is a non-native tree. These were planted by the Ministry of Transportation and Highways in 1959 as 18-inch seedlings. Increment cores taken in 1980 indicated that the trees were 21 years old.

Distribution

Living specimens occurred in Richmond, British Columbia. Pheromone trapping with equal amounts of the two acetates and two alcohols failed to catch any *Choristoneura* sp. on Scots pine in Norway, (Dr. A. Bakke, Norsk Institutt For Skogforskning, Postboks 61, Norway, personal communication). Similarly, traps baited with this blend failed to trap any *Choristoneura* sp. in Japan, (Dr. S. Suzuki, Hokkaido Forest Experiment Station, Hokkaido, Japan, personal communication). Monitoring with pheromone traps traced the origin of the Scots pine to a Richmond nursery (Fig. 2) which had imported the trees in the early 1950s, probably from Ontario or Washington State. This was confirmed by talking to the nursery owners but the trees' origin could not be verified due to the length of time that had lapsed.

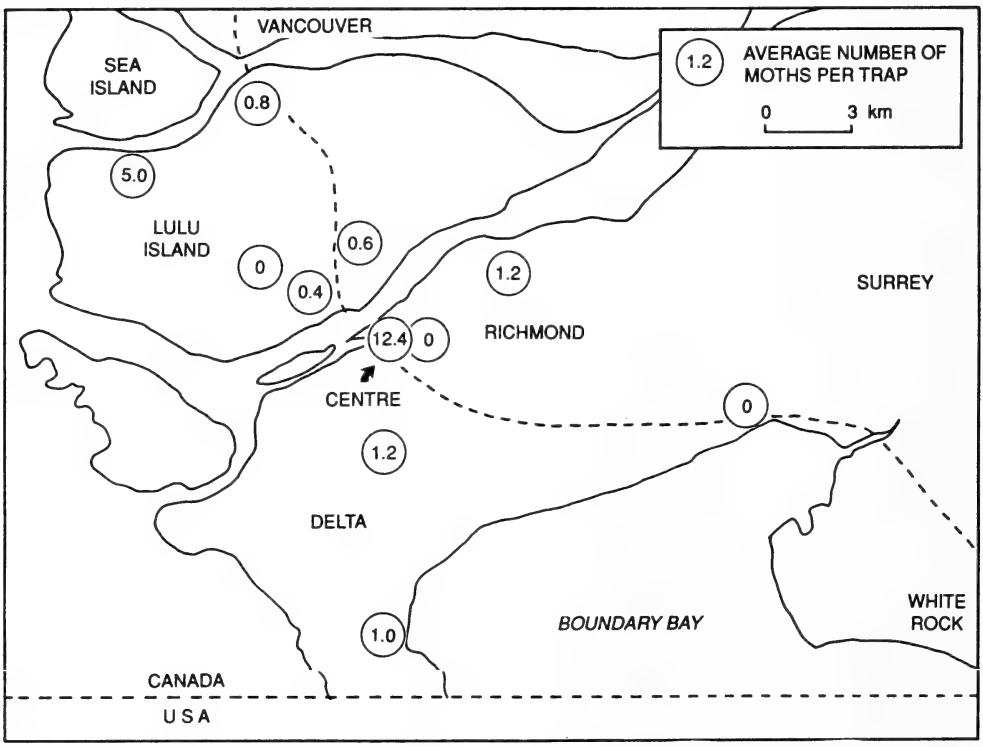

Fig. 2. Distribution of *Choristoneura* n. sp. around the location where it was first discovered at the George Massey Tunnel, Richmond, B.C.

Associated Insects

No parasitoids were encountered during this insect's life cycle, either in the 35 egg masses, or in more than 100 fourth- and fifth-instar larvae collected and reared. The most common lepidopteran present on the host trees was the European pine shoot moth, *Rhyacionia buoliana* (Schiffermüller), and in 1980 six out of ten new candles contained a shoot moth larva. The oblique-banded leaf roller, *Choristoneura rosaceana* (Harris), was also present in limited numbers, as was *Ditula* (*Batodes*) *angustiorana* (Haworth); both of these species are known to be polyphagous feeders. Silverspotted tiger moth larvae, *Lophocampa argentata* (Packard), were observed feeding on old foliage of several trees.

IDENTIFICATION OF PHEROMONE COMPONENTS

Methods

Late instar larvae were hand picked and reared to pupation on clipped branches in moist sand in a propagation box in a greenhouse at about 20°C. The pupae were sexed, separated and placed in petri dishes with moist filter paper. The female pupae were kept under a 16:8 L:D photoperiod and maintained at that regime after eclosion.

Abdominal tips were excised from unmated females 2 to 4 days old at 1 to 3 hours into the scotophase (Gray *et al.* 1984). Each tip was washed with 5 µl of redistilled hexane and the wash was injected into a Hewlett-Packard 5880A capillary gas chromatograph (CGC) in splitless mode, equipped with a flame ionization detector. The capillary column was 0.25 mm i.d. x 30 m methyl silicone (SE-30) (Hewlett-Packard Co., Palo Alto, CA), programmed at 80°C for 2 min, warming at 15°C/min to 180°C and isothermal at 180°C. Injector and detector temperatures were 275°C. Standards were run under identical conditions to enable the comparison of retention times.

A pooled sample of washes from five females was analyzed on a Hewlett-Packard 5985 capillary gas chromatograph/mass spectrometer (GC/MS) in the splitless mode. The 0.32 mm i.d. x 15 m SE-30 column (J & W Scientific, Folsom, CA) was programmed at 70°C for 1 min, warmed at 4°C/min to 210°C and isothermal at 210°C.

Field testing of candidate components was conducted in 1980 on Scots pine using delta traps (made from 2-L milk cartons) coated inside with Bird Tanglefoot (The Tanglefoot Co., Grand Rapids, MI 49504). The traps, with a trapping surface of 495 cm^2, were baited with candidate chemicals in polyvinylchloride (PVC) 5% w/w (Daterman 1974) which were impaled with a pin inside the delta traps. The lures were PVC rods 3 mm in diameter and 5 mm in length containing 1250 µg of the candidate chemical; they were aged for 5 days at 20°C prior to use to stabilize the release rate. The chemical lures were replicated four times while unmated females of *C. pinus pinus* and *C.* n. sp. were replicated twice.

Results and Discussion

Capillary gas chromatographs of individual tip washes indicated four pheromone compounds. No aldehyde component was detected, indicating that the species was more closely related to *C. orae* and the pine feeding *Choristoneura*, which lack an aldehyde component in their attractive blends (Gray *et al.* 1984; Harvey 1985; Silk *et al.* 1985). The four detected compounds had retention times coincident with *E*-11-tetradecen-1-ol (*E*-11-14:OH), *Z*-11-tetradecen-1-ol (*Z*-11-14:OH) (*E*/*Z*~ 2:1), *E*-11-tetradecenyl acetate (*E*-11-14:Ac) and *Z*-11-tetradecenyl acetate (*Z*-11-14:Ac) (*E*/*Z*~ 2.5:1). There was no indication of any saturated alcohols or acetates present in the single insect traces. Capillary GC/MS indicated identical retention times and fragmentation patterns for the four detected compounds and synthetic standards.

Field bioassays conducted in 1980 (Table 1) indicated that an equal mixture of *E*/*Z*-11-14:Ac and *E*/*Z*-11-14:OH was a better attractant than the individual compounds, although the means were not significantly different with the exception of the poor response to *Z*-11-14:Ac. Additional testing in 1981 (Table 2) again indicated that an equal mixture of *E*/*Z*-11-14:Ac and *E*/*Z*-11-14:OH was the most attractive blend and was able to attract more moths than did unmated females. The ability of unmated female *C. pinus pinus* to attract a considerable number of male *C.* n. sp. (Table 2) would suggest a taxonomic closeness, at least chemically if not morphologically (Dang 1985). An initial test in 1979 using a similar chemical blend as that proposed for *Choristoneura occidentalis* (Cory *et al.* 1982) containing *E*/*Z*-11-tetradecenals failed to attract any male *Choristoneura*. We therefore recommend as an effective sex attractant lure for detection and monitoring *Choristoneura* n. sp. *E*/*Z*-11-tetradecenyl acetates and *E*/*Z*-11-tetradecen-1-ols in equal amounts and a lure loading of 312 µg of each chemical.

CONCLUSIONS

This undescribed insect may be considered by some authorities as being a hybrid, or a host race, "a noninterbreeding sympatric population, which differs in biology but not, or scarcely,

Table 1. Number of Choristoneura n. sp. captured from 23 to 27 July 1980 at Richmond, B.C.

Lure	Composition %	Males caught	Average/ night/trap
E/Z-11-14:Ac+ E/Z-11-14:OH	25/25/25/25	54	3.38 a
Z-11-14:OH	100	38	2.38 a
E-11-14:Ac	100	37	2.31 a
E-11-14:OH	100	24	1.50 a
Z-11-14:Ac	100	1	0.06 b

Treatment totals followed by the same letter are not significantly different, Duncan's new multiple range test, $p < 0.05$.

Table 2. Number of males captured from 16 to 31 July 1981 at Richmond, B.C. when testing unmated females and synergism of isolated pheromone-like compounds.

Lure	Composition %	Males caught	Average/ night/trap
E/Z-11-14:Ac+ E/Z-11-14:OH	25/25/25/25	307	4.8 a
E/Z-11-14:Ac+ E-11-14:OH	33/33/33	274	4.3 a
E/Z-11-14:Ac	80/20	206	3.2 a
E/Z-11-14:Ac+ Z-11-14:OH	33/33/33	185	2.9 a
E-11-14:Ac+ E/Z-11-14:OH	33/33/33	12	0.2 b
E-11-14:Ac	100	6	0.1 b
Z-11-14:Ac+ E/Z-11-14:OH	33/33/33	3	0.05 b
Z-11-14:Ac	100	0	-- b
subtotal		993	
♀ Choristoneura n.sp.		158	3.4
♀ Choristoneura pinus pinus		108	2.5
Total		1259	

Treatment totals followed by the same letter are not significantly different. Duncan's new multiple range test, $p < 0.05$.

in morphology ... (and which are) prevented from interbreeding by preferences for different food plants or other hosts" (Mayr *et al.* 1953).

We believe that this insect is in fact a distinct species for several reasons: it possesses a unique pheromone, and is thus reproductively isolated; the ovipositing females display a distinct host preference, in this case Scots pine; the geographic distribution of the population, the ability of larvae to feed on Scots pine; and the feeding behavior of larvae, all these appear to be unique within this genus.

The origin of this species is unknown. The restricted distribution, proximity to international marine import terminals, exotic host, and the lack of parasites suggest that it may be an introduced species. However, taxonomically it appears closely related to *C. orae* and *C. pinus pinus*, both of which are Canadian species.

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PROBABILITY OF DAMAGE TO SITKA SPRUCE BY THE SITKA SPRUCE WEEVIL, *PISSODES STROBI*

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ABSTRACT

A nine-year record of attacks to Sitka spruce, *Picea sitchensis* (Bong.) Carr., by the Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck), was analyzed to determine the probability of attack on a tree based on the length of its terminal leader. Equations describing the relationship were developed. Tall trees with long leaders had higher rates of attack than short trees with short leaders.

Additional key words: Pest, impacts, insects, loss, *Picea sitchensis*.

RÉSUMÉ

Les données compilées pendant neuf ans sur les dégâts causés par le charanon du pin blanc (*Pissodes strobi* Peck.) à des épinettes de Sitka (*Picea sitchensis* Bong.) ont été analyses afin de déterminer les probabilités qu'un arbre soit attaqué d'après la longueur de sa pousse apicale. Des équations reflétant cette relation ont été â aborées. Les arbres de haute taille portant de longues pousses apicales étaient plus fréquemment attaqués que les arbres de faible hauteur à pousses apicales courtes.

INTRODUCTION

The Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck), is the most damaging pest of Sitka spruce, *Picea sitchensis* (Bong.) Carr., in coastal British Columbia, Washington and Oregon. In early spring, adult weevils crawl or fly to the terminal leader of the previous season and females lay eggs in niches excavated under the bark. The larvae kill the leader by mining and consuming the phloem. Following an attack, the lateral branches from the whorl immediately below the damaged leader develop negative geotropism and assume a vertical position. This process usually results in the formation of crooks and forks at the point of injury (Silver 1968, McMullen 1976, Alfaro 1989). Repeatedly attacked trees are stunted and overtopped by competing vegetation; a severely attacked plantation may be worthless (Alfaro 1982).

Modern pest management is greatly assisted by computer models that integrate pest biological and epidemiological factors into stand growth dynamics. Of particular importance are the factors that determine whether a particular stand or an individual tree within a stand is attacked. Several factors determine the rate at which Sitka spruce is attacked by the Sitka spruce weevil. Because of a climate unfavorable to insect development, stands in coastal locations and on the northern extremes of the distribution of Sitka spruce are less susceptible than stands on inland or southern locations (McMullen 1976, Heppner and Wood 1984). Similarly, a lower susceptibility of trees growing under shade, apparently caused by an unsuitable microclimate, has been reported for the eastern host of *P. strobi*, the eastern white pine *(Pinus strobus L.)* (Graham 1918; Wallace and Sullivan 1985), as well as for Sitka spruce (McLean 1989).

Plantations in the most susceptible areas are infested when trees are about 4 to 5 years old; attack intensity (number of trees attacked/year) increases rapidly thereafter, reaching a maximum when the plantation is 10 to 30 years old (Alfaro 1982; McMullen *et al.* 1987). The overall susceptibility of a stand decreases as trees reach heights above 12 m (Harris *et al.* 1968; McMullen 1976, McMullen and Condrashoff 1973). This makes the Sitka spruce weevil a pest of primarily young forests. Overhulser *et al.* (1972) indicated that weevil oviposition and emergence is lower in trees that had previous attacks, relative to trees that had never been

attacked. Based on this finding, they hypothesized that older plantations have lower attack rates because they have a small number of unattacked trees and hence do not produce large numbers of weevils.

Graham (1951) studied the attack records for a Sitka spruce plantation established in 1930-1932 at Green Timbers Nursery, in Surrey, British Columbia. He concluded that the frequency of *P. strobi* attacks per tree could not be attributed to chance alone, but that some trees had higher rates of repeated attack than others. Graham did not speculate on the reasons for this non-randomness. In 1960, G.T. Silver, formerly with the Canadian Forestry Service in Victoria, British Columbia, established four plots to study the biology of this insect and possible means of control. Silver(1968) analyzed data collected in these plots between 1960 and 1963 and reported that the tallest trees in a stand, with the longest leaders, had higher rates of attack than shorter trees with short leaders. Gara *et al.* (1971) and VanderSar and Borden (1977) corroborated Silver's (1968) findings. McMullen *et al.* (1987) and McLean (1989) present figures that display the relationship between proportion of trees attacked and their leader length. However, these authors did not develop mathematical equations to quantify the relationship. The pictorial relationship in McMullen *et al.* (1987) is one of the several relationships used in a comprehensive population dynamics model these authors report in the same paper.

McMullen *et al.* (1987) used data collected by Silver between 1960 and 1963. Silver continued the measurement of his plots until 1968. In this paper I analyze Silver's full 9-year record and develop equations that describe the probability of a tree being attacked based on leader length and on weevil population level.

MATERIALS AND METHODS

Silver's 1960s Study

Four plots were established in the fall of 1959 in an area of natural Sitka spruce regeneration which originated after clearcut logging, near Nitinat Lake on Vancouver Island. The plots were rectangular, had a combined area of 1 ha, and initially included 692 trees which were marked with metal tags. One plot was left untreated and the others treated in certain years with insecticides. At the time of establishment, average tree age and height were 7 years and 1.3 m, respectively. In the early spring of every year, from 1960 until 1968, each tree was examined and tree height, the length of all leaders (including multiple leaders), and attack status (i.e., whether it was attacked or not) were recorded. Since the examinations were conducted before growth started, they represented tree condition at the end of the previous growing season.

Data Analysis

The data used in this paper were obtained from Silver's check plot; they therefore represent uncontrolled damage levels. This plot occupied 0.32 ha and initially included 231 trees.

To describe the stand and trees being attacked each year, the distribution of tree heights and leader lengths were tested for normality using the Kolomogorov test (Stephens 1983). This test was also applied to tree heights and leader lengths sorted by attack status. The data for every year were tested (Student's t-test) for significant differences in height or leader length between attacked and unattacked trees.

A logistic model (Hamilton 1974) was fitted to the binary attack data to relate the probability of a tree being attacked to its leader length. Leader lengths were converted to percentiles (Mendenhall 1975) of the leader length distribution for each year to allow comparisons between years, which were independent of the mean value. This is important because leader length increases with tree height and age up to a maximum which varies by site quality. Therefore, a particular length of leader may be considered long or short depending on plantation height and age at the time.

The probability of attack might depend not only on leader length but also on the level of the weevil population in a particular year. For this reason, in addition to the logistic model, separate linear models were calculated to describe the relationship between the percentage of attack in trees sorted by leader length percentile class in years of different attack severity. Severity classes were as follows:

LIGHT: the percentage of trees attacked in the year was 10% or less;
MODERATE: the percentage of trees attacked in the year was between 10% and 20%;
SEVERE: the percentage of trees attacked in the year was greater than 20%.

The percentage of trees attacked refers to the percent of the stand trees attacked. Trees with multiple leaders were considered attacked if they had an attack in at least one of the leaders.

RESULTS

Tree height at the end of the 1959 and 1968 growing seasons averaged 1.3 and 4.6 m, respectively; the trees grew an average 3.3 m in the period. Leader length increased linearly with tree height until the trees were 3 to 4 m tall; it then reached a plateau at about 60 cm of growth per year (Figure 1). Fewer than 20% of the trees were attacked in the years from 1959 to 1961. The percentage of trees attacked reached a maximum of 36% in 1964; thereafter, the attack rate oscillated around 30% per year (Table 1).

The tests of normality indicated that, in every year, tree heights were distributed normally. Separate analysis of tree height distribution by attack status (attacked *versus* non-attacked) indicated no significant departure from normality (Kolomogorov D statistic test, $P > 0.05$). The distributions of the lengths of all leaders departed significantly from the normal distribution in four of the nine years studied. The difference, however, was only minor (probability of the D statistic was barely significant) and consisted of an excess frequency in the larger length classes. The distribution of leader lengths in leaders sorted by attack status were generally normal (Figure 2) with only two years in each class where a marginal departure from normality occurred, again due to an excess number of long leaders. The distributions of tree heights and leader lengths in attacked and non-attacked trees overlapped widely. In 1962, for example, the weevil attacked leaders as short as 25 cm but declined to attack many trees with 50- to 80-cm leaders.

Pissodes strobi preferred the tallest trees with the longest leaders in all years (Table 1). The difference in height and leader length between attacked and non-attacked trees averaged 0.8 m and 17.1 cm, respectively, over all years.

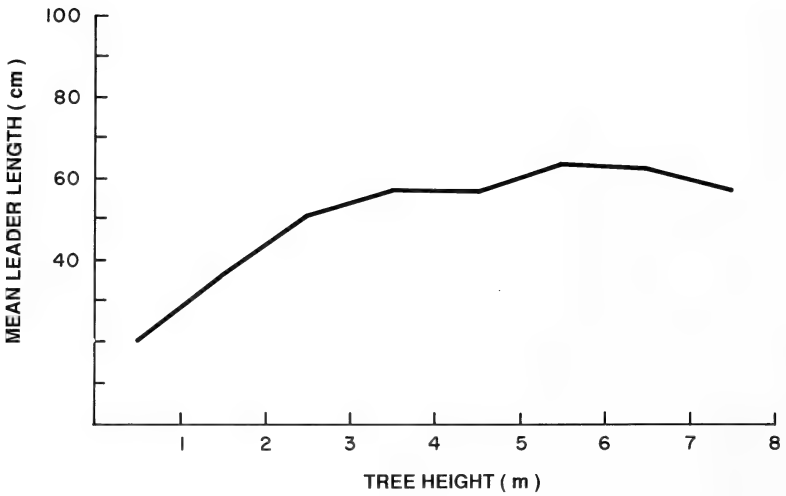

FIGURE 1. Average leader growth of Sitka spruce tabulated by height at the start of the season (trees grouped by 1-m height class)

TABLE 1. Percentage of Sitka spruce trees attacked by the Sitka spruce weevil and height and leader length of attacked and unattacked trees.

Year[a]	Attack[b] (%)	Mean tree height (m) attacked	not-attacked	Mean leader length (cm) attacked	not-attacked
1959[c]	18	2.0	1.4 **[d]	37.0	22.0 **
1960	9	2.3	1.8 **	48.0	33.0 **
1961	14	2.9	1.9 **	56.7	33.6 **
1962	28	3.1	2.2 **	58.6	37.0 **
1963	33	3.5	2.3 **	62.5	44.0 **
1964	36	3.7	2.6 **	62.6	55.1 ns
1965	35	3.9	3.1 **	64.0	42.3 **
1966	29	4.3	3.6 *	58.7	39.9 **
1967	29	4.6	3.9 *	61.6	48.9 **

[a] Year of leader formation

[b] Attacks occurred 1 year after leader formation

[c] Average age in 1959 was 7 years.

[d] Significance of difference between mean tree heights or leader lengths were tested by the Student t-test, and are indicated by *=P< 0.05, **=P< 0.01, and ns= P> 0.05.

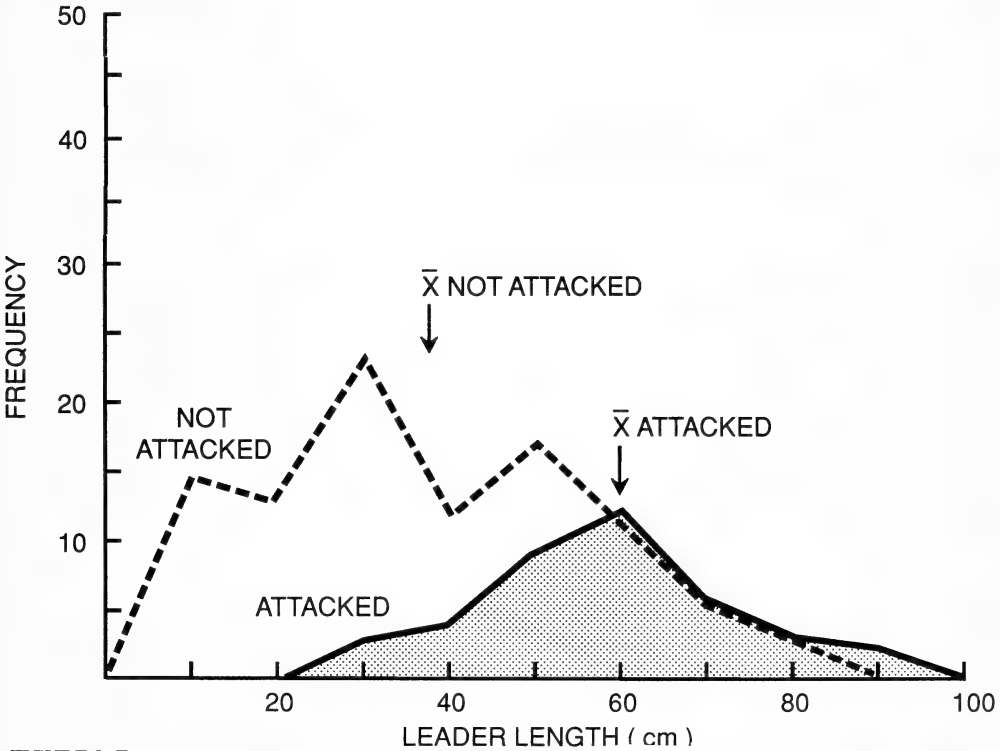

FIGURE 2. Frequency distribution of Sitka spruce leader lengths of trees attacked and not attacked by the Sitka spruce weevil, *Pissodes strobi*, in a representative year (1962), near Nitinat Lake, Vancouver Island.

The logistic model:

$$P = \{1+EXP\ (A + B\ X\ LLENGTH)\}^{-1} \qquad (1)$$

where P is the probability of a tree being attacked in a particular year, and *LLENGTH* is the length of the leader as percentile of the leader length distribution for that year, and $a = 2.816$, and $b = -3.118$, was highly significant ($F=273$, $P<0.01$). However, although this model provided a good estimate of the average probability of attack in any year (Figure 3), considerable variation remained unexplained (correlation coefficient = 0.33). This variation is due, in part, to the fact that the probability of attack on a tree depends not only on the length of the leader, but also on the population level of the weevil: in years of low population, a tree with a given leader length will have a lower probability of attack than in years with a high population.

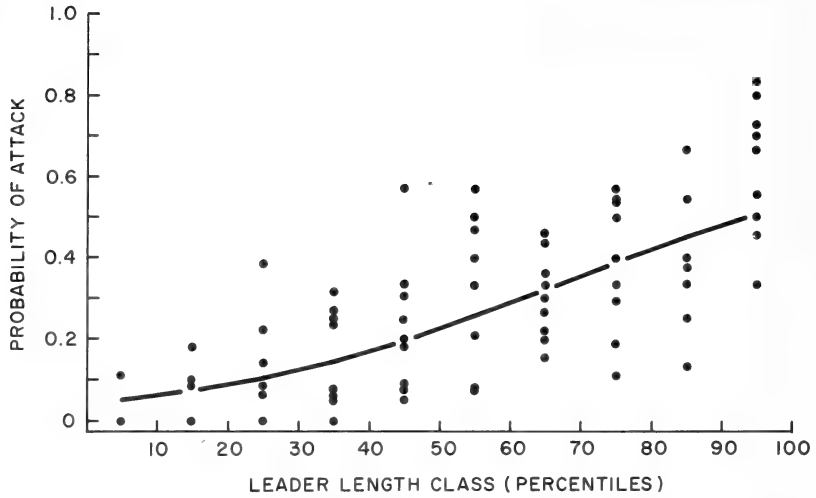

FIGURE 3. Percentage of attack (dots) and probability of attack (solid line) by *Pissodes strobi* weevils in Sitka spruce leaders sorted by leader length class. Lengths were expresed as percentiles of the leader length distribution for each year. The width of the percentile length class was 10%. These data were collected over 9 years near Nitinat Lake, Vancouver Island.

The linear models for each severity class were highly significant (Fig. 4). The models were refitted to eliminate non-significant intercepts, yielding the functions:

Population level LIGHT:
$P = 0.002 \times LCLASS$
$r^2 = 0.68$, $F = 23.8$

Population level MODERATE
$P = -0.121 + 0.006 \times LCLASS$
$r^2 = 0.77$, $F = 60.9$

Population level SEVERE:
$P = 0.006 \times LCLASS$
$r^2 = 0.71$, $F = 145.2$

where *P* is the probability of a tree being attacked in a particular year; *LCLASS* is the midpoint of leader length class (Length is expressed as a percentile of the leader length distribution. Length classes have a width of 10% of the total length distribution, with mid-points at 5%, 15%, 25%, etc.); and LIGHT, MODERATE and SEVERE are population levels as defined in the Methods section.

DISCUSSION

The attack rates increased from less than 20% to a maximum between 30% and 40% of the trees per year. This epidemiological pattern is very similar to that reported by Alfaro (1982) for a severely attacked plantation at Green Timbers, near Surrey, British Columbia and by McMullen *et al.* (1987) in plantations in the Klanawa River area of Vancouver Island. Alfaro (1982) indicated that attacked trees take 2 or 3 years to develop a new leader. During this period, the tree is generally not available for re-attack, unless the tree has developed multiple tops or the tree is re-attacked in the internode below the previous year's attack. In the Prince George area, Cozens (1987) found that in interior spruce *(Picea glauca* x *engelmanni)* up to 20% of the attacks were re-attacks on trees attacked in the previous year. Therefore, attack rates of 30 to 40%, such as the ones reported here, are probably near the maximum attack rate that a weevil population may sustain in a stand. Higher attack rates would deplete the oviposition sites and would lead to a reduction in the weevil population.

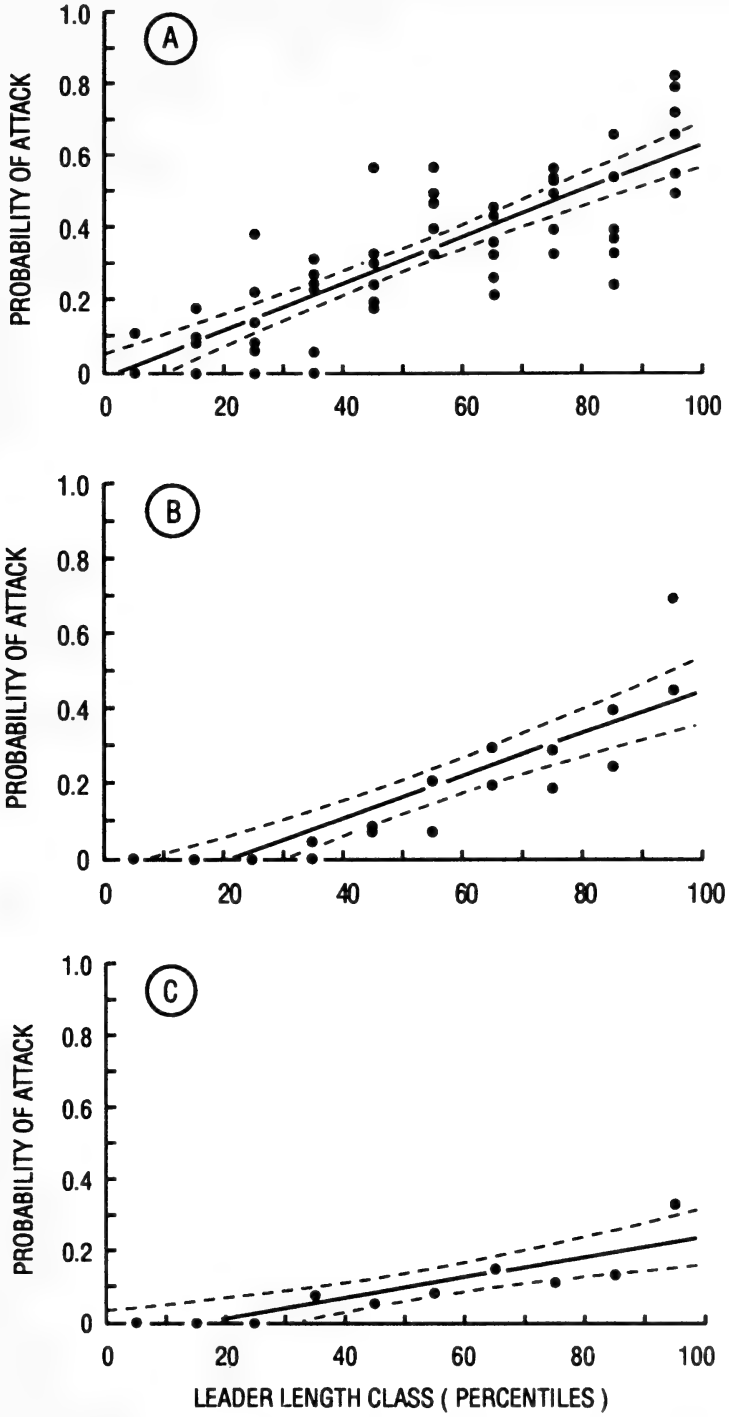

FIGURE 4. Percentage of attack (dots) and probability of attack (solid line) by *Pissodes strobi* weevils in Sitka spruce leaders sorted by leader length class. A) When attack intensity is LIGHT i.e. the percentage of trees attacked in a stand is 10% or less; B) When attack intensity is MODERATE i.e. the percentage of trees attacked in a stand is greater than 10% but less than or equals to 20%; C) When attack intensity is SEVERE i.e. the percentage of trees attacked in a stand is greater than 20%. Lengths were expresed as percentiles of the leader length distribution for each year. The width of the percentile length class was 10%. These data were collected over 9 years near Nitinat Lake, Vancouver Island. Dotted line represents the 95% confidence interval.

The fact that the frequency distributions of attacked and non-attacked leaders overlap widely (Figure 2) suggests that, in addition to leader length and population level, other factors determine whether a tree is attacked or not. My own unpublished observations indicate that the spatial distribution of the weevil population and of the attacks in young plantations is clumped. Attack intensity in trees within population clumps would be higher than that between clumps, forcing the weevils to attack smaller leaders in the clump areas and leaving relatively longer leaders unattacked in the areas between clumps.

The preference of *P. strobi* for the longest leaders in the stand is an adaptation of significance to the survival of a weevil population. It ensures that the leaders with the maximum food supply (more phloem in longer leaders) will be colonized; offspring production per leader is therefore optimized.

The equations developed here could form an integral part of a pest management model such as the one presented by McMullen *et al.* (1987), to predict the damage caused by the Sitka spruce weevil to Sitka spruce in British Columbia.

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A POTENTIAL COLLECTION METHOD FOR *AGAPETA ZOEGANA* (LEPIDOPTERA: COCHYLIDAE), A KNAPWEED-ROOT-FEEDING MOTH

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ABSTRACT

This paper describes a method for collecting living, undamaged *Agapeta zoegana* (L.) moths, especially recently mated females. The objective was to gather this potential biological control agent for subsequent distribution to land infested with knapweeds (*Centaurea* spp.) Sweep-netting and baiting techniques were inappropriate collection methods, because the moths were delicate and did not appear to forage. The moths did not move to the plant tops at particular temperatures or times of day and therefore could not easily be collected by aspiration. However, males and virgin and mated females within large field cages were attracted to UV light and, during their daily period of reproductive activity from dusk to midnight, could be collected in a *Heliothis* trap (Sentry) illuminated by a blacklight. In the open, neither this method nor a mobile-blacklight technique were successful in 1988, but both warrant further work. Results are discussed in the context of *A. zoegana* establishment in B.C.

INTRODUCTION

Diffuse (*Centaurea diffusa* Lam.) and spotted (*C. maculosa* Lam.) knapweed, introduced from Europe in the early 1900's, pose a serious threat to range- and pasture-lands in B.C. (Cranston, 1980). The knapweeds outcompete native forage species on disturbed or over-grazed sites, and are of low value as forage (Harris and Myers 1984). Chemical control of knapweed in most areas is neither economically practical nor environmentally desirable (Cranston 1980). Therefore, recent research has concentrated on introducing biological control agents from knapweed habitats in Europe (e.g. Harris and Myers 1984; Muir and Harris 1986, 1987).

The knapweed-root-feeding moth, *Agapeta zoegana* (L.), was introduced from Europe in 1982, 1983 and 1984 (Muir and Harris 1987). However, unlike previous releases of other natural enemies of knapweed (the seed flies, *Urophora affinis* (Frfld.) and *U. quadrifasciata* Mg.; the moth, *Metzneria paucipunctella* (Zeller) (Harris and Myers 1984); and the beetle, *Sphenoptera jugoslavica* (Obenb.) (Powell and Harris 1986)), introduction did not result in establishment (Muir and Harris 1987). Efforts to import enough *A. zoegana* larvae for subsequent releases were unsuccessful, since many larvae shipped from Europe died from parasitism and other factors, and because knapweed habitats in Europe were fast disappearing (Muir and Harris 1987). Therefore, a propagation facility, operated by the B.C. Ministry of Forests, was set up at the Agriculture Canada Research Station in Kamloops, B.C.

Since 1985, *A. zoegana* has been reared successfully on cultivated knapweed enclosed in large steel-frame field cages, then released onto knapweed infestations in B.C. (Muir and Harris 1987). It is hoped that *A. zoegana* will become established and amenable to collection from these sites for distribution elsewhere (R. Tucker, pers. comm.). However, there is little evidence of establishment to date.

I have attempted to develop a technique for collecting large numbers of undamaged *A. zoegana* moths, especially recently mated females. I considered three methods: sweep-netting, as used for the two *Urophora* species (Harris 1986a,b) and for *S. jugoslavica*; attraction to sugary baits (Borror *et al.* 1976); and attraction to a blacklight live-trap (Frost 1952, Mikkola 1972). Experience showed that *A. zoegana* moths were too delicate to be collected by sweep-netting and unlikely to be attracted to sugary baits, as adults have never been seen nectaring, either during the day (V. Fediuk, H. Müller, pers. comm.), or at night (pers. obs.). However, *A. zoegana* moths are attracted to UV light between dusk and midnight (Tucker and Fediuk 1987). Therefore, a blacklight live-trap seemed the collection method most likely to succeed.

To determine the optimum time for trapping, I quantified nocturnal activity patterns. Because light traps often attract more males than females (Mikkola 1972), I paid particular attention to reproductive behaviour that might result in male- biased catches. I also observed diurnal activities to see if the moths ever moved up to the plant tops from which they could be collected by aspiration.

MATERIALS AND METHODS

All observations of *A. zoegana* activity were carried out from June until August, 1988, on moths maintained in 12 steel- frame field cages (3 x 3 x 2.5 m high) at the Kamloops rearing facility. Knapweed (predominantly spotted) within the enclosures was planted from seed, watered, weeded and fertilized. *A. zoegana* moths, which are bright yellow and ~1 cm long, began emerging from below-ground pupation sites in mid-June. Although moths apparently do not nectar, two feeders, each consisting of a honey-soaked wick in a 50-ml Erlenmeyer flask, were suspended 5 cm above the knapweed canopy in each cage, and renewed every few days. Mated females oviposited on knapweed foliage from June until August, and neonate larvae migrated to the roots where they fed, reducing the plant vigour, until pupation. Predators such as ants and spiders were excluded by applications of insecticide (carbaryl) around the outer boundaries of each cage. Predators seen within cages were killed by hand.

To quantify the diurnal movement of these sedentary moths, I measured their heights within the canopy as a function of time and temperature. Temperatures were read from a max-min thermometer suspended 5 cm above the tallest knapweed plants in one of the cages.

At night, moths perching within or flying above the canopy were not easily seen. Therefore, I compared day- and nighttime activity by counting the number of moths perching on the cage walls above the canopy. Night observations were carried out by the light of a flashlight dimmed with several layers of paper towel and filtered (Kodak Wratten #29) to exclude all wavelengths but red, to which moths are least sensitive (Mikkola 1972). As observations indicated that moth activity was greatest at and after dusk, I assessed reproductive activity at this time by observing females confined in net sleeve-cages (45 x 15 cm) placed over knapweed plants. The mating status and egg complement of these females was determined by dissection. *A. zoegana* males transfer a spermatophore (a mass of sperm and accessory gland secretions enclosed in a cuticular sac (Rutowski 1979; Drummond 1984) to the female reproductive tract during mating. Tracts of mated *A. zoegana* females contained either a full spermatophore or one or two partially or fully collapsed cuticular sacs. Females have two ovaries, each consisting of four ovarioles filled with oocytes (Fitzpatrick 1988), most of which were filled with yolk and yolk precursors and appeared white, while those nearest the terminal filament (Happ 1984) were smaller and clear.

The blacklight live-trap was a *Heliothis* trap (Sentry; and see Webster *et al.* 1986) suspended 15 cm above the tallest knapweed plants, and illuminated from the top by a mining-type blacklight (principal wavelength 360 nm; Fig. 1). The trap's lower cone was covered with white organdy cloth to enhance UV reflectance. Knapweed below the trap was parted to allow a white cloth to be placed there. Care was taken to shield the worker's eyes from direct UV rays. Power was provided by a portable Honda generator of 1 kW. In one instance, the blacklight was placed behind a sheet of white cotton stretched over a frame (20 x 20 cm) and mounted on the front of a four-wheel-drive all-terrain- vehicle (Honda 4-Track) to provide a moving collection device. Moths needed for field tests of collection devices were aspirated with an Insect Vac (Bioquip) from field cages.

The data were tested by analysis of variance (ANOVA) followed, if appropriate, by Tukey's test. Chi-square tests were applied to frequency data.

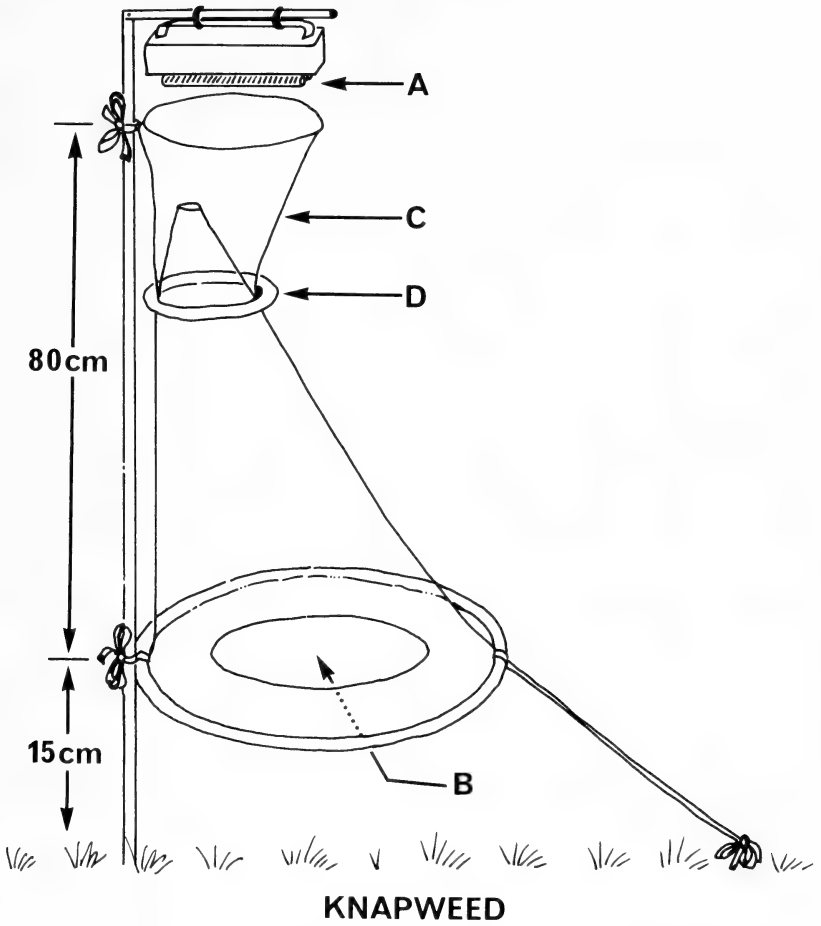

Figure 1. Schematic lateral view of blacklight live-trap. Moths, attracted by blacklight suspended at (A), enter the lower cone (B) of the *Heliothis* trap (Sentry) and fly up to the containment chamber (C), which can be removed by releasing Velcro at (D).

RESULTS AND DISCUSSION

Diurnal and nocturnal activity

A. zoegana moths remained within the knapweed canopy during the day, rarely flying. Of 28 moths observed every 2 h on June 24, 53% remained in one place from 0800 h (20.0°C) until 1500 h (30.0°C). On warm days (e.g. July 14; Fig. 2B) most moths were found in the middle to upper canopy, while on an unseasonably cool, windy day (June 30; Fig. 2A) they remained in the lower half. The moths showed no daily vertical migration to the top of the canopy, although in one case (June 30-July 1) their mean height was significantly greater at 0800 h than at 2000 h the previous evening (Fig. 2; ANOVA on heights). Therefore, aspirating the moths from plant tops was not a feasible collection method.

From morning until mid-afternoon, *A. zoegana* moths were usually difficult to disturb. They were most easily startled into flight in late afternoon and early evening, when they made short flights of 1-2 s to nearby plants or cage walls. About dusk, many of both sexes flew in 3-4 s zigzagging flights up onto the cage walls above the canopy (Fig. 3; *cf.* Muir and Harris, 1987). Despite efforts to control predators, spiders caught many of the moths perching on the walls, particularly early in the season (Fig. 3). The moths did not fly during cool, cloudy, windy weather.

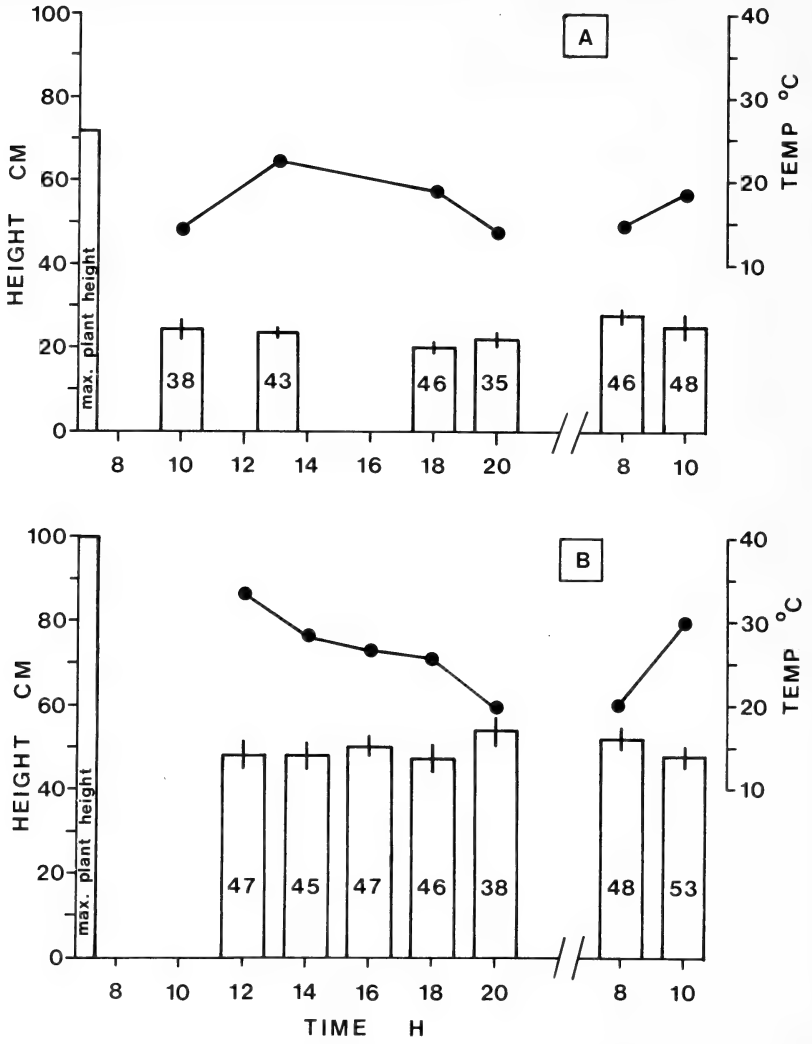

Figure 2. Mean heights (± 1 standard error) of *A. zoegana* moths perching within the knapweed canopy in field cages at the Kamloops Research Station on (A) June 30 - July 1 and (B) July 14-15, 1988. Number of moths observed is shown within each histogram. Daytime temperatures are shown ●——●. Minimum temperatures, recorded about dawn, were 10.0°C on July 1 and 5.0°C on July 15.

Female activity was monitored on three nights. On June 16, two females were placed in a sleeve cage over a spotted knapweed plant, and observed hourly from 2200-0400 h (22.0-13.5°C). Both moved to the top of the cage at dusk (~2200 h). One female was observed ovipositing at 2200, 2300 and 2400 h, while the other was seen in the "calling" posture, described by Turgeon and McNeil (1982), at 2300 and 2400 h. Both females then remained stationary at the top of the cage for the rest of the night. On June 23, six females were confined to a sleeve cage and observed every 15 min from 2100-0030 h (18.5-11.0°C). The same females were observed every 20 min from 2100-2320 h (22.5-18.5°C) on June 24. One female began ovipositing several minutes before 2100 h on both evenings, and continued in bouts until 2245 h (16.0°C) June 23 and 2240 h (18.0°C) June 24. The remaining five females moved to the top of the cage between 2145 h (17.5°C) and 2300 h (16.0°C) June 23, and between 2100 h (23.0°C) and 2140 h (21°C) June 24, where they alternately fluttered and perched. None of the five was observed calling or ovipositing, and all six stayed motionless near the top of the cage after 2300 h.

The female that called on June 16 contained 189 white eggs but no spermatophore, indicating that she had not been mated, while the other deposited ~100 eggs on the cage and contained 55 white eggs plus a partially collapsed spermatophore. Status of the six females observed on June 23-24 is shown below.

	Number of eggs			
Female	White	Clear	Total	Spermatophore
1	128	79	207	1
2	252	149	401	0
3	141	127	268	0
4	51	80	131	1
5	140	136	276	0
6	160	140	300	?

The only female seen ovipositing on those nights was #4, identified by her worn appearance. All the females dissected in the course of this study (Fitzpatrick 1988) contained more eggs than previously reported for this species (Müller *et al.* 1988).

Since moths of both sexes were active from dusk until midnight, I ran the blacklight trap during that period. I expected that the trap might capture proportionally more males, which were probably flying through and above the knapweed canopy in search of mates, than females which, although found above the canopy at dusk, probably returned to knapweed plants shortly thereafter to call or to oviposit.

Blacklight-trap tests: Within field cages

The blacklight trap (Fig. 1) was tested on four occasions. On the first, it was used from 2100 h on June 30 (1.5 h before total darkness) until early dawn at 340 h on July 1, in a field cage containing 10 males and 16 females. The minimum temperature that evening was 10.0°C. To encourage moths to fly up out of the canopy, the plants were disturbed with a stick at 2300 h (11.0°C) and 2325 h (12.0°C). At least 10 *A. zoegana* moths were observed in and on the trap at 2300 h. The next morning, five males and three females (at least one mated) were recovered from the trap. Although this sex ratio did not differ statistically from that in the cage, 13 of the 16 females were not trapped. This may have been due to windy, cloudy conditions and unseasonably cool temperatures that day and evening. *A. zoegana* females have larger body masses than males (pers. obs.), and may need a higher ambient temperature than males to initiate and sustain flight (as do *Thymelicus lineola* (Ochsenheimer) females (Pivnick and McNeil 1986)).

On July 14-15, the trap was illuminated from 2130-0300 h (15.0-8.0°C) and the plants were disturbed with a stick at 2200, 2300 and 2330 h. The trap caught 36 males and 13 females (six mated, four unmated, one of unknown status). This male-biased ratio was not significantly different from the ratio of 45 males to 19 females in the cage. All six untrapped females had been mated.

To determine if canopy disturbance had any adverse effect on trap catch, plants were left untouched during the following two tests. On July 15-16, from 2130-0300 h (13.0-7.0°C), the trap caught 40 males and five mated females. Only three males and three females were not trapped. The sex ratio of trapped moths was not different from the original male:female ratio. On July 28-29, when the trap was run from 2115-0300 h (22.0-10.0°C), 24 males and 4 mated females were collected. This ratio was not different from the original ratio in the cage. Of the six females not trapped, five were mated.

Thus the trapping method used was effective over a short range. The trap catch was neither increased nor reduced by flushing moths out of the knapweed.

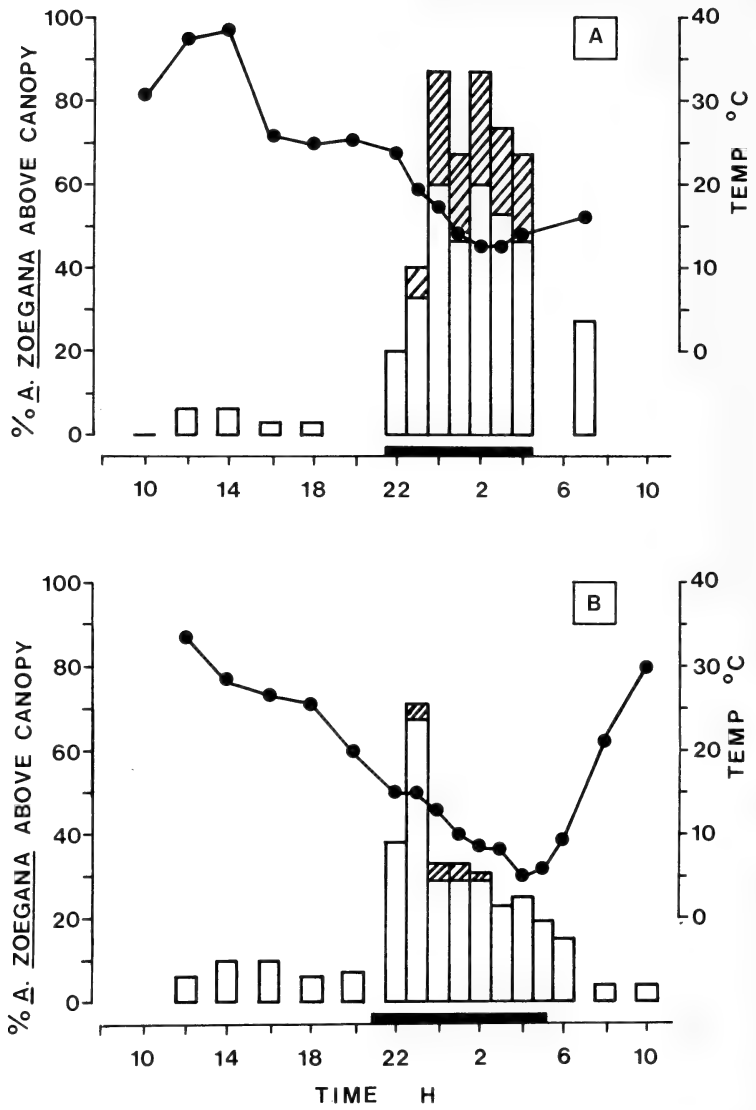

Figure 3. *Activity of A. zoegana* moths observed inside field cages on (A) June 16-17 and (B) July 14-15, 1988. Histograms show the percentage of moths seen above the knapweed canopy on cage walls. Total number of moths observed was: (A) 35 from 1000-1800 h and 15 thereafter; (B) 52 until 0600 h and 55 thereafter. Hatched portions of histograms show moths captured by spiders. Scotophase (dusk to dawn) is shown by solid bars along X-axes and temperatures are shown ●——●.

Blacklight-trap tests: In the open

The blacklight trap was tested three times in the field. The first test took place at a 1987 release site near Clearwater, where *A. zoegana* larvae had been recovered early in 1988 (V. Fediuk, pers. comm.). Two *A. zoegana* moths, one worn and one apparently newly emerged, were observed in this area at 2230 h July 21. The trap was illuminated from 2130-0300 h (19.5-12.0°C) and knapweed in a 50-m radius around it was disturbed with a stick at 2200, 2230 and 2300 h. A single *A. zoegana* male was captured, with many other insects. On July 22,

two workers spent a total of 4 h *or* 2 h each examining all knapweed plants in a 100 x 10 m area surrounding the trap. No *A. zoegana* were sighted there, nor were any seen during a wider but less-thorough search. Given the sedentary nature of the moths during the day and the fact that both searchers were accustomed to looking for *A. zoegana*, it is unlikely that the bright yellow moths went unnoticed. There were probably too few *A. zoegana* to allow for an accurate test of the trap.

An established population of *A. zoegana* could not be found, so the next two tests used moths aspirated from the field cages at the Kamloops Research Station and released at a nearby spotted knapweed infestation. At 1030 h on August 4, 100 moths (51 males and 49 females) were released onto two clumps of knapweed 20 m apart (~50 moths/clump). Moths flew to the knapweed immediately upon release. Within 1 min of release, one *A. zoegana* moth had to be rescued from an ant that was dragging it away. Although some moths probably fell prey to the numerous ants in the area, at least 10 moths were observed at the release site 10 h later. The trap was set up midway between the two release points, and run from 2100-0300 h. The knapweed was disturbed with a stick every half-hour from 2130 to 2300 h (25.0, 23.0, 21.0 and 20.0°C, respectively), but only three males were caught, and all were in the trap by 2300 h.

Thus the blacklight trap, which worked well in a small enclosure, was not effective under these field conditions. Since *A. zoegana* adults would not come to the blacklight in the field, we attempted to take the blacklight to them.

In the final test, 136 moths (53 males and 83 females) were released on three clumps of knapweed (~45 moths/clump) at 1700 h on August 18. The blacklight was attached to the front of a four-wheel all-terrain vehicle (ATV) at headlight level, and covered with a piece of white cotton, 20 x 20 cm, stretched over a wooden frame. At 2115 h (15.0°C), the ATV made 5 non-overlapping passes through the release area. Three male *A. zoegana* landed on the cloth and remained there long enough to be aspirated off.

Neither blacklight method was a success but both warrant further testing. The first test at Clearwater may have failed due to a paucity of *A. zoegana*. The second and third may have failed because the moth's behaviour was altered by capture and transport, or because released moths were quickly taken by predators. More work with established field populations of *A. zoegana* is needed.

A. zoegana establishment in B.C.

Some of these results suggest that ecological factors may account for the apparent failure of *A. zoegana* to become established, *e.g.* climatic adaptation. *A. zoegana* habitats in Europe are generally warm enough for the insect to complete two or three generations per year (Müller *et al.* 1988) whereas in the B.C. interior, *A. zoegana* is restricted to one (Muir and Harris 1987). Other factors are soil-moisture conditions and type of knapweed. Released *A. zoegana* seem most likely to survive on moist, cool, stands of spotted knapweed (*e.g.* Clearwater) rather than on dry, warm sites where diffuse knapweed predominates (V. Fediuk, R. Tucker, pers. comm.). Diffuse knapweed often germinates from seed each spring and dies in fall, making it impossible for root-inhabiting insects to overwinter (V. Fediuk, pers. comm.).

Plant vigour probably affects larval development and adult fecundity. Larval development on cultivated *vs.* field knapweed has not been assessed, but it is known that the Kamloops rearing facility yielded females containing from 150-400 eggs (Fitzpatrick 1988), fecundities greater than the maximum of 95 eggs laid by females reared in Europe from field-collected larvae (Müller *et al.* 1988). It is important to know what proportion of moths reared on cultivated knapweed will leave progeny able to survive on field knapweed.

Nothing is known of predation on *A. zoegana* adults in Europe or B.C., although several parasitoids and predators of larvae in Europe have been identified (Müller *et al.* 1988, 1989). My observations suggest that predation by ants and spiders may represent a significant mortality factor to *A. zoegana* moths here.

Finally, the sex ratio of released moths and the timing of release deserve consideration.

Early in the emergence period, males predominate (Muir and Harris 1987). Prior to 1988, the moths were not sexed before release, thus some areas may have received males only. Releases should probably coincide with the appearance of new growth because females apparently prefer to oviposit on succulent tissue (H. Müller, pers. comm.), whether on plant tops (Fitzpatrick 1988; V. Fediuk, pers. comm.) or on rosettes (Müller *et al.* 1988). Foliage quality at the oviposition site may be important to the survival of neonate larvae, which appear to mine the foliage slightly on their way to the roots (unpub. data).

Further work on any of these is needed.

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PARASITISM OF ORANGE TORTRIX ON CANEBERRY, *RUBUS* SPP. IN WESTERN OREGON AND WASHINGTON

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ABSTRACT

Larvae and pupae of *Argyrotaenia citrana* (Fernald), were collected from commercial caneberry fields, *Rubus* spp., in western Oregon and Washington from 1981 to 1984 and reared in the laboratory to identify parasitoid species and determine levels of parasitism. Twelve species of Hymenoptera (Braconidae, Eulophidae, and Ichneumonidae) and one species of Diptera (Tachinidae) were identified. Over 80% of total parasitism was by the braconids, *Apanteles aristoteliae* Viereck and *Meteorus argyrotaeniae* Johansen. *M. argyrotaeniae* was also reared successfully from several other leafroller hosts: *Choristoneura rosaceana* (Harris), *Archips rosana* L., and *Cnephasia longana* (Haworth). No other hosts of *A. aristoteliae* were collected in caneberries.

Key Words: *Argyrotaenia citrana*, caneberry, *Rubus*, parasitoids

INTRODUCTION

The orange tortrix, *Argyrotaenia citrana* (Fernald), (Lepidoptera: Tortricidae), is an occasional pest of a wide variety of fruit crops along the Pacific coast of North America (Powell 1964). In the Pacific Northwest orange tortrix can be an important pest of red raspberry, *Rubus idaeus* L. and other *Rubus* cane fruits (Breakey & Batchelor 1948, Rosenstiel 1949, LaLone 1980, Knight *et al.* 1988). Larvae generally do not feed directly on fruit, but contaminate harvested fruit, especially that which is machine harvested (Kieffer *et al.* 1983). Recent biological studies of orange tortrix have reported on overwintering mortality factors (Knight & Croft 1986), phenology (Coop 1983, Knight & Croft 1987a), and regional population dynamics (Knight & Croft 1987b). These studies have led to the development of an effective management program using sex pheromone traps to monitor populations that has reduced unnecessary early season applications of insecticides (Knight et al. 1988).

This reduction of insecticide usage in caneberry may prove to be very important in enhancing biological control of orange tortrix. Although parasitoids have been given credit for reducing orange tortrix abundance on a number of crops (Anonymous 1926, Basinger 1935, Rosenstiel 1949, Breakey 1951, Madsen & McNelly 1961, Kido *et al.* 1981), very little biological or host information is recorded for most of the complex (Krombein *et al.* 1979). Therefore, a study was initiated to identify larval and pupal parasitoid species and record levels of parasitism in commercial caneberry fields. Data were also collected on the parasitism of alternate lepidopterous hosts within caneberry.

MATERIALS AND METHODS

Commercial fields of red raspberry, *R. idaeus* L.; marionberry, *R. ursinus* Cham. & Schlecht; and evergreen blackberry, *R. laciniatus* Willd. located in W Oregon and SW Washington were sampled from 1981 through early 1984. Each field was sampled several times from April through October, except for 1983 and 1984 when fields were sampled biweekly from April through May. During early spring, leafroller larvae and pupae were collected from dead leaves tied along the wire trellises. In summer and fall, leafroller larvae were collected primarily from terminal leaf clusters along canes. All larvae and pupae were reared in 28 ml plastic cups with artificial diet (Lyon *et al.* 1972) at 20 ± 1°C, >70% RH, and a photoperiod of L:D 16:8 h.

RESULTS AND DISCUSSION

Thirteen primary and two secondary parasitoid species were identified from over 2000 orange tortrix larvae and pupae that were field collected (Table 1). Parasitism in the samples

TABLE 1

Summary of parasitoid species reared from orange tortrix larvae and papae collected from commercial caneberry *Rubus* ssp. fields in western Oregon and Washington, 1981-1984.

Species	Family	Mode[a]	Other hosts[b] Cr	Ar	Cl
Apanteles aristoteliae Viereck	Braconidae	larval endo solitary	no	no	no
Meteorus argyrotaeniae Johansen	Braconidae	larval endo solitary	yes*	yes*	yes*
Phytodietus vulgaris Cresson	Ichneumonidae	larval ecto solitary	no	no	yes*
Enytus eureka (Ashmead)	Ichneumonidae	larval endo solitary	yes	yes	yes
Diadegma ssp.	Ichneumonidae	larval endo solitary	yes	no	yes
Oncophanes americanus (Weed)	Braconidae	larval ecto greg	yes	no	yes*
*Meteorus dimidiatus** (Cresson)	Braconidae	larval endo solitary	yes	no	no
Meloboris sp	Ichneumonidae	larval endo solitary	no	yes	no
Meteorus trachynotus Viereck	Braconidae	larval endo solitary	no	no	no
*Parania geniculata** (Holmgren)	Ichneumonidae	larval-pupal endo solitary	no	no	no
Pseudoperichaeta erecta (Coquillet)	Tachinidae	larval-pupal endo solitary	yes	no	no
*Elachertus** sp	Eulophidae	larval ecto solitary	yes	no	no
Itoplectis quadricingulata (Prov)	Ichneumonidae	pupal endo solitary	no	no	no
Stictopisthus sp	Ichneumonidae	hyper on *A. aristoteliae*	no	no	no
*Spilochalcis** sp	Chalcididae	hyper on *A. aristoteliae*	no	no	no

[a] Mode of parasitism is categorized as either **larval, larval-pupal** or **hyper**parasitism; **endo**parastitism or **ecto**parasitism; and **solitary** or **greg**arious parasitism.

[b] Other hosts include: *Choristoneura rosaceana, Archips rosanus,* and *Cnephasia longana.*

* Represents a new host record.

ranged from 0 to 56% and averaged 27.5%. The braconids, *Apanteles aristoteliae* Viereck and *Meteorus argyrotaeniae* Johansen, were the most commonly and widely collected species in our samples, accounting for > 80% of the parasitoids reared. The ichneumonids, *Enytus eureka* (Ashmead) and several unidentified species of *Diadegma*, were also commonly collected though parasitism levels were generally very low, *i.e.* < 5%. The two ectoparasitoids, *Phytodietus vulgaris* Cresson and *Oncophanes americanus* (Weed), were collected from only a few sites during late summer and early fall. Yet, levels of parasitism averaged 9 and 14% for these two species, respectively, when they were present in collections. Seven additional parasitoid species were also collected, but only occasionally (Table 1). Of these, *Parania geniculata* (Holmgren), *Meteorus dimidiatus* (Cresson), and *Elachertus* sp. are new host parasitoid records (Krombein et al. 1979). *Itoplectis quadricingulata* (Provancher), the only pupal parasitoid collected, was widely distributed among fields. A few specimens of the hyperparasitoids, *Stictopisthus* sp. and *Spilochalcis* sp. were reared from *A. aristoteliae* cocoons.

Parasitoids were also reared from larvae of three other leafroller species occasionally found

in caneberry: *Choristoneura rosaceana* (Harris), *Archips rosana* (L.), and *Cnephasia longana* (Haworth). Seven species reared from *C. rosaceana*, two species reared from *A. rosana*, and five species reared from *C. longana* were also collected from orange tortrix (Table 1). Interestingly, *M. argyrotaeniae* was collected from all four hosts, but *A. aristoteliae* was restricted to orange tortrix.

These other three leafrollers are polyphagous (Powell 1964) and are common pests of filberts, *Corylus avellana* L. (AliNiazee 1980). The proximity of caneberry fields and filbert orchards to one another and the dispersal capacity of both hosts and parasitoids may be important in maintaining this complex of parasitoid species in the geographical region studied during periods when suitable stages of orange tortrix are not available. In contrast, it is not clear what importance temporal asynchrony of *A. aristoteliae* and orange tortrix populations in the spring and the apparent lack of alternative hosts has in reducing populations of this important parasitoid species in caneberry during the summer.

No attempt was made in our study to correlate spray practices or host densities with levels of parasitism or the presence of individual species. However, these relations are of importance in more fully assessing the role of parasitoids in management of orange tortrix populations. Further investigations should determine the effects of early season insecticide applications, cultural practices, and surrounding habitat on the performance of these species.

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PSEUDODIPHASCON ARROWSMITHI, A NEW SPECIES OF TARDIGRADE FROM BRITISH COLUMBIA, CANADA (MACROBIOTIDAE: EUTARDIGRADA: TARDIGRADA)

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ABSTRACT

A new species of macrobiotid tardigrade was found on two mountains on Vancouver Island, British Columbia, during a study of the tardigrades on five mountains on the island. *Pseudodiphascon arrowsmithi*, n. sp., is distinguished from other species in the genus by its three large macroplacoids with the third as long as or longer than the first, the very large microplacoid and the presence of lunules.

INTRODUCTION

Because the literature dealing with tardigrades in Canada, and particularly in British Columbia, is very sparse, a survey of tardigrades on Vancouver Island was undertaken to document their presence and to compare it with the only two previous publications on tardigrades from B. C. (Richters, 1908; Murray, 1910). Three other publications (Mathews, 1938; Baumann, 1960; Schuster and Grigarick, 1965) listing tardigrades from B. C. merely reiterate the species found by Richters and Murray.

MATERIALS AND METHODS

A total of 41 specimens of *Pseudodiphascon arrowsmithi*, n. sp., were collected on two mountains on Vancouver Island (Fig. 1): 14 were collected at 760 m elevation on Green Mountain in the moss *Dicranum fuscescens* on 17 July 1986, and 27 on Mt. Arrowsmith--26 on 09 July 1986 at 760 m in three species of mosses, *D. fuscescens*, *Claopodium bolanderi* and *Mnium spinulosum*, and one individual on 10 July 1987 at 1370 m in *D. fuscescens*.

The samples of moss were placed in paper bags and air-dried for several months. Each sample was then removed from the bag, placed in a stoppered funnel and allowed to soak in water for eight hours, after which the moss was removed and shaken in a separate container of water several times. The water and its contents were poured into a 45 μm mesh sieve to retain the tardigrades, which were placed in a gridded petri dish and extracted using a stereomicroscope. Each tardigrade was placed in Hoyer's mounting medium on a microscope slide and sealed with a cover slip. After complete drying of the mountant the cover slip was ringed with nail polish to prevent further air penetration.

Identifications were made using a phase-contrast compound microscope with oil immersion. All measurements were made using a calibrated eyepiece micrometer. Buccal tube length was considered the distance between the anterior end of the buccal tube excluding the mouth ring and the beginning of the spiralling; pharyngeal tube length was the distance from the beginning of the spiralling to the pharyngeal apophyses; and total length of the tardigrade was the distance from the anterior end of the head to the junction of the fourth pair of legs. The drawings were made with a drawing tube attached to the compound microscope.

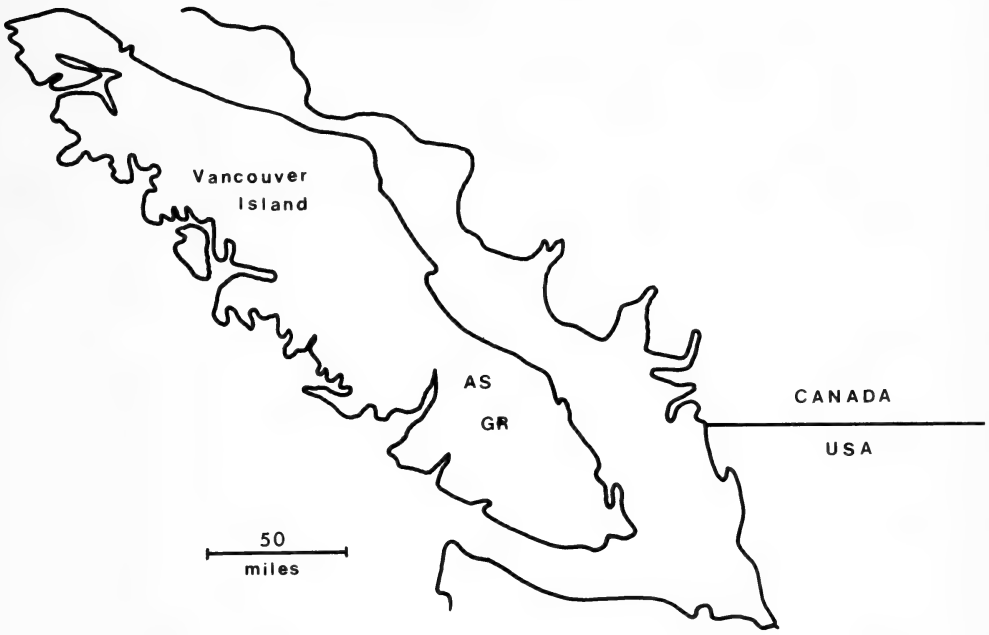

Figure 1. Location of sampling areas on Vancouver Island, British Columbia, Canada. AS = Mt. Arrowsmith, GR = Green Mountain.

TAXONOMIC ACCOUNT

Eutardigrada Marcus, 1927
Macrobiotidae Thulin, 1928
Pseudodiphascon Ramazzotti, 1964
Pseudodiphascon arrowsmithi, n. sp.
(Fig. 2)

Description. Holotype. Total length 430 µm; colorless; cuticle smooth; eyes absent (Fig. 2A). Ten buccal lamellae present. Mouth ring with crests and distinct dentation, rectangular-shaped. Buccal tube with ventral tube support, extended almost to stylet support insertions; buccal tube length 26 µm, width 4.4 µm. Pharyngeal tube walls thickened, spiralled and flexible; length 19 µm, width 4.4 µm; pharyngeal tube with evident spiralling starts immediately below stylet support insertions. Pharyngeal bulb large and round. Pharyngeal apophyses large; 3 macroplacoids, the first 5.5 µm long, second 3.1 µm and third 5.5, third with inward-projecting enlargement at posterior end; microplacoid large, 3.1 µm (Fig. 2B). All legs small, with fourth pair slightly smaller than the first 3 pairs. Claw sequence 2112; claws on 4th pair of legs larger than on first 3 pairs; primary branch of internal and external claws with 2 accessory points; lunules present but small, more evident on claws of 4th leg (Figs. 2C, 2D). Collected at 760 m on Green Mountain in the moss *D. fuscescens*, 17 July 1986. USNM #235439.

Paratypes. Total lengths 206-515 µm. Buccal tube lengths 16-27 µm, widths 2.0-4.4 µm; pharyngeal tube lengths 11-19 µm, widths 2.0-4.4 µm. First macroplacoid lengths 1.9-5.5 µm; second 1.3-4.4 µm; third 2.5-6.3 µm; the third is usually as long as or longer than the first; microplacoid 1.3-3.8 µm. USNM #235437, 235438, 2 specimens; Dastych collection, 1 specimen; Kristensen collection, 1 specimen; Nelson collection, 2 specimens; Kathman collection, 34 specimens; all from Mt. Arrowsmith or Green Mountain on Vancouver Island.

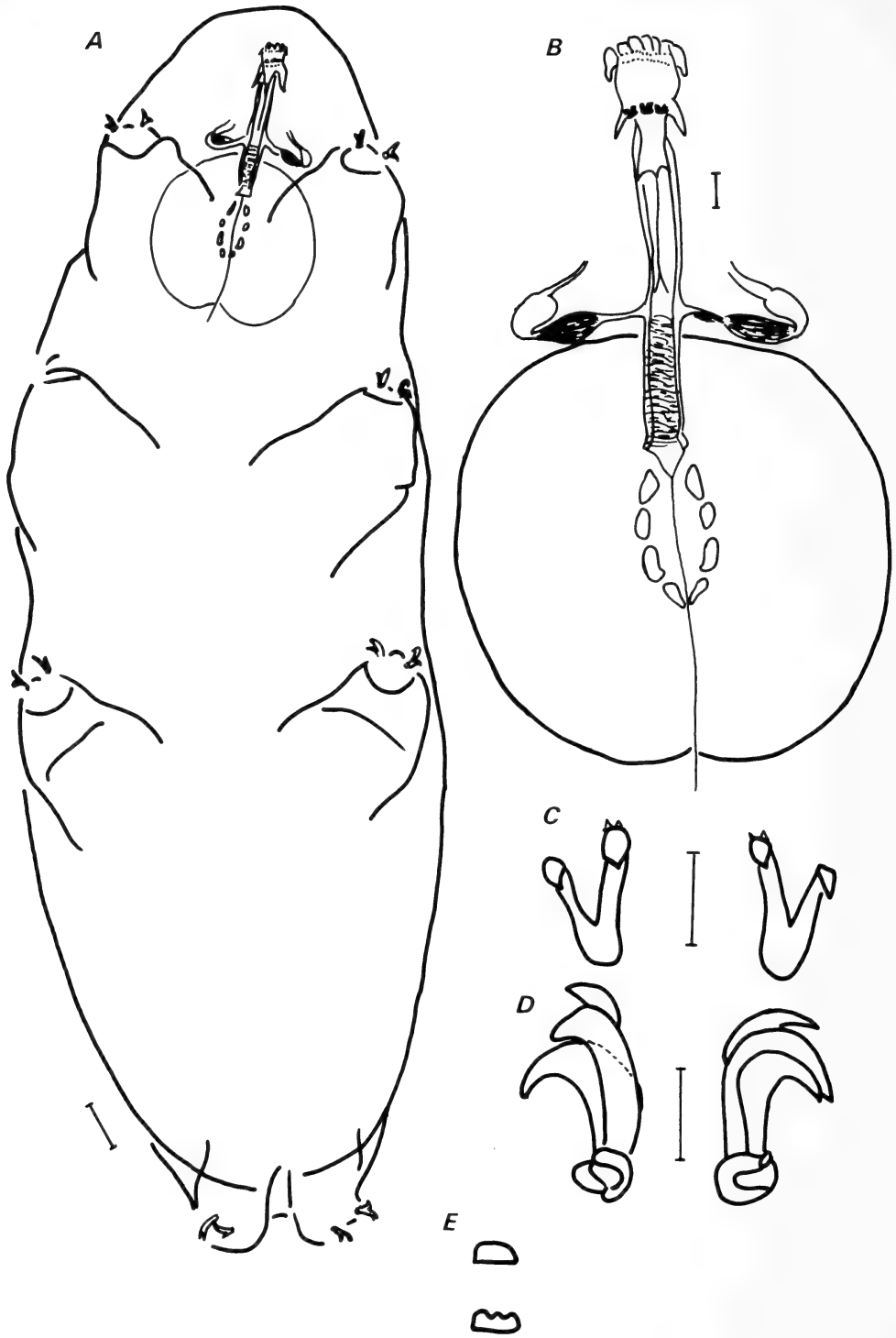

Figure 2. *Pseudodiphascon arrowsmithi.* A, Whole animal, ventral view; B, Buccopharyngeal apparatus; C, Claws, 2nd pair of legs; D, Claws, 4th pair of legs; E, Profile of macroplacoids, a = *arrowsmithi*, b = *bindae*. Scale bars in μm as follows: A, 20; B, 6.3; C-D, 4.8; E, no scale.

Type locality. Northwest slope of Mt. Arrowsmith at 760 and 1370 m and southwest aspect of Green Mountain at 760 m, both on Vancouver Island, British Columbia, Canada.

Etymology. Named after Mt. Arrowsmith, one of the mountains on which it was collected. Although the International Commission of Zoological Nomenclature recommends the "ensis" or "iensis" ending for geographical locations, the alternative procedure (Appendix D, Section IV, 22b) of using the masculine noun in the genitive case is adopted here as it is more euphonious.

DISCUSSION

Three of the four known species of *Pseudodiphascon* have been tentatively placed in this genus despite incomplete descriptions or lack of specimens to allow sufficient detail of important morphological characters. The original descriptions do not mention a spiralled flexible pharyngeal tube nor a ventral tube support in the buccal tube for *P. diphasconoide* Iharos, 1969, *P. inflexum* Arcidiacono, 1964, and *P. dubius* Schuster and Toftner, 1982. *P. diphasconoide* appears to be a much smaller tardigrade, with a thinner and shorter buccopharyngeal tube than *P. arrowsmithi*. *P. diphasconoide* has 2 small round macroplacoids, with the first a little longer than the second, and no microplacoid. This species was found only in Vietnam. The total length of *P. inflexum* coincides with that of *P. arrowsmithi*, but the buccopharyngeal tube is much narrower in *P. inflexum*. *P. inflexum* has 2 macroplacoids, the first longer than the second, and a very small microplacoid. The dentate lunule in *P. inflexum* is very large with 8-12 teeth, whereas in *P. arrowsmithi* it is very small with no discernable dentation. *P. inflexum* has been collected only in Sicily. *P. dubius* is a small tardigrade (length 240 μm) with a thin, short buccopharyngeal tube (length 31 μm). There are 3 small macroplacoids, all equal in length (1.5 μm) and a minute microplacoid. This species has only been reported from the Dominican Republic. *P. bindae* Christenberry and Higgins, 1979, collected in Alabama, USA, is the species most closely related to *P. arrowsmithi*. The largest specimen found was 437 μm (cf. 515 μm for *P. arrowsmithi*). Christenberry and Higgins (1979) stated that the 10 buccal lamellae could only be seen using SEM; in *P. arrowsmithi* they are evident with a phase microscope. Eyes are absent in *P. arrowsmithi* and present in *P. bindae*. There is no evident dentation above the crests in *P. bindae*. The buccal and pharyngeal tubes are longer in *P. bindae* (27-44 μm; 16-35 μm, respectively) than in *P. arrowsmithi* (16-27 μm; 11-19 μm, respectively); combined length for *P. bindae* is 43-79 μm, whereas for *P. arrowsmithi* it is 29-45 μm. The width of the buccopharyngeal tube for *P. bindae* and *P. arrowsmithi* is about the same (2.4-4.0 μm, 2.0-4.4 μm, respectively), but the ratio of width to length for *P. bindae* is much larger. The spiralling in *P. arrowsmithi* starts immediately below the insertion of the stylet supports and is a tight, dense type of spiralling, often difficult to see, whereas in *P. bindae* it begins well below the stylet support insertions and is a large, loose type of spiralling, easily seen. In *P. bindae* the first macroplacoid is always the longest and the second is the shortest, with the microplacoid slightly shorter than the second macroplacoid. In profile the macroplacoids of *P. arrowsmithi* are always smooth-edged, whereas in *P. bindae* they are rough (Fig. 1E). In *P. arrowsmithi* the third macroplacoid is equal to or longer than the first, and in some cases the second is only slightly shorter than the first. The microplacoid is very large, often equal to or larger than the second macroplacoid. Lunules are absent on *P. bindae* and present on *P. arrowsmithi*.

It appears that *P. arrowsmithi* could be classified as one of Ramazzotti and Maucci's (1983) montane or alpine species, since it was collected only at 760 m or higher on Vancouver Island, despite many samples of the same moss species being collected at several lower elevations, down to sea level. The two mountains on which it was found are approximately 26 km apart.

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NEW AND LITTLE KNOWN SCALE INSECTS (HOMOPTERA: COCCOIDEA) FROM BRITISH COLUMBIA

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ABSTRACT

Thirty-six species of scale insects (Coccoidea) belonging to 6 families were recovered during a recent collecting trip in British Columbia. Of these, 16 species (*Orthezia newcomeri, Anisococcus oregonensis, Heterococcus nudus, Phenacoccus capensis, Phenacoccus colemani, Phenacoccus solani, Spilococcus geraniae, Spilococcus keiferi, Tridiscus* sp., *Trionymus caricis, Trionymus utahensis, Acanthococcus greeni, Physokermes concolor, Physokermes hemicryphus, Physokermes taxifoliae, Stramenaspis kelloggi*) are new records for Canada and 26 new for British Columbia. The latter now has 42 species. The level of infestation, phenological stage, host plant data (including several new associations) and the localities of collections are also presented.

Résumé

Lors d'un récent voyage de cueillette effectué en Columbie-Britannique, on a rapporté trente-six espèces de cochenilles (Coccoidea) appartenant à 6 familles. Seize de ces espèces (*Orthezia newcomeri, Anisococcus oregonensis, Heterococcus nudus, Phenacoccus capensis, Phenacoccus colemani, Phenacoccus solani, Spilococcus geraniae, Spilococcus keiferi, Tridiscus* sp., *Trionymus caricis, Trionymus utahensis, Acanthococcus greeni, Physokermes concolor, Physokermes hemicryphus, Physokermes taxifoliae, Stramenaspis kelloggi*) sont de nouveaux records pour le Canada, et 26 d'entre elles sont nouvelles en Colombie-Britannique, qui compte maintenant 42 espèces. Le rapport traite du degré d'infestation et du stade phénologique; il fournit également des données sur les plantes hôtes (y compris plusieurs nouvelles associations) et sur les localités où a eu lieu la cueillette.

INTRODUCTION

The scale insect fauna of Canada is poorly known. Scudder (1979) noted that 56 species have been recorded from Canada. No comprehensive work exists for the Coccoidea of Canada, however, Foottit and Williams (pers. comm.) have prepared a list of the scale insect species in the slide holdings of the Canadian National Collection.

Venables (1939) published a preliminary checklist of scale insects of British Columbia, listing 14 species, primarily from the Okanagan Valley and Vancouver areas. Limited additional records (host associations, localities) for the province can be found in the taxonomic works of Ferris (1937-1955) and Richards (1958) and in the applied entomological literature (Downing *et al.* 1956; Glendenning 1925; Evans 1982, 1983; Furniss and Carolin 1977; Hopping 1937; Kondo and Moody 1986; Madsen and Morgan 1975; Rubin and Beirne 1975; Waddell 1952). Our paper presents the results of brief collecting trips in the vicinity of Penticton (late June), and Vancouver and Victoria (early July), British Columbia during 1988. It is hoped that the records presented here will stimulate additional studies of the Coccoidea in British Columbia and Canada.

Microscope slides of the species collected are deposited in the collection of the Plant Protection Institute, Hungarian Academy of Sciences (Budapest, Hungary), with duplicates deposited in the collection of the Pacific Forestry Centre (PFC), Forestry Canada (Victoria, B.C.). As well, for those host plants indicated by an '*', dry plant material with scale insects is deposited in the PFC reference collection.

RESULTS

A total of 36 species of scale insects belonging to 6 families, was collected in British Columbia in late June and early July, 1988. The species collected are listed by family. Data for each species are given in the following order: scientific name, geographic location and date of collection, (day, month, year), place (niche) of collection, sex and developmental stage(s) of scales, level of infestation, and identification number (in parentheses) of slides in the collection of the senior author. Forest Insect and Disease Survey (FIDS) registration numbers are provided for specimens originating from the PFC reference collection. Additional information such as taxonomic characters and geographic distribution is presented for some species. Those species which represent new records for the Canadian fauna are marked with an X and those new for British Columbia are marked with an O before the scientific name. Names of native species of host plants conform to those of Scoggan (1978a,b, 1979). The level of infestation is marked as F (frequency) (on a scale of 0 to 4) (Kozár and Viktorin 1979). All collection data without special reference are those of the senior author, assisted in some cases by L.M. Humble.

I. Ortheziidae

1. O *Arctorthezia occidentalis* Douglas, 1891. Furry Creek, 5 km S of Britannia, 07.07,1988, among mosses, females, nymphs, F=1 (3307); Victoria (Highland Rd.), 12.07,1988, between mosses*, female, first instar nymphs, eggs, F=2 (3330). While this species normally has 8-segmented antennae, all females from our collections have 7-segmented antennae. Morrison (1952) also reported one specimen with 7-segmented antennae. This variation needs further study, as it may indicate that *A. occidentalis*, as currently understood, includes some undescribed species. This species is widely distributed from California to Alaska, including the Vancouver area (Morrison 1925, 1952).

2. O X *Orthezia newcomeri* Morrison, 1952. Summerland, 30.06,1988, *Artemisia frigida* Willd. (Compositae), on the leaves, female, first instar nymphs, F=1 (3278). This species was previously recorded on *Penstemon* (Scrophulariaceae) from Yakima County, WA, USA (Morrison 1952).

II. Pseudococcidae

3. O X *Anisococcus oregonensis* Ferris, 1950. Summerland, 30.06,1988, *Antennaria parvifolia* Nutt. (Compositae), on leaves, females, F=1 (3289). Our specimens differ from the

original description (Ferris 1950) in that the antennae are 9-segmented instead of 8, the ostioles are hardly noticeable, and there are some differences evident in the structure of the frontal cerarii. It will be necessary to collect additional material to determine the significance of this variation. Until now this species was known only from California and Washington (USA) on *Eriogonum umbellatum* Torr. (Polygonaceae) (McKenzie 1967).

4. O X *Heterococcus nudus* (Green, 1926). Summerland, 30.06,1988, *Haplopappus* sp. (Compositae), on roots, female, F=1 (3281); Langford (Savory Rd.), 12.07,1988, *Agropyron* sp. (Gramineae), in leaf sheaths, females (yellowish), first instar nymphs, eggs, F=2 (3344). This species is widely distributed in Palearctic and Nearctic regions. In the United States it is known also from Yakima, WA (Miller 1975).

5. *Phenacoccus aceris* (Signoret, 1875). Victoria (urban), 10.07,1988, *Ulmus* sp. (Ulmaceae), dead females, eggs, F=1 (3313); Victoria (urban), 10.07,1988, *Acer* sp. (Aceraceae), dead females, eggs, F=2 (3314); Victoria (urban), 10.07,1988, *Prunus* sp. (Rosaceae), dead females, F=2 (3321). This species is a widely distributed pest in the Holarctic Region (Kosztarab and Kozár 1988), and is well known in Canada (Ferris 1950).

6. O X *Phenacoccus capensis* Ferris, 1950. Hwy. 99, 17 km N of Brackendale, 07.07,1988, *Spiraea douglasii* Hook. (Rosaceae), on roots, females, F=1 (3302). Our specimens differ from the original description by having fewer thin tubular ducts ventrally and more thick tubular ducts dorsally. Based on these characters, our specimens resemble *P. colemani*; however, the latter lacks the cerarian-like structure on its dorsum. Until now this species was known only from Mexico on *Phyllanthus* (Euphorbiaceae) (Ferris 1950).

7. O X *Phenacoccus colemani* Ehrhorn, 1906. Furry Creek, 5 km S of Britannia, 07.07,1988, *Holodiscus discolor* (Pursh) Maxim. (Rosaceae), on twig, female, F=1 (3311). This species was previously known only from the southern part of the Nearctic Region on *Arctium* and *Encelia* (Compositae), *Arctostaphylos* (Ericaceae), *Eriogonum* (Polygonaceae), *Garrya* (Garryaceae), *Lantana* (Verbenaceae), *Mahonia* (Berberidaceae), *Castilleia* and *Pedicularis* (Scrophulariaceae), *Phacelia* (Hydrophyllaceae), *Rubus* (Rosaceae), and *Symphoricarpos* (Caprifoliaceae) (Ferris 1950; McKenzie 1967).

8. O X *Phenacoccus solani* Ferris, 1918. Summerland, 30.06,1988, *Haplopappus* sp., on roots, female, F=1 (3281); Summerland, 30.06,1988, *Centaurea diffusa* Lam. (Compositae), on roots, female, F=1 (3288). This species is widely distributed in the Nearctic Region (McKenzie 1967) and in other parts of the world (Williams, Blair and Khasimuddin 1985).

9. O *Pseudococcus affinis* (Maskell, 1894) [=*obscurus* Essig, 1909]. Victoria (indoor), 13.07,1988, *Amaryllis* sp. (Amaryllidaceae), females, nymphs and eggs, F=3 (3350). A cosmopolitan pest species, found on a wide variety of unrelated hosts. In the northern parts of the temperate zone it is found only in greenhouses (Cox 1987; Furniss and Carolin 1977; McKenzie 1967).

10. O X *Spilococcus geraniae* (Rau, 1938). Hwy. 99, 17 km N of Brackendale, 07.07,1988, *Gaultheria shallon* Pursh. (Ericaceae), on roots, females (greenish), nymphs and eggs, F=2 (3303). This species was previously known only from New York and California on *Geranium robertianum* L. (Geraniaceae) and *Artemisia douglasiana* Bess. (Compositae), respectively (McKenzie 1967).

11. O X *Spilococcus keiferi* McKenzie, 1960. Summerland, 30.06,1988, *Haplopappus* sp., on roots, females, F=2 (3281); Summerland, 30.06,1988, *Antennaria parvifolia*, on roots, females, F=1 (3289). This species is known from California and Washington on *Ambrosia* and *Franseria* (Compositae) and various Gramineae (McKenzie 1967).

12. O X *Tridiscus* sp. Victoria (sea coast), 10.07,1988, *Agropyron* sp.*, in leaf sheaths, female, eggs, F=2 (3320). This is a new species and will be described elsewhere (Kozár and Foottit, pers. comm.).

13. O X *Trionymus caricis* McConnel, 1941. Langford (Savory Rd), 12.07,1988, *Elymus* cf. *innovatus* Beal (Gramineae) and *Vulpia microstachys* (Nutt.) Munro* (Gramineae), in leaf sheaths, females (lilac), eggs, F=1 (3345). This species is almost identical to the Palearctic *T. radicum* (Newstead, 1895). *T. caricis* was previously known only from the USA (California, Maryland and Tennessee) on *Carex* (Cyperaceae) and *Elymus* and *Uniola* spp. (Gramineae) (McKenzie, 1967).

14. O X *Trionymus utahensis* (Cockerell, 1916). Summerland, 30.06,1988, *Elymus piperi* Bowden (Gramineae), in leaf sheaths, females, eggs, first instar nymphs, F=1 (3292); Langford (Savory Rd.), 12.07,1988, *Agropyron* sp., in leaf sheaths, females (lilac), eggs, first instar nymphs, F=1 (3344). Previously, this species was known only from the USA on various grasses (McKenzie 1967).

III. Eriococcidae

15. O X *Acanthococcus greeni* (Newstead, 1898). Summerland, 30.06,1988, *Agropyron intermedium* (Host) Beauv.* (Gramineae), on leaves, females, eggs, F=3 (3283); Summerland, 30.06,1988, *Festuca ovina* L.* (Gramineae), on leaves, females, F=1 (3286). The specimens agree with the descriptions of *A. greeni* given by Williams (1985). It is a common grass-inhabiting species occuring throughout the Palearctic including the Far East and Siberia in the U.S.S.R. (Danzig, 1980). Some morphological similarities to *A. bahiae* (Ehrhorn) were also evident; however, the latter species has been found only on the roots of *Bahia* sp. (Compositae) from California (Ferris 1950). Because of the incomplete knowledge of the Eriococcidae in North America, the taxonomic status of the species is questionable.

16. O *Gossyparia spuria* (Modeer, 1778). Summerland, 30.06,1988, *Ulmus* sp.*, females F=3 (3282); Vancouver (UBC), 07.07,1988, *Alnus crispa* ssp. *sinuata* (Regel) Hult.* (Betulaceae), females, first instar nymphs, F=2 (3298). A common pest of *Ulmus* in the Holarctic Region, including Canada (Kosztarab and Kozár 1988; Furniss and Carolin 1977).

IV. Coccidae

17. O *Chloropulvinaria (Pulvinaria) floccifera* (Westwood, 1870). Vancouver (UBC), 07.07,1988, *Prunus laurocerasus* L.* (Rosaceae), on leaves, females, eggs, first instar nymphs, F=3 (3299). A cosmopolitan pest, previously known from Canada (Furniss and Carolin 1977; Hamon and Williams 1984).

18. O *Coccus hesperidum* (Linnaeus, 1758). Victoria (indoor), 13.07,1988, *Citrus* sp.* (Rutaceae), females and nymphs, F=3 (3349). A common cosmopolitan pest, also well known in Canada. In northern regions found in greenhouses only (Hamon and Williams 1984).

19. *Eulecanium tiliae* (Linnaeus, 1758). Vancouver (Stanley Park), 01.07,1988, *Rosa* sp.* (Rosaceae) and *Acer* sp., dead females and male test, F=3 (3294, 3295); Vancouver (Stanley Park), 01.07,1988, *Vaccinium* sp. (Ericaceae), dead females, F=1 (3296); Vancouver (UBC), 07.07,1988, *Alnus crispa* ssp. *sinuata**, dead females, male tests, second instar nymphs, F=3 (3298); Furry Creek, 5 km S of Britannia, 07.07,1988, *Holodiscus discolor*, dead females, male tests, F=1 (3311); Furry Creek, 5 km S of Britannia, 07.07,1988, *Alnus rubra* Bong.* (Betulaceae), female, male, first instar nymphs, F=1 (3312); Victoria (urban), 10.07,1988, *Ulmus* sp., dead females, male tests; F=3 (3313); Victoria (urban), 10.07,1988, *Malus pumila* Mill. (Rosaceae), dead females, male tests, F=1 (3319); Victoria (urban), 10.07,1988, *Prunus domestica* L. (Rosaceae), dead females, male tests, F=1 (3319); Victoria (urban), 10.07,1988, *Prunus domestica*, dead females, male tests, F=3 (3321); Victoria (PFC), 11.07,1988, *Crataegus monogyna* Jacq.* (Rosaceae), female, male, F=1 (3325); Duncan (Chesterfield Rd.), 12.07,1988, *Sorbus* sp.* (Rosaceae), dead females, F=1 (3340); Duncan (Koksilah), 12.07,1988, *Betula papyrifera* Marsh.* (Betulaceae) and *Acer campestre* L.* (Aceraceae), dead females, first instar nymphs, F=1 (3341, 3343); Langford (Savory Rd.), 12.07,1988, *Salix* sp.* (Salicaceae), dead females, male tests, first instar nymphs, F=1 (3346). A common cosmopolitan pest, well known in Canada (Kosztarab and Kozár 1988).

20. O *Neopulvinaria (Pulvinaria) innumerabilis* (Rathvon, 1854). Summerland, 30.06,1988, *Spiraea* sp., dead females, F=1 (3275). Widely distributed in the USA and Canada (Gill 1988; Furniss and Carolin 1977).

21. *Parthenolecanium corni* (Bouché, 1844). Summerland, 30.07,1988, *Cornus* sp. (Cornaceae), dead females, F=1 (3273); Summerland, 30.06,1988, *Spiraea* sp., dead females, first instar nymphs, F=1 (3275); Summerland, 30.06,1988, *Rosa acicularis* Lindl. (Rosaceae), dead females, F=1 (3275); Victoria (Highland Rd.), 12.07,1988, *Acer* sp., dead female, male tests, F=1 (3329). A common pest in the northern hemisphere, including Canada (Furniss and Carolin 1977; Kosztarab and Kozár 1988).

22. O *Parthenolecanium pruinosum* (Coquillett, 1891). Victoria, 13.07,1964, *Veronica* sp. (Scrophulariaceae), from the collection of the Pacific Forestry Centre, FIDS 64.1570.01, (3350). A common pest in North America, including Canada (Gill 1988).

23. O *Parthenolecanium quercifex* (Fitch, 1859). Duncan (Koksilah), 12.07,1988, *Quercus coccinea* Muenchh. (Fagaceae), females, F=2 (3343). This species is morphologically identical with the European species, *P. rufulum* (Cockerell, 1903), but the question of synonomy will require study of the types.

24. O X *Physokermes concolor* Coleman, 1903. Tofino, 12.06,1987, *Picea sitchensis* (Bong.) Carr. (Pinaceae), females, eggs, first instar nymphs, from the PFC reference collection, FIDS 87.349.01, (3350a). This species was identified on the basis of post reproductive females only. There were also several first instar nymphs on the needles and in the female bodies which showed extreme morphological variability. Additional study of young females and first and second instar nymphs of both sexes is needed to determine the range of natural variation of these characters. The species was previously known only from California on *Abies concolor* Hoopes (Pinaceae) (Gill 1988).

25. O X *Physokermes hemicryphus* (Dalman, 1826). Vancouver (Stanley Park), 01.07,1988, *Picea abies* Karst. (Pinaceae), dead females, eggs, first instar nymphs, F=1 (3293); Vancouver (UBC), 07.07,1988, *Picea glauca* (Moench) Voss*, dead females, first instar nymphs, F=2 (3301); Victoria (PFC), 11.07,1988, *Picea engelmannii* Engelm.*, females, eggs, first instar nymphs, F=1 (3324); Duncan (Chesterfield Rd.), 12.07,1988, *Picea abies**, dead females, first instar nymphs, F=3 (3338); Summerland, 07.06,1982, *Picea glauca**, females, from the PFC reference collection, FIDS 82.0115.01, (3351). The latter material needs further study, especially of the first and second instar nymphs, which are the most useful stages for the identification of species of *Physokermes*. Until recently most collections of *Physokermes* in the USA and Canada were identified as *Physokermes piceae* (Schrank) (Gill 1988; Kondo and Moody 1986). Most identifiable lots of *Physokermes* on spruce in the United States have now been shown to be the similar Palearctic species, *P. hemicryphus*, not *P. piceae* (Gill 1988). The same may also be true for Canada, but will require additional collection and study.

26. O X *Physokermes taxifoliae* Coleman, 1903. Duncan (Chesterfield Rd.), 12.07,1988, *Pseudotsuga menziesii* (Mirb.) Franco (Pinaceae), females, eggs, first instar nymphs, F=1 (3334). Well known in California and Oregon (Gill 1988). The first instar nymphs of *P. taxifoliae* are very similar to those of *P. fasciatus* Borchsenius from U.S.S.R. (Central Asia) and *P. inopinatus* Danzig and Kozár from Hungary. However, there are some differences in the female morphology which require further study.

V. Asterolecaniidae

27. *Asterodiaspis variolosa* (Ratzeburg, 1870), Victoria (urban), 10.07,1988, *Quercus* sp.* (Fagaceae), females, eggs, nymphs, F=3 (3315); Langford (Savory Rd.), 12.07,1988, *Quercus garryana* Dougl.*, dead females, eggs, first and second instar nymphs, F=1 (3348). Widely distributed in the USA and Canada (Ferris 1955).

VI. Diaspididae

28. *Carulaspis juniperi* (Bouché, 1851). Summerland, 30.06, 1988, *Thuja plicata* Donn* (Pinaceae), females, eggs, F=2 (3280); Victoria (PFC), 11.07,1988, *Juniperus communis* L.* (Pinaceae), females, eggs, first instar nymphs, F=3 (3328); Duncan (Chesterfield Rd.), 12.07,1988. *Chamaecyparis nootkatensis* (D. Don) Spach* (Pinaceae), females, eggs, first instar nymphs, F=4 (3336). A cosmopolitan pest, widely distributed in North America (Borchsenius 1966; Furniss and Carolin 1977). In early North American literature this species was sometimes referred to as *Carulaspis visci* (Schrank) (Ferris 1937).

29. *Chionaspis pinifoliae* (Fitch, 1856). Summerland, 30.06,1988, *Pinus ponderosa* Laws.* (Pinaceae), second instar nymphs, F=3 (3279); Vancouver (UBC), 07.07,1988, *Pinus* prob. *contorta* Dougl. ex Loudon*, dead females, eggs, first instar nymphs, F=3 (3300); Victoria (urban), 10.07,1988, *Pinus* sp., dead females, F=1 (3316); Victoria (PFC), 11.07,1988, *Pinus* sp. and *Pseudotsuga menziesii*, females, F=1 (3322, 3323); Victoria (PFC), 11.07,1988, *Picea engelmannii*, females, F=1 (3324); Victoria (PFC), 11.07,1988, *Pinus ponderosa*, females, eggs, F=2 (3326); Duncan (Chesterfield Rd), 12.07,1988, *Pseudotsuga menziesii*, females, F=1 (3334); Duncan (Chesterfield Rd.), 12.07,1988, *Pinus mugho* Turra*, females, eggs, F=2 (3335); Duncan (Chesterfield Rd.), 12.07,1988, *Pinus* sp., dead females, F=1 (3337). A widely distributed pest in North America (Borchsenius 1966; Furniss and Carolin 1977).

30. *Lepidosaphes ulmi* (Linnaeus, 1758). Summerland, 30.06,1988, *Cornus* sp., dead females, F=1 (3273); Summerland, 30.06,1988, *Populus balsamifera* L.* (Salicaceae), dead females, first instar nymphs, F=3 (3274); Summerland, 30.06,1988, *Rosa acicularis**, dead females, first instar nymphs, F=3 (3276); Summerland, 30.06,1988, *Malus pumila*, dead females, first instar nymphs, F=3 (3277); Summerland, 30.06,1988, *Ribes cereum* Dougl. (Saxifragaceae), dead females, first instar nymphs, F=4 (3284); Furry Creek, 5 km S of Britannia, 07.07,1988, *Salix sitchensis* Sanson* (Salicaceae), dead females, first instar nymphs, F=2 (3310); Furry Creek, 5 km S of Britannia, 07.07,1988, *Alnus rubra**, dead females, F=1 (3312); Victoria (urban), 10.07,1988, *Crataegus oxyacantha* L.* (Rosaceae) and *Malus pumila*, dead females, first instar nymphs, F=3 (3317, 3318); Langford (Savory Rd.), 12.07,1988, *Holodiscus discolor**, dead females, first instar nymphs, F=3 (3347). Widely distributed pest all over the world (Kosztarab and Kozár 1988; Furniss and Carolin 1977).

31. *Nuculaspis californica* (Coleman, 1903). Summerland, 30.06,1988, *Pinus ponderosa**, females, F=3 (3279); Duncan (Chesterfield Rd), 12.07,1988, *Picea abies*, dead females, F=1 (3338); Summerland, 07.06,1982, *Picea glauca* from the PFC reference collection, FIDS 82.115.01, (3351). Widely distributed pest in North America (Borchsenius 1966; Furniss and Carolin 1977).

32. O *Quadraspidiotus gigas* (Thiem and Gerneck, 1934). Langford (Savory Rd.), 12.07,1988, *Salix* sp.*, dead females, F=1 (3346). Widely distributed pest in the northern hemisphere (Kosztarab and Kozár 1988), but its distribution in North America is not well known.

33. *Quadraspidiotus ostreaeformis* (Curtis, 1843). Duncan (Chesterfield Rd.), 12.07,1988, *Aesculus hippocastanum* L. (Hippocastanaceae), dead females, F=1 (3339). Widely distributed pest all over the world (Kosztarab and Kozár 1988).

34. *Quadraspidiotus perniciosus* (Comstock, 1881). Summerland, 30.06,1988, *Malus pumila*, females, first instar nymphs, F=4 (3277). Widely distributed pest all over the world (Kosztarab and Kozár 1988).

35. O *Rhizaspidiotus dearnessi* (Cockerell, 1898). Summerland, 30.06,1988, *Erigeron filifolius* Nutt.* (Compositae) and *Artemisia frigida**, females, F=1 (3290, 3291). This species is known only from Canada, USA and Mexico (Borchsenius 1966).

36. O X *Stramenaspis kelloggi* (Coleman, 1903). Victoria (PFC), *Pinus* sp., 11.07,1988, females, F=1 (3323). This species was previously known only from the USA (Borchsenius 1966; Furniss and Carolin 1977).

DISCUSSION

Our collection of scale insects in British Columbia yielded 36 species belonging to 6 families, namely Ortheziidae (2), Pseudococcidae (12), Eriococcidae (2), Coccidae (11), Asterolecaniidae (1) and Diaspididae (8). Of the species collected, 16 proved to be new for the scale insect fauna of Canada and 26 are new for British Columbia.

From a zoogeographical point of view the scale-insect fauna of British Columbia is very heterogenous. Boreal or montane species such as *Arctorthezia occidentalis, Heterococcus nudus*, and *Acanthococcus greeni* as well as thermophilous species such as *Anisococcus oregonensis, Phenacoccus capensis, Spilococcus geraniae* or the subtropical *Chloropulvinaria floccifera* are represented in the diverse habitats examined. Our limited collections show that the British Columbia fauna seems to be rich in scale insects, and therefore, deserves more intensive studies.

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NEW RECORDS OF SLENDER WINTER STONEFLIES (PLECOPTERA: CAPNIIDAE) IN BRITISH COLUMBIA

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ABSTRACT

Distribution data for 15 species of Capniidae are presented, supplementing the annotated checklist of Ricker and Scudder (1975). Five species (*Bolshecapnia milami*, *Capnia coloradensis*, *C. petila*, *C. sextuberculata* and *Utacapnia trava*) are reported from British Columbia for the first time.

INTRODUCTION

Since the publication of Ricker and Scudder's (1975) annotated checklist of the Plecoptera of British Columbia, knowledge of the local distribution of the slender winter stoneflies (Capniidae) has increased considerably. Ricker (1943) documented the occurrence of many valley inhabiting species in southwestern British Columbia, but made few visits to higher altitudes during the winter and early spring. In recent years many collections have been made in these habitats, especially in the southern part of the province. However, the central and northern sections of the province remain largely *terra incognita*, although recent collecting in the Yukon allows some interpolation of range information. The following data are largely the result of collections made by myself and colleagues; these specimens are in the Spencer Entomological Museum, University of British Columbia. However, collections in Rocky Mountain parks made by D.B. Donald and R.S. Anderson of the Canadian Wildlife Service are also included; the lentic stoneflies of these collections were reported in a summary fashion in Donald and Anderson (1980). These specimens are in the collections of the Canadian Wildlife Service, Edmonton, Alberta.

NOMENCLATURE

The nomenclature follows Zwick (1973) and differs from that of Ricker and Scudder (1975) in the recognition of *Mesocapnia* and *Utacapnia* as separate genera, rather than as subgenera of *Capnia*. Ricker and Scudder also treated *C. gracilaria* as *C. promota* Frison.

SPECIES LIST

This list includes only those records that extend or fill in gaps in ranges as indicated by the list of Ricker and Scudder (1975). Many records in the following list are from E.C. Manning Provincial Park, which is therefore abbreviated (MPP) following the initial record. Each record is followed by the collector's name or initials in parentheses. The key to initials is as follows: H&AB – Hugh and Aileen Brock; RJC – R.J. Cannings; SGC – S.G. Cannings; DBD – D.B. Donald; CSG – C.S. Guppy; LM – L. Moore [Vasington]; RM – R. Moore.

Bolshecapnia milami (Nebeker and Gaufin)

Manning Provincial Park, Similkameen R., near park headquarters, 1190 m, 11.ii.1976 (SGC), 19.iii.1982 (SGC); MPP, Similkameen R. at Chuwanten Cr., 1190 m, 1.iii.1981 (SGC).

These are the first records for British Columbia; this species was previously known from the Rocky Mountains of Alberta and northern United States (Donald and Anderson 1977, Baumann *et al.* 1977).

B. sasquatchi (Ricker)

MPP, Similkameen R., Cambie Cr. ski area, 1350 m, 19.iii.1983 (SGC); MPP, Skagit R., 838 m, 18.ii.1983 (SGC).

Capnia cheama Ricker

Bulkley R., Smithers, 19.iv.1989 (D. Weir); Sedan Cr., 10 km W of Kitwanga, 6.iv.1989 (D. Weir); Skeena R., 5 km W of Kitwanga, 2.iv.1989 (D. Weir).

These records fill in a huge gap between the type locality near Chilliwack, B.C. and a record from Rampart House in the northern Yukon (specimens in Canadian National Collection, Ottawa). This rare species of large streams and rivers is also known from the Rocky Mountains of Alberta and Montana (Baumann *et al.* 1977).

Capnia coloradensis Claassen

Kelsall L. area, Haines Road, 28.iv.1981 (S. Hannon), 2.v.1982 (M. Taitt); MPP, Similkameen R., at Chuwanten Cr., 1.iii.1981 (SGC); MPP, Similkameen R., near park headquarters, 1190 m, 11.ii.1976 (SGC), 16.iii.1980 (RJC), 14.ii.1982 (SGC), 19.iii.1982 (SGC); Shingle Cr., 21.iii.1982 (SGC); Similkameen R., Princeton, 19.iii.1982 (SGC); Similkameen R., 2 km below Similkameen Falls, 20.ii.1982 (SGC), 19.iii.1982 (SGC); Skeena R., 5 km W of Kitwanga, 22.iii.1989 (D. Weir).

These are the first records for British Columbia, and extend the known distribution into the Coast and Cascade Mountains for the entire length of the province. Baumann *et al.* (1977) give the range as the Rocky Mountains of the United States, and Flannagan and Cobb (1983) extended it as far east as Manitoba on the Canadian Great Plains.

C. elongata Claassen

Mamquam R., 1.6 km upstream of Squamish R., 4.ii.1979 (SGC).

C. gracilaria Claassen

Ellis Cr., Penticton, 10.iii.1985 (J.A. Garland); Garibaldi Provincial Park, Garibaldi L., 1.vii.1976 (K. Cehak), 13.vi.1981 (SGC); Keremeos Cr., 15.vii.1976 (SGC); MPP, Similkameen R. near park headquarters, 16.iii.1980 (RJC), 14.ii.1982 (SGC, R&LM), 19.iii.1982 (SGC), 19.iii.1983 (SGC), 6.iii.1983 (SGC); *ibid.*, 1250 m (first bridge south of pass), 6.iii.1983; *ibid.*, Cambie Cr. ski area, 1350 m, 19.iii.1983 (SGC); *ibid.*, 24.iii.1984 (H&AB); *ibid.*, 2.iv.1989 (SGC, H&AB); MPP, Sumallo R., 14.iii.1982 (SGC), 19.iii.1982 (SGC); Penticton Cr., 21.iii.1982 (SGC); Shatford Cr., 21.iii.1982 (SGC); Shingle Cr., 21.iii.1982 (SGC); Similkameen R., Princeton, 19.iii.1982 (SGC); Similkameen R., 2 km below Similkameen Falls, 19.iii.1982 (SGC), Skeena R., 5 km W of Kitwanga, 22.iii.1989 (D.Weir), 2.iv.1989 (D. Weir).

After *C. nana*, this is probably the commonest montane *Capnia* in British Columbia. Although these records are all from the southern end of the province, *C. gracilaria* is also common in the southern Yukon (unpublished data), so it is undoubtedly widely distributed in British Columbia. Baumann *et al.* (1977) give its range as the Coast, Cascade and Rocky Mountains and the Northern Great Plains; in Canada it reaches as far east as Manitoba (Flannagan and Cobb 1983).

C. melia Frison

Botanie L., Lytton, beside creek, 1067 m, 31.iii.1983 (CSG); Cypress Provincial Park, 13.iii.1982 (SGC); Garibaldi Provincial Park, Diamond Head Trail, 1067-1372 m, 5.iv.1981 (SGC), 17.iv.1981 (SGC); Keremeos Cr., 15.ii.1976 (SGC); MPP, Fat Dog Cr., 28.iv.1985, H&AB; MPP, Similkameen R., near park headquarters, 14.ii.1982 (SGC, R&LM); 19.iii.1982 (SGC), 6.iii.1983 (SGC), 19.iii.1983 (SGC); MPP, Similkameen R., "Cambie Cr." ski area, 2.iv.1989 (SGC); MPP, Sumallo R., 14.ii.1982 (SGC).

C. nana Claassen

Botanie L., Lytton, beside creek, 1067 m, 31.iii.1983 (CSG); Cypress Provincial Park, 1000 m, 4.iv.1980 (RJC); Ellis Cr., Penticton, 10.iii.1985 (J.A. Garland); Glacier National Park, Loop Brook, 1170 m, 18.iv.1980 (J.G. Woods); Keremeos Cr., 15.ii.1975 (SGC); MPP, Castle Cr., 11.ii.1979 (SGC), 14.ii.1982 (SGC); MPP, Chuwanten Cr., 1.iii.1981 (SGC, R&LM), 14.ii.1982 (SGC); MPP, Fat Dog Cr., 6.iii.1983 (SGC), 19.iii.1983 (SGC), 28.iv.1985 (H&AB); MPP, Fat Dog Cr., upper headwaters, 1524-1830 m, 28.ii.1981 (SGC); Flash L. and "Flash Cr.", 18.ii.1983 (SGC); MPP, Monument 83 Trail, 1220-1372 m, 1.iii.1981 (SGC, LM); MPP, Similkameen R., 17.ii.1983 (SGC); *ibid.*, "Cambie Cr." ski area, 1350 m, 16.ii.1980 (SGC), 16.iii.1980 (SGC), 14.iii.1981 (C. Edman), 15.iii.1981 (C. Edman), 19.iii.1983 (SGC), 24.iii.1984 (H&AB), 2.iv.1989 (SGC, H&AB); *ibid.*, 1400-1450 m, 19.iii.1983 (SGC); MPP, Similkameen R., at Chuwanten Cr., 17.ii.1980 (SGC), 1.iii.1981 (SGC); *ibid.*, near park headquarters, 1190 m, 16.ii.1976 (SGC), 11.ii.1979 (SGC), 16.iii.1980 (RJC), 14.ii.1982 (SGC, R&LM), 19.iii.1982 (SGC), 6.iii.1983 (SGC), 19.iii.1983 (SGC); *ibid.* near confluence of Pasayten R., 20.ii.1982 (SGC); *ibid.*, 1250 m, first bridge south of Allison Pass, 6.iii.1983 (SGC); Paulson Summit, near Castlegar, 26.ii.1982 (P. Wood); Shingle Cr., Penticton, 21.iii.1982 (SGC); Skeena R., 5 km W of Kitwanga, 2.iv.1989 (D. Weir); Wells Gray Provincial Park, Blackwater Cr., 701 m, 24.ii.1985 (T. Goward); Wells Gray Provincial Park, McLeod Hill, 853 m, 16.iii.1985 (T. Goward).

This is by far the most abundant capniid of small mountain streams in British Columbia; the fact that Ricker and Scudder (1975) report only three previous records is an indication that few entomologists have collected in the mountains in the early spring.

C. petila Jewett

Botanie L., Lytton, beside creek, 1067 m, 31.iii.1983 (CSG); MPP, Similkameen R., "Cambie Cr." ski area, 24.iii.1984 (H&AB), 2.iv.1989 (SGC, H&AB), Skeena R., 5 km W of Kitwanga, 22.iii.1989 (D. Weir); 2.iv.1989 (D. Weir).

These are the first records for British Columbia. This is a relatively rare species, but is widely distributed in the Western Cordillera. Baumann *et al.* (1977) give the range as the Cascade and Rocky Mountains (north to Banff) and recent unpublished records from the southwestern Yukon extend the range throughout British Columbia. It appears to emerge later than *C. nana* and other, more common, congeners.

C. sextuberculata Jewett

Botanie L., Lytton, beside creek, 1067 m, 31.iii.1983 (CSG).

This is the first record for British Columbia; previously recorded from the Cascade Mountains of Oregon and the Rocky Mountains of Alberta and Montana (Baumann *et al.* 1977).

Isocapnia spenceri Ricker

Atnarko R., spawning channel near Stuie, 11.iv.1989 (M. Wigle).

Mesocapnia autumna (Baumann and Gaufin)

Similkameen R., Keremeos, 9.x.1982 (SGC); Similkameen R., Princeton, 11.x.1982 (SGC).

Mesocapnia oenone (Neave)

Elk Lake Provincial Park, lower Elk Lake, 1735 m, 28.viii.1977 (DBD); MPP, Similkameen R., near park headquarters, 1190 m, 12.x.1981 (SGC); Hamber Provincial Park, Fortress L., 1337 m, 26.ix.1979 (DBD).

Utacapnia columbiana (Claassen)

Atlin L., Warm Bay, found dead in *Picea* sap, 22.vi.1982 (SGC); Bulkley R., Smithers, 19.iv.1989 (D. Weir); Sedan Cr., 10 km W of Kitwanga, 6.iv.1989 (D. Weir); Skeena R., 5 km W of Kitwanga, 22.iii.1989 (D. Weir); 2.iv.1989 (D. Weir); Tetsa R., campground on Alaska Highway, 16.vi.1982 (SGC).

U. trava (Nebeker and Gaufin)

Akolkolex Cr., at Columbia R., 460 m, 24.ii.1980 (J.G. Woods); Beatty L., 31.vii.1977 (DBD); MPP, Lightning Lakes, beside open section of lake, 1220 m, 18.ii.1983 (SGC); MPP, Similkameen R., at Chuwanten Cr., 1.iii.1981 (SGC); *ibid.*, near park headquarters, 1190 m, 11.ii.1979 (SGC), 14.ii.1982 (SGC, R&LM), 6.iii.1983 (SGC); *ibid.*, near Pasayten R., 20.ii.1982 (SGC); Mount Robson Provincial Park, Kinney L., 985 m, 9.vi.1979 (DBD); Mount Robson Provincial Park, Yellowhead Lake, 1104 m, 23.v.1976 (DBD); Similkameen R., at Bromley Provincial Park, 19.iii.1982 (SGC); *ibid.*, Keremeos, 19.iii.1982 (SGC); *ibid.*, Princeton, 19.iii.1982 (SGC); *ibid.*, 2 km below Similkameen Falls, 20.ii.1982, 19.iii.1982 (SGC).

These are the first detailed records for the province, although Donald and Anderson (1980) and Donald and Patriquin (1983) used British Columbia records in analyses of lentic stoneflies. These records extend the known distribution into the Cascade Mountains. Baumann *et al.* (1977) give the range as the Canadian and Northern Rocky Mountains (north to Banff); Dosdall and Lemkuhl (1979) and Flannagan and Cobb (1983) extended it onto the Canadian Great Plains.

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CHALCIDOIDS (HYMENOPTERA) REARED FROM *ARTEMISIA TRIDENTATA* (ASTERACEAE) GALLS IN BRITISH COLUMBIA, CANADA

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While on a collecting trip in British Columbia (Canada), I took 39 stem galls from sagebrush, *Artemisia tridentata* (Nuttall) (Asteraceae). Four chalcidoid spp. (Hymenoptera) emerged from the galls, representing four families. This paper reports the times of emergence after collection, diameter and location of exit holes and wasp's lifespans.

The galls were collected along a roadside, 15 kms NW of Lower Nicola, B.C., on 22 June 1988 and placed in 35 ml plastic cups. The ovate galls were located mostly on the basal two-thirds of the shoots. Sixteen of the reared galls (41%) produced chalcidoids. The galls, which were kept at room temperature were observed daily and were not moistened, to prevent the

spread of fungi. No food was provided to the wasps. The maximum lengths and widths to it (= width) were measured for the 14 galls from which insects emerged. They averaged 12.1 mm long (sd = 2.8, range = 9-18) and 7.7 mm wide (sd = 2.4, range = 7-12). All galls were dissected 211 days after collection; which was 180 days after the last emergence. The dissected galls were examined for remains of insect associates within the gall. Puparia, or their remains, possibly of tephridids were found inside most galls. For each taxon, only the ranges for parameters are given because of the small sample size. The specimens, labelled VOUCHER SPECIMEN, are deposited in the Systematic Entomology Laboratory (Beltsville, MD, USA).

***Torymus citripes* (Huber) (Torymidae)**

Sample size: two males, five females. Time of emergence: males, 11 and 14 days; females, 3 to 14. In five cases the emergence hole was located at the apical third (one male emerged at the very apex); two cases with no gall association. Exit hole diameter varied from 0.72 to over 1.85 mm; most within 1 - 2 mm. Lifespan, males three to four days; females three to six. This wasp is widespread in western North America, reported in association with *Helianthus lenticularis* (Compositae) and parasitizes the tephritid flies, *Euaresta bullans* (Wied.), *Eutreta diana* (O. S.), and *Gymnocarena tricolor* (Doane) (Krombein *et al.* 1979).

Two dwarf males emerged and they appear to be conspecific (Grisell, *pers. comm.*); their data as follows: time of emergence, 11 and 14 days; emergence hole at apex, diameter range, 1.05 - 1.14 mm; lifespan, two to three days.

***Eurytoma* sp. (Eurytomidae)**

Sample size: one male, four females. Time of emergence: male, 15 days; females 9 to 14. In all cases, the emergence hole was located at the apical third (one female emerged at the very apex). Exit hole diameter range: females 0.66 to over 1.54 mm; male, 0.43 mm. Lifespan, male two days; females four to seven. .LP *Eupelmus* sp. (Eupelmidae)
Sample size: one female. Time of emergence, 27 days; emerged at apical third apex. Exit hole, 0.54 mm. Lifespan, five days.

***Sympiesis* sp. (?) (Eulophidae)**

Sample size: one male (?). The gall has a large, (≥ 4.13 mm) orifice (apparently emergence hole of the gall former) located at the apical third. Lifespan, 15 days.

Several species of torymids, eupelmids, pteromalids, platygasterids and encyrtids (Hymenoptera) have been reared from galls of *A. tridentata* (Jones *et al.* 1983). Although often torymids are ectoparasites of gall forming insects in the Cecidomyiidae and the Tephritidae (Diptera) (Yoshimoto 1984), their biologies can not be inferred without more extensive and detailed observations (Grisell 1988). One species, *Torymus aeneoscapus* Huber, has been determined to be a parasitoid of gall-forming midges in Idaho (Jones *et al.* 1983). All of the insects herein reported are new insect association records for *A. tridentata* for British Columbia.

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THE APHIDS (HOMOPTERA:APHIDIDAE) OF BRITISH COLUMBIA 19. FURTHER ADDITIONS

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ABSTRACT

Four species of aphids and new host records are added to the taxonomic list of the aphids of British Columbia.

INTRODUCTION

Three hundred ninety-seven species of aphids collected from 1052 hosts or in traps, and 2043 aphid-host plant associations were recorded in fourteen previous lists of the aphids of British Columbia (Forbes, Frazer and MacCarthy 1973; Forbes, Frazer and Chan 1974; Forbes and Chan 1976, 1978, 1980, 1981, 1983, 1984, 1985, 1986a, 1986b, 1987, 1988; Forbes, Chan and Foottit 1982). The present list adds 4 aphid species (indicated with an asterisk in the list) and 183 aphid-host plant associations to the previous lists. Seventy-one of the new aphid-host plant associations are plant species not recorded before. As *Aphis herachella* Davis is synonymized with *A. helianthi* Monell (Addicott 1981), the additions bring the number of known aphid species in British Columbia to 400. Aphids have now been collected from 1124 different host plants and the total number of aphid-host plant associations is 2233.

Two of the four newly recorded aphid species are of economic importance. The Russian wheat aphid, *Diuraphis noxia* (Mordvilko ex Kurdjumov), was first detected in Creston in November 1988, as a result of a survey conducted in the winter wheat fields and grass seed fields. It poses a serious threat to production of cereals and grass seeds in British Columbia. The tobacco aphid, *Myzus nicotianae* Blackman (red form), feeding on tobacco in Victoria is the first confirmed record of this aphid in Canada. It has the same host range as *Myzus persicae* (Sulzer), and was shown to be a vector of beet western yellows and potato leaf roll viruses (unpublished data).

The aphid names are listed alphabetically by species and are in conformity with Eastop and Hille Ris Lambers (1976), except *Glabromyzus schlingeri* Hille Ris Lambers has been changed to *Utamphorophora schlingeri* (Hille Ris Lambers) based on Cook's finding (1984). The location of a new collection site is given in Table I. The reference point is the same as that shown on the map which accompanies the basic list (Forbes, Frazer and MacCarthy 1973).

TABLE 1.

Collection site of aphids, with airline distance from reference point.

Locality	Reference Point	Dir	Distance km	Distance mi
Garvin Creek	Prince George	NW	13	8

LIST OF SPECIES

ALNIFOLIAE (Williams 1911), PROCIPHILUS
Pinus monticola: Oliver, Sep24/88.
*ANTIRRHINII (Macchiati 1883), MYZUS
Datura stramonium: Vancouver (CDA), Oct18/88.

ASCALONICUS Doncaster 1946, MYZUS
Alchemilla vulgaris: Vancouver (CDA), Feb20/89.
Anthriscus cerefolium: Vancouver (CDA), Feb20/89.
Fragaria vesca 'Semperflorens': Vancouver (CDA), Feb20/89.
Horminum pyrenaicum: Vancouver (UBC), Apr15/88.
Potentilla alba: Vancouver (UBC), Apr15/88.
Stellaria media: Vancouver (UBC), Sep16/88.
Verbena 'Ideal Florist': Vancouver (CDA), Mar3/89.
ASPARAGI (Mordvilko 1929), BRACHYCORYNELLA
Asparagus officinalis: Vancouver (CDA), Dec29/88.
AVELLANAE (Schrank 1801), CORYLOBIUM
Corylus maxima 'Purpurea': Vancouver (UBC), Apr26/88, May30/88.
BERBERIDIS (Kaltenbach 1843), LIOSOMAPHIS
Berberis actinacantha: Vancouver (UBC), Jul20/88.
BETULAE (Koch 1855), EUCERAPHIS
Betula pendula: Vancouver (UBC), Sep8/87, Sep29/87.
BRASSICAE (Linnaeus 1758), BREVICORYNE
Brassica oleracea var. *gemmifera 'Jade Cross'*: Vancouver (UBC), Sep30/88.
BREVISPINOSA (Gillette & Palmer 1924), CINARA
Pinus contorta: Lac La Hache, Jun27/80.
CALLIPTERUS (Hartig 1841), CALLIPTERINELLA
Betula pendula: Vancouver (UBC), Sep8/87.
CAPILANOENSE Robinson 1969, AULACORTHUM
Rubus spectabilis: Peace Arch Park, Aug1/88; Vancouver, Jun21/88.
CARNOSUM (Buckton 1876), MICROLOPHIUM
Urtica dioica: Peace Arch Park, Aug1/88.
CERASI (Fabricius 1775), MYZUS
Prunus domestica: Pemberton, Apr12/88.
CERTUS (Walker 1849), MYZUS
Gomphrena globosa: Vancouver (CDA), Oct18/88.
Nicotiana clevelandii: Vancouver (CDA), Mar1/89.
CIRCUMFLEXUM (Buckton 1876), AULACORTHUM
Akebia quinata: Vancouver (UBC), Jun14/88.
Aquilegia x *hybrida 'Dragonfly Mix'*: Vancouver (UBC), Nov22/88.
Gomphrena globosa: Vancouver (CDA), Feb20/89.
Schizophragma hydrangeoides: Vancouver (UBC), Jun30/88, Aug5/88.
Vitis vinifera 'Concord': Vancouver, May29/88.
CITRICOLA van der Goot 1912, APHIS
Stranvaesia davidiana: Vancouver (UBC), Jun14/88.
COLORADENSIS (Gillette 1917), CINARA
Picea glauca: Garvin Creek, Sep4/87.
COWENI (Cockerell 1905), TAMALIA
Arctostaphylos uva-ursi ssp. *stipitata*: Vancouver (UBC), Sep30/88.
Arctostaphylos uva-ursi 'Vancouver Jade': Vancouver, Sep15/88.
DORSATUM Richards 1967, AULACORTHUM
Gaultheria shallon: Vancouver (UBC), Apr15/87, May4/88, Jun14/88, Jun30/88.
ENIGMAE Hottes & Frison 1931, RHOPALOSIPHUM
Typha orientalis: Vancouver (UBC), Sep29/87, Nov24/87.
EUPHORBIAE (Thomas 1878), MACROSIPHUM
Arachis hypogaea 'Early Spanish': Vancouver (CDA), Feb20/89.
Chenopodium amaranticolor: Vancouver (CDA), Mar1/89.
Eucalyptus cinerea: Vancouver (UBC), Aug24/88.

Ruta graveolens: Vancouver (UBC), Jun8/88.
Ulmus americana: Burnaby, Jul21/84.
FABAE Scopoli 1763, APHIS
Dracunculus vulgaris: Vancouver, Jun18/88.
Rheum rhabarbarum: Vancouver, Jun19/88.
FOENICULI (Passerini 1860), HYADAPHIS
Lonicera 'Dropmore Scarlet': Vancouver (UBC), Sep30/88.
FRAGAEFOLII (Cockerell 1901), CHAETOSIPHON
Potentilla anserina: Goldstream, Aug20/59; Sea Island, Aug21/59.
FRAGARIAE (Walker 1848), SITOBION
Typha orientalis: Vancouver (UBC), Nov24/87.
GENTNERI (Mason 1947), FIMBRIAPHIS
Crataegus monogyna: Vancouver, Apr26/88.
GILLETTEI Davidson 1915, EUCERAPHIS
Alnus rubra: Vancouver (UBC), Sep28/87, Oct8/87, Oct9/87.
HELICHRYSI (Kaltenbach 1843), BRACHYCAUDUS
Myosotidium hortensia: Vancouver (UBC), Feb24/88.
Prunus cerasifera 'Atropurpurea': Vancouver, Jun23/88.
HOLODISCI Robinson 1984, APHIS
Holodiscus discolor: Vancouver (UBC), Jun9/88.
HUMBOLDTI (Essig 1941), UTAMPHOROPHORA
Physocarpus malvaceus: Vancouver (UBC), Nov4/88.
HUMULI (Schrank 1801), PHORODON
Prunus cerasifera 'Atropurpurea': Kamloops, Jun26/88; Vancouver, Jun23/88.
IDAEI van der Goot 1912, APHIS
Rubus idaeus: Vancouver, Aug25/60.
LACTUCAE (Passerini 1860), ACYRTHOSIPHON
Lactuca serriola: Kamloops, Jun26/88.
LONGICAUDA (Richards 1963), EOESSIGIA
Spiraea douglasii ssp. *menziesii*: Vancouver (UBC), Jun8/88, Jul9/88.
LONICERAE (Siebold 1839), RHOPALOMYZUS
Lonicera 'Dropmore Scarlet': Vancouver (UBC), Sep30/88.
MACROSIPHUM (Wilson 1912), ACYRTHOSIPHON
Amelanchier laevis: Vancouver (UBC), Jul22/88.
MENZIESIAE (Robinson 1969), ILLINOIA
Menziesia ferruginea ssp. *ferruginea*: Mount Seymour, Sep3/88.
MODESTUM (Hottes 1926), MYZODIUM
Polytrichum juniperinum: Vancouver (UBC), Sep8/87.
NERVATA (Gillette 1908), WAHLGRENIELLA
Arbutus menziesii: Vancouver (UBC), Dec16/88.
*NICOTIANAE Blackman 1987, MYZUS
Alchemilla vulgaris: Vancouver (CDA), Sep3/88.
Anthriscus cerefolium: Vancouver (CDA), Nov9/88.
Apium graveolens: Vancouver (CDA), Nov9/88.
Arachis hypogaea 'Early Spanish': Vancouver (CDA), Nov9/88.
Asparagus officinalis: Vancouver (CDA), Nov9/88.
Beta vulgaris: Vancouver (CDA), Dec9/88.
Brassica juncea 'Florida Broadleaf': Vancouver (CDA), Sep3/88.
Brassica juncea 'Tendergreen Mustard Spinach': Vancouver (CDA), Sep3/88.
Brassica pekinensis: Vancouver (CDA), Sep3/88.
Capsella bursa-pastoris: Vancouver (CDA), Sep12/88.
Catharanthus roseus: Vancouver (CDA), Sep3/88.
Chenopodium capitatum: Vancouver (CDA), Nov9/88.
Chenopodium murale: Vancouver (CDA), Nov9/88.
Chenopodium quinoa: Vancouver (CDA), Nov9/88.

Claytonia sibirica var. *sibirica*: Vancouver (CDA), Feb20/89.
Cucumis sativus 'Straight Eight': Vancouver (CDA), Feb28/89.
Datura stramonium: Vancouver (CDA), Sep3/88.
Daucus carota: Vancouver (CDA), Nov9/88.
Dianthus barbatus: Vancouver (CDA), Jan5/89.
Fragaria vesca 'Semperflorens': Vancouver (CDA), Nov9/88.
Lactuca sativa: Vancouver (CDA), Jan5/89.
Lycopersicon lycopersicum 'Rutgers': Vancouver (CDA), Jan15/89.
Mimosa pudica: Vancouver (CDA), Feb20/89.
Nicotiana benthamiana: Vancouver (CDA), Sep26/88.
Nicotiana clevelandii: Vancouver (CDA), Sep26/88.
Nicotiana debneyi: Vancouver (CDA), Sep26/88.
Nicotiana glutinosa: Vancouver (CDA), Sep26/88.
Nicotiana rustica: Vancouver (CDA), Sep26/88.
Nicotiana sp.: Victoria, Jun15/88.
Nicotiana sylvestris: Vancouver (CDA), Sep26/88.
Nicotiana tabacum 'Harrownova': Vancouver (CDA), Oct10/88.
Nicotiana tabacum 'Havana 425': Vancouver (CDA), Oct10/88.
Nicotiana tabacum 'Samsun': Vancouver (CDA), Oct10/88.
Nicotiana tabacum 'White Burley': Vancouver (CDA), Oct10/88.
Nicotiana tabacum 'Xanthi': Vancouver (CDA), Oct10/88.
Petunia 'Coral Magic': Vancouver (CDA), Sep3/88.
Physalis pubescens: Vancouver (CDA), Sep3/88.
Plantago lanceolata: Vancouver (CDA), Jan5/89.
Plantago major: Vancouver (CDA), Jan26/89.
Raphanus sativus: Vancouver (CDA), Dec9/88.
Solanum tuberosum: Vancouver (CDA), Sep3/88.
Verbena 'Ideal Florist': Vancouver (CDA), Feb28/89.
Verbesina encelioides: Vancouver (CDA), Jan5/89.
Vicia faba: Vancouver (CDA), Mar1/89.
Zinnia elegans: Vancouver (CDA), Sep3/88.

*NIGRA (Wilson 1919), CINARA
Pinus contorta: Quesnel, Aug11/80.

*NOXIA (Mordvilko ex Kurdjumov 1913), DIURAPHIS
Phleum pratense: Creston, Nov23/88.
Triticum x *aestivum*: Creston, Nov23/88.

NYMPHAEAE (Linnaeus 1761), RHOPALOSIPHUM
Anthriscus cerefolium: Vancouver (CDA), Feb20/89.
Lemna minor: Vancouver (UBC), Sep23/88.

ORNATUS Laing 1932, MYZUS
Abelia x *grandiflora*: Vancouver (CDA), Dec9/88.
Anthriscus cerefolium: Vancouver (CDA), Mar8/89.
Capsella bursa-pastoris: Vancouver (UBC), Feb23/88.
Catharanthus roseus: Vancouver (CDA), Feb20/89.
Euonymus japonica 'Albo-marginata': Vancouver (UBC), Jan5/89.
Fatsia japonica: Vancouver (UBC), Jan26/89.
Garrya elliptica: Vancouver (UBC), Dec16/88.
Lactuca sativa: Vancouver (CDA), Jan13/89, Feb20/89.
Lavandula angustifolia ssp. *angustifolia*: Vancouver (UBC), Jan26/89.
Oxalis adenophylla: Vancouver (UBC), Jul20/88.
Plantago lanceolata: Vancouver (CDA), Jan26/89.
Potentilla fruticosa: Vancouver (UBC), Jun9/88.
Rumex obtusifolius ssp. *obtusifolius*: Vancouver (UBC), Feb23/88.

PARVIFOLII Richards 1967, MACROSIPHUM
Vaccinium alaskaense: Mount Seymour, Sep3/88.

PERGANDEI (Wilson 1919), CINARA
Pinus contorta: Williams Lake, Jun18/80.
PERSICAE (Sulzer 1776), MYZUS
Alchemilla vulgaris: Vancouver (CDA), Oct18/88.
Arachis hypogaea 'Early Spanish': Vancouver (CDA), Oct18/88.
Brassica juncea 'Florida Broadleaf': Vancouver (CDA), Oct18/88.
Brassica juncea 'Tendergreen Mustard Spinach': Vancouver (CDA), Oct18/88.
Brassica oleracea var. *gemmifera 'Jade Cross'*: Vancouver (UBC), Sep30/88.
Brassica pekinensis: Vancouver (CDA), Oct18/88.
Catharanthus roseus: Vancouver (CDA), Feb20/89.
Chenopodium amaranticolor: Vancouver (CDA), Feb20/89.
Chenopodium capitatum: Vancouver (CDA), Feb20/89.
Chenopodium murale: Vancouver (CDA), Feb20/89.
Chenopodium quinoa: Vancouver (CDA), Feb20/89.
Cucumis sativus 'Straight Eight': Vancouver (CDA), Nov21/88.
Dianthus barbatus: Vancouver (CDA), Nov21/88.
Fragaria vesca 'Semperflorens': Vancouver (CDA), Nov21/88.
Lycopersicon lycopersicum 'Rutgers': Vancouver (CDA), Nov21/88.
Nicotiana benthamiana: Vancouver (CDA), Nov21/88.
Nicotiana clevelandii: Vancouver (CDA), Nov21/88.
Nicotiana debneyi: Vancouver (UBC), Nov21/88.
Nicotiana rustica: Vancouver (CDA), Nov21/88.
Nicotiana sylvestris: Vancouver (CDA), Nov21/88.
Nicotiana tabacum 'Xanthi': Vancouver (CDA), Nov21/88.
Petunia 'Coral Magic': Vancouver (CDA), Feb20/89.
Plantago lanceolata: Vancouver (CDA), Jan15/89.
Raphanus sativus: Vancouver (CDA), Sep9/88.
Solanum tuberosum: Surrey, Aug15/88.
Verbena 'Ideal Florist': Vancouver (CDA), Jan15/89.
Verbesina encelioides: Vancouver (CDA), Jan15/89.
PISUM (Harris 1776), ACYRTHOSIPHON
Arachis hypogaea 'Early Spanish': Vancouver (CDA), Feb20/89.
POMI de Geer 1773, APHIS
Photinia x *fraseri*: Richmond, Jul14/88.
PRUNI (Geoffroy 1762), HYALOPTERUS
Typha orientalis: Vancouver (UBC), Aug25/87.
PSEUDOTAXIFOLIAE Palmer 1952, CINARA
Pseudotsuga menziesii: Garvin Creek, Sep4/87.
PTERINIGRUM Richards 1972, AULACORTHUM
Akebia quinata: Vancouver (UBC), Jun14/88, Nov17/88.
Alchemilla vulgaris: Vancouver (UBC), Nov17/88.
QUADRITUBERCULATA (Kaltenbach 1843), BETULAPHIS
Betula pendula: Vancouver (UBC), Sep8/87.
RHAMNI (Clarke 1903), SITOBION
Rhamnus purshiana: Vancouver (UBC), Nov5/88.
RIBISNIGRI (Mosley 1841), NASONOVIA
Lapsana communis: Vancouver, Jun6/88.
ROSAE (Linnaeus 1758), MACROSIPHUM
Rosa 'Peace': Vancouver (UBC), Jan26/89.
Rosa 'Playboy': Vancouver (UBC), Mar21/88.
Rosa rugosa 'Rubra': Vancouver (UBC), Nov17/88.
Rosa 'Vienna Woods': Vancouver (UBC), Mar21/88.
ROSARUM (Kaltenbach 1843), MYZAPHIS
Potentilla fruticosa: Vancouver, Jun25/88.
Rosa rubrifolia: Vancouver (UBC), Jun9/88.

SAMBUCI Linnaeus 1758, APHIS
Sambucus nigra: Vancouver (UBC), Jun8/88.
SCHLINGERI (Hille Ris Lambers 1966), UTAMPHOROPHORA
Juncus effusus var. *pacificus*: Vancouver (CDA), Jan13/89.
SOLANI (Kaltenbach 1843), AULACORTHUM
Anthriscus cerefolium: Vancouver (CDA), Feb20/89.
Arachis hypogaea 'Early Spanish': Vancouver (CDA), Nov9/88.
Camassia cusickii: Vancouver (UBC), Apr15/88.
Chenopodium capitatum: Vancouver (CDA), Mar1/89.
Chenopodium murale: Vancouver (CDA), Mar1/89.
Chenopodium quinoa: Vancouver (CDA), Mar1/89.
Cyclamen persicum: Vancouver, Jun11/88.
Davidia involucrata: Vancouver (UBC), Jun14/88.
Nicotiana clevelandii: Vancouver (CDA), Jan15/89.
Nicotiana debneyi: Vancouver (UBC), Feb20/89.
Potentilla alba: Vancouver (UBC), Apr15/88.
STAPHYLEAE (Koch 1854), RHOPALOSIPHONINUS
Abelia x *grandiflora 'Select'*: Vancouver (UBC), Feb24/88.
Akebia quinata: Vancouver (UBC), Jun14/88.
Alstroemeria chilensis: Vancouver (UBC), Feb24/88.
Anthriscus cerefolium : Vancouver (CDA), Mar3/89.
Apium graveolens: Vancouver (CDA), Jan26/89.
Artemisia stelleriana: Vancouver (UBC), Feb24/88.
Arum pictum: Vancouver (UBC), Feb24/88.
Aucuba japonica var. *borealis*: Vancouver (UBC), Feb24/88.
Baccharis magellanica: Vancouver (UBC), Feb24/88.
Bergenia stracheyi: Vancouver (UBC), Feb24/88.
Campanula punctata: Vancouver (UBC), Jan5/89.
Campanula raddeana: Vancouver (UBC), Feb14/89.
Cephalaria gigantea: Vancouver (UBC), Feb24/88.
Cotyledon orbiculata: Vancouver (UBC), Feb24/88.
Dianthus giganteus ssp. *banaticus*: Vancouver (UBC), Jan5/89.
Dichelostemma volubile: Vancouver (UBC), Feb24/88.
Draba lindensii: Vancouver (UBC), Feb24/88.
Eucomis bicolor: Vancouver (UBC), Jan5/89.
Euonymus fortunei var. *radicans*: Vancouver (UBC), Feb14/89.
Glaucium corniculatum: Vancouver (UBC), Feb24/88.
Hebe 'Quick Silver': Vancouver (UBC), Feb24/88.
Helleborus orientalis: Vancouver (UBC), Feb24/88.
Hesperis matronalis: Vancouver (UBC), Mar21/88, Apr7/88.
Iris aucheri: Vancouver (UBC), Feb24/88.
Iris warleyensis: Vancouver (UBC), Feb24/88.
Lapeirousia anceps: Vancouver (UBC), Feb24/88.
Lavatera cachemiriana: Vancouver (UBC), Feb24/88.
Luetkea pectinata: Vancouver (UBC), Feb14/89.
Notholirion bulbiferum: Vancouver (UBC), Feb24/88.
Penstemon procerus var. *tolmiei*: Vancouver (UBC), Feb14/89.
Phoenicaulis cheiranthoides: Vancouver (UBC), Jan5/89.
Polemonium elegans: Vancouver (UBC), Jan5/89.
Ribes fasciculatum var. *chinense*: Vancouver (UBC), Feb24/88.
Romulea ramiflora: Vancouver (UBC), Feb24/88.
Scrophularia aquatica 'Variegata': Vancouver (UBC), Feb24/88.
Tellima grandiflora: Vancouver (UBC), Feb24/88.
Tellima grandiflora 'Purpurea': Vancouver (UBC), Feb24/88.

STELLARIAE Theobald 1913, MACROSIPHUM
Chenopodium murale: Vancouver (CDA), Mar2/89.
Chenopodium quinoa: Vancouver (CDA), Feb20/89.
Cucumis sativus 'Straight Eight': Vancouver (CDA), Feb20/89.
Verbena 'Ideal Florist': Vancouver (CDA), Mar1/89.
TENUICAUDA Bartholomew 1932, MACROSIPHUM
Urtica dioica: Ladner, Jun6/81, Jul14/81.
Urtica dioica ssp. *gracilis* var. *lyallii*: Rosdale, Aug10/88.
TREMULAE (Linnaeus 1761), ASIPHUM
Picea glauca: Prince George, Sep28/88.
Pseudotsuga menziesii: Nelson, Aug21/87.
TRIRHODUS (Walker 1849), LONGICAUDUS
Aquilegia x *hybrida 'Dragonfly Mix'*: Vancouver (UBC), Nov22/88.
VARIABILIS Richards 1961, BOERNERINA
Alnus viridis ssp. *sinuata*: Vancouver (UBC), Jul11/88.
XYLOSTEI (de Geer 1773), PROCIPHILUS
Pseudotsuga menziesii: Nelson, Aug21/87.

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GLOVER'S SILKMOTH, *HYALOPHORA GLOVERI* (STRECKER)(LEPIDOPTERA: SATURNIIDAE), NEW TO BRITISH COLUMBIA

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Royal British Columbia Museum
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Two rather common species of giant silkmoths of the subfamily Saturniinae (Lepidoptera: Saturniidae) occur in southern British Columbia. Both species, the Polyphemus Moth (*Antheraea polyphemus* [Cramer]) and the Ceanothus Silkmoth (*Hyalophora euryalis* [Boisduval]) are large and spectacular, and evoke comment from anyone who sees them. Both range northwards to at least the central Cariboo region. Three other striking species of the subfamily occur in the Peace River district of Alberta, but these moths, the Cecropia Moth (*Hyalophora cecropia* [Linnaeus]), the Columbia Silkmoth (*H. columbia* [S.I. Smith]), and Glover's Silkmoth (*H. gloveri* [Strecker]) have never been reported from British Columbia. Therefore, it was a surprise when a specimen of *H. gloveri* was recently captured and sent to us from the Peace River district of the province.

A female *H. gloveri* (Fig. 1) was discovered by Carolyn and Terry Wood and their family on the northeast shore of Charlie Lake near Fort St. John. The moth was clinging to a branch of a small aspen tree (*Populus tremuloides* Michx.) about 2.5 m from the water's edge on 22 May 1989 at 20:00 h (MDT). The moth's wings were expanded, but the insect had evidently only recently emerged; there were fluid stains on the branch below the moth and its red colour faded to brown as it dried. The cocoon from which the insect had emerged was not found, although a second, intact one was attached to the branch near the perching moth. This cocoon is 5 x 2.5 x 2.5 cm. According to Carolyn Wood (*in litt.* 26 May 1989) none of the local residents, when questioned, had ever seen a similar moth in the area before.

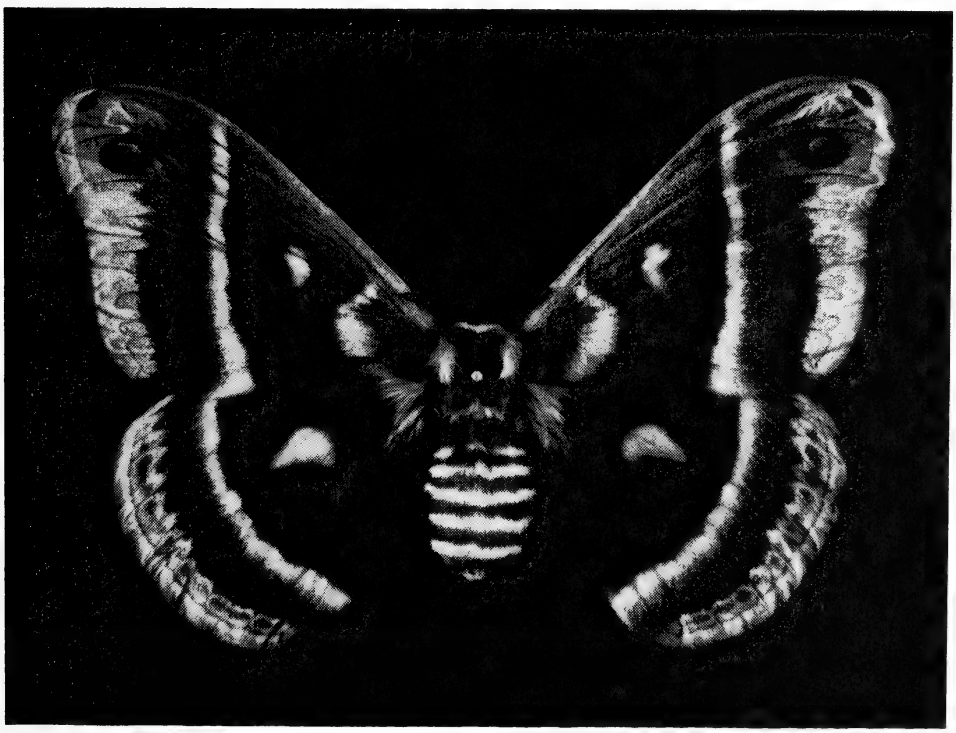

Figure 1. *Hyalophora gloveri* (Strecker), female. Charlie Lake, Fort St. John, B.C., 22 May 1989.

H. gloveri larvae have been recorded feeding on silverberry (*Eleagnus argentea* Pursh) and willows (*Salix* spp.) in Canada. In the United States the species has been reared on willows, alder (*Alnus* spp.) wild currant (*Ribes* spp.), chokecherry (*Prunus virginiana* L.), and buffaloberry (*Shepherdia* spp.) (Ferguson 1972). The details of larval coloration are apparently geographically variable (Ferguson 1972), but in general the mature larvae are very large, hairless, green caterpillars. Along both sides of the back the larva has prominent yellow tubercles with black bristles, and along the sides there are rows of white tubercles with black bristles. The legs and prolegs are yellow (Packard 1914, plates 8-9).

H. gloveri occurs from the United States-Mexican border north along the Rocky Mountains to Alberta, and east through southern Saskatchewan to Manitoba (Ferguson 1972). There is a specimen in the Canadian National Collection (Agriculture Canada, Ottawa) from Hay River, NWT (D. Lafontaine, *pers. comm.*). Ferguson (1972) gives the northern limits of the range in Alberta as about 60 miles northwest of Edmonton, but both *H. gloveri* and *H. columbia* have been collected in the Peace River district of Alberta by E.M. Pike (pers. comm.). In addition, *H. cecropia* has been collected at Beaverlodge in the same area (Ferguson 1972). Further investigation in the Peace River district of British Columbia might reveal populations of *H. columbia* and *H. cecropia*. The former feeds on eastern larch or tamarack (*Larix laricina* [Du Roi] K. Koch); the latter eats various broadleaved plants such as Manitoba Maple (*Acer negundo* L.), wild cherries (*Prunus* spp.), and willows (*Salix* spp.). Discovery of these two moths in British Columbia, in addition to the present report of *H. gloveri*, would raise the province's silkmoth fauna to five species.

The specimen of *H. gloveri* is deposited in the collection of the Royal B.C. Museum, Victoria.

ACKNOWLEDGEMENTS

We thank Carolyn Wood (Fort St. John) for sharing her discovery of Glover's Silkmoth with us, and donating the specimen to the RBCM. Don Lafontaine (Biosystematics Research Centre, Agriculture Canada, Ottawa) provided data from the Canadian National Collection, and Ted Pike (Calgary) contributed information on silkmoths from the Peace River district of Alberta.

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AN ASIAN HORNET, *VESPA SIMILLIMA XANTHOPTERA* (HYMENOPTERA: VESPIDAE) IN NORTH AMERICA

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While examining wasps in the Royal B.C. Museum's collection, I came across a large specimen standing under the name *Vespa crabro* L., the European Hornet. The label indicated that the insect had been collected by Mr. A. Rumsby at Shawnigan Lake, B.C., just north of Victoria, in August 1977. Wanting to know more about the circumstances surrounding the capture, I contacted him.

According to Mr. Rumsby, the hornet had been seen flying around raspberry bushes in his garden for two days before it ws collected. Because of its notable size the specimen was considered unusual and was brought to Dr. Robert Carcasson, then Curator of Entomology at this museum, who identified it as *Vespa crabro*. I was not so sure. The specimen did not have the bold yellow and brown abdominal pattern of *V.c. germana*, the subspecies introduced and established in eastern North America (Akre *et al.* 1980); rather it was a uniform golden-brown colour. This eliminated the possibility of the wasp having arrived in British Columbia from eastern North America; nevertheless, perhaps it was a member of one of the other subspecies that range as far east in Asia as Japan.

After considerable sleuthing by several entomologists, the specimen was finally identified as a queen of a different species, *Vespa simillima xanthoptera* Cameron, a taxon found in the Japanese archipelago south of Hokkaido. The nominate subspecies occurs in Hokkaido, Korea, and the southeastern U.S.S.R. (R.S. Jacobson, *in litt.*). This is the first record of the species in North America.

Ships carrying lumber from Canada to Japan regularly call at Cowichan Bay, 10 km due north of Shawnigan Lake. Probably this specimen or its ancestors arrived from Japan on such transport; the fact that it was a queen flying late in the summer suggests that a colony may have developed in the area. Thus, it is possible that a population of these hornets occurred, at least at one time, near Shawnigan Lake, although in the eleven years since the capture of the specimen, no others have been reported.

ACKNOWLEDGEMENTS

I thank Mr. A. Rumsby of Shawnigan Lake, B.C. for collecting the hornet and providing information on its capture, and Dr. Albert Finnamore, Provincial Museum of Alberta, Edmonton, for his interest in the problem and his help in the identification of the specimen. Dr. Roger Akre, Washington State University, Pullman, also examined the hornet, and criticized the manuscript. Dr. Robert Jacobson, East Carolina University, Greenville, N.C., made the identification.

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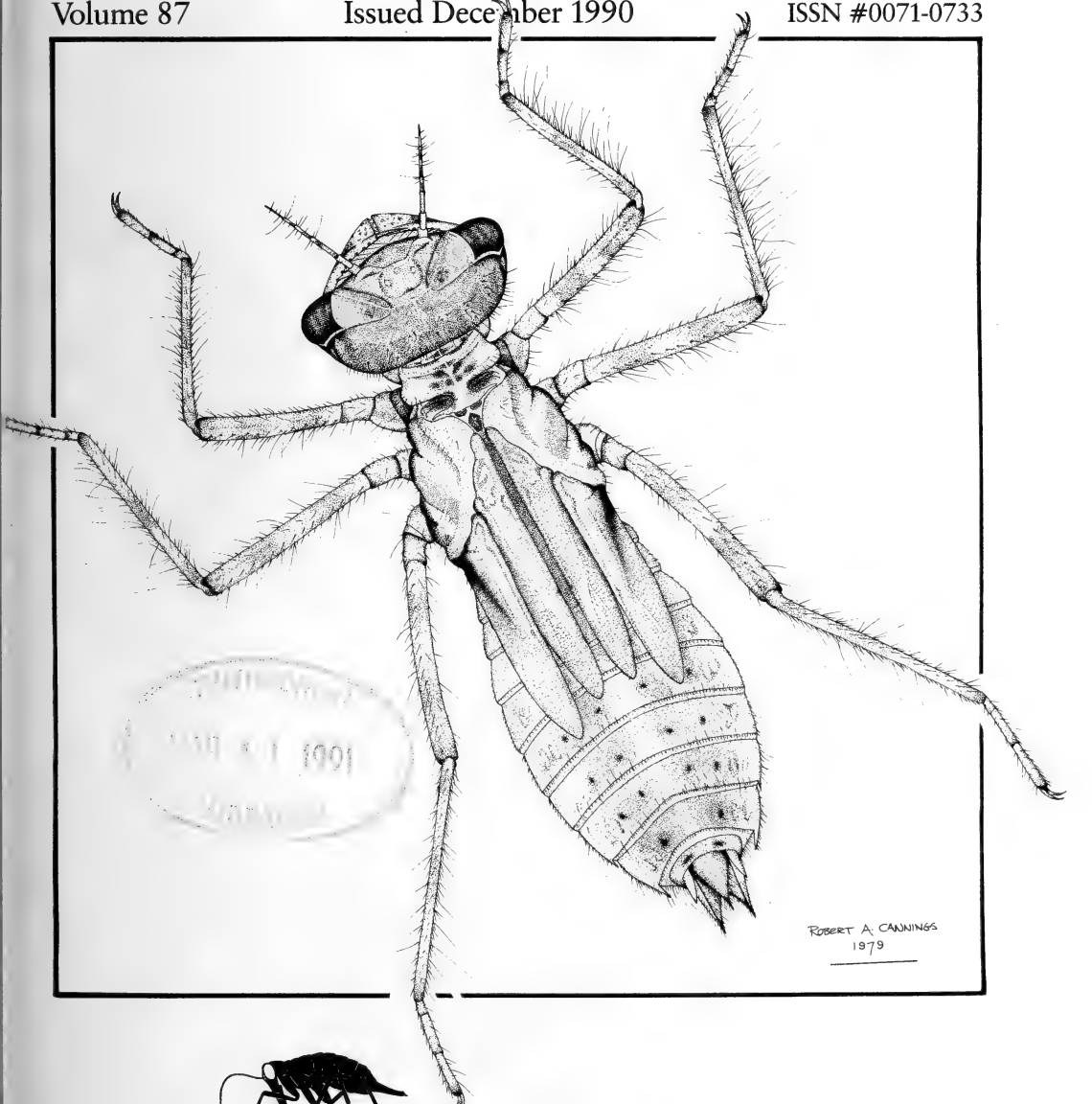

ESBC Entomological Society of British Columbia

COVER: The larva of the widespread western dragonfly *Sympetrum madidum* (Hagen) was first described by Rob Cannings from specimens he collected in Victoria and the Chilcotin (see Pan-Pacific Entomologist 57(2):341–346, 1981). The species lives in shallow ponds, often those that dry up in summer. It ranges from the Northwest Territories south through British Columbia to California and east to Manitoba and Missouri. The adults of the genus *Sympetrum* are a common sight in British Columbia from May through October, but are especially evident in the late summer and fall. Most are reddish; *S. madidum* can be identified by its white thoracic stripes and the venation of its orange-tinged wings. The pen and ink drawing is by Rob Cannings.

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First records of *Enarmonia formosana* (Scopoli) in North America (Lepidoptera: Tortricidae)

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ABSTRACT

Enarmonia formosana (Scopoli), a widespread Palaearctic species, was recently found infesting cherry trees in the Richmond area of British Columbia, Canada. Descriptions, illustrations of male and female genitalia, and a photograph of an adult, are provided to help identify the species in North America.

INTRODUCTION

In May 1989, at the request of a homeowner in Richmond, B.C., Agriculture Canada inspectors were asked to look at some cherry trees exhibiting symptoms of yellowing foliage and bark damage that included cankers, gumosis and frass. Larval and adult specimens were collected from the site and submitted for identification. Other specimens were submitted from cherry trees exhibiting similar symptoms in Surrey and Vancouver. In the early spring of 1990, a series of adults emerged in the laboratory from infested cherry logs that were collected at Surrey in 1989. *Enarmonia formosana* (Scopoli), the cherry bark tortrix, was positively identified based on detailed examinations of these specimens. *E. formosana* specimens from France were also examined to further support this identification. It is believed that *E. formosana* has been in the Richmond area for some time, judging from the size of lesions on the host trees caused by repeated infestations of larvae, and from the large number of adults caught in pheromone traps set in these areas during the summer of 1990. The description, illustrations, photograph, and review of biological aspects of this species, provided in the present article, will help researchers to recognize and identify the pest. This information will be particularly useful in survey, monitoring and control programs for this species in Vancouver and neighbouring areas. Various morphological aspects of the species, including illustrations and/or photographs, can also be found in Benander (1950), Bradley *et al.* (1979), Graaf Bentinck and Diakonoff (1968), Hannemann (1961), Kennel (1921), Kuznetsov (1978), and Pierce and Metcalfe (1922). All specimens studied are deposited in the Canadian National Collection in Ottawa.

DIAGNOSTIC FEATURES

Description.

E. formosana can be recognized by the intricately well-defined colours and patterns of the forewing and its distinctive genitalia (Figs. 1–4). Specimens collected in Richmond are darkly pigmented, almost black, with silver and golden-brown markings. There is little variation or sexual dimorphism in this species.

Head. Head black with blue tinge dorsally, creamy-yellow posteriorly; frons black; antenna black dorsally, creamy-yellow ventrally; labial palpus mostly dark blue except for basal segments, median transverse band on segment 3 and ventral and mesal sides of palpus paler, creamy-yellow.

Thorax (Fig. 1). Notum black with narrow golden-brown cross band; tegula black, golden brown basally and distally; pleural area bluish gray. Fore wing: length 7–8 mm; ground colour black; basal third black, distinctly mottled with small irregular silvery-white to yellow patches forming irregular concentric arching bands; median cross band

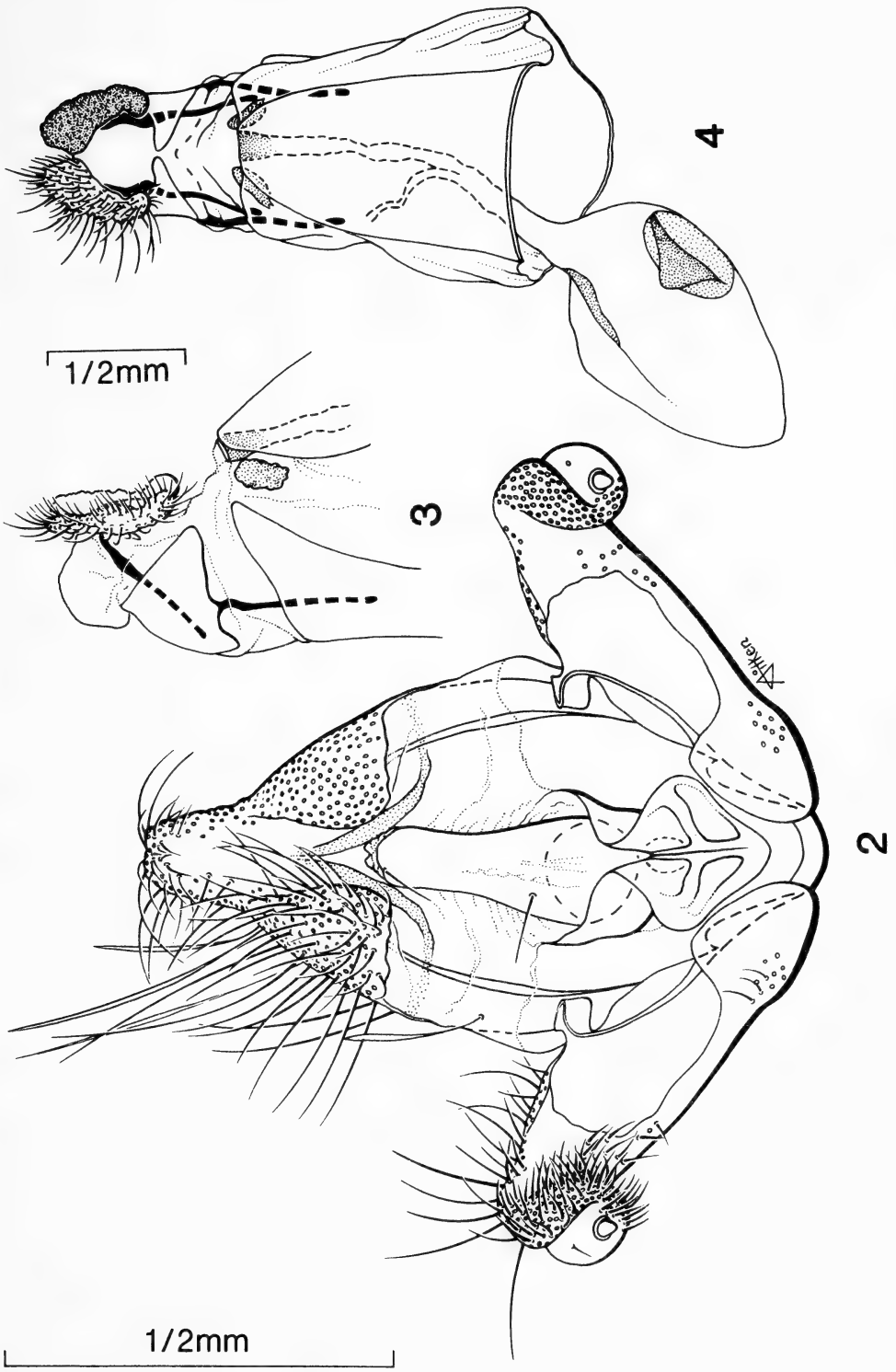
1

arched toward wing apex, extending from basal third of costa to center of wing and to middle of posterior wing margin, mostly silvery, with narrow creamy-yellow borders, portion from costa to vein Rs golden-brown, surrounded with black, silvery and creamy-yellow or golden-brown rings respectively; tornal eye spot conspicuous, about 1/2 as wide as termen, outer ring narrow golden-brown, inner ring wider silvery, center large with eight alternating black and golden-brown longitudinal dashes; costal strigulae well defined, extending from basal 3/5 to apex, and consisting of five shiny white oblique comma-shaped streaks separated by black areas; three longitudinal bands successively of golden-brown, silvery and golden-brown located along areas immediately posterad and basad of these streaks. Hind wing black. Legs banded, formed by combination of two contrasting colours: creamy-white on ventral side, both ends of each segment, tibial spurs and median area of front tibia; black on other areas.

Abdomen. Black dorsally, creamy-white ventrally.

Male genitalia (Fig. 2). Uncus well developed, fleshy and stout, bearing numerous slender setae; socius large, triangular, fused to uncus and tegumen and attached to ventral side of tegumen, bearing numerous long and slender setae. Gnathos weak, lightly sclerotized. Transtilla absent. Tegumen longer than basal width, horseshoe-shaped. Valva slender, gently arched posteriorly, finger-shaped, distal end broadly and deeply grooved forming bifid apex with ventral part bearing dense setae and dorsal part bearing single conical stout seta. Aedeagus cylindrical, broadly enlarged basally; cornutus absent.

Female genitalia (Figs. 3A–B). Bursa copulatrix oval, densely reticulate; signum well developed and sclerotized, nearly circular with large, internal, triangular, blade-like ridge; area anterad and ventrad of ductus bursa lightly sclerotized. Antrum small, lightly sclerotized. Pleural areas immediately laterad of antrum with pair of small rectangular sclerites. Abdominal tergite 9 spiculate.



Figs. 1–4, morphological aspects of *E. formosana: 1.* dorsal aspect of adult ♂; *2.* ventral aspect of male genitalia with partially spread valvae; *3.* lateral aspect of distal portion of female genitalia; *4.* ventral aspect of female genitalia.

REMARKS

The fore wing markings, particularly the tornal eye spot and the well-defined costal strigulae of *Enarmonia formosana,* resemble those of a number of nearctic *Cydia* species. The fore wings of specimens of *Eucosmomorpha albersana* (Hübner), an introduced palaearctic species belonging to the Enarmonini, collected in Michigan, U.S.A. (Miller 1983) and Saskatchewan, Canada (CNC) also show markings similar to *E. formosana*. However, *E. formosana* can be easily distinguished from the above-mentioned species on the basis of its rather unique structures of the male and female genitalia.

DISTRIBUTION AND BIOLOGY

The cherry bark tortrix occurs throughout Europe, temperate Asia and North Africa. The larvae feed on the bark and sapwood of a variety of plants of the family Rosaceae including *Cydonia* (quince), *Malus* (apple), *Prunus* (almond, apricot, cherry, nectarine, peach and plum), *Pyracantha* (firethorne), *Pyrus* (pear) and *Sorbus* (mountain ash). The larvae feed within bark tissue and may extend damage into the cambium. Attacks are more obvious on older or previously injured trees. Detailed descriptions of the biology and life history are outlined in Balachowsky (1966) and Alford (1984). The Plant Protection Division of Agriculture Canada is in the process of surveying the Lower Mainland of British Columbia to determine the current distribution of cherry bark tortrix.

ACKNOWLEDGEMENTS

We thank Shane Sela, Owen Croy, Ed Ross and Chris Yeoh, Agriculture Inspection Directorate, Agriculture Canada for collection of specimens and providing information from British Columbia; J. Chambon, INRA, France, for providing specimens of *Enarmonia formosana* from Europe for comparison; Stephen Aitken for illustrating the male and female genitalia and Bill Lukey for taking the photograph of the adult.

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Ephemeroptera of the Bella Coola and Owikeno Lake watersheds, British Columbia Central Coast

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ABSTRACT

Collection records of Ephemeroptera from the Bella Coola and Owikeno Lake watersheds on the British Columbia central coast are presented for the first time. Twenty-six species, representing eleven genera and five families, are listed along with ecological notes.

INTRODUCTION

The Ephemeroptera (Mayflies) of the British Columbia central coast have not yet been characterized. No published collection records exist for this area (Scudder 1975). Between June 1987 and August 1990, one of the authors (M.W.) collected and identified at least 26 different Ephemeroptera species from the Bella Coola and Owikeno Lake watersheds. This report summarizes the findings.

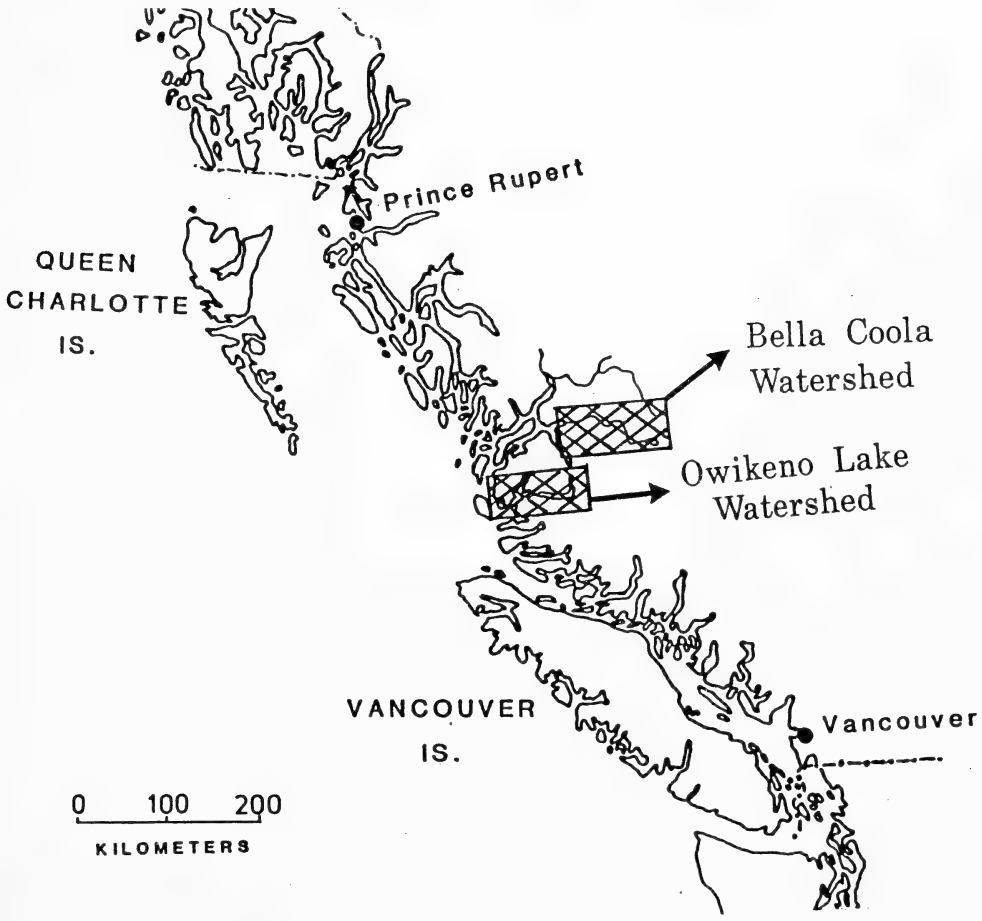

Fig. 1. Pacific Coast of British Columbia showing the location of the Bella Coola and Owikeno Lake watershed areas.

THE STUDY AREA

Mayfly (Ephemeroptera) nymphs and adults were collected from the Bella Coola and Owikeno Lake drainage systems (Fig. 1). These watersheds are situated in the rugged Coast Mountains of British Columbia between latitudes 51°30′ and 52°30′ N, and longitudes 125°15′ and 127°15′ W. This area of the British Columbia central coast features numerous fjords, channels, and mountains which rise sharply from valley bottoms at less than 150 m elevation to peaks exceeding 2,400 m in less than 4 km. Mean annual precipitation exceeds 250 cm. The predominant biogeoclimatic zones in the two watersheds are Coast Western Hemlock at low elevations, Mountain Hemlock at subalpine levels, and Alpine Tundra at the highest elevations (Baer 1973, Leaney and Morris 1981). Highway 20 connects Bella Coola, at the head of North Bentinck Arm with Williams Lake, 480 km to the east but Owikeno Lake is accessible only by boat, plane, or helicopter. Logging roads have been built in many of the main valleys opening into the Bella Coola valley, and into Owikeno Lake, and these provide some access into the terrain.

The Bella Coola River system drains an area of approximately 6,500 km^2, whereas the Owikeno Lake system drains a slightly smaller area (Leaney and Morris 1981). Fig. 2 and 3 show the primary collection sites. There were nine primary collection sites in the Bella Coola watershed, namely: Thorsen Creek, Snootli Creek, Sato Creek, Lower Fish Creek, Salloomt River, Noosgulch River, Nusatsum River, the Atnarko River and spawning channel, and Leech Lake. Sato Creek and Lower Fish Creek are two small creeks located in Hagensborg. There were nine primary collection sites in the Owikeno Lake watershed, namely: Dallery Creek, Ashlum Creek (two sites), Neechanz River, the shores of Owikeno Lake near Genesee Creek, Sheemahant River, Washwash River, and Inziana River (two sites) (Fig. 3.). Benthic sampling for mayfly nymphs and aerial sampling for adults was confined to the lower reaches of the streams and rivers except for the Nusatsum River sampling site located 25 km south of Highway 20 along a logging road. All collection sites were below 500 m except for the Nusatsum River site which was

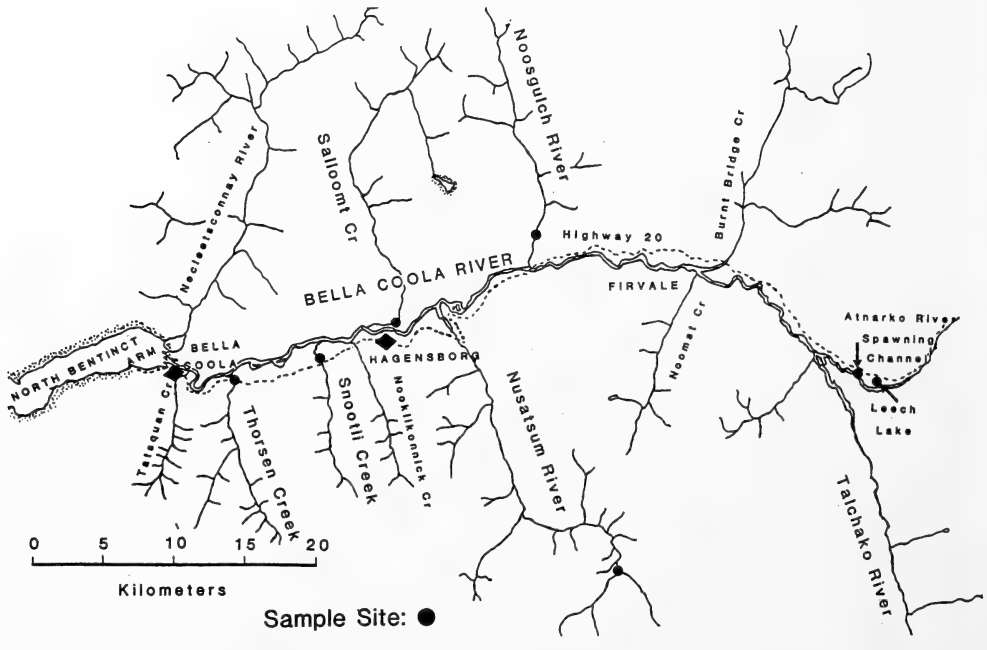

Fig. 2. Bella Coola watershed showing the main collection sites.

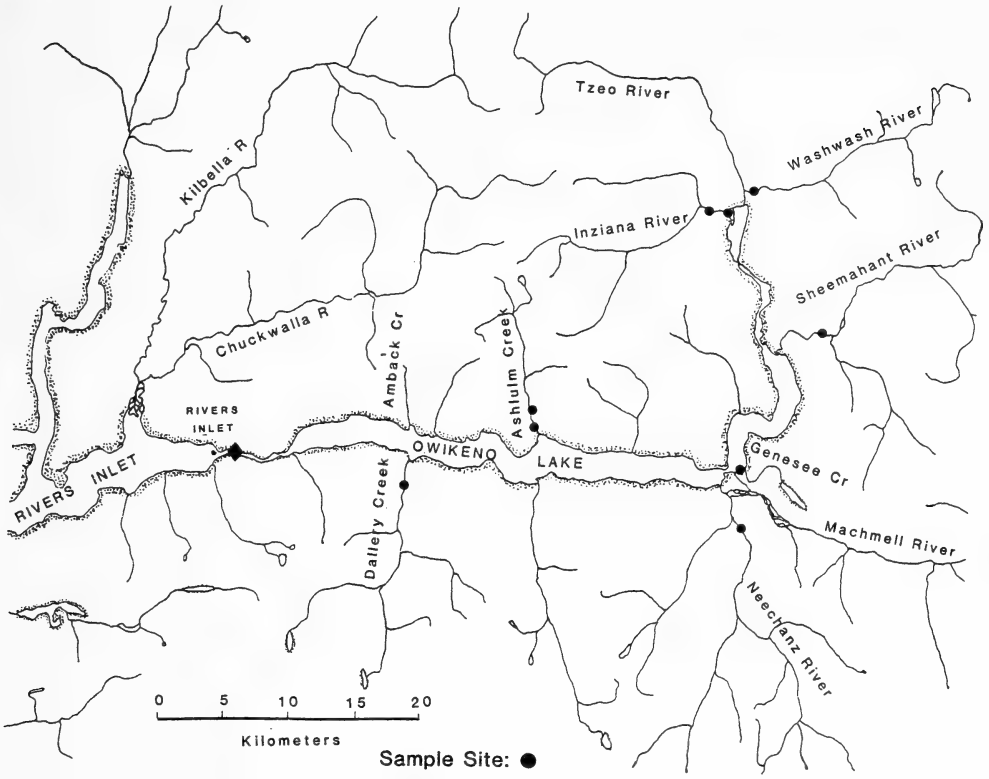

Fig. 3. Owikeno Lake watershed showing the main collection sites.

at approximately 900 m elevation. Most collection sites featured relatively shallow, clear, moderate to fast flowing water with gravel and cobble substrate. The Atnarko River spawning channel has slow to moderate flowing, clear water; Leech Lake is a small, still kettle pond; the Sheemahant River is a moderate to fast flowing river with high glacial silt load. All creeks and rivers sampled are glacier fed, except for the Atnarko River and Leech Lake. The former flows from several large lakes; the latter is fed from spring or ground water (Hynes 1970).

METHODS

From June 1987 to August 1990 mayfly (Ephemeroptera) nymphs and adults were collected from the Owikeno Lake, and Bella Coola River areas. Streams with noticeable flows were sampled using a Surber-type benthic sampler with a mesh size of 1.0 mm. Ponds, lakes and backwater sloughs were sampled with a plankton tow net through submerged vegetation of the littoral zone. Adults were sampled by sweeps through aerial mating swarms, sweeps through stream-side vegetation, and some were also collected by handpicking them from the streamside vegetation (usually females) or cobble and rubble stream banks (usually subimago males and females) (Pennak 1978). Hand constructed emergence traps made with 1.0 mm sized mesh were used from May 1990 to August 1990 in Sato Creek, Lower Fish Creek, and Salloomt Creek collection sites. Mature nymphs from collection sites were introduced into the emergence traps. Traps were checked regularly for emerging subimagos, these were collected in wide mouth jars and reared to imagos at home. Water temperatures were frequently recorded at collection sites with a field thermometer. All specimens were identified with the aid of a Kyowa SDZ-TR stereomicroscope. Articles and keys used for identification were those of Allen and Edmunds (1962, 1963, 1965), Day (1956), Edmunds *et al.* (1976), Edmunds and Allen

(1964), Jensen (1966), Lehmkuhl (1968, 1970a, 1970b, 1971, 1979), McCafferty (1983), Morihara and McCafferty (1979) and Traver (1935). Existing geographic ranges were determined primarily from Allen (1980), Jensen (1966), and Scudder (1975). The specimens were stored in 70% isopropyl alcohol and were given to the Royal British Columbia Museum, Victoria, B.C. for verification and preservation.

SPECIES LIST

Siphlonuridae

Ameletus validus McDunnough

Washwash River, approximately 100 meters upstream from the mouth at Owikeno Lake, 7-IX-1989, mature nymph. Water temperature was 10°C. Mature specimens were also collected from the Atnarko River spawning channel in October of 1990. Typical habitat consists of moderate velocity riffle runs with small and large gravel and cobble substrate. These findings extend the known distribution of *A. validus* in British Columbia northwesterly from the Penticton area.

Ameletus species

Snootli Creek, near the Snootli Creek Hatchery outflow creek, 17-II-1989, mature nymph. Specimens collected have been quite large, 16–18 mm long. Habitat consists of moderate velocity riffle runs with gravel and cobble substrate.

Baetidae

Baetis tricaudatus Dodds

Atnarko River spawning channel, 12-II-1989, mature nymphs. Mature nymphs have also been collected from February to May in the main Atnarko River and in Thorsen Creek. Subimago and imagos were collected in March 1990 in the Atnarko River. Mature nymphs and adults were collected from the Owikeno Lake area in September 1989. Emergence of subimagos was noted, 13-IX-1989, at the mouth of Dallery Creek. Water temperature was 10°C. These subimagos were held to maturity for identification. Typical habitat consists of moderate flow riffle runs with gravel and cobble substrate. These findings extend the known range of *B. tricaudatus* in British Columbia northwesterly from the Salmon Arm area.

Baetis bicaudatus Dodds

Washwash River, approximately 100 meters from the mouth at Owikeno Lake, 23-IX-1989, mature nymphs. Water temperature was 10°C. Mature nymphs were also found in other Owikeno Lake streams throughout September 1989, and the Bella Coola watershed, including the Upper Nusatsum River collection site, 15-VII-1989. Typical habitat consists of moderate flow riffle runs with gravel and cobble substrate. These findings extend the known distribution of *B. bicaudatus* in British Columbia northwesterly from the Lillooet area.

Callibaetis nigritus Banks

Leech Lake, 10-IV-1989, mature male nymph and four male imagos. The mature nymph was collected in submerged weed habitat of the lake shore. The imagos were observed in a mating swarm over the entire one hectare lake surface. Swarm height was between 0.3 to 1.5 meters above the surface. Dragonflies, damselflies, and cutthroat trout were feeding heavily on spent swarmers and emerging subimagos at this time. Nymphs have also been found in other slow flow to stagnant ponds in the Bella Coola watershed, *e.g.*, Millpond along the Salloomt Road near Hagensborg, and Walker Island beaver pond near Snootli Park. Nymphs are most plentiful from fall to spring. These findings extend the known distribution of *C. nigritus* west from the Springhouse, Chilcotin area.

Heptageniidae

Cinygma integrum Eaton

Dump Creek approximately 300 meters upstream from Highway 20 and 200 meters east of Thorsen Creek, 8-II-1989, nymph. Nymphs have also been found from May to July in small feeder creeks near outflows into mainstem creeks and rivers of the Bella Coola watershed. Water temperatures typically range from 9 to 13°C at these sites. Imago males and females were collected throughout June and July 1990 at Sato Creek. On clear, warm evenings, females were observed exhibiting egg depositional behavior. This behavior consisted of the females hovering between 30 to 100 cm above water, then dropping and touching their egg covered abdominal tips to the water surface. Two females repeated this hovering and dropping behavior approximately 30 times before flying vertically upwards and out of sight. Nymphal habitat is characteristically slow to moderate flow riffle runs, usually associated with submerged wood and cobble substrate. These findings extend the known range of *C. integrum* northerly along the Pacific coast from the Alto Lake and Mons areas.

Cinygmula uniformis McDunnough

Atnarko River, 22-IV-1990, mature nymphs, male and female subimagos. Subimagos were reared to imagos. Water temperature was 7°C. Sample area consisted of moderate flow riffle runs with gravel substrate. The range of this species is extended northwesterly from the Penticton area.

Cinygmula species

Atnarko River spawning channel, 11-IV-1989, mature nymphs and male and female subimagos. These specimens vary markedly in size and general body coloration. The sample area consists of moderate flow riffle runs with gravel substrate.

Epeorus (*Ironopsis*) *grandis* McDunnough

Upper Nusatsum River, 1-VII-1989, mature nymphs. Mature nymphs were abundant at this collection site until mid-July. Mature nymphs have also been collected in the lower reaches of Thorsen Creek and the Atnarko River spawning channel. Habitat is characteristically moderate to fast flow riffle runs with gravel and cobble substrate. Upper Nusatsum River, 9-VII-1989 and 15-VII-1989, male and female imagos. The female imagos were collected on streamside vegetation near midday. The male imagos were collected from a small mating swarm over a side channel of the Nusatsum River. The swarm height ranged from 1.5 to 4 meters above the water surface between 1130 to 1500 hours. Water temperature was 11.5°C and weather warm and sunny with cloudy periods. Winds were negligible. These findings extend the known range of this species northwesterly from the Hedley, Seton Lake, and Peachland areas of British Columbia.

Epeorus (*Iron*) *albertae* McDunnough

Atnarko River, approximately 300 meters downstream from Fisheries Pool, 6-VII-1989 and 9-VII-1990, mature nymphs. These specimens were collected from an area of moderate to fast flow with gravel and cobble substrate. Water temperatures were 16 to 17°C and depth approximately 20 to 40 cm. The range for this species is extended northwesterly from the Summerland area.

Epeorus (*Iron*) *longimanus* Eaton

Thorsen Creek, approximately 200 meters downstream from Highway 20 bridge, 2-VII-1989, mature nymphs. Mature nymphs have also been collected from Nusatsum, Salloomt, and Noosgulch Rivers throughout July 1989. Typical habitat consists of fast flow riffles with cobble substrate. A single male subimago was collected on the evening of 28-V-1990 over Sato Creek. These findings extend the known range of *E. longimanus* northerly along the Pacific Coast from the Alta Lake area.

Epeorus (*Iron*) *deceptivus* McDunnough

Ashlum Creek approximately 200 meters upstream from the mouth of Owikeno Lake, 8-IX-1989, mature nymphs. Water temperature was 9.5°C. Noosgulch River approx-

imately 5 kilometers upstream from the mouth at Bella Coola River, 22-VII-1989, mature nymphs. Specimens have also been collected from the Sheemahant River (12-IX-1989), Inziana River (19-IX-1989) (Fig. 3), and the Atnarko River spawning channel (May 1989) (Fig. 1). Habitat is characteristically moderate to fast flow riffle rapids with gravel and cobble substrate. These findings extend the known range of *E. deceptivus* in British Columbia westerly from the Barkerville area.

Epeorus (*Ironodes*) *nitidus* Eaton
Sato Creek, approximately 2 km east of Hagensborg, 30-XI-1989, intermediately developed nymphs. Nymphs were collected in moderate flow, shallow riffles, approximately 10 cm deep, under cobble size rocks of substrate. Water temperature was approximately 5.5°C. The specimens in this nymphal collection range from light gray-brown to darker yellow brown (ochrous) to reddish brown. Specimens range in length from 7 to 10 mm. Wingpads were noticeable but not fully developed. Because of difficulty in identifying these nymphs to species, additional nymphs were collected from Sato Creek and Lower Fish Creek on a monthly basis between December 1989 to July 1990. Nymph maturation was characterized by minimal increase in total length, but progressive development of wingpads. A female subimago was observed emerging at 1500 hours 1-VI-1990 from Lower Fish Creek on a clear, warm day. Water temperature was 8°C. Additional subimagos were collected from emergence traps between 26-V-1990 and 7-VII-1990 and reared to imagos. *E. nitidus* has not previously been listed for British Columbia (Scudder 1975).

Rithrogena hageni Eaton
Salloomt River approximately 1 km upstream from the mouth at the Bella Coola River, 2-VII-1989, single nymph. Additional mature nymphs were collected in July and August 1990. These specimens were collected in moderate to fast riffle runs with gravel and cobble substrate. These specimens extend the range of *R. hageni* in British Columbia northwesterly from Summerland and Steelhead areas.

Rithrogena robusta Dodds
Upper Nusatsum River collection site, 1-VII-1989, mature nymphs. The specimens were collected from fast flow riffle rapids with gravel cobble and boulder substrate. Water temperature was 9 to 10°C. Upper Nusatsum River collection site, 15-VII-1989, two male imagos and two female imagos. A mating swarm consisting of 60 to 70 males and females in a vertical column 3 to 12 meters above the water surface was observed from 1200 to 1600 hours. Weather was sunny and warm with intermittent clouds. There was no wind. Water temperature was approximately 11°C. These specimens extend the known range of *R. robusta* in British Columbia northwesterly from the Keremeos area.

Leptophlebiidae
Paraleptophlebia debilis Walker
Mill pond approximately one km north on Salloomt Road, 31-VII-1989, male imagos. A male swarm was observed and collected over a beaver pond shoreline at approximately 2000 hours on a clear evening. They showed a vertical rise and fall of approximately 40 to 50 cm at a height just above vegetation, *i.e.,* 1 to 2.5 meters above ground level. A similar male swarm was observed near the Walker Island beaver pond near Snootli Creek (14-VII-1989). Lower Fish Creek, 28-VI-1989, four female imagos and one subimago. These females were found on streamside vegetation on the underside of leaves. Owikeno Lake shore, 9-IX-1989, mature nymphs and male imagos. Mature nymphs were collected in the gravel and cobble shallows of the lake shore near the mouths of creeks and rivers. Adults were observed in small swarms along the shoreline until mid-morning in shaded areas. Nymphs have also been found in many of the creeks and rivers in the Bella Coola watershed. Mature nymphs seem more abundant in the quiet backwaters of creeks and rivers, whereas the immature nymphs seem to be more abundant in moderate flow riffle run habitats. These findings extend the known range of *P. debilis* in British Columbia northerly along the Pacific coast from the Agassiz and Nicola Creek areas.

Paraleptophlebia temporalis McDunnough
Atnarko River spawning channel, 5-II-1989, nymphs. Specimens were collected in slow to moderate flow runs with gravel substrates. Sato Creek, 29-V-1990, five female imagos. Weather was warm and sunny but these female imagos were collected in a heavily shaded area of the creek between 1600 and 1630 hours. Water temperature was 9°C. The females were observed exhibiting ovipositing behavior. They would hover 10 to 15 cm over the water surface and then move in quick up and down motions approximately 15 cm distances before dropping to the water surface. These female imagos repeated this sequence several times before they were collected. Collected female imagos had whitish egg masses protruding from their genital openings. These nymph and imago specimens extend the known range of *P. temporalis* in British Columbia northerly along the Pacific coast from the Alto Lake and Mons areas.

Paraleptophlebia vaciva Eaton
Upper Nusatsum River, 2-VII-1990, three male imagos. These were observed and collected from a mating swarm located over a logged clearing approximately 75 meters from the river. Swarm height was between 1.5 to 3 meters above ground level. Weather was clear, sunny, and warm and the specimens were collected between 1000 to 1200 hours. The known range of *P. vaciva* is extended northwesterly from Clinton, Mt. Apex, Hope and Keremeos areas.

Ephemerellidae
Drunella coloradensis Dodds
Upper Nusatsum River collection site, 9-VII-1989, nymphs. Nymphs collected at this time were generally at an intermediate stage of development with small wing pads and were approximately 8 to 10 mm long. Mature nymphs found were approximately 12 to 14 mm long. Washwash River approximately 100 meters upstream from the mouth at Owikeno Lake, 7-IX-1989, mature nymphs, cast and male subimago. All specimens collected at this time were mature and ranged from 11 to 14 mm long. Typical habitat for *D. coloradensis* in these areas consisted of moderate to fast flow riffle runs with gravel and cobble substrate and 10°C water. The range for this species in British Columbia is extended along the Pacific coast northerly from the Capilano River area near Vancouver.

Drunella doddsi Needham
Upper Nusatsum River collection site, 30-VII-1989, mature nymphs and subimagos. Subimagos were observed emerging from a fast flow riffle rapids area at this time. Mature nymphs collected from this area were observed undergoing ecdysis. Water temperature was approximately 13 to 14°C. Mature nymphs of *D. doddsi* have also been collected from numerous creeks and rivers of moderate to fast flow with clean gravel and cobble substrates in the Bella Coola watershed. The finding of these specimens fills a gap between the Kispiox River area and the lower mainland around the Alouette River, Capilano River and Skagit River areas.

Drunella flavilinea McDunnough
Atnarko River approximately 300 meters downstream from Fisheries Pool, 6-VIII-1989, one nymph. This single nymph was collected from a moderate flow riffle run habitat with gravel and cobble substrate. Water temperature was approximately 17°C. At the same site on 9-VII-1990, mature nymphs were collected in abundance. To date we have had no success rearing adults in emergence traps. The presence of *D. flavilinea* in the Atnarko River may be due to the noticeably warmer water temperature of this river compared to other creeks and rivers in the Bella Coola watershed (Jensen 1966). The presence of these specimens in the Bella Coola watershed extends the known range of *D. flavilinea* in British Columbia northerly along the Pacific coast.

Drunella grandis ingens McDunnough
Atnarko River spawning channel, April/May 1989, mature nymphs. Specimens have also been collected from many of the creeks and rivers of the Bella Coola watershed. Typical

habitat consists of slow to moderate flow associated with gravel substrates or among submerged vegetation. Nymphs are abundant in these habitats until June, then are negligible in summer samples except at higher elevations. Immature nymphs were found in samples from October. The range of this species in British Columbia is extended northwesterly from Oliver, Summerland, Penticton, and Peachland areas.

Drunella spinifera Needham
Upper Nusatsum River collection site, 9-VII-1989, mature nymphs. Specimens were collected from moderate to fast flow riffle runs with gravel and cobble substrates throughout July 1989 at this site. The range of this species in British Columbia is extended northerly along the Pacific coast from the Alouette River area.

Ephemerella aurivillii Eaton
Atnarko River spawning channel, IV-1989, mature nymphs. Mature nymphs have also been collected from many other creeks and rivers of the Bella Coola watershed. Specimens are usually collected from moderate flow riffle runs with gravel and cobble substrates. Some specimens have been found in submerged weeds in slow to moderate flow creeks and, in many cases, in association with *D. grandis ingens*. The finding of *E. aurivillii* in the Bella Coola watershed extends the known range northwesterly from the Cache Creek area.

Ephemerella inermis McDunnough
Upper Nusatsum River collection site, 15-VII-1989, nymphs. Specimens were collected from moderate flow riffle runs with gravel and cobble substrates. The finding of *E. inermis* in the Bella Coola watershed extends the range of this species in British Columbia northerly along the Pacific coast from the Alouette River area. Other specimens have come from the Penticton and Shuswap Lake areas.

Ephemerella infrequens McDunnough
Salloomt River, 15-VII-1990, mature nymphs. Two female imagos were reared in emergence traps. Water temperature was 10°C. The range of this species in British Columbia is extended northwesterly from the Seton Lake area.

Serratella tibialis McDunnough
Noosgulch River approximately 300 meters upstream from the mouth at the Bella Coola River, 13-VIII-1989, mature nymphs. Specimens are typically found in moderate to fast flow riffle runs with gravel and cobble substrate. Mature specimens of *S. tibialis* have also been found in samples taken from creeks and rivers of the Owikeeno Lake watershed. They were relatively abundant in samples taken until mid-September; thereafter a decline in numbers collected was noticed. Salloomt River, 26-VII-1990 throughout August 1990, male and female imagos reared in emergence traps. The range of this species in British Columbia has been extended northerly along the Pacific coast from the Mosquito Creek area near Vancouver.

DISCUSSION

Twenty-six Ephemeroptera species in eleven genera and five families were collected from the Bella Coola and Owikeno Lake watersheds in the British Columbia central coast. This preliminary list for the area represents approximately 25 percent of the known provincial fauna. The geographic ranges for nine species are extended north along the British Columbia Pacific coast; for twelve species, they are extended northwesterly; and for two species are extended westerly. The finding of *Drunella doddsi* Needham fills in a gap between the Kispiox River and lower mainland collection sites such as the Capilano River, Alouette River, and Skagit River. *Epeorus* (*Ironodes*) *nitidus* is recorded for the first time in British Columbia. This species has been collected in Oregon, U.S.A. (Jensen 1966). *Drunella flavilinea* and *Epeorus albertae* were found only in the Atnarko River. This river is unique in being warmer (summer range of 16 to 18°C) than the vast majority of rivers and creeks in the central coast (summer range 10 to 14°C). Jensen (1966) had previously noted that both *D. flavilinea* and *E. albertae* occupy the warmer portions of

streams. The finding of bivoltism for *Baetis tricaudatus* in the central coast is consistent with previous reports in other areas (Edmunds *et al.* 1976). There appears to be two or possibly three species of the genus *Cinygmula* indigenous to the area. Mature nymphs of *Cinygmula* have been collected in the spring and fall and several of these vary markedly in size and general body coloration. Hopefully more adult specimens will eventually be collected or reared in an aquarium or emergence trap to verify this premise. It should be pointed out that the majority of sampling sites were below 500 meters altitude, and in moderate to fast flowing glacial streams with gravel and cobble substrate. Future plans include sampling higher elevation streams, rivers and mountain lakes, and also the gathering of more seasonal and quantitative information.

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Growth response in a Douglas-fir/lodgepole pine stand after thinning of lodgepole pine by the mountain pine beetle: A case study

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ABSTRACT

Diameter growth response was measured in a mixed stand of lodgepole pine, *Pinus contorta* Dougl. ex Loud, and interior Douglas-fir, *Pseudotsuga menziesii* var *glauca* (Beissn.) Franco, in the Cariboo Forest Region of British Columbia, 14 years after an outbreak of the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, killed 76% of the pine. Nearly all Douglas-fir and a large proportion of the lodgepole pine responded to the beetle-induced thinning with a diameter growth increase which persisted 14 years after the infestation. Douglas-fir trees gained an average 1.4 cm or 11.7% in diameter over the estimated size the trees would have reached in the absence of the thinning effect. Annual growth rates of Douglas-fir in the post-outbreak period averaged 2% per year without the beetle-induced thinning and 2.9% after thinning. The surviving lodgepole pine trees gained an average 1 cm or 5.4% in diameter over the size the trees would have reached in the absence of the thinning effect. In the post-outbreak period, annual diameter growth rates of the pine doubled from 0.4% per year without the thinning, to 0.8% per year with thinning. The thinning response in Douglas-fir was inversely related to the initial diameter and age of the trees at the start of the infestation but that of pine was not.

INTRODUCTION

Mixed stands of lodgepole pine, *Pinus contorta* Dougl. ex Loud, and interior Douglas-fir, *Pseudotsuga menziesii* var glauca (Beissn.) Franco, are typical of large areas of the Cariboo Forest Region of British Columbia (B.C.). Throughout this region, the mountain pine beetle, *Dendroctonus ponderosae* Hopkins, kills mature and overmature lodgepole pine in extensive infestations that last for several years (Safranyik *et al.* 1974). A series of outbreaks in many stands in the east-central area of the Region occurred during the 1970–80 period. For example, an outbreak which began on the Chilcotin Plateau in 1971/72 continued unabated until 1985, killing approximately 22,000,000 m^3 of pine over 1,700,000 ha (Doidge, personal communication) before collapsing after two extremely cold winters in 1985/86. Most infestations collapsed prior to the depletion of a highly susceptible host. In mixed stands, because of a selective killing of lodgepole pine, a thinning or release effect, manifested as an acceleration of the trees' growth rates, was expected to occur among the Douglas-fir and the surviving lodgepole pine. Such a release was demonstrated by Cole and Amman (1980) who detected growth acceleration in lodgepole pine after each of several beetle infestations. Because the beetles tend to kill mainly the large diameter lodgepole pine trees in a stand (Craighead 1925, Cole and Amman 1969, Safranyik *et al.* 1974), the type of thinning that the beetles cause correspond to a thinning from above (Smith 1962).

Information on the growth response of interior Douglas-fir and lodgepole pine to thinning is relatively scanty. Knutson and Tinning (1986) studied the response to thinning of young Douglas-fir with varying degrees of infection by dwarf mistletoe and

concluded that trees with no or low infection responded to thinning with a significant increase in radial growth, while severely infected trees did not. Studying a lodgepole pine stand in Alberta, which underwent a combination of thinning from above and below, Johnstone (1982) demonstrated that semi-mature (77-year-old) lodgepole pine responded well to thinning. Waring and Pitman (1985) concluded that 120-year-old lodgepole pine responded to thinning and fertilization with increased growth efficiency and vigor, which in turn decreased the risk of beetle-caused tree mortality.

This paper quantifies the diameter growth response in a mixed Douglas-fir–lodgepole pine forest 14 years after the start of a mountain pine beetle infestation, which over a number of years, selectively killed a large proportion of the pine.

MATERIALS AND METHODS

The studies were conducted in an area known as Bull Mtn., about 4 km north of Williams Lake, B.C. (Latitude 52°15′, Longitude 122°7′) in the Cariboo Forest Region. The area studied occupied about 65 ha, was located at an elevation of approximately 970 m, on relatively flat terrain (≤ 8% slope) and included the B.C. Forest Service forest types PL631 and F841. The stands are in the IDFdk3 biogeoclimatic subzone (Ray Coupé, pers. comm.) and growing on a medium quality site (Ordell Steen, pers. comm.). The site potential is rated as relatively good for the Cariboo Forest Region. The forest cover consisted of a two-storied mixture of Douglas-fir and lodgepole pine with a minor component of white spruce, *Picea glauca* (Moench) Voss. An outbreak of the mountain pine beetle started in the Bull Mtn. area in 1971 and lasted until 1975 when the epidemic completely collapsed (Doidge 1974, 1975). At the end of the infestation, many but not all lodgepole pines had been killed. By 1985 the average age of the Douglas-fir component was 63 years; surviving lodgepole pine averaged 107 years. The understory, defined as trees which are less in height than the average lowest live branches of the overstory (approximately 7 m), was well stocked and primarily Douglas-fir.

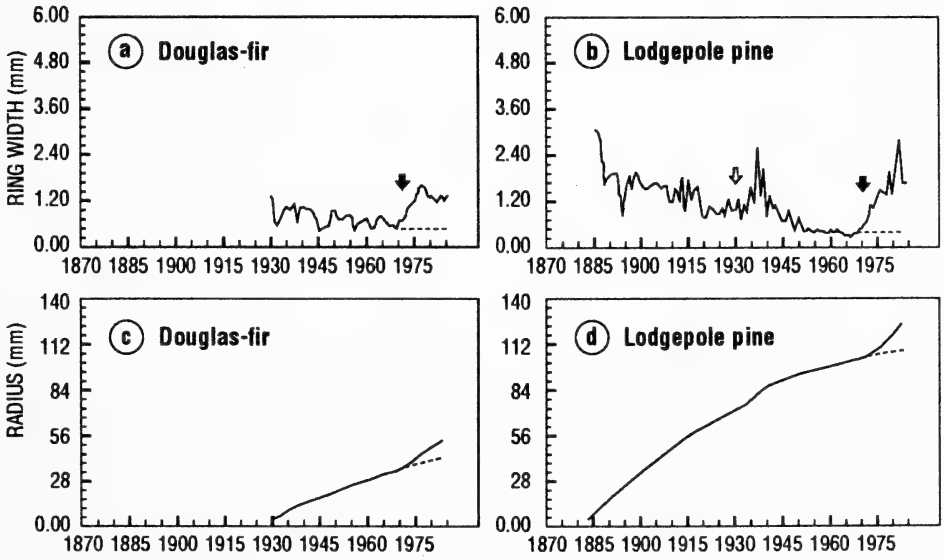

Fig. 1. Radial increment (a,b) and cumulative radial growth curve (c,d) from one surviving Douglas-fir and one lodgepole pine tree from the Bull Mountain area of British Columbia, showing the growth increase that occurred after the mountain pine beetle selectively killed a large proportion of the lodgepole pine starting in 1971. The dotted line corresponds to a projection of the growth trend (by linear regression) of the 20 years before 1971. The solid arrow points to the year 1971, the year in which the outbreak began. The open arrow indicates the start of an earlier release period, around 1930, possibly caused by a previous mountain pine beetle epidemic.

Two surveys of the area were conducted by the B.C. Min. of Forests and Lands, Cariboo Region. The first, in 1975, consisted of 98 pairs of concentric circular plots on a 50 × 50 m grid. One of the plots in the pair was 0.008 ha in area and was intended to measure overstory conditions; the second was 0.002 ha in size and was used to collect data on the regeneration (File Report by R. Gasson, August 1976, on file at the Cariboo Regional Office). The second survey was conducted in the fall of 1985, and consisted of 49 pairs of concentric circular plots on a 100 × 100 m grid. In this case, the plot sizes at each point were 0.01 ha and 0.005 ha for the overstory and understory plots, respectively. The objective of both surveys was to establish the amount and condition (alive or dead) of the overstory and understory. For every overstory tree, diameter at breast height (DBH) was measured. Growth rates after the beetle outbreak were determined in 1985 through collection of one breast-height increment core in each overstory plot from a live dominant or co-dominant Douglas-fir (i.e., a total of 49 Douglas-fir cores collected). Cores were also collected from 20 living dominant and co-dominant lodgepole pine randomly selected throughout the stand.

Thinning response was measured by comparing the actual diameter of the cored trees as of 1985 with a theoretical diameter the trees would have reached by this date in the absence of the beetle outbreak. The theoretical diameter was calculated as follows. Annual ring increments were measured on the cores to the nearest 0.01 mm using a DIGIMIC tree ring measuring device (Holmann Electronics, Fredericton, N.B., Canada) and the software developed by Alfaro *et al.* (1984). Every ring increment series was plotted *versus* date of ring formation and crossdated (Stokes and Smiley 1968). A linear regression curve was then fitted to the ring increments grown in the 20 years preceding the initiation of the outbreak in 1971 (Fig. 1). By projection of this linear regression, theoretical increments without thinning were calculated for every year between 1972 and 1985. In a few cases where the linear regression method gave poor projections (e.g., projected increments dipped below the X-axis), the projection was discarded and theoretical increments for the 1972-1985 period were assumed equal to the average growth of the 5 years that preceded 1972. Theoretical radii and diameters were determined by accumulation of the tree ring series but using the theoretical increments for the 1972–1985 period. The actual and theoretical diameters are respectively referred to hereafter as the thinned and unthinned tree diameter.

For both Douglas-fir and lodgepole pine, mean diameter and basal area gain per tree due to thinning was calculated as the difference between the thinned and unthinned tree diameter. In addition, a study was done of the relationship between diameter and basal area gain per tree *versus* tree diameter and age at the start of the infestation (1971). The percentage annual growth of thinned and unthinned trees for the period between 1971 and 1985 was calculated using the compound interest formula (Husch *et al.* 1972).

To confirm that any increase in growth rate during the post-outbreak years was due to a thinning effect and not to a coincident period of abnormally favourable weather, increment cores were randomly collected from a 20 additional lodgepole pine trees of similar age and size to those on Bull Mtn., but from a stand which had not undergone a beetle outbreak. The stand selected was located near Lyne Creek, about 10 km northwest of the Bull Mtn. study site, and was approximately 100 years old in 1985 (age range 83–112). It was located in the same biogeoclimatic subzone, had similar stocking levels, and was also growing on a medium site (Steen, pers. comm.). Annual ring widths in these cores were measured and graphed *versus* dates, with the same instruments and methods used for the Bull Mtn. cores.

RESULTS AND DISCUSSION

Although no direct data are available on the stand structure before the beetle epidemics at this location, an approximation was obtained by adding the figures for the number of beetle-killed and live trees reported in 1975. Before the beetle outbreak, the overstory

contained approximately 560 living stems/ha, consisting of 80% lodgepole pine, 19% Douglas-fir and 1% white spruce. In 1985, 14 years after the start of the beetle epidemic, the stand contained 430 living stems/ha, with the pine component reduced to 20% and the Douglas-fir and white spruce increased to 77% and 3%, respectively. These changes in stand structure were due to the high mortality of the pine induced by the beetle and to the acceleration of Douglas-fir growth which resulted in understory trees being recruited into the overstory. Seventy-six percent of the pine stems/ha were dead (81% by basal area) which represented 38% of the total stems/ha in the stand (43% by basal area).

In 1975, the understory contained an average 3190 trees/ha composed of 90% Douglas-fir and 5% each of lodgepole pine and white spruce. In 1985, the understory contained 2698 trees/ha with a similar composition; 91% Douglas-fir, 7% lodgepole pine and 2% white spruce.

Thinning response of Douglas-fir

All but one of the 49 Douglas-fir trees cored showed a marked increase in radial growth in the period that followed the beetle outbreak, relative to the trend line fitted to the growth prior to the start of the infestation in 1971 (Fig. 1). The increase began 1 to 4 years from the start of the infestation, and reached a maximum 5 to 7 years after. By 1985, many trees still had growth rates above the trend line. However, considerable tree-to-tree variation occurred which was probably due to spatial and temporal differences in pine mortality, to a relatively heterogeneous stand structure and to variations in the sample trees' crown size and position in the crown canopy.

Average DBHib (DBH inside bark) of Douglas-fir in 1985 was 13.4 cm (range 8.3–24.6). The 1985 DBHib in the absence of the thinning effect, was estimated at 12.0 cm (7.2–23.6). Hence, the average diameter gain due to the beetle-induced thinning was 1.4 cm (0–4.4), which amounted to an average increase of 11.7% (0–57%) over the size of the unthinned tree (average increase of 21% by basal area).

Regression analysis indicated that the thinning response (as measured by the difference in DBH with and without thinning) was lower in the large diameter and older trees than in small diameter and younger trees ($F = 6.0$ and $F = 5.9$, for the diameter and age relationships, respectively; both significant at $P < 0.05$). However, there was considerable variation in the response, particularly among trees of small diameter or of young age. The regression line explained only about 10% of the variance. Inclusion of the number or percentage of lodgepole pine trees killed in each plot in the analysis did not improve the regression.

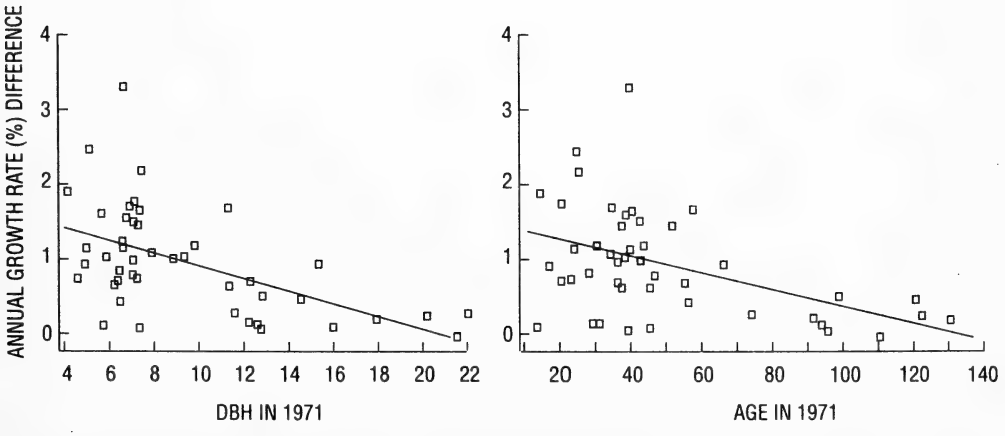

Fig. 2. Difference between thinned and unthinned annual growth rates (%) of Douglas-fir *versus* initial DBH (cm) and tree age (years) in 1971. Thinning was the result of a mountain pine beetle outbreak, which killed a large proportion of the lodgepole pine.

Based on the 1971 and 1985 diameters, and using the compound interest formula, thinned and unthinned annual growth rates averaged 2.9% (0.2–6.5%) and 2% (0.1–5.7%) per year, respectively. In terms of basal area, the average annual growth rate was 6% (0.3–13.5%) per year with thinning, and 4% (0.2–11.7%) per year without thinning. The difference between thinned and unthinned annual growth rates is shown in Fig. 2. Again, these figures show larger percentage growth gains among the small diameter trees of young age relative to larger or older trees. Trees with diameters greater than 21 cm or older than 140 years showed no response. For the same age or diameter, there was a large tree to tree variation in the thinning response (Fig. 2).

Thinning response of surviving lodgepole pine

Fourteen out of the 19 lodgepole pine sampled showed a similar growth acceleration period after the start of the beetle outbreak of 1971 to that in Douglas-fir. The increase started 2–6 years from the start of the outbreak and peaked 5–9 years after; growth still remained above the trend line as of 1985.

Average 1985 DBHib for lodgepole pine was 19.5 cm (range 12.6–26.5 cm). The 1985 mean unthinned diameter was estimated at 18.5 cm (12.7–25.0 cm). Hence, the average diameter gain due to thinning (including the trees that did not show a response), over the 14 year post-outbreak period was 1.0 cm which was equivalent to a 5.4% increase over the size of the unthinned tree (12.3% by basal area). In lodgepole pine the degree of response to thinning was not significantly related ($P > 0.05$) to the diameter or age of the trees at the start of the infestation.

The percentage annual diameter growth rates for the 14 year period ending in 1985, doubled from 0.4% per year (0.1–0.7%) without thinning to 0.8% per year (0.1–1.7%) with thinning. Annual basal area growth rates averaged 1.7 and 0.8% per year with and without thinning, respectively.

Examination of the plots of annual ring increment for lodgepole pine at Bull Mtn. indicated an earlier release period starting about 1930 (Fig. 1), probably caused by an earlier beetle infestation. The Douglas-fir in the stand was younger than the lodgepole pine and originated about that date, possibly by seeding into the openings created by the bark beetle.

Growth in the Lyne Creek area

Increment cores of lodgepole pine from Lyne Creek did not show the increase in diameter growth after 1971 seen at Bull Mtn. On the contrary, tree rings from this area showed the normal pattern of decline with age and growth in the 1972–1985 period was, on average, 17% less than growth in the previous 10 years. Since the two locations are exposed to similar climatic conditions, it was concluded that the release at Bull Mtn. was due to the beetle-induced thinning.

DISCUSSION

The mountain pine beetle caused a drastic change in the stand structure in this area as the overstory changed from largely lodgepole pine, a shade intolerant species, to predominantly Douglas-fir, a more tolerant species. Removal of the mature pine, a seral species on this site, increased the rate of successional change towards a Douglas-fir dominated stand. The same pattern of change does not occur in much of the Chilcotin where lodgepole pine is a pyraledaphic climax species and no shade-tolerant conifer species are available to replace beetle-killed pine. Stands in the IDFdk3 biogeoclimatic subzone with significant Douglas-fir or white spruce components can withstand heavy pine mortality levels and still become commercially viable in a reasonable period. Overstory Douglas-fir stocking densities on Bull Mtn. increased from 106 stems/ha (19% of the stand) in 1975 to 331 stems/ha (77% of the stand) in 1985 with an average inside bark diameter of 13.4 cm. The diameter growth response of the Douglas-fir and residual lodgepole pine will help produce a commercially viable stand on the site within 15–20 years (assuming an economic threshold mean outside bark DBH of 25–30 cm). The shift

to a higher value species like Douglas-fir will have an additional economic impact on the stand.

Several bark beetle researchers have indicated that vigorous growth increases tree resistance to bark beetle attack and shortens outbreak duration (Brown *et al.* 1987, Cole and Amman 1969, Nebeker and Hodges 1983, Vité and Wood 1961, Waring and Pitman 1985). Before the bark beetle outbreak, lodgepole pine growth rates were near stagnation and the large proportion of the lodgepole pine that showed release response in this study could have been a factor in the termination of the outbreak in the area, along with a depletion of the most attractive host.

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Role of needles in close-range host selection by the white pine weevil on Sitka spruce

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ABSTRACT

The white pine weevil, *Pissodes strobi* Peck, is apparently induced to feed and oviposit on the cortex of leaders of Sitka spruce, *Picea sitchensis* (Bong.) Carr, in part through the influence of needles. In laboratory feeding bioassays, mature needles were shown to contain non-volatile feeding deterrents, which probably direct weevils away from them to feed on the bark. In addition, weevils fed more frequently on agar bark discs with spruce needles or toothpicks inserted in them than on control discs, suggesting that the needles have a positive thigmatactic effect on close range host selection.

INTRODUCTION

Stands of Sitka spruce, *Picea sitchensis* (Bong.) Carr (Silver 1968), Englemann spruce, *Picea engelmanni* Parry (Stevenson 1967), and eastern white pine, *Pinus strobus* L. (Belyea and Sullivan 1956) are seriously plagued by attacks of the white pine weevil, *Pissodes strobi* Peck. In the spring, the weevils apparently orient visually to the terminal leader of the tree (VanderSar and Borden 1977a). They are induced to feed on the bark by chemical stimulants (VanderSar and Borden 1977b; Alfaro *et al.* 1980), and feed and oviposit in the one-year-old leader directly below the apical bud cluster (Silver 1968). Although the needles contain some cuticular feeding stimulants (Alfaro *et al.* 1980), no feeding has been observed on them. However, leaders with sparse needle growth are less often attacked than those with high needle density (unpublished observation). The weevils find the terminal bud through positive phototaxis and negative geotaxis (VanderSar and Borden 1977c), but the precise mechanisms by which the weevils orient to the bark on one-year-old branches for feeding and on leaders for feeding and oviposition, while avoiding other sites, are unknown. Our objective was to investigate the role of Sitka spruce needles in regulating feeding activity by *P. strobi*.

MATERIALS AND METHODS

Terminal leaders of Sitka spruce containing mature *P. strobi* larvae were collected from Nootka Island and Vancouver Island and stored, until required, in a cold room at 2°C for up to 4 months. Weevils emerged at room temperature in cages, and were maintained at 4°C on a modified diet (Zerillo and Odell 1973). Some adult weevils were also collected in the spring from plantations in the University of British Columbia Forest, Maple Ridge, B.C. All Sitka spruce samples were collected from sapling trees at the U.B.C. Research Forest or Harrison Hot Springs in the lower mainland of British Columbia. They were stored at 5°C until used.

Laboratory experiments employed the feeding bioassay developed by Alfaro *et al.* (1979). Single or paired agar discs containing the candidate stimuli were covered with lens paper, and set in paraffin wax in petri dishes. The number of feeding punctures made by weevils in the lens paper indicated the amount of feeding activity in response to the stimulus incorporated in the agar. Each replicate (dish), containing three weevils, was placed on a counter-top at room temperature and constant light. As weevils of either sex

feed similarly (VanderSar and Borden 1977b), no distinction was made as to the sex of the weevils used.

To test for possible feeding deterrents in the needles, single agar disc treatments were prepared. A control treatment contained 1% dried and ground Sitka spruce bark while experimental treatments contained, in addition to 1% bark, dried and ground Sitka spruce needles from the leader. These were incorporated at concentrations of 0.1, 1.0, 2.5 and 10% into the agar. Each treatment was tested for 8 h and had 15 replicates.

The physical effect of needles on feeding activity was assessed by two paired experiments with all agar discs containing 1% dried bark. Mature needles were cut from lateral branches and their cut ends were sealed by dipping in paraffin wax. In the first experiment, one agar disc had three needles inserted into the agar perpendicular to the surface, while the other disc had no needles. The second experiment had one disc with three inserted needles and one with three inserted toothpicks, cut to needle length. Initially there were 20 replicates in each 40 h experiment, but replicates in which weevils did not feed at all (four in the first, and one in the second experiment) were deleted. Paired means in each experiment were compared by t tests, $\alpha = 0.05$.

RESULTS AND DISCUSSION

When the weevils were given a choice between Sitka spruce bark agar discs and those with needle powder added, there was a prounounced deterrent effect of the needles, especially at higher concentrations (Fig. 1). Thus non-volatile feeding deterrents in the needles appear to override the effect of weak, cuticular feeding stimulants (Alfaro *et al.*

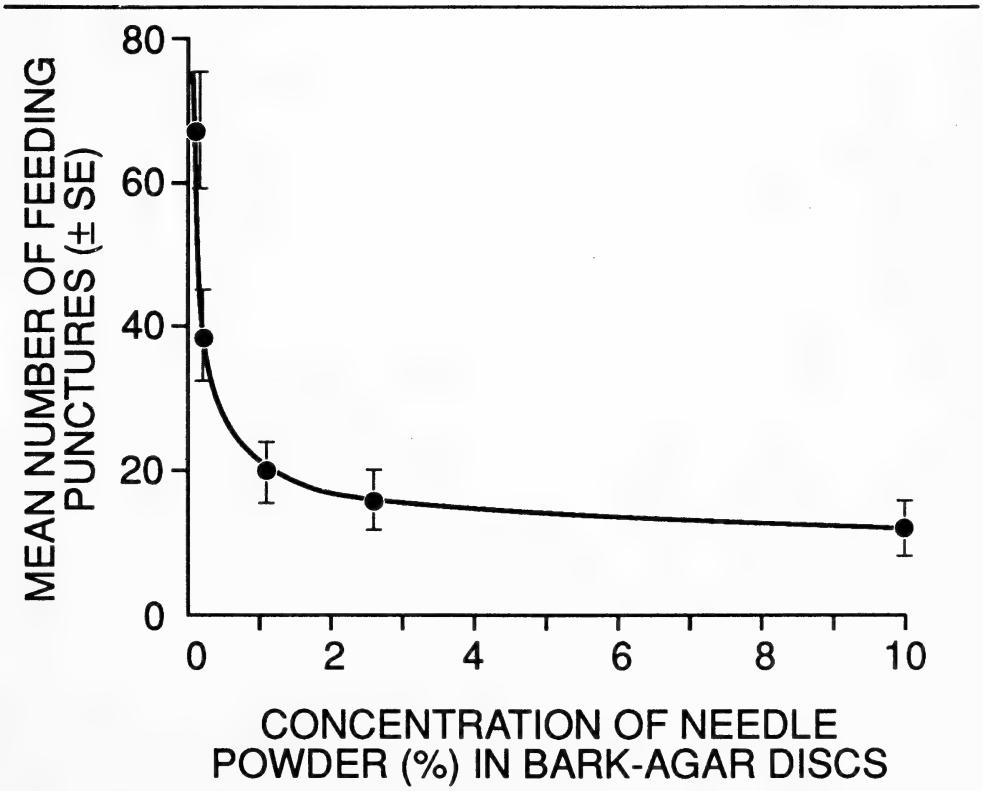

Fig. 1. Feeding response of *P. strobi* to Sitka spruce bark agar disks containing increasing amounts of Sitka spruce needle powder. Curve fitted by hand.

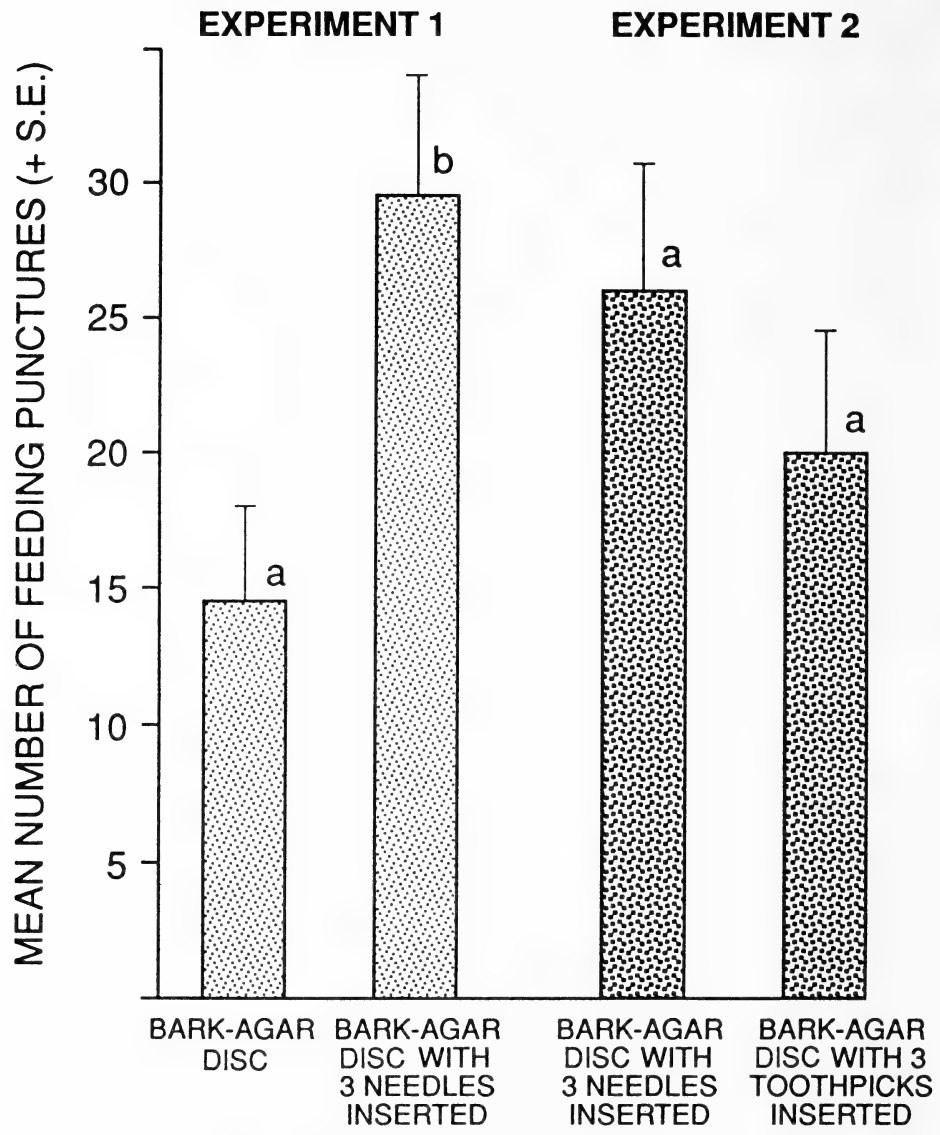

Fig. 2. Feeding response of *P. strobi* to Sitka spruce bark agar discs in the presence of spruce needles or toothpicks. Bars topped by the same letter are not significantly different, t test, $P < 0.05$.

1980), and may in part direct the weevils away from the needles towards the appropriate site for feeding and oviposition, i.e. the bark surface.

Vertically implanted needles in Sitka spruce bark agar discs significantly increased feeding by weevils (Fig. 2). The weevils did not discriminate between Sitka spruce needles and plain toothpicks inserted into the agar. They were observed to feed preferentially while touching the needles or toothpicks, suggesting that there is a thigmotactic response.

A thigmotactic requirement also occurs in the smaller European elm bark beetle, *Scolytus multistriatus* (Marsham), which feeds in the crotch of elm twigs (Peacock *et al.* 1967). The hypothesis for a thigmotaxis is supported by our field observations that the majority of feeding weevils are found in direct contact with needles. This behavior may be of adaptive advantage to the weevils, as the needles may provide concealment or physical protection from predators such as birds.

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Efficacy of deltamethrin and *Bacillus thuringiensis* Berliner ssp *kurstaki* on larvae of winter moth, *Operophtera brumata* (L.) (Lepidoptera: Geometridae) attacking blueberry in the Lower Mainland of British Columbia

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ABSTRACT

Two pesticides were evaluated for control of the European winter moth, *Operophtera brumata* (L.), in blueberries in Richmond, British Columbia. The pyrethroid, deltamethrin (Decis), was effective against this pest. The *Bacillus thuringiensis* product Dipel (WP) was ineffective. Deltamethrin provides an alternative to the currently used organo-phosphate pesticides.

INTRODUCTION

The European winter moth, *Operophtera brumata* (L), was first introduced to the east coast of North America (Nova Scotia) as early as the 1930s (Cuming 1961, Embree 1965, 1970), and to southern Vancouver Island (Victoria, British Columbia) prior to 1970 (Gillespie *et al.* 1978, Roland 1988). Since then, the winter moth has spread to the mainland of British Columbia and is most prevalent in the southwestern communities of Ladner, Tsawwassen and Richmond.

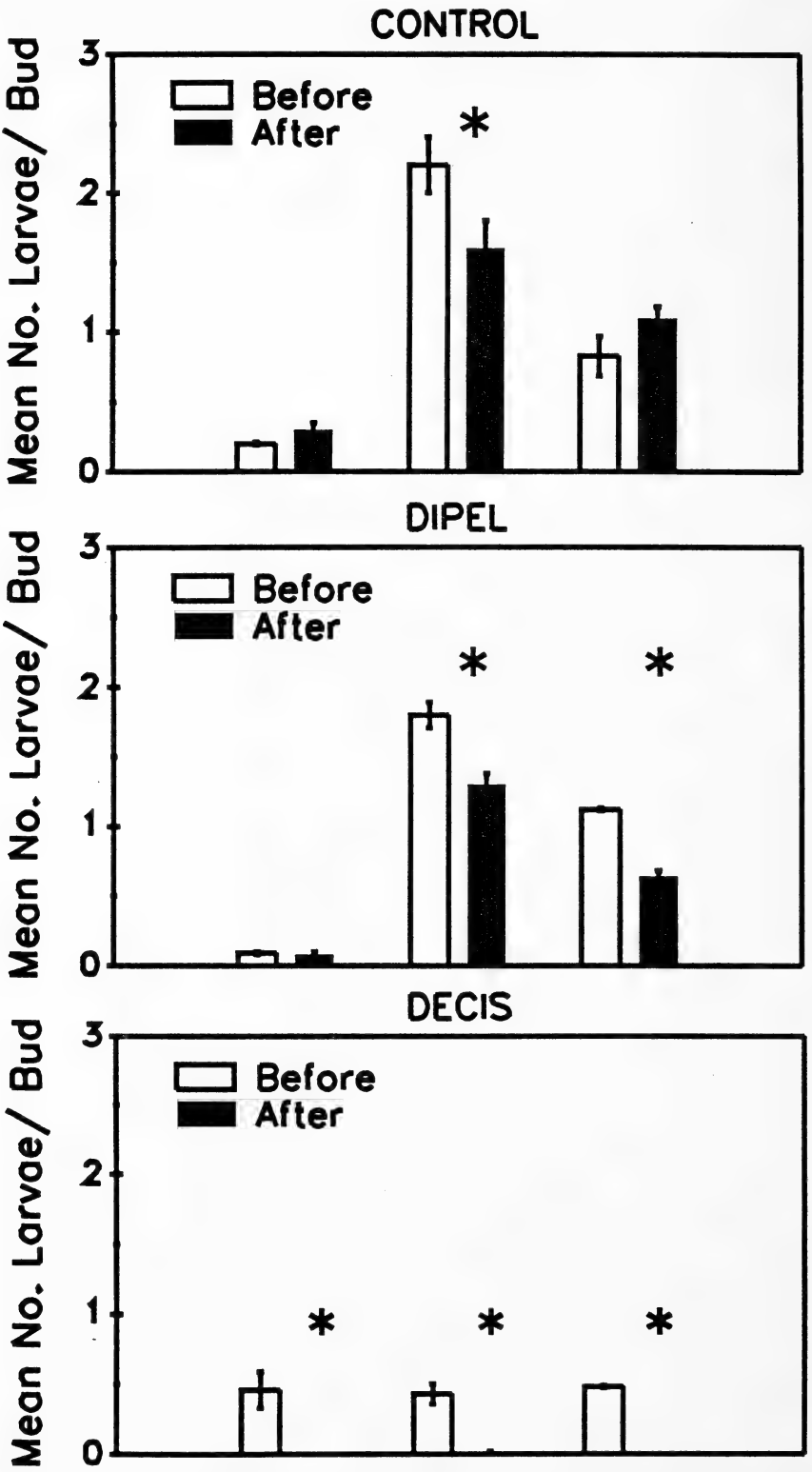

Fig. 1. Mean number of winter moth larvae/bud in 3 replicates of control, deltamethrin (Decis), and *Bacillus thuringiensis* plots before (April 11, 1990) and after treatment (April 18, 1990). * indicates plots that significantly declined in density over this period in t-test comparisons. S.E. bars given.

Winter moth eggs hatch in early April and larvae immediately begin to feed on new buds. In Richmond, *O. brumata* have reached high densities in *Betula* (birch) woodland, causing near total defoliation in some areas. Since 1988 winter moth larvae have severely damaged unsprayed commercial blueberries, *Vaccinium ovatum* L. Blueberry growers have had varied success combating this new pest with organo-phosphorus compounds such as malathion, carbaryl and azinphos-methyl. The time, method and number of applications of these compounds probably determined the success rate. This study evaluates the effectiveness of two insecticides with low toxicity to terrestrial vertebrates—the microbial pesticide *Bacillus thuringiensis* Berliner ssp *kurstaki* (Dipel WP), and the synthetic pyrethroid deltamethrin (Decis 2.5 EC)—for control of winter moth on commercial blueberry bushes.

MATERIALS AND METHODS

Studies were conducted in a 1/4 ha blueberry field in Richmond, south of Vancouver. The plants, mostly of the variety Blue Crop, had not been pruned or commercially harvested for several years. Nine plots, each containing three rows of three bushes, were allotted randomly to the two treatments (*B. thuringiensis* and deltamethrin) and the untreated control. From previous observations we knew that winter moth were not evenly distributed in the field so we attempted to locate plots so that each treatment was represented in different parts of the field. However, the treatments were not completely blocked. Each plot was bordered by two rows of unsprayed bushes to prevent spray drift, and pruned so that sprayed bushes did not contact unsprayed bushes.

From mid-March blueberry buds were searched every 3 or 4 days for hatched larvae. Larvae were first observed on 4 April, 1990. Pre-treatment larval counts were made on April 10, 1990, six days after the first larvae were found at the site. Counts were made by arbitrarily selecting 24 fruit buds from each bush, six from each side of the bush in the ordinal positions (216 per plot). Of the 24 buds selected from each bush, 15 were randomly chosen and a dissecting microscope used to count the number of larvae per bud. For the post-treatment counts on April 18 and May 1 only 16 buds per bush were selected. Sprays were applied using a hand-pumped backpack sprayer on April 11. Bushes were sprayed lightly, each receiving approximately 1/2 l of spray material. Dipel was applied at 1100 grams of active ingredient per hectare (approximately 0.5 g per bush). Decis was applied at 100 ml (2.5 g active ingredient) per hectare (approximately 0.13 ml or 32.5 mg active ingredient per bush).

The effect of *B. thuringiensis* was tested in a laboratory study. Twenty field collected larvae were placed in individual thin plastic cups and fed blueberry leaves dipped in the *B. thuringiensis* product Dipel. Cups containing larvae were placed in an open air insectary and fed fresh leaves after four days. New untreated leaves were provided every two days following the treatment. Death rates were compared to twenty control individuals fed fresh untreated leaves. This experiment was carried out twice, once beginning on April 23, 1990 and again beginning on May 14, 1990.

RESULTS AND DISCUSSION

The mean number of larvae/bud varied greatly among plots (Figure 1). By chance two of the three control and *B. thuringiensis* plots had approximately twice the density of winter moths prior to treatment than did the plots to be treated with Decis. Unfortunately, because we did not identify the bushes so as to identify pre- and post-treatment samples from the same bushes we were not able to carry out an analysis of covariance. We have therefore compared changes in density for each plot in each treatment using a t-test as indicated on Figure 1 and tested for overall change in larval density before and after treatment by using the three replicates for each treatment in a t-test (Table 1).

Overall, *B. thuringiensis* (Dipel WP) did not significantly reduce numbers of winter moth larvae (Table 1) although numbers of larvae were significantly lower on 18 April in two of the plots (Figure 1). Since larvae in the flower buds have a major impact on

Table 1
The effect of two insecticides against *Operophtera brumata* in blueberries.
Richmond, B.C. 1990. N = 3 for all means.

	Mean Number of Larvae/Bud (S.E.)		
	April 10	April 18	May 1
Bacillus thuringiensis (Dipel WP)	1.00 (0.50)	0.67 (0.35)	0.83 (0.46)
Deltamethrin (Decis 2.5 Ec)	0.46 (0.01)	0.01 (0.01)*	0.00 (0.00)*
Control	1.07 (0.59)	1.0 (0.37)	0.67 (0.15)

* $t = 36$, $P < 0.01$ for both comparison of density after treatment to before.

blueberry production, for sufficient control, almost complete mortality is necessary. *Bacillus thuringiensis* did not provide this. Tonks *et al.* 1978, observed significantly lower densities of winter moth larvae as compared to controls in apple leaf buds following applications of Dipel W.P. and Thuricide HPC, but they do not report the date or how long after egg hatch these sprays were applied. In similar tests on filberts (*Corylus avellanae* L.) in Oregon, *B. thuringiensis* (Thuricide HPC) was also ineffective in the control of winter moth damage (AliNiazee 1986). *Bacillus thuringiensis* (Dipel) also did not control Bruce's spanworm (*Operophtera bruceata* [Hulst]) on the blueberry variety Rancocas (Raine and Clements 1984).

In our laboratory study, *B. thuringiensis* had no effect on the winter moth larvae fed on April 23 when compared with the controls, but survival was poor in both groups. However, in the second test, fourth and fifth instar larvae fed blueberry leaves soaked in Dipel died much more rapidly than the controls. In the first week 30% of the larvae fed with *B. thuringiensis* had died compared to only 5% of the controls (Chi-squared = 4.33, $P < 0.05$). By the end of the second week, 80% of the test larvae died compared to 40% of the controls (Chi-squared = 6.7, $P < 0.05$). By May 30, 10 control larvae had pupated while only 3 *B. thuringiensis* fed larvae pupated.

Deltamethrin provided complete control in this study. In the first count after treatment (April 18), only one larva was found alive (Figure 1) and the reduction in the density of winter moth larvae was significant ($t = 36$, $P < 0.01$ $N = 3$) (Table 1). If any larvae hatched after spraying, they did not survive and no winter moth larvae successfully invaded the bushes from the surrounding unsprayed plants. No live larvae were counted on May 1 on these plots. Tonks *et al.* 1978 found similar good control of winter moth with another synthetic pyrethroid, permethrin, on apples, and another synthetic pyrethroid, fenvalerate, significantly reduced winter moth on filberts (AliNiazee 1986). Raine and Clements (1984) found that deltamethrin significantly reduced the number of Bruce's spanworm in blueberry. Sanford (1985) obtained good control of winter moth on the McIntosh variety of apples with deltamethrin.

Growers in Richmond who have successfully controlled the winter moth during the last few years have applied organo-phosphate sprays several times between initial and final egg hatch in early to mid-April. The timing of different chemical sprays has been shown to be important in the control of winter moth on filberts (AliNiazee 1986). AliNiazee recommended that sprays should be applied at 90–95 percent hatch to prevent damage from larvae that hatch after spraying. This, of course, risks damage to the crop from the initial outbreak. Multiple applications of organo-phosphates can prevent early and late damage (personal communication from growers).

However, a single spray of deltamethrin (Decis) was sufficient in our tests to provide complete control, and the synthetic pyrethroid fenvalerate, was equally successful on filberts (AliNiazee 1986). Although no data are available from our study to show percentage hatch at the time of spray, Embree (1970) found mid-hatch to occur approximately seven days after initial hatch. We sprayed seven days after the first larvae were observed.

The advantage of using the synthetic pyrethroids is that they are less toxic to mammals (lethal oral dose for a rat is 135 mg/kg for Decis and 4.4 mg/kg for Guthion, a spray commonly used by blueberry growers [Thompson 1989]). Dead vertebrates (ring-necked pheasants, eastern cottontail rabbits and numerous small mammals) have been found in the blueberry fields suggesting that a side effect of the potency of some of the organo-phosphate pesticides used (Sheppard, personal observation). However, of concern is the toxicity of pyrethroids to fish and the dangers of contamination of water from the marshy habitat in which blueberries are grown. Also, while pyrethroids currently successfully control winter moth larvae, the high mortality will undoubtedly rapidly select for resistant strains of moths. Because winter moth eggs hatch early in April and only a single application is necessary, deltamethrin can be used before pollinators are active in the blueberry fields. Therefore, deltamethrin should have little impact on this important component of the system.

Our laboratory study of *B. thuringiensis* also suggests that winter moth larvae are more susceptible to this pesticide at later instars. This may be related to the greater consumption of leaf material and therefore more *B. thuringiensis* by the larger caterpillars. Although *B. thuringiensis* has little potential as a control agent in blueberries, it may be a safe and sufficiently effective agent to be used in urban areas to reduce damage from later instars of winter moth larvae on non-crop plants. This potential application needs further study.

ACKNOWLEDGEMENTS

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Recommendations for sampling and extracting the eggs of the western hemlock looper, *Lambdina fiscellaria lugubrosa*, (Lepidoptera: Geometridae)

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ABSTRACT

No significant differences were found in the numbers of both new and old western hemlock looper eggs per 100 grams of lichen between three crown levels. Representative samples may be collected from lower crown levels with pole pruners, rather than from upper crown levels, which usually involves tree felling.

Hot water is more efficient than 2% chlorine bleach for extracting the eggs from the lichen on which they are laid. However, the bleach method is non-destructive and allows the eggs to be reared in order to assess parasitism and fertility. These characteristics can also be identified through egg color using the hot water method, but the parasitoid species cannot be identified. It is recommended that the hot water method be used for forecasting population trends and the bleach method for specific information about parasitoids.

RÉSUMÉ

Aucune différence notable n'a été trouvée entre le nombre d'oeufs d'arpenteuses présents, par 100 grammes de lichen, sur les spécimens jeunes et sur les spécimens âgés de pruches de l'Ouest, les échantillons ayant été prélevés à trois niveaux de la cime. Pour éviter l'abattage, l'échantillonnage se fait non pas au faîte mais au bas de la cime, au moyen d'un échenilloir-élagueur.

Pour extraire les oeufs de leur support de lichen, l'eau chaude donne de meilleurs résultats que l'emploi d'une solution chlorée à 2%. Mais la méthode de la solution chlorée est non destructive et permet de maintenir en vie les oeufs pour en dégager les caractéristiques parasitologiques et la fertilité. Précisons toutefois que si la méthode de l'eau chaude permet de caractériser les parasitoïdes par l'observation de la coloration des oeufs, elle ne permet pas d'en identifier les espèces. On recommande donc la méthode de l'eau chaude pour étudier les tendances générales des populations de parasitoïdes et celle de la solution chlorée pour dégager des données spécifiques sur celles-ci.

INTRODUCTION

The western hemlock looper (WHL), *Lambdina fiscellaria lugobrosa* (Hulst) (Lepidoptera: Geometridae), is periodically a destructive defoliator of western hemlock, *Tsuga heterophylla* (Raf.) Sarg., and to a lesser extent other associated coniferous tree species (Harris *et al.* 1982). A reliable population index is required to predict an approaching epidemic of western hemlock looper. Estimates of frass quantity (Thomson 1949), and numbers of eggs (Kinghorn 1952; Thomson 1958; Carolin *et al.* 1964), larvae (Harris *et al.* 1982) and pupae (Shore 1989), have all been examined as population indicators. The egg is the preferred stage for sampling WHL because it is the overwintering stage, and is relatively stable in numbers, position and time through the fall and winter months.

Most of the early research on the WHL was done in coastal forests (e.g., Hopping 1934; Richmond 1947; Wyatt 1946; Thomson 1949, 1957; Kinghorn 1954; Carolin *et al.* 1964), but since the 1950s most infestations in British Columbia have occurred in interior forests (Harris *et al.* 1982). This change in outbreak location is probably due to a reduction in area of mature western hemlock forest on the coast because of a longer history of logging. On the coast it was found that the WHL laid most ot its eggs in moss on tree trunks, limbs, logs and on the forest floor (Hopping 1934; Carolin *et al.* 1964). However, in interior forests the preferred oviposition site is on lichens (*Alectoria* spp.) which grow mainly on the branches of trees (Thomson 1958). The Forest Insect and

Disease Survey (FIDS) of Forestry Canada developed a sampling index based on the number of WHL eggs per 100 grams dry weight of these lichens (Shore 1985, FIDS General Instruction Manual, Forestry Canada, unpub.).

A study was conducted comparing the number of WHL eggs per 100 grams of lichen between three crown levels of hemlock trees. If the number of eggs found in lichen from the lower crown is the same, or can be related to the number of eggs in lichen in the mid- and upper crown levels then sampling can be simplified; lichen can usually be collected from the lower crown using pole pruners, whereas sampling from other crown levels often necessitates felling the tree.

Removing insect eggs by hand from the substrate to which they have been attached is extremely time consuming and inefficient (Carolin *et al.* 1964, Condrashoff 1967, Otvos and Bryant 1972). Several methods have been presented for washing eggs from the substrate including NaOH solution (Condrashoff 1967, Shepherd and Gray 1972), hot water (Eidt and Cameron 1970, Gray *et al.* 1973) and chlorine bleach solution (Otvos and Bryant 1972). The hot water method was adapted by FIDS for removing western hemlock looper eggs from the lichen (Shore 1985). However, the chlorine bleach method has the advantage of being non-destructive to live eggs (Otvos and Bryant 1972), unlike the hot water and NaOH methods, and therefore it can be used for biological studies to determine viability and parasitism. An experiment was conducted in which the bleach method was compared with the hot water method for WHL egg extraction from lichen samples.

METHODS AND MATERIALS

Comparison of number of eggs at three tree crown levels

To examine the effect of tree crown level on the number of eggs per 100 g lichen, recently felled western hemlock trees were examined at four locations in B.C.: Kingfisher Creek (10 trees) in the Kamloops Forest Region, Cranberry Creek (4 trees) and Red Rock Harbour (5 trees) in the Nelson Forest Region, and Abbott Creek (7 trees) in the Cariboo Forest Region. Average tree diameter at breast height was 43.0 cm (standard error 11.6). Each tree crown was divided into thirds and lichen samples were collected from each third. The lichen samples were processed using the bleach extraction method and the numbers of eggs found were standardized per 100 g dry weight of lichen. Numbers of healthy (h), parasitized (p), infertile (i), new (h + p + i), and old eggs per 100 g dry weight of lichen were transformed to log10(x + 1) and compared for three crown levels across the four locations by repeated measures analysis of variance (SAS 1985). Old eggs are those from previous years whereas new eggs include healthy, parasitized and infertile eggs from the current year.

Comparison of egg washing methods

Lichen was collected, using pole pruners, from 10 western hemlock trees in each of three locations in the Nelson Forest District of B.C. Trees were a minimum of 25 cm diameter at breast height, and enough lichen was collected to fill a 5 × 10 × 25 cm polyethylene bag. The lichen from each tree was divided approximately in half and air dried in the laboratory. One half of each lichen sample was processed using the hot water egg extraction method and the other half was processed using the chlorine bleach extraction method, both of which are described below. Egg counts were standardized by converting them to per 100 g dry weight of lichen sample. Color, confirmed by other physical characteristics (Thomson 1958), was used to classify the eggs as to type: healthy, infertile, parasitized, or old (Table 1). For the non-destructive chlorine bleach extraction method, a sample of these eggs was reared to confirm the classification. Rearing was conducted on a moistened blotter in a screen vial which was kept at 0°C for two months and then at 20°C until hatching was complete. Based on the rearing results the numbers of healthy and parasitized eggs removed by the bleach method were corrected. The numbers of WHL eggs of each type extracted by the two methods, were compared using a paired t-test. The relationship between the number of healthy eggs extracted by the hot water method and the number extracted by the bleach method was described by linear regression.

Table 1
Color characteristics of western hemlock looper egg types removed from lichen by the bleach or hot water methods

Type of egg	Bleach Method[1]	Hot water method
Healthy	Brown	Bronze
Parasitized	Black	Black
Infertile	Green	Yellow
Old	Opaque	Opaque

1. From Otvos and Bryant (1972).

Hot Water Extraction Method:

Each lichen sample was placed in a 2 l plastic bucket. Water, heated to 100°C, was poured over the sample until the lichen was immersed. The sample was swirled with tongs to shake the eggs free of the lichen. The contents were then poured through nested strainers consisting of a large meshed (1000 micron) top strainer to remove the debris but allow the eggs through, and a close-meshed (250 micron) bottom strainer which retained the eggs. The contents of the top strainer were rewashed to remove eggs which remained attached during the first rinse. The bottom strainer was then inverted in a funnel and the contents rinsed into a glass jar. Finally, the contents of the glass jar were extracted onto filter paper using a vacuum filter. Egg counts were made by examining the filter paper with a dissecting microscope.

Chlorine Bleach Extraction Method:

Lichen samples were teased apart, placed into a 2 l plastic bucket and covered with a solution of 2% chlorine bleach in water. The buckets were mechanically shaken at the lowest setting for 45 minutes. Each sample was then processed as described for the hot water method with the additional step of rinsing the contents of the bottom strainer with tap water for 10 minutes to halt the corrosive action of the bleach.

RESULTS

Comparison of number of eggs at three tree crown levels

There were no significant differences among crown levels across the four locations for either new (h + p + i) or old WHL eggs (Table 2). When the new eggs were analyzed separately by type, no significant differences were found among crown levels for healthy ($P > .69$), parasitized ($P > .67$), or infertile ($P > .24$) eggs. There were no significant interactions between crown levels and location for any of the egg types (new: $P > .89$, old: $> .94$, h: $> .44$, p:$> .47$, i: $> .09$).

Table 2
A comparison of the mean number of western hemlock looper eggs per 100 gram lichen sample from three tree crown levels

Location	Number of trees	Mean number of new eggs[1] (± SEM)[2]			Mean number of old eggs (± SEM)[2]		
		Upper crown	Mid crown	Lower crown	Upper crown	Mid crown	Lower crown
Kingfisher	10	12.9± 5.1	3.6± 1.4	7.1± 3.5	23.7± 6.1	26.6± 6.9	27.7±14.9
Cranberry	4	23.9± 5.3	25.1± 5.1	23.2± 7.0	198.0±32.6	125.4±28.2	111.0±22.2
Red Rock	5	34.5±13.7	28.8± 7.7	49.5± 9.7	184.2±89.0	197.2±21.1	179.5±15.5
Abbott	7	75.5±10.5	61.6± 9.9	46.8± 9.9	49.2±12.2	50.3±10.0	59.1±18.4

1. New eggs includes healthy, infertile and parasitized eggs of the current year.
2. No significant differences among crown levels were found within egg types across locations, Repeated Measures ANOVA on data transformed to $\log_{10}(x+1)$; new: $F = .43$; $P > .65$, old: $F = .25$, $P > .78$.

Table 3
A comparison of the mean number of western hemlock looper eggs per 100 gram lichen sample extracted from lichen by the bleach and hot water methods

	Bleach method		Hot water method	
Type of Egg	Mean[1]	S.E.M.	Mean[1]	S.E.M.
Healthy	74.0	12.7	122.6	17.3
Parasitized	28.1	2.6	44.6	6.1
Infertile	29.8	4.2	53.9	6.5
Old[2]	66.8	7.8	118.7	16.1
New[2]	131.9	18.4	221.1	26.5
Total	198.8	25.2	339.8	41.0

1. Mean numbers of all types of eggs were significantly greater for the hot water method than the bleach method, paired t-test, $P < 0.01$, $n = 30$.
2. Old eggs were those from previous years, new eggs included healthy, parasitized and infertile eggs from the current year.

Comparison of egg extraction methods

There was no significant difference between the weights of the lichen sample halves assigned to the bleach or hot water treatment (paired t-test, $t = 1.17$, $n = 30$).

Significantly more of all types of WHL eggs (healthy, parasitized, infertile, old, new and total) were removed from the lichen substrate by the hot water method than by the bleach method (Table 3).

The number of healthy eggs removed by the hot water method was regressed on the number removed by the bleach method to provide an equation for converting egg numbers derived from one extraction method to the other. A linear model was used and three points were identified as outliers (Freund and Littell 1986) and removed from the regression. As the intercept was not significantly different from zero ($p > 0.2$) the regression was forced through the origin, producing the following relationship ($R^2 = 0.89$; s.e. slope 0.01):

$$\text{No. healthy eggs (hot water)} = 1.473 \times \text{No. healthy eggs (bleach)}$$

The difference in color between healthy and parasitized eggs removed by the bleach method is not so distinctive as for the hot water method. Of 180 "healthy" eggs reared, parasitoids emerged from 26 indicating that 14.4% of the "healthy" eggs were misclassified. Misclassification cannot be quantified for the destructive hot water method; however, because the color of the healthy egg type is more distinctive it is assumed that misclassification is minimal. Support for this assumption can be found by comparing the percentage of total eggs in each egg type extracted by the two methods. Initially, healthy eggs represented a higher percentage and parasitized eggs represented a lower percentage of total eggs for the bleach method than for the hot water method (Fig. 1). However, when the numbers of healthy and parasitized eggs extracted by bleach were corrected for the 14.4% misclassification found in the rearing study, all egg types represented similar percentages of the total number of eggs for both extraction methods (Fig. 1).

DISCUSSION

The finding that there were no significant differences between tree crown levels for number of WHL eggs per 100 g lichen should simplify egg sampling procedures for this insect species. In the past, trees frequently have been felled to obtain egg samples for WHL from the upper part of the crown. Lower crown samples, which can usually be collected with pole pruners, should provide reliable estimates of WHL egg density.

The hot water method was more efficient at removing WHL eggs from the lichen than was the bleach method. As a result, when the insect is at low population densities, egg counts obtained by the hot water method should be more sensitive than those obtained by the bleach method. Also, the colors of the egg classes (h, p, i) were more distinctive with

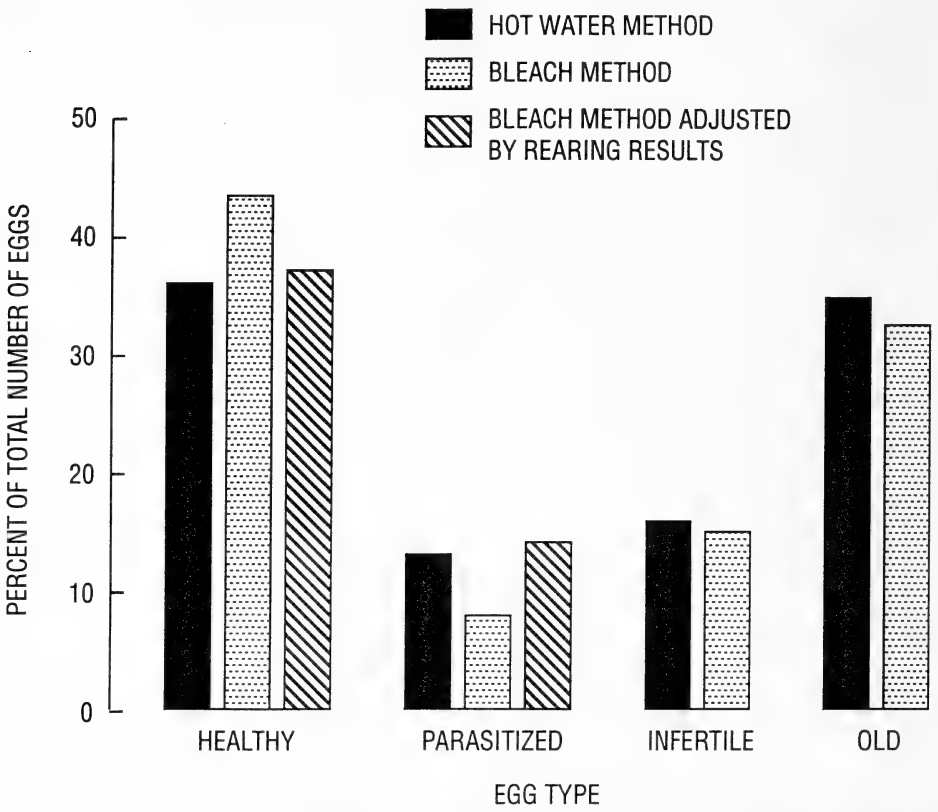

Fig. 1. A comparison of the percentage of total western hemlock looper eggs that were healthy, parasitized, infertile, or old, extracted by the bleach or hot water methods from lichen substrate.

hot water than with bleach and it seemed that misclassification was lower. For these reasons, it is recommended that the hot water method be used when the objective is relative population density estimation for damage prediction.

If the objective is to evaluate WHL egg mortality attributable to parasitism, and species specific information about parasitoids is required, the bleach method should be used. This method is non-destructive and therefore permits the user to rear the eggs to confirm classification and to identify parasite species.

ACKNOWLEDGEMENTS

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A review of mosquito collecting in the Yukon

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The first formal record of a mosquito collected in the Yukon was in 1904 when J. Keele caught *Anopheles occidentalis* in the Mayo River valley (Dyar 1921). In 1916 three females of *Aedes nearcticus* were collected on Herschel Island, off the north coast of the Yukon, by Frits Johansen of the Canadian Arctic Expedition (Dyar 1919). These species, now known as *An. earlei* and *Ae. impiger* respectively, were identified at the time by Dr. Harrison Dyar at the United States National Museum in Washington.

Dyar, himself, visited the Yukon in June and July of 1919. He travelled from Carcross in the south, along the Yukon valley to Dawson which is less than half way to Herschel Island. He recorded 16 species (Dyar 1920, 1921) including nearly 2,000 specimens of *Ae. cataphylla* which he found to be the dominant species with *Ae. campestris, Ae. communis* and *Ae. punctor* also common (Table 1). He described three new species from his Yukon material: *Ae. nearcticus* from Herschel Island, the Northwest Territories and Alaska (Dyar 1919); *Ae. callithotrys* from Whitehorse and Takheena River in the Yukon and from Alaska; and *Ae. mercurator* from 65 specimens collected around Dawson (Dyar 1920). He later synonymised *Ae. callithotrys* with *Ae. campestris* (Dyar 1928).

By the 1920s Whitehorse was attracting tourists and, in 1926, presumably as a result of their complaints, Eric Hearle, who had already reduced the mosquito nuisance in the Lower Fraser Valley of B.C. and the resorts of Banff and Lake Louise in Alberta, was invited to make recommendations on controlling mosquitoes in the Yukon (Hearle 1927). He probably collected adults and larvae when he assessed the problem around Whitehorse.

The Dominion Entomologist, Arthur Gibson, reported on mosquito control in Canada from 1923–1941 to the Annual Meetings of the New Jersey Mosquito Control Association, but did not refer to any work in the Yukon.

From 1947 to 1950, mosquitoes were collected from several arctic and subarctic localities as part of the Northern Insect Survey, a joint endeavour of the Canada Department of Agriculture and the Department of National Defense. An Interim Report by Freeman (1952) of the mosquitoes obtained during the Survey consisted mainly of distribution maps. The 16 species reared from sites in the Yukon were mainly from Dawson or Whitehorse. Vockeroth (1954a) addressed the difficult problem of identifying the females and discussed their distribution. *Ae. nigripes* was not found in the Yukon during the Survey but he thought it was probably present because it is the most abundant species elsewhere in the arctic. Vockeroth (1954b) examined the type specimens of several arctic species. He pointed out that mosquitoes identified up to that time as *Ae. nearcticus* were in fact *Ae. impiger* and that the specimens from Dawson and elsewhere, identified in the Canadian National Collection as *Ae. impiger,* belonged to a new species which he described and named *Ae. implicatus.*

In his guide to the mosquito larvae of Western Canada, Rempel (1950) noted that 8 to 10 of the species in the guide occurred in the Yukon. He did not refer to collecting there himself but he may have seen representative specimens in collections loaned to him from the Canadian National Collection in Ottawa and the U.S. National Museum in Washington.

In the summers of 1949 and 1950, Colin Curtis, an entomologist from the Veterinary and Medical Entomology Laboratory at Kamloops, B.C., collected 21 species around Whitehorse and Watson Lake (Table 1). He noted that although *Ae. cataphylla* was common, the predominant pest mosquitoes were *Ae. communis* followed by *Ae. punctor* and *Ae. pionips* (Curtis 1953).

Dr. D.M. McLean, a medical microbiologist from the University of British Columbia, collected mosquitoes in northern B.C. and the Yukon during several seasons in a survey for mosquito-borne encephalitis viruses. He collected mainly adults and some larvae at about a dozen locations in the boreal forest region from Marsh Lake near Whitehorse in the southeast to an area near the Dempster Highway at 67°N and 137°W. He found seven species infected with viruses: *Ae. canadensis, Ae. cinereus, Ae. communis, Ae. hexodontus, Ae. nigripes, Ae. punctor,* and *Cs. inornata* (McLean, Judd & Shives 1981; McLean & Lester 1984).

One of the largest collections of mosquitoes from the Yukon was made in 1972 and 1973 by John Nelson, a Master of Pest Management student at Simon Fraser University, Burnaby, B.C. He set up New Jersey light traps and bite sampling stations at 28 sites from Watson Lake in the south to Old Crow within the Arctic Circle (Nelson 1977). Of about 27,000 specimens caught by him in 1972, the commonest biting species were *Ae. pionips, Ae. hexodontus, Ae. cataphylla, Ae. communis, Ae. campestris,* and *Ae. nigripes,* in that order, although it probably varied considerably from place to place. In addition to many of the species found by Dyar and Curtis, he listed nine more, five of them verified by Wood, Dang & Ellis (1979) and Wood (1989, personal communication), and four others, three of which are probably correct (Table 1), bringing the number of mosquito species in the Territory to about 30.

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Table 1
Mosquitoes recorded from the Yukon Territory

Dyar's species
- *Anopheles earlei* (*occidentalis**)
- *Aedes campestris* (*callithotrys**)
- *Ae. cataphylla*
- *Ae. cinereus*
- *Ae. communis*
- *Ae. excrucians*
- *Ae. fitchii*
- *Ae. impiger* (*nearcticus**)
- *Ae. mercurator*
- *Ae. pionips*
- *Ae. pullatus*
- *Ae. punctor*
- *Ae. stimulans* (Dyar's reference to it in the Yukon should probably be to *Ae. mercurator* Wood, Dang & Ellis 1979)
- *Culiseta alaskaensis*
- *Cs. impatiens*
- *Cs. incidens*
- *Cs. morsitans* (*dyari**)

Curtis's additional species
- *Ae. canadensis*
- *Ae. diantaeus*
- *Ae. flavescens*
- *Ae. hexodontus*
- *Ae. nigripes*
- *Ae. riparius*
- *Culex territans* (*apicalis**)

Nelson's additional species
- *Ae. decticus*
- *Ae. intrudens*
- *Ae. implicatus*
- *Ae. vexans*
- *Cs. inornata*

The following 4 of Nelson's species were not recorded as occurring in the Yukon by Wood, Dang & Ellis 1979 and Wood, 1989, Personal Communication. The last three probably do occur there, but *Ae. sticticus* has not been found north of Terrace, B.C., in Western Canada.
- *Ae. sticticus*
- *Ae. euedes*
- *Ae. provocans*
- *Cx. tarsalis*

* Names in parentheses were used in the publications referred to in the text.

Response of *Frankliniella occidentalis* (Thysanoptera: Thripidae) and *Trialeurodes vaporariorum* (Homoptera: Aleyrodidae) to fluorescent traps in a cucumber greenhouse

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ABSTRACT

This paper describes the responsiveness of the western flower thrips, *Frankliniella occidentalis* (Pergande) and the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) to fluorescent and non-fluorescent colored sticky traps in a cucumber greenhouse. As in previous studies, thrips preferred blue, white or yellow painted traps. The fluorescent pigments Horizon Blue, Saturn Yellow and Arc Yellow were not significantly different in attractiveness from non-fluorescent blue and yellow pigments. Whiteflies preferred non-fluorescent yellow, Saturn Yellow, Arc Yellow and Signal Green traps over the other colors tested. Where a single trap color is desired for sampling both pest species, a yellow pigment with high reflective intensity around 550 nm is recommended.

INTRODUCTION

In greenhouses, the western flower thrips, *Frankliniella occidentalis* (Pergande) preferentially alights on traps painted white, blue or yellow (Vernon and Gillespie, 1990; Brodesgaard, 1989). The degree of response to painted traps has been shown to depend on interactions between wavelengths reflected at 350 nm (ultraviolet), 440 nm (blue) and 550 nm (yellow) (Vernon and Gillespie, 1990). Blue traps attract optimally when the reflectance intensity at 440 nm is high, and the reflectance intensities at 350 and 550 nm are low. Conversely, yellow traps are attractive, but only if wavelength reflectance intensity at 550 nm is above 60 percent, and if reflectance intensities at 350 and 440 nm are low. White traps are attractive to thrips at high reflectance intensities of wavelengths between 400–650 nm, but lose attractiveness with the gradual addition of black or UV.

The multiple regression models derived to explain the relationships between wavelength and thrips response (Vernon and Gillespie, 1990) suggest that blue and yellow traps with an increasing proportion of attractive wavelengths (440 nm and 550 nm, respectively) to non-attractive wavelengths, will be increasingly attractive to *F. occidentalis*. This also suggests that fluorescent blue and yellow pigments, being highly reflective at wavelengths 440 nm and 550 nm, may be more attractive to *F. occidentalis* than the non-fluorescent paints tested by Vernon and Gillespie (1990).

This paper investigates the attractiveness of fluorescent versus non-fluorescent paints to *F. occidentalis* in a cucumber greenhouse. In addition, the attractiveness of these paints to the greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), is examined with the objective of selecting a single color for simultaneous monitoring of both species.

MATERIALS AND METHODS

The non-fluorescent paints blue 871, yellow 776 and white semi-gloss enamel (Cloverdale Paint and Chemicals Ltd., Surrey, B.C. V8W4Z1, Canada) were applied in two coats to one side of a sheet of white cardboard (56 by 72 cm; 4-ply Railroad Board, Domtar Fine Papers, Toronto, Ontario). The fluorescent paints Rocket Red, Arc Yellow, Saturn Yellow, Signal Green and Horizon Blue (Day-Glo, Color Corporation, Cleveland, Ohio,

Table 1
Trap catch response of western flower thrips, *Frankliniella occidentalis* and greenhouse whiteflies, *Trialeurodes vaporariorum* on 5 fluorescent and 3 non-fluorescent colored sticky traps. Studies were conducted in a cucumber greenhouse from 21–22 August, 1989.

	F. occidentalis[1]					*T. vaporariorum*[1]	
COLOR:	Females	S.E.	Males	S.E.	Sex Ratio M:F	Mean	S.E.
Rocket Red	9.5 a	1.20	0.8 a	0.25	1:11.9	0.3 a	0.15
Arc Yellow	19.8 b	1.84	2.6 b	0.40	1:7.6	4.0 b	1.20
Saturn Yellow	29.7 cd	2.50	7.0 c	1.45	1:4.2	11.1 c	3.52
Signal Green	8.0 a	0.80	0.9 a	0.41	1:8.9	14.3 c	6.73
Horizon Blue	75.5 e	7.91	6.2 c	1.16	1:12.2	0.0 a	0.00
Yellow 776	23.3 bc	2.66	3.9 bc	0.59	1:6.0	14.1 c	5.32
Blue 871	75.4 e	10.18	4.8 bc	1.10	1:15.7	0.0 a	0.00
Non-UV White	40.9 d	5.21	6.8 c	1.24	1:6.0	0.5 a	0.27

1. Means followed by the same letter within a column are not significantly different (Duncan's multiple range test; P = .05).

44103) were applied in one coat to cardboard previously painted with one coat of white semi-gloss enamel. The spectral reflectance profiles (350–700 nm) of all non-fluorescent colors used was measured relative to a white magnesium oxide standard using a Cary 17 recording spectrophotometer. Reflectance spectra for the fluorescent colors were obtained from the manufacturer and all spectra are shown in Fig. 1. The painted sheets were cut into 8.5 × 17 cm rectangles, folded into squares, and coated with Stikem Special (Seabright Enterprises, Emeryville, CA, 94608).

The study was done from 21–22 August, 1989 in a commercial cucumber greenhouse infested with *F. occidentalis* and *T. vaporariorum*. The traps were clipped to the top 8.5 cm of upright 1 × 3 × 30 cm garden lathes which were fixed 38 cm apart to a horizontal 4 × 4 × 300 cm board. These trap stands, painted black, were positioned above and between two rows of mature cucumbers. Traps were 2.4 m above ground and 0.6 m above the crop, with opposing sticky sides facing north and south. The experiment was conducted using a randomized complete block design with ten replicates. Transmission of light through a sample of the greenhouse glass was measured previously (Vernon and Gillespie, 1990), and was from 90 to 97% efficient in transmitting wavelengths between 350–700 nm. Transmission of higher energy UV wavelengths dropped sigmoidally from 90% at 350 nm to 0% at 300 nm.

Data were subjected to an analysis of variance after log10 (X + 1) transformation, and means were ranked by Duncan's (1955) multiple range test at P = 0.05.

RESULTS AND DISCUSSION

Significant differences in alighting by *F. occidentalis* on the 8 different colored traps were observed for males (F = 16.19; df 7, 63; P = .0001) and females (F = 63.23; df 7, 63; P = .0001). Of the non-fluorescent colors, blue 871 traps caught significantly more females than yellow 776 or white traps (Table 1). This result is consistent with the results of Vernon and Gillespie (1990), who tested the same colors in the same greenhouse. The fluorescent pigments Horizon Blue, Saturn Yellow and Arc Yellow were not significantly different from their non-fluorescent blue and yellow counterparts. Signal Green and Rocket Red were the least attractive pigments tested. Similar trends in trap preference were evident for males, except that significant differences were not observed in alightment on the yellow (except Arc Yellow), blue and white traps (Table 1). The male to female sex ratios captured on the fluorescent and non-fluorescent blue traps were higher than those occurring on the yellow and white traps (Table 1). Similar sex ratios were observed on non-fluorescent blue, yellow, and white traps previously tested at the same time of the previous year by Vernon and Gillespie (1990). Reasons for these color specific

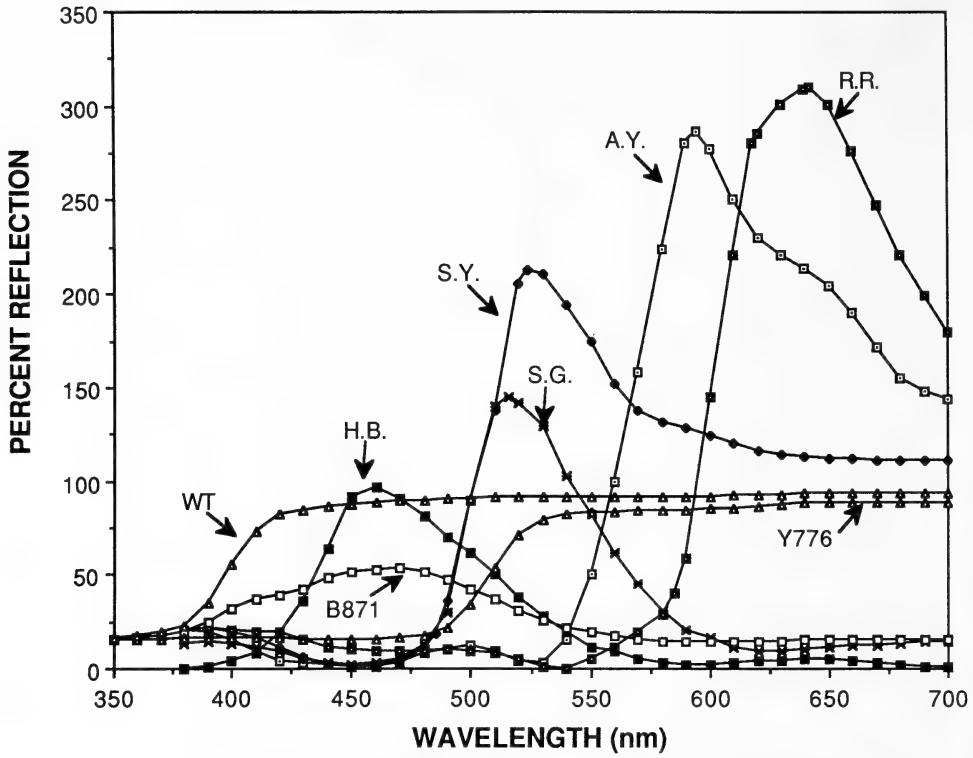

Fig. 1. Spectral reflectance curves of 5 fluorescent and 3 non-fluorescent color pigments used in trapping *F. occidantalis* and *T. vaporariorum* in a cucumber greenhouse. The codes used are: R.R. = Rocket Red; A.Y. = Arc Yellow; S.Y. = Saturn Yellow; S.G. = Signal Green; H.B. = Horizon Blue; WT = non-fluorescent white; B871 = non-fluorescent blue; and Y776 = non-fluorescent yellow.

differences in sex ratio are not known. The results reported herein as well as those of Vernon and Gillespie (1990), however, suggest that subtle differences in color preference or visual behavior may exist between males and females.

The regression models proposed for the attraction of *F. occidentalis* to colored traps (Vernon and Gillespie, 1990), predicted that blue 871 and yellow 776 would be, respectively, 1.82 and 1.05 times more attractive than white. In this study, blue 871 and yellow 776 caught, respectively, 1.84 and 0.57 times more thrips than white traps. The catch on blue 871 traps was closely predicted, but the catch on yellow was lower than predicted, and was considerably lower relative to white than in 12 studies conducted previously (Vernon and Gillespie, 1990; Gillespie and Vernon, 1990; Gillespie, unpublished data). This atypical response to yellow could indicate that the relative response of thrips to yellow and white may be influenced by unknown biotic or abiotic factors presently not considered in the prediction models. Using the manufacturers' spectral reflectance data for Horizon Blue and Saturn Yellow (Fig. 1), the regression models predicted much higher trap responses than actually occurred (i.e., 91.8 and 288.4 times more attractive than white traps, respectively). This may indicate that there is an upper threshold for thrips' visual attraction to blue and yellow colored traps, and that the reflective intensities (RI) of key wavelengths in Horizon Blue and Saturn Yellow, along with their counterparts blue 871 and yellow 776 were at or near to this threshold.

Significant differences ($F = 29.26$; df 7, 63; $P = .0001$) in catches of *T. vaporariorum* on the 8 color traps were also observed. Yellow 776, Signal Green, Saturn Yellow and Arc Yellow, with peak RIs between 520 and 590 nm (Fig. 1), were significantly more

attractive than Rocket Red, Horizon Blue, blue 871 and white. Saturn Yellow (Peak RI = 527 nm), Signal Green (Peak RI = 518 nm) and yellow 776 (Peak RI = 550 nm) were equivalent in attraction, but significantly more attractive than Arc Yellow (Peak RI = 595 nm). These results compare favorably with those of Vaishampayan *et al.* (1975) who found *T. varporariorum* was most attracted to surfaces with peak RI in the "yellow-green" region (520–610 nm), and that the "blue-violet" (400–480 nm) and "red" (610–700 nm) spectral regions were not attractive and possibly inhibitory to alightment. Our work also compares with that of Affeldt *et al.* (1983), who found that fluorescent Saturn Yellow and Signal Green traps were not significantly different in catches of *T. vaporariorum,* and that these colors were not significantly better than non-fluorescent yellow traps.

These data indicate that blue, yellow and white colored traps are adequate for trapping *F. occidentalis*, and that traps with peak RI between 520–550 (green-yellow) are most attractive for trapping *T. vaporariorium* in greenhouse. Where a single trap is desired for sampling both species, a yellow hue with high RI between 530–550 is preferred. Fluorescent paints, which are more expensive than non-fluorescent paints, would not contribute significantly to the trapping of either species in greenhouses.

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Observations on the biology of the bronze flea beetle *Altica tombacina* (Coleoptera: Chrysomelidae) in British Columbia

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ABSTRACT

Populations of *A. tombacina* were monitored for 2 years at three field sites of varying elevation on Vancouver Island. In 1988, population densities of overwintered adults were greatest at the middle elevation (615m) followed by the highest (830m) and lowest at the low elevation (185m). Egg densities remained below 10/m^2 at 185m but exceeded 200/m^2 in places at 615m and 400/m^2 at 830m. Egg mortality was exceedingly high at all sites ranging from 98% at 185m, 95% at 615m and 99% at 830m; very few larvae appeared to survive. Only 2 adults were counted the following spring at the lowest elevation where eggs and larvae were exceedingly difficult to find. No life stages could be found at either of the higher elevation sites. Cold weather early in June, 1988, appeared to be responsible

for this population decline. Overwintered adults of *A. tombacina* were also reared in the laboratory at constant temperatures of 18° and 25°C. The rate of oviposition was greater by a factor of 2 at the higher temperature. The egg-adult survival rate was approximately 15% at 25°C and there was no completed development at 18°. Each larva surviving to pupation consumed a mean of about 28mg. dry weight of leaf.

INTRODUCTION

The bronze flea beetle, *Altica tombacina* Mannerheim (Coleoptera: Chrysomelidae), is a common inhabitant of early successional communities of the Pacific northwest from Oregon to British Columbia. Its natural host is fireweed, *Epilobium angustifolium* L. (Onagrcaeae), but it has also been described as a pest of strawberry and roses (Dirks-Edmunds 1965). The *Altica-Epilobium* relationship is probably a very ancient one. Closely related species, *e.g. A. lythri* Aube, *A. oleracea* L. and *A. palustris* L., are also found in the old world associated with various *Epilobium* spp. (Phillips 1977, Port & Guile 1986).

In temperate regions the Alticinae are almost exclusively monovoltine and overwinter as adults in the plant litter. Phillips (1977) noted that a second period of oviposition sometimes occurred in various old-world species. Dirks-Edmunds (1965) stated that the progeny of lab-reared *A. tombacina* collected in Oregon began reproduction without diapause, a fact suggesting that bivoltinism may be facultative in this species. Adult sex ratios commonly range from 5:1 to >15:1 in favor of females according to my own observations. Skewed sex ratios apparently occur frequently in the Alticinae. Port & Guile (1986) have reported sex ratios exceeding 6:1 for *Altica britteni* (Sharp) and *A. ericeti* (Allard) in Great Britain.

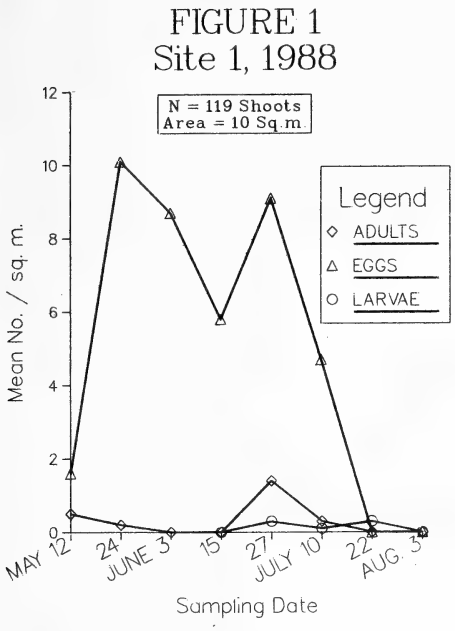
The life history of *A. tombacina* has been described by Dirks-Edmunds (1965) and is not dissimilar from that of other new world Alticinae (Woods 1918). There are three larval instars; both adults and larvae feed in exposed locations on the foliage of their host plant. Under optimal conditions eggs hatch in 3 to 5 days and the larvae feed for 12 to 14 days before pupating. Pupation requires another 10 to 14 days after which adults eclose and feed briefly before dispersing. In late summer, the quality of fireweed foliage declines and aggregations of beetles can sometimes be found feeding on the buds and tender bark of red alder, *Alnus rubra* L.

A common feature of most *Altica* species appears to be marked and unpredictable fluctuations in population density (Woods 1918, Port & Guile 1986). Large populations occasionally result in severe defoliation of the host plants, primarily as a result of feeding by larvae. In the case of *A. tombacina* this has been cause for concern among apiarists in British Columbia who rely upon fireweed for a valuable midsummer honey flow. Defoliation by larvae can inhibit flowering (Michaud 1990) and reduce nectar secretion (Michaud 1989), even causing the die-back of entire shoots (Atkins 1964).

The following study was designed to observe the trajectories of three field populations over 2 years and to establish techniques for rearing the flea beetles in the laboratory. I also wanted to test the effects of temperature on oviposition rate and the survival of eggs, larvae and pupae and to estimate larval consumption.

MATERIALS AND METHODS

Three sites varying in elevation were selected for study near Lake Cowichan, Vancouver Island. Quadrats of $2m^2$ were staked out in early May, 1988, as the first over-wintered adults emerged. Site 1 was at an elevation of 185m a.s.l. near the lake shore and five quadrats were located here. Sites 2 and 3 were located 20 km west of the lake at elevations of 615m and 830m, respectively. Ten quadrats were placed at each of these two sites. All three sites were relatively recent clear-cuts that had been replanted to Douglas fir, *Pseudotsuga menziesii* (Mirb.) Franco within the last 3 years. All quadrats were examined at 10–12 day intervals and the beetle's life stages were tallied (adults, eggs and larvae). Pupation is subterranean and pupae were not counted.



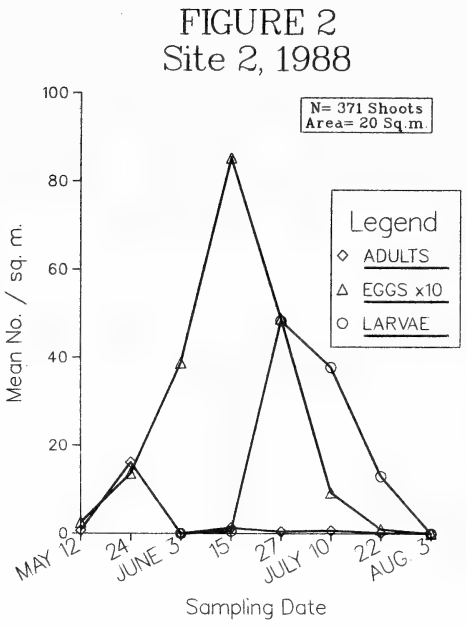


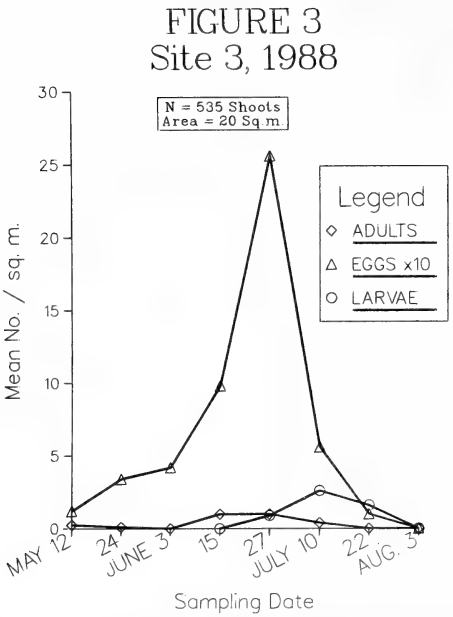
Fig. 1. Population trajectory of *A. tombacina* at site 1 (el. 185m) in 1988 showing emergence of over-wintered adults, oviposition, and appearance of larvae.

Fig. 2. Population trajectory of *A. tombacina* at site 2 (el. 615m) in 1988 showing emergence of over-wintered adults, oviposition, and appearance of larvae.

Several hundred overwintered adults were collected during the last week of April at a number of roadside sites in Burnaby, B.C. Specimens of *A. tombacina* were identified by L. LeSage of the Biosystematics Research Institute, Ottawa, Ontario, where voucher speciments were consigned. A number of different enclosures were tested for suitability in rearing the insects. Large ventilated plastic petri dishes were finally employed with a layer of moist sand covered by filter paper. Fresh leaves were provided every 2 days and appeared to remain acceptable as food over this time. There remained the problem of containment while food and filter paper were being changed. This procedure was best accomplished within the confines of a conventional plexiglass insect cage so that escapees could be readily caught and returned to their respective containers. Larvae were reared in similar containers and they pupated in the moist sand beneath.

To assess the influence of temperature on reproductive rate, two separate colonies of overwintered adults were established. Beetles were sexed on the basis of size (males are generally much smaller) and by separating pairs observed in copula. Each colony was adjusted to contain 35 females and 15 males. One colony was maintained in a greenhouse where the temperature averaged 25° (± 4°) and the other in a growth chamber at 17° (± 2°). RH was maintained as close as possible to 80% in both treatments but sometimes dropped as low as 60% in the greenhouse. Fresh leaves of fireweed were provided every 2 days, and all eggs removed and counted. This experiment was begun on April 29 and ended on May 27.

Some of the eggs were collected, placed into separate dishes, and maintained under the same thermal regime as their respective parental colonies. As the larvae hatched, they were transferred to a series of dishes with fresh leaves. Mature larvae usually found their way under the filter paper to burrow and pupate in the moist sand, although some did so directly on the surface of the paper. As the adults eclosed, they were transferred to another series of dishes, also provisioned with fresh leaves.



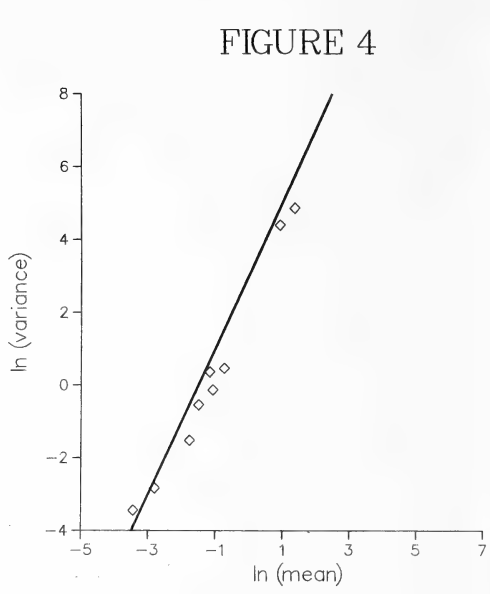


Fig. 3. Population trajectory of *A. tombacina* at site 3 (el. 830m) in 1988 showing emergence of over-wintered adults, oviposition, and appearance of larvae.

Fig. 4. Data for site 2 (el. 615m) on May 25, 1988 plotted as ln(variance) #'s of adults/shoot against ln(mean) showing a significant departure from random distribution (regression line slope = 2).

To assess larval consumption, 60 1st-instar larvae were segregated into various dishes immediately upon hatching. Fresh leaves were weighed before they were given to the larvae, and again upon removal 2 days later. The 25° temperature regime was used because it appeared to be the most favorable for development. Fresh leaves lost 24.6% of their original weight due to moisture loss over the 2 day period under these conditions. Fresh leaves contained a mean of 78.2% water by weight. Mean consumption per larvae surviving to pupation was then determined according to the following equation:

$$\Sigma[(\mathrm{wi} - \mathrm{wo} \times \mathrm{mlc}^{-1}) \times \mathrm{dwc}](\#1)^{-1}$$

wi = weight in (grams)
wo = weight out (grams)
mlc = moisture loss constant = .754
dwc = dry weight conversion factor = .218
#1 = number of larvae alive

RESULTS AND DISCUSSION

The patterns of emergence of overwintered adults, oviposition and appearance of larvae in 1988 are represented in Figs. 1–3 by mean densities for each sampling date on a site by site basis. The exact numbers of adults, eggs and larvae respectively counted on each sample date, quadrat by quadrat, are reported in the Appendix. It should be noted that counts of '0' adults occurred for all quadrats on June 3 because wind and rain during the previous 24 hours drove all insects to seek shelter in the litter.

Adults displayed a highly clustered distribution on shoots. For example, at quadrat 4 on May 24, 159 adults were counted. Of the 40 shoots of fireweed in quadrat 4, site 2, only 22 had beetles residing on them. Of these 22 shoots, one had 71 adults, one 16, and one 12. The remainder had fewer than 10 per shoot but only 3 had a single occupant. Likewise at quadrat 3, site 2 on the same sampling date, of the 110 adults counted on 43

FIGURE 5

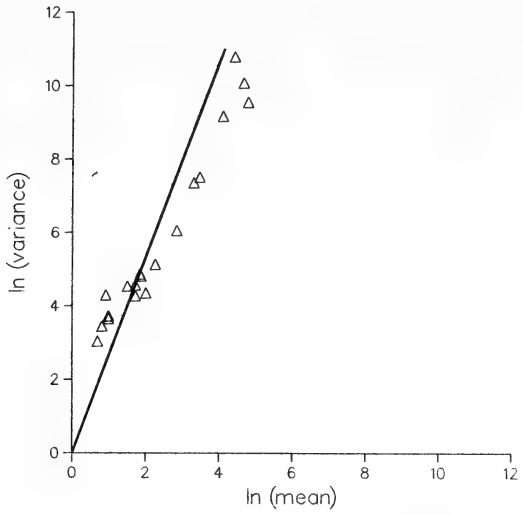


Fig. 5. Data for sites 2 (el. 615m) & 3 (el. 830m) on June 15, 1988 plotted as ln(variance) of #'s of eggs/shoot against ln(mean) showing a significant departure from random distribution (regression line slope = 2.26).

shoots, 85 occurred on 2 plants. Fig. 4 illustrates the clumping of adults with a plot of ln(variance) vs ln(mean) using data from each quadrat at site 2 in which adults were counted on May 25, 1988. The slope of the regression line is 2 and indicates a distribution significantly more clumped than random (slope = 1). This clumping of adults may be related to the low frequency of males that forces females to congregate. A sex ratio estimate based on a dissected sample of some 200 beetles collected on the same date indicated that females out-numbered males 15:1 in this population. This skew in the sex ratio must dictate a polygamous mating system, which in turn results in a highly clumped distribution of overwintered individuals.

Ovipositing females similarly appeared to favor particular shoots. On June 3, 1988, 2704 eggs were counted quadrat 4 of site 2. Of these, 1900 (70%) occurred on only 17% of the 40 available shoots. On June 14, 4791 eggs were counted in this quadrat, 88% of which occurred on 18 shoots. Fig. 5 illustrates the clumping of eggs on shoots with a plot of ln(variance) vs ln(mean) using data from sites 2 and 3 on June 15, 1988. The regression line slope is 2.26 and indicates a distribution significantly more clumped than random.

Dividing the total numbers of eggs by total numbers of 1st-instar larvae provided a rough estimate of the mortality rate of eggs: 95% in site 1, 99% in site 2, and 98% in site 3. The primary cause of mortality appeared to be cold weather. Many eggs never hatched but eventually darkened and decayed. The remainders of egg casings adhering to leaves provided evidence of some predation, while other eggs had been drained of their contents, presumably by some insect with sucking mouthparts.

Most larvae appeared to die in the first instar and left only small feeding scars on the undersides of leaves. I again suspected that cold weather was the primary cause of mortality. Apart from direct effects on survival, cold weather seemed to slow the development and growth of both eggs and larvae, probably rendering them more vulnerable to predation. Fig. 6 charts the trajectory of mean daily temperature during the period of egg and larval development. During the last week of May and the first week of

FIGURE 6

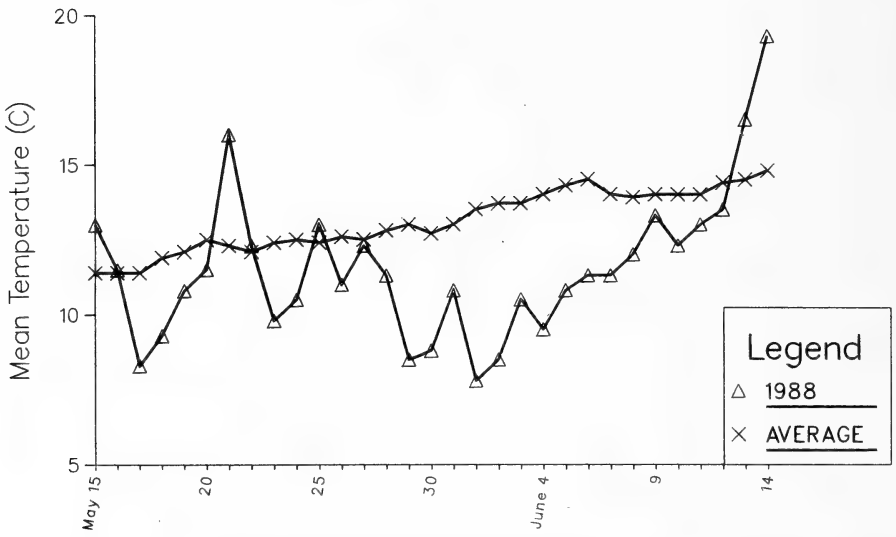


Fig. 6. Trajectory of mean daily temperature in °C for Lake Cowichan during spring of 1988 plotted with normal values for the period.

June, mean temperatures averaged some 3–4°C below normals and daily maxima remained below 19°.

No adults were observed after July 22, indicating that by this time the overwintered cohort was dead. However, the possible emergence of some callow adults may have gone undetected. Based on laboratory observations these tend to be reclusive and spend most of the time hiding under leaf litter, emerging occasionally to feed. This is also the stage when most dispersal appears to occur and during which adults can occasionally be found feeding on alternate hosts such as *Alnus rubra*. In 1989, only two adults were observed at site 1 and, subsequently, a few eggs and larvae. No life stages were encountered at sites 2 or 3 despite extensive searches. Cursory observation of roadside populations on the B.C. lower mainland over some 4 years revealed that mainland populations did not appear to undergo population fluctuations similar to those observed on Vancouver Island, but appeared to remain stable at very moderate densities.

Ovipositing beetles in the laboratory colonies laid slightly more than twice as many eggs (2954) at 25° as they did during the same period at 18° (1390) (one-way ANOVA, $P < 0.01$). Greenhouse temperature oscillated by $\pm 4°$ about a mean of 25° so it may be concluded that temperatures up to 30° are stimulatory to oviposition relative to lower temperatures.

A total of 650 eggs was incubated at 18° but only four of these hatched, for a survival rate of $< 0.1\%$. Many became covered with a white mycelial growth, although it could not be determined if fungal infection was the cause of death. The four larvae that hatched were transferred to a clean dish and given fresh leaves but they fed little and grew slowly, dying in the second instar.

A total of 457 eggs was incubated at 25°C of which 160 hatched for a survival rate of 35%. Of the 120 newly hatched, 1st instar larvae reared at 25°, 77 survived to pupation for a survival rate of 64%. Of these, 53 (68%) eclosed as viable adults, giving an egg-adult survival rate of about 15%. These values suggest that the egg is probably the most vulnerable life stage. The principal source of mortality in the pupal stage appeared to result from fungal infection, but a number of adults eclosed with marked elytral deformities and were presumed non-viable. This may have been an artifact of the

constant temperature regime under which the insects were reared. Such an effect of constant temperatures on development has been noted for other Chrysomelid beetles. Mason & Lawson (1980) were unable to rear any normal adults of the american aspen beetle, *Gonioctena americana* (Schaeffer), under constant temperature conditions, whereas development was normal in oscillating temperature.

A total of 35 larvae pupated in the larval consumption assay. The mean consumption per larva surviving to pupation was estimated to be 27.6 mg dry weight of leaf. Larvae feed selectively on the undersides of leaves, leaving behind several layers of cells on the upper leaf surface that subsequently senesce. Therefore the amount of leaf actually consumed underestimates foliar damage by as much as 50%.

Callow adults eclosing in the laboratory behaved very differently from the overwintered adults collected in the spring. They responded photonegatively and tended to aggregate underneath the filter paper in the dishes, remaining relatively inactive, emerging only at night to consume small amounts of the leaves provided. They were also observed to consume portions of alder leaves, *Alnus rubra*, when these were made available together with fireweed. Larvae would not accept alder, even in a no-choice situation. On several occasions, pairs in copula were observed, and a few eggs were eventually deposited on the leaves and filter paper. This was apparently less ovipositional activity than that observed by Dirks-Edmunds (1965) in 1st-generation adults reared in Oregon. This author concluded that two complete generations may occur in that region. It is possible, nevertheless, that a partial second period of oviposition may occur in B.C. under suitable conditions.

Of six overwintered adults collected on May 22, 1987, near Shawnigan Lake on Vancouver Island, two were parasitized and yielded pupae that were incubated until eclosion. The emerging parasite adults were identified[1] as males of the genus *Medina* Robineau-Desvoidy (tribe Blodeliini), probably *M. barbarta,* although identification to species could not be made with certainty.

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ACKNOWLEDGEMENTS

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APPENDIX

Numbers of *A. tombacina* Adults—1988

	May 12	May 24	June 3	June 15	June 27	July 10	July 22
SITE 1							
Q1	2	1	0	0	1	0	0
Q2	0	1	0	0	2	1	0
Q3	3	0	0	0	0	9	0
Q4	0	0	0	0	9	0	0
Q5	0	0	0	0	3	1	0
SITE 2							
Q1	2	7	0	4	0	1	0
Q2	1	5	0	1	1	0	0
Q3	1	110	0	1	0	0	1
Q4	4	159	0	0	1	2	0
Q5	2	11	0	4	0	0	2
Q6	1	11	0	0	1	0	0
Q7	1	16	0	2	3	1	0
Q8	0	0	0	6	0	3	0
Q9	0	3	0	5	1	4	0
Q10	1	1	0	3	3	3	0
SITE 3							
Q1	0	0	0	1	0	0	0
Q2	0	1	0	3	1	0	0
Q3	0	0	0	5	0	2	0
Q4	0	0	0	0	1	2	0
Q5	2	0	0	0	2	0	0
Q6	0	0	0	2	13	1	0
Q7	1	0	0	0	0	1	0
Q8	1	0	0	2	1	0	0
Q9	1	0	0	6	0	0	0
Q10	0	0	0	1	2	0	0

Numbers of *A. tombacina* Eggs—1988

	May 12	May 24	June 3	June 15	June 27	July 10	July 22
SITE 1							
Q1	0	5	9	0	20	11	0
Q2	5	1	2	0	12	1	0
Q3	9	82	47	15	30	24	0
Q4	0	9	19	26	24	7	0
Q5	2	4	10	17	5	4	0
SITE 2							
Q1	46	215	300	3287	926	92	11
Q2	25	163	117	936	684	78	9
Q3	101	819	1882	3565	626	35	0
Q4	226	746	2704	4791	1300	22	0
Q5	24	176	421	883	904	113	0
Q6	28	387	1560	2066	679	16	0
Q7	21	63	266	174	362	19	0
Q8	4	41	179	324	670	266	0
Q9	0	89	232	847	2932	970	9
Q10	24	22	88	173	675	254	0
SITE 3							
Q1	9	15	38	127	388	51	0
Q2	20	106	115	318	551	73	0
Q3	14	69	134	276	808	118	0
Q4	78	220	180	208	586	130	0
Q5	10	40	63	122	567	95	0
Q6	6	21	50	154	830	281	2
Q7	30	39	79	97	285	94	0
Q8	12	65	44	47	189	59	0
Q9	14	18	86	358	671	132	0
Q10	36	77	49	244	236	78	5

Numbers of *A. tombacina* Larvae—1988

	June 27	July 10	July 22	Aug 3
SITE 1				
Q1	0	0	3	0
Q2	0	0	0	0
Q3	3	1	0	0
Q4	0	0	0	0
Q5	0	0	0	0
SITE 2				
Q1	6	3	1	0
Q2	3	21	0	0
Q3	460	46	5	0
Q4	212	121	2	0
Q5	121	37	0	0
Q6	131	112	1	0
Q7	0	0	0	0
Q8	0	34	23	0
Q9	33	300	212	0
Q10	0	80	14	0
SITE 3				
Q1	0	0	1	0
Q2	13	0	1	0
Q3	0	6	7	0
Q4	5	14	7	0
Q5	0	8	0	0
Q6	0	8	0	0
Q7	0	8	3	0
Q8	0	7	5	0
Q9	0	0	0	0
Q10	0	0	12	0

A rapid method of sampling for aphids on strawberries

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ABSTRACT

A rapid system of sampling for strawberry aphids, *Chaetosiphon fragaefolii* (Cockerell) was developed for use by pest management scouts. Regression equations relating mean numbers of aphids/leaf, variances of those means and the proportion of unifested leaves (P_0) were developed from samples of aphids from single leaves. Using the equations, mean aphid density per leaf and standard errors can be estimated from P_0 and the sample size. The accuracy of the estimations were tested on data from 155 samples from commercial strawberry fields sampled by a professional pest management company. Means estimated from P_0 were sufficiently accurate for the intended purpose and only 2 hours were required to sample 300 leaves compared to 16 hours when all aphids on all leaves were counted from only 80 leaves. An electronic recorder was programmed to prompt an IPM scout for data entry, allow correction of errors and permit sampling from different subplots within a field.

INTRODUCTION

Sixteen species of aphids have been recorded on species of *Fragaria* worldwide (Blackman and Eastop 1984). All but two species have been found in south-western British Columbia, but only nine have been collected from strawberries (Forbes and Chan 1987). The strawberry aphid (*Chaetosiphon fragaefolii* [Cockerell]), of North American origin, is present in most commercial strawberry growing areas of the world. Aphids of all species cause infrequent and limited direct damage to strawberries, but plant viruses transmitted by aphids are responsible for major economic losses and increased costs of production in B.C. and most other areas of commercial strawberry production (Aerts, 1973).

C. fragaefolii is the most numerous and efficient vector of viruses transmissable to strawberries by aphids (Mellor and Forbes, 1960; Frazier and Converse 1980). Virus infection results in a progressive decline in vigor and yield (Martin and Converse, 1977) that necessitates replanting. In California, yields are commercially acceptable for only 15 to 18 months (Trumble *et al.*, 1983). In B.C., replanting is required every 3 to 5 years depending upon the degree of isolation between fields.

Strategies to protect strawberries from virus infection vary regionally depending upon the aphid fauna, virus complex and adequacy of certification programs to produce virus-free plants. Insecticide applications can reduce aphid numbers and retard the spread of viruses, but even when aphid numbers are very low, plants can become infected by one or more viruses within their first year of field exposure (Converse and Aliniazee, 1987). Breeding strawberries for tolerance to viruses and controlling aphids reduces damage and virus spread thereby prolonging plant vigour (Barritt and Daubeny, 1982). Even well-managed commercial fields of tolerant cultivars are replanted regularly because of the deleterious accumulated effects of viruses.

Modern pest management relies upon the results of sampling to make decisions about pest control. An effective sampling program must produce reliable results in a short time. Collecting 80 leaves from a field, removing and counting aphids in the laboratory can take as long as 16 hours for one person to do. Aphids must be removed to avoid counting them more than once. This is an economically unacceptable amount of effort for a grower or pest management scout.

Progress has been made (Nachman, 1984; Raworth and Merkens, 1987) in estimating the density of mites on strawberries from the proportion of pest habitats that are *not* infested (P_0). P_0 of strawberry aphids on immature leaves was correlated with the total population on individual plants (Trumble *et al.*, 1983).

This paper describes the development and testing of a method of sampling for *C. fragaefolii* based on P_0.

METHODS AND MATERIALS

Development of Sampling Program

A research plot (12 matted rows, each one meter apart and 30 m long) of Totem strawberries planted 1 May 1986, was sampled at about weekly intervals when picking, cultivation and irrigation permitted during 1987 and 1988 from 1 May until first frost in November. No insecticides were used on the plot but one application of simazine at 2.25 (ai) kg/ha for weed control was applied one month before sampling began each year.

Sampling consisted of collecting one new leaf from each of 80 plant crowns selected arbitrarily from sites evenly spaced throughout the plot. Selected leaves had elongate petioles with lamina that had not unfurled, the leaves preferred by *C. fragaefolii* (Dicker, 1952). Leaves were placed singly in plastic bags kept on crushed ice in a cooler. The number and instar of aphids on each leaf were counted and recorded after being removed from each leaf under a microscope ($\times 30$). The mean number of aphids per sample (M) and its variance (V) were calculated and ln(V) was regressed against ln(M) following Taylor (1961). The proportion of leaves that had no aphids (P_0) were calculated for each sample, transformed to $\ln(-\ln[P_0])$ and regressed against M (Nachman, 1984).

Evaluation

A private company (Monagro Consultants Inc.) sampled 27 commercial strawberry fields during 1987 to advise growers of aphid densities and give recommendations for the control of aphids. Leaves were examined in the field with a $\times 10$ magnifier mounted on a headband. The data were made available to us and consisted of 220 records of mean aphids per leaf (M), the sample size (N) and P_0. We were not given the age, cultivar, location or history of pesticide applications of the sampled fields. Samples from less than 40 leaves were discarded, leaving 155 samples for analysis.

Statistical analyses were done with SPSS-PC+ (SPSS Inc.) on a CompaQ Deskpro 286 microcomputer. The level of significance used for hypothesis testing was 5%.

RESULTS

Linear regressions between ln(M) and ln(V) (Taylor, 1961) (Fig. 1A) and between ln(M) and $\ln(-\ln[p_0])$ (Fig. 1B) were developed with data from the research plots.

$$\text{Eq. 1. } \ln V = 1.285 + 1.2061 \ln M \quad R^2 = 0.93 \text{ df} = 31$$

$$\text{Eq. 2. } \ln M = 0.964 + 1.043 \ln(-\ln[p_0]) \quad r^2 = 0.97 \text{ df} = 31$$

Evaluation

A linear relationship (Fig. 1B) between ln(M) and $\ln(-\ln[p0])$ was calculated for the data from the commercial fields. The slope and intercept of the line were not significantly different from those of the relationship from the research plots (Fig. 1B). The data from the research plots and commercial fields were combined and the relationship between ln(M) and $\ln(-\ln[P_0])$ recalculated.

$$\text{Eq. 3 } \ln M = 0.964 + 1.043(\ln(-\ln P_0)) \quad r^2 = 0.87 \text{ df} = 199$$

A computer program based on a FORTRAN-77 program (Raworth and Merkens, 1987) was written in Turbo Pascal 4.0 (Borland International, Scotts Valley, California) (program available on request). For various levels of P_0 estimated from sampling, the program calculates, using equations 1 and 3, M and the standard error of M that results

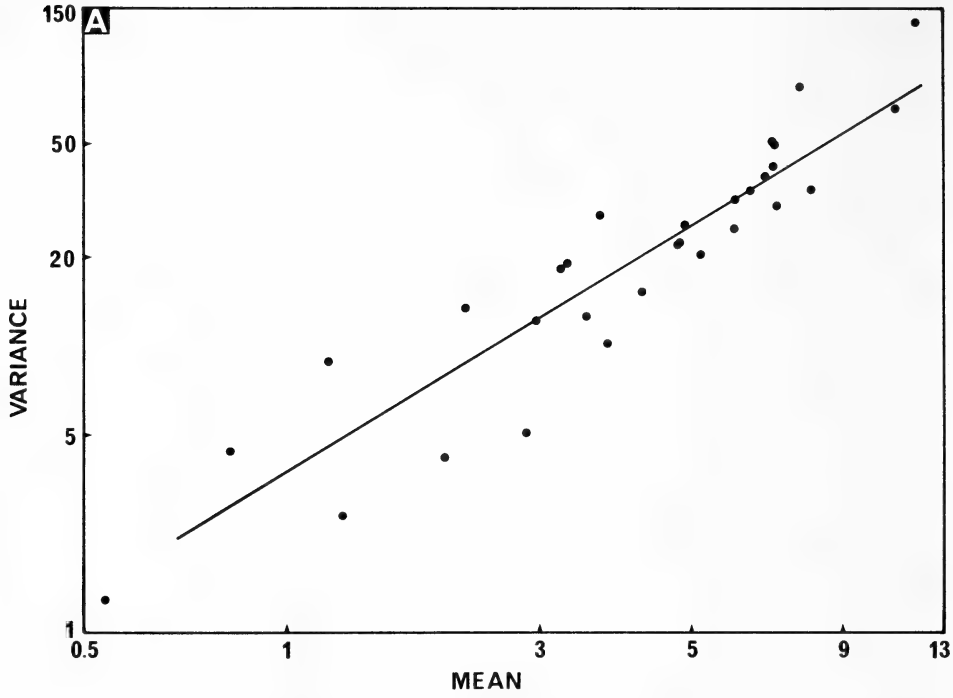

Fig. 1A. Relationship between the mean and variance in samples of *Chaetosiphon fragaefolii* from leaves in a research planting of strawberries.

when P_0 is estimated from various numbers of single leaves (Table 1). If a sample of 200 leaves were taken and P_0 was equal to 0.6, the mean level of infestation would be 1.47 aphids per leaf with a standard error of ± 0.22 (15% of 1.47, Table 1). The computer program is easily modified to print tables with gradations in P_0 and standard errors as fine as desired.

A field to be sampled was measured with the aid of a Rolatape (Rolatape Corporation, Spokane, Washington) measuring wheel and the number and spacing of rows determined. The field was then drawn to scale and a plan for sampling the field was developed.

In 1989 our interest was primarily in evaluation the utility and efficiency of the P_0 method of sampling and in determining if the edges of fields should be sampled separately from the centre of fields. While 20 commercial strawberry fields were sampled, each in a manner to answer specific research questions, results from only one are presented. That field was a 3.6 ha rectangle of 2 year old Totem strawberries. It was sampled 6 times during the growing season when agricultural operations were permitted. Sampling was done separately from each edge of the field and from two central areas separated by a road. A sample was taken approximately every 7m as the sampler walked through the field. One sample of the field required 2 hours to complete. Three hundred leaves were inspected from each field, 50 from each edge and each central strip of the field.

A model 600 Polycorder (Omnidata International, Logan, Utah) was programmed to prompt the operator for input and permit corrections to entered data. The instrument displayed a code number representing the particular area of the field being sampled and the number of leaves that had been sampled. The Polycorder stored the area code and each sample outcome (leaf with or without aphids). We programmed the instrument to request, on a relative subjective scale, the temperature, leaf wetness, cloud cover and wind speed.

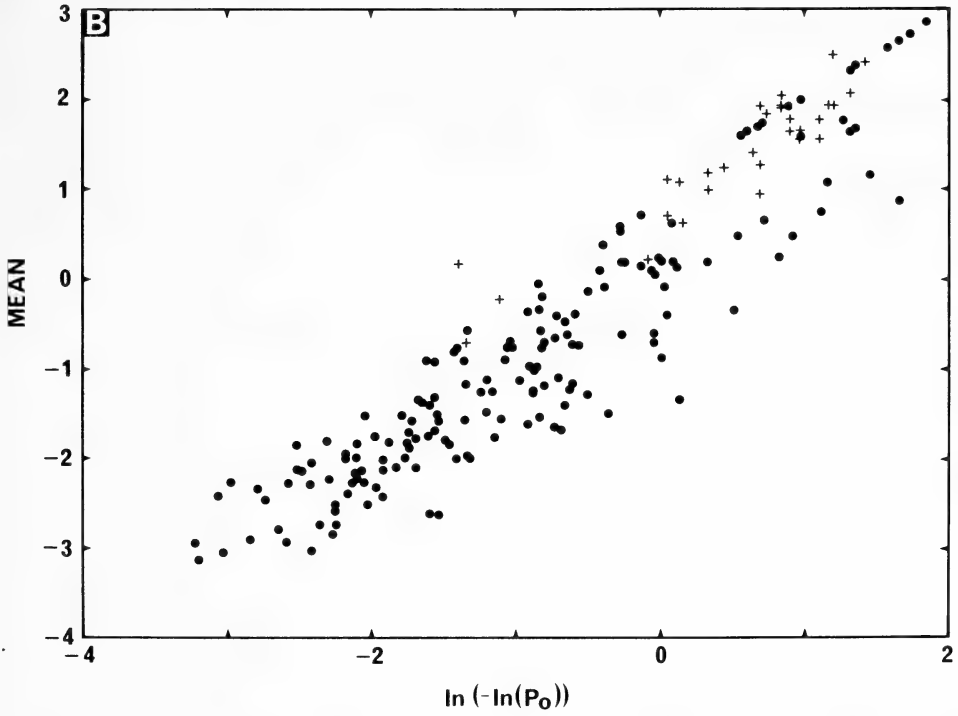

Fig. 1B. Relationship between mean number of *Chaetosiphon fragaefolii* per leaf and the proportion of uninfested leaves (P_0) in samples collected from research (+) and commercial (•) plantings of strawberries.

The data from the Polycorder were downloaded to a microcomputer for estimation of P_0 and the corresponding M. The program for the Polycorder is available from the authors. The mean density of aphids in the 6 sampled areas of the field (Table 2) was similar for most of the year except on 8 July when the edges had only one-half the density of aphids on the central subplots.

DISCUSSION

Sampling strawberry aphids on a presence or absence basis provides estimates of the mean sufficiently accurate for pest management purposes. When most leaves have aphids (P_0 = 0.05), aphid density exceeds 9/leaf with a variance of 53. At that level of infestation and dispersion, very heavily infested leaves are evident in every meter of row. When densities are very low (high P_0), large sample sizes would be needed to determine a mean level of infestation with accuracy. However, at low density, great accuracy is not required because further reduction of the density would not be contemplated. If the initial sample size is too low for the level of precision required, more samples can be taken before the scout leaves the field. The grower can be immediately informed of the results and future sampling scheduled at that time. The Polycorder and the programs developed to operate it, while not essential, greatly simplify recording and help the scout to be correctly oriented in large fields and to count the number of samples made.

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Table 1

Numbers of strawberry leaves, mean numbers of *Chaetosiphon fragaefolii* per leaf and standard errors resulting from observed proportions of uninfested leaves (P_0). Standard errors are expressed as percentages of means. An asterisk denotes sample sizes in excess of 10,000 leaves.

P_0	Mean	Number of Leaves at Each Standard Error									
		5%	10%	15%	20%	25%	30%	35%	40%	45%	50%
0.05	9.31	*	482	162	87	55	39	30	23	19	16
0.10	7.08	*	360	131	71	46	33	25	19	16	13
0.15	5.78	*	322	122	67	44	31	24	19	15	13
0.20	4.87	*	308	121	67	44	31	24	19	15	13
0.25	4.17	7815	306	123	69	45	32	24	19	16	13
0.30	3.60	4590	311	127	71	47	33	25	20	16	14
0.35	3.12	3553	322	133	75	49	35	27	21	17	15
0.40	2.71	3101	337	141	80	53	38	29	23	19	16
0.45	2.34	2907	359	152	86	57	41	31	25	20	17
0.50	2.02	2871	387	165	94	62	44	34	27	22	18
0.55	1.73	2962	423	181	103	68	49	37	30	24	20
0.60	1.47	3191	470	202	115	76	55	42	33	27	23
0.65	1.23	3609	534	229	131	86	62	47	37	31	26
0.70	1.01	4347	622	266	152	100	72	55	43	36	30
0.75	0.81	5764	751	319	182	120	86	65	52	42	36
0.80	0.62	9167	957	399	226	149	107	81	64	53	44
0.85	0.45	*	1332	538	302	197	141	107	85	69	58
0.90	0.28	*	2211	829	456	295	210	159	126	103	86
0.95	0.13	*	6201	1817	943	596	419	315	248	201	168

Table 2
Mean number of *Chaetosiphon fragaefolii* per strawberry leaf in six areas of a field. An asterisk indicates when means on the perimeter of field were significantly different from those of the central areas.

		Area of Field						
		Perimeter				Center		Total
Julian Day	Date	West	North	East	South	West	East	
125	May 5	0.0	0.05	0.0	0.0	0.0	0.0	0.01
151	May 31	0.16	0.10	0.16	0.10	0.16	0.16	0.14
156	June 6	0.05	0.22	0.16	0.05	0.34	0.22	0.17
189	July 8	2.50	2.10	2.10	1.40	0.54	0.50	1.42*
198	July 17	1.34	1.16	0.91	0.75	0.99	1.64	1.12
237	Aug 26	0.79	1.70	1.44	0.61	1.21	1.09	1.12

Toxicity of foliar residues of phosmet to the apple maggot, *Rhagoletis pomonella* (Diptera: Tephritidae)[1]

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ABSTRACT

Mortality of apple maggot (AM), *Rhagoletis pomonella* (Walsh), was determined in the laboratory on spray deposits of phosmet (Imidan®) applied to apple foliage and fruit at rates of 0.6 and 1.2 g active ingredient (AI)/liter (0.5 and 1 pound [AI]/100 gallons). Mortality of AM adults was 100% with both rates until 16 days post-treatment. Thereafter, mortality decreased inversely with time. Probit analysis revealed insecticide residual toxicity of 24 days for 95% mortality (ET_{95}) for both rates, and 51 and 55 days, respectively, for 50% mortality (ET_{50}) at 0.6 and 1.2 g (AI)/liter. The intercepts and slopes of probit regression were not significantly different for the two rates tested, indicating little difference between their persistence and efficacy against AM adults.

INTRODUCTION

The apple maggot (AM), *Rhagoletis pomonella* (Walsh), was first reported in the western United States near Portland, Oregon (AliNiazee and Penrose, 1981). It is now well established in six western states including Oregon, Washington, California, Idaho, Utah, and Colorado (AliNiazee and Brunner, 1986). Most AM infestations in the western United States are associated with abandoned and unsprayed apple trees and hawthorn species, both the native *Crataegus douglasii* Lindley and the introduced ornamental *C. monogyna* Jacquin. Isolated infestations of prunes in the Willamette Valley of Oregon (AliNiazee, 1985) and of cherries in Utah (Jorgensen *et al.* 1986) have also been noticed. The only commercial apple-growing area infested with AM in the western United States is near Salem, Oregon (AliNiazee, 1988).

Therefore, in Oregon and Washington, the primary objective of AM control and localized eradication programs is to kill all AM females that immigrate into commercial orchards from surrounding natural habitats before oviposition occurs. Consequently, protective application of insecticides on a regular basis against immigrating AM females is the key to successful management of AM in commercial orchards of the Pacific Northwest (AliNiazee, 1988).

Azinphosmethyl and phosmet are the two most commonly used insecticides against AM in eastern North America (Reissig, 1988) and phosmet is extensively used in the west also (AliNiazee, 1988). The AM eradication program pursued in northern California for the past four years, was exclusively dependent on the use of phosment (Dowell, 1988). Bancroft *et al.* (1974) evaluated the toxicity of about 25 insecticides against AM adults in the laboratory by topical applications and concluded that phosmet was as toxic to AM adults as azinphosmethyl. Unlike azinphosmethyl, which has been tested extensively against AM, both in the laboratory (Bancroft *et al.* 1974; Reissig *et al.* 1980, 1983) and in the field (Pree *et al.* 1976; Reissig *et al.* 1978; Weires and Alm, 1981) relatively little experimental data are available on the toxicity and persistence of residue deposits of phosmet against AM adults in apple orchards. A residual toxicity of two to three weeks is generally expected but no experimental data are available to support this conclusion. Here, we report the residual toxicity against AM adults of two rates of phosmet applied in the field on apple foliage and fruit.

1. Oregon Agricultural Experiment Station Technical Paper No. 8900.

MATERIALS AND METHODS

Phosmet (Imidan 50% wettable powder [WP], Stauffer Chemical Company, Westport, CT) was applied at rates of 0.6 and 1.2 g (AI)/liter (0.5 and 1 pound [AI]/100 gallons) on young 'Red Delicious' apple trees (1–1.5meters high). The application was made to the point of drip with a backpack sprayer, in the first week of August 1987 at the Oregon State University Entomology Research Farm, Corvallis, OR. Each tree had approximately 50 fruit at the time of treatment. Four trees were treated with each rate of phosmet.

Samples of treated apples and leaves were collected in plastic bags without touching the treated surfaces at 24 h after treatment and at 4-day intervals until 56–60 days post-treatment. If adequate numbers of AM adults were not available for the tests, the sampling date was skipped and the treated apples and leaves were collected at the next consecutive sampling date.

Test insects were obtained from a continuous non-diapausing laboratory colony (Mohammad and AliNiazee 1989) maintained at a temperature of 25 ± 1°C, 70 ± 5% RH, and in constant light. The AM adults were provided with a food mixture of yeast hydrolysate enzymatic (United States Biochemical Corporation, Cleveland, OH) and honey, mixed in a ratio of 1:4. Other rearing procedures were similar to those described by Kamasaki *et al.* (1972). The colony had been reared for 4–5 generations until these bioassays. Five to 10-day-old AM adults were used in these tests.

Each post-treatment laboratory test was replicated four times. Ten AM adults (5 males and 5 females) were tested in each replication. Two additional replications with unsprayed apples and foliage were also included for assessing the natural mortality of AM flies. Modified translucent plastic canisters (Rubbermaid Servin' Saver 12 × 13.5 cm diameter) were used in an inverted position to expose each batch of AM flies to the treated apples and foliages, as described by Mohammad and AliNiazee, (1989). One treated apple and 10–12 treated leaves were placed on a paper towel and a modified canister was inverted, so that the apple and the foliage were in the center of the canister without touching the sides. Provisions were made for aeration, water, and food for the AM flies in these canisters. The tests were conducted at 25 ± 1°C in a walk-in controlled environment chamber under fluorescent lights with a photoperiod of 16:8 (L:D). The

Table 1
Mortality of apple maggot (AM) adults in the laboratory on residue deposits of phosmet on apple foliage and fruit collected at different intervals after spray applications.

Days after spray applications	AM mortality (%)[1]	
	Field rate of phosmet (g [AI]/liter)	
	0.6	1.2
1, 4, 8, 12, 16	100	100
20	100	94.6
24	94.6	94.6
28	89.1	94.6
32	83.7	75.5
36	70.1	89.1
40	–	83.7
44	75.5	–
48	–	51.1
52	45.7	–
56	–	0[2]
60	21.2[2]	–

1. Mortality corrected by Abbott's formula (Abbott, 1925).
2. Excluded from probit analysis.
Natural mortality of AM flies on unsprayed foliage was 8% (n = 300).
No. of AM flies used in each test = 40 (20 males & 20 females). Mortality counts were made after 48 h exposure.

numbers of live and dead flies were recorded after 48 hours. Flies which were unable to walk were considered dead. The mortality counts were corrected by Abbott's formula (Abbott, 1925) and the data were analyzed by probit analysis (Russell *et al.* 1977) for estimation of time to 95% and 50% mortality (ET_{95} and ET_{50}) (Pree *et al.* 1976).

RESULTS AND DISCUSSION

Residues of phosmet caused 100% mortality for 16 days at both rates (Table 1); thereafter, mortality declines inversely with time. The deposits of phosmet caused ⩾50% AM mortality until 48 days post-treatment at both rates, thus suggesting a slow rate of degradation and loss of efficacy. Residual efficacy declined rapidly at 56 and 60 days post-treatment and the insecticide was ineffective after 60 days. The average temperatures in the field for August, September, and October 1987 were 19.9, 17.1, and 14.1°C, respectively; the precipitation in Corvallis during these months was 0.43, 0.13, and 0.68 cm, respectively.

Results of probit analysis indicated that for both rates of phosmet, the estimated time to 95% mortality (ET_{95}) of AM flies from residue deposits was 24.1 days (95% CL = 21.1–26.5), and 52.8 days (95% CL = 48.0–60.9) for 50% mortality (ET_{50}). The slopes and intercepts of the probit regressions for both dosages were similar (x^2 [likelihood ratio test for equality of slopes and intercepts] = 0.458; df = 2) and the data for both dosages of phosmet (0.6 and 1.2 g [AI]/liter) could be represented by a common slope (-4.83 ± 0.56; n = 960; *t* ratio = −8.58;) and a common intercept (8.33 ± 0.87; n = 960; *t* ratio = 9.53). The probit analysis therefore, indicated little differences between efficacies of residue deposits of the two rates for a period of 48–52 days post-treatment.

Bancroft *et al.* (1974) suggested that phosmet and azinphosmethyl were equally toxic to AM adults in laboratory, and Pree *et al.* (1976) reported that foliar residues of dimethoate and azinphosmethyl caused 50% mortality (ET_{50} levels) for 28–30 and 18–20 days, respectively. Data presented here (ET_{95} = 24.1 days and ET_{50} = 52.8 days) show that phosmet was much more persistent in Oregon than either of the two insecticides tested in New York and Ontario.

Reissig *et al.* (1983) determined mortality and oviposition behavior of gravid AM females after various exposure periods on different concentrations of surface residues of azinphosmethyl and found oviposition inhibition in addition to adult mortality. Even at sublethal dosages, the inhibition of oviposition was noticeable. Most AM adults used in our study were 5–10 days old and had not yet begun oviposition, thus oviposition inhibition effects of phosmet residues were not studied. It is likely, however, that phosmet residues may also have similar oviposition deterrent effects in addition to mortality of AM adults.

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Predators associated with the twospotted spider mite, *Tetranychus urticae*, on strawberry at Abbotsford, B.C., and development of non-chemical mite control

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ABSTRACT

Populations of the twospotted spider mite, *Tetranychus urticae* Koch on strawberry were sampled from 1983-86. The predaceous mite, *Amblyseius fallacis* (Garman), was predominant. Active adults were observed in February and November, earlier in the spring and later in the autumn than any other predator. *Amblyseius fallacis*, cecidomyiid flies of *Aphidoletes* sp. and the ladybird beetle, *Stethorus punctum picipes* Csy., all responded numerically to introductions of the twospotted mite but *A. fallacis* responded to the greatest degree. The rate of increase of *A. fallacis* on a $\log_e$ scale was 1.0335 ± 0.0621 per 100 degree-days above 4C (DD_4) in the spring and summer, and 0.5481 ± 0.0845 per 100 DD_4 in late summer, about $2.1\times$ and $1.6\times$ per week on an arithmetic scale. Slide dip tests showed that populations of *A. fallacis* in the Lower Fraser Valley were resistant to the chemical compounds cyhexatin, endosulfan and malathion, partially resistant to diazinon and very susceptible to carbofuran, demeton, dicofol and dimethoate. Biocontrol of *T. urticae* is discussed in the context of integration with the chemical control of aphids, and predator release rates.

INTRODUCTION

The twospotted spider mite, *Tetranychus urticae* Koch, has long been a sporadic problem on cultivated strawberry, *Fragaria* x *ananassa* Duch., in the Lower Fraser Valley. Although miticides have been used to regulate this pest, researchers and extension workers have thought for some time that alternative methods of mite control should be developed. Work was initiated in 1983 to determine an economic threshold for *T. urticae* on strawberry (Raworth 1986a), to develop simple sampling methods that can be used by pest managers (Raworth and Merkens 1987), and to develop a management plan for the pest (Raworth and Strong 1990). To date, however, there has been no satisfactory alternative method for regulating twospotted mites on strawberry. This paper presents data about natural predators that have been found on strawberry during the previous studies and discusses biocontrol strategies.

MATERIALS AND METHODS

Twospotted Mite Introductions and Field Samples.

A 0.54 ha field of 'Totem' strawberries was planted at Abbotsford 3-6 May, 1983. The crowns were 60 cm apart within rows and 120 cm between rows. Runners were allowed to propagate, forming a 'matted row.' The field was sprayed once with diazinon every April for aphid control and with simazine (Simadex 500 F) each autumn for weed control. No other pesticides were applied. *Tetranychus urticae* was mass-reared in the laboratory for field introductions by splitting one mite-infested leaflet between every eight leaflets of potted strawberry plants and allowing the populations to increase for 10–14 days at 22°C. On 19 May, 1983 every second plant in the field was infested with twospotted mites. Samples of 900 leaflets were collected every 2 weeks and processed with a mite brushing machine. Unknown mites and insects were saved in 90% EtOH and sent to the Biosystematics Research Centre for identification. In 1984 the field was divided into 16 plots, each consisting of seven 7-m matted rows. Plots were separated from each other by 10 m of untreated field. Twospotted mites were introduced into the plots at different rates during 1984–86 (Table 1). Accurate counts of the twospotted mite and its associated predators in each plot were made by collecting mature leaflets at random, holding them at 4°C, and examining them later with a $12\times$ stereomicroscope. The average number of

Table 1
Introduction levels of the twospotted spider mite, *Tetranychus urticae*, and the predatory mite, *Phytoseiulus persimilis*, replication, experimental design, and sample sizes per replicate on each sampling date

Trial	Treatment	Rate (Mite infested leaflets per plot)[1]	Reps	Design[2]	Introduction Date (D/M/Y)	*Sample sizes per rep* Mite sample No. leaflets	Plant sample No. quadrats
1.	*T. urticae*	0:42:126:378	4	RCB	26/4/84	35	7
2.	*T. urticae*	140	16		26/4/85		
	P. persimilis	0:28:84:168	4	RCB	2/5/85	35	7
3.	*T. urticae*	0:294	4	R	7/5/86	70	7
4.	*T. urticae*	0:450	2	R	2/7/86	70	7

1. These rates apply only to *T. urticae*. Rates for *P. persimilis* are the number of adult predators on *P. persimilis*-infested leaflets, per plot. *Phytoseiulus persimilis* eggs and immatures were also introduced on the leaflets.
2. RCB—Randomized complete block; R—Completely randomized.

mature leaves in 30 cm of row was also determined for each plot by using quadrats (Table 1). Densities of mites and insects were expressed as numbers per row-meter. The sample data were transformed using natural logarithms and analyzed by ANOVA, setting sample-day as a split-plot. Standard errors were calculated from the residual variation used to test treatment differences. Data were analyzed only for species that consistently appeared in the samples. An index of total numbers for each species during the season, "*T. urticae*-days" and "predator-days," was derived by interpolating the geometric mean number of each species for each day between samples, and summing the estimates for the whole sample period.

Resistance of the predatory mite, *Amblyseius fallacis* (Garman) to Pesticides. During 1986, 10 commercial fields were sampled for twospotted mites. *Amblyseius fallacis* was found in five of the fields between Langley and Agassiz. Collections from four of these locations were maintained in isolated cultures and tested for resistance to field rates of eight pesticides (Table 2) that were commonly used to control pests of strawberry. The slide-dip methodology followed Anonymous (1968) and the modification of Croft et al. (1976), but with 10 *A. fallacis* females per slide rather than 50. The proportion of females alive 48 h after exposure to a pesticide was transformed by arc-sine square-root and analyzed by ANOVA. Duncan's New Multiple Range Test was used to separate means.

Table 2
Proportion of adult female *Amblyseius fallacis* surviving, 48 h after exposure to a pesticide mixed at a concentration equivalent to the maximum recommended field rate (Anonymous 1986). Each replicate 'n' tested survivorship of 10 females

Pesticide	Class[1]	Concentration (ppm)	Proportion alive[2]	n	S.E.[3]	Proportion alive[4]
demeton (Systox SC; 240 g/L)	OP	500	0.0 a	12	4.193	0.0
dimethoate (Cygon 480 E)	OP	1600	0.0 a	8	5.135	0.0
carbofuran (Furadan 480 F)	C	1100	2.30a	8	5.135	0.0016
dicofol (Kelthane EC; 18.5%e.c.)	OC	400	13.5 a	8	5.135	0.054
diazinon (Diazinon 50 EC)	OP	900	48.4 b	16	3.631	0.56
endosulfan (Thiodan 4 E)	OC	800	66.3 c	16	3.631	0.84
cyhexatin (Plictran 50 W)	OT	600	69.3 c	16	3.631	0.88
malathion (Malathion 50 EC)	OP	1200	69.9 c	16	3.631	0.88
distilled water			78.3 c	28	2.745	0.96

1. C—carbamate; OC—organochlorine; OP—organophosphate; OT—organotin
2. Data transformed by arc-sine square-root. Means followed by different letters are significantly different ($p < 0.01$) according to Duncan's New Multiple Range Test.
3. Standard errors given in transformed scale
4. Means back-transformed to original scale

Table 3
Natural predators collected from 'Totem' strawberry leaflets that were infested with the twospotted spider mite, *Tetranychus urticae*, at Abbotsford, British Columbia

Predator name		Date
ACARI: MESOSTIGMATA		
Phytoseiidae	*Amblyseius andersoni* (Chant)	2 Aug. 1983
	A. fallacis (Garman)	30 Aug. 1983
	A. isuki Chant & Hansell	2 Aug. 1983
	A. okanagensis (Chant)	31 May 1985
	Typhlodromus pyri Scheuten	2 Aug. 1983
ACARI: PROSTIGMATA		
Anystidae	*Anystis* sp.	20 June 1985
Bdellidae	*Thoribdella* nr. *simplex*	4 July 1984
COLEOPTERA:		
Coccinellidae	*Stethorus punctum picipes* Csy.	19 July 1984
DIPTERA:		
Cecidomyiidae	*Aphidoletes* sp.	4 July 1984

RESULTS

Twospotted Mite Introductions and Field Samples.

Seven species of predaceous mites and two of predaceous insects were found to occur naturally (Table 3). The introduction levels of twospotted mites in 1984 resulted in significantly different population levels of the pest ($p < 0.01$, Fig.1), the predatory mite, *A. fallacis* ($p < 0.01$, Fig.2), a cecidomyiid fly of *Aphidoletes* sp. ($p < 0.05$, Fig.3) and a ladybird beetle, *Stethorus punctum picipes* Csy. ($p < 0.05$, Fig.4). No twospotted mites or predators were seen in three samples of 60 leaflets collected from the field prior to the experiment (27 March, 10 and 24 April). *Amblyseius fallacis* and larvae of *Aphidoletes* sp. appeared simultaneously in the mid-June sample. The beetle larvae appeared in the next sample, but the eggs had been seen in the mid-June sample, indicating predation on

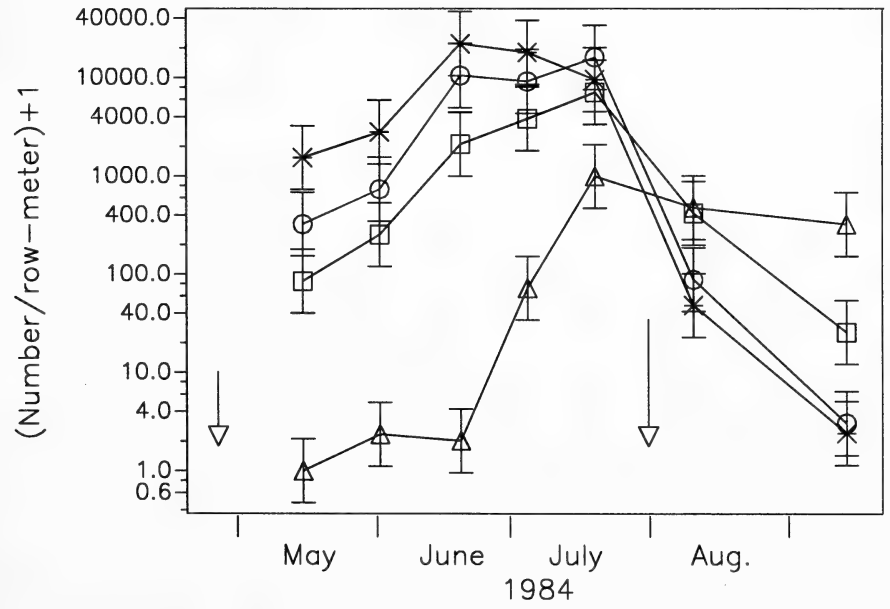

Fig 1. Population trends of *Tetranychus urticae* in 1984 at four introduction levels (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

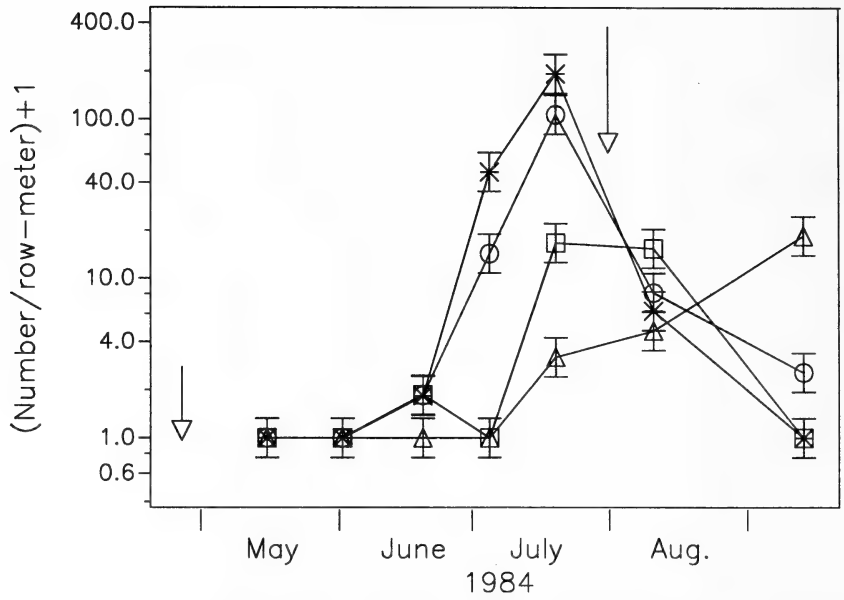

Fig. 2. Population trends of *Amblyseius fallacis* in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

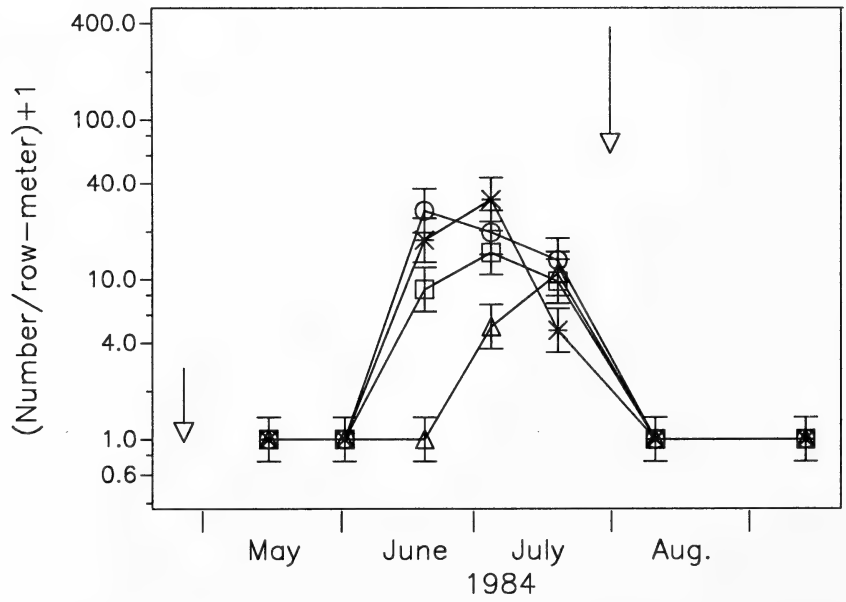

Fig. 3. Population trends of *Aphidoletes* sp. larvae in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. See Table 1). Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

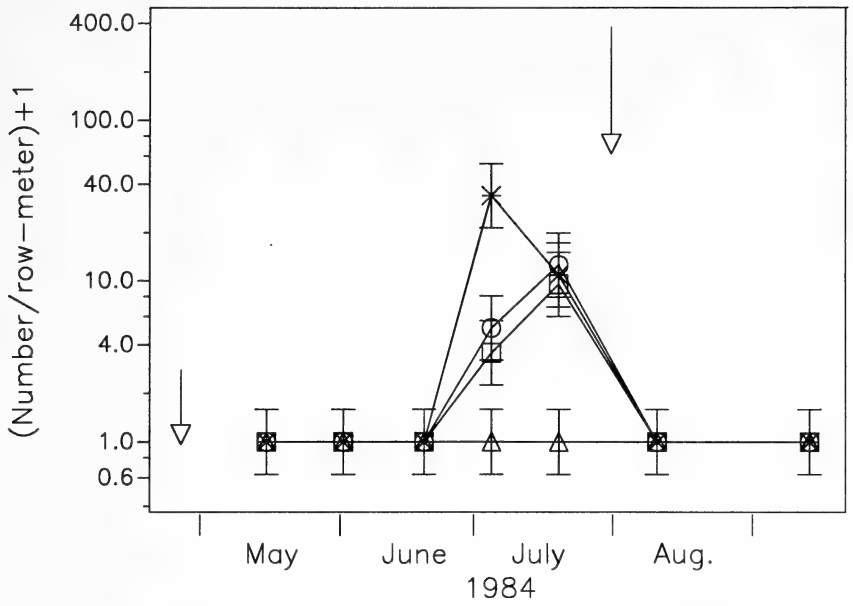

Fig. 4. Population trends of larvae of *Stethorus punctum picipes* in 1984 at four introduction levels of twospotted mites (high—asterisk; medium—circle; low—square; control—triangle. (See Table 1.) Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the mowing of the field.

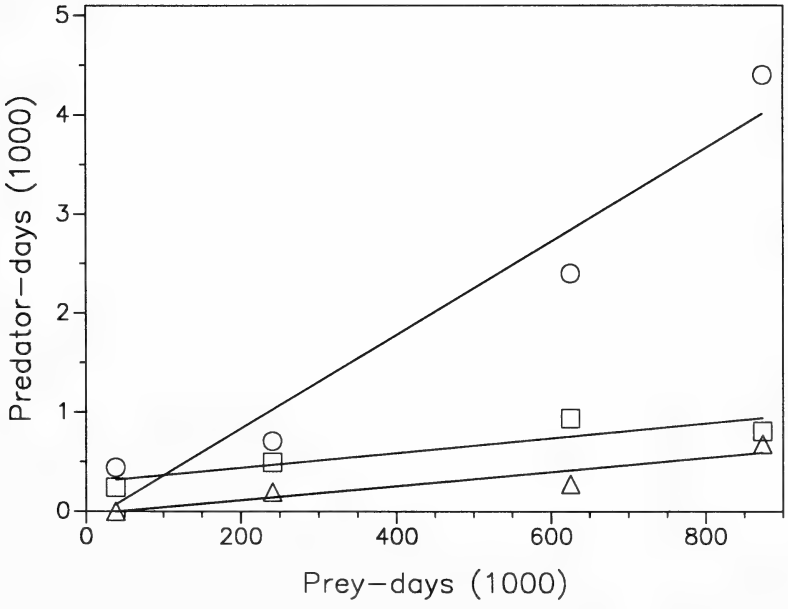

Fig. 5. The number of predator-days (*Amblyseius fallacis*—circle; *Aphidoletes* sp. larvae—square; and *Stethorus punctum picipes* larvae—triangle) as a function of twospotted-mite-days. The overall within-species regression was statistically significant ($p<0.01$ $r=0.714$ 8df), and the slopes of the individual regressions were significantly different ($p<0.01$; *A. fallacis* 0.0047; *Aphidoletes* sp. 0.00075; and *S. punctum picipes* 0.00071 where ±1 SE = 0.0005009).

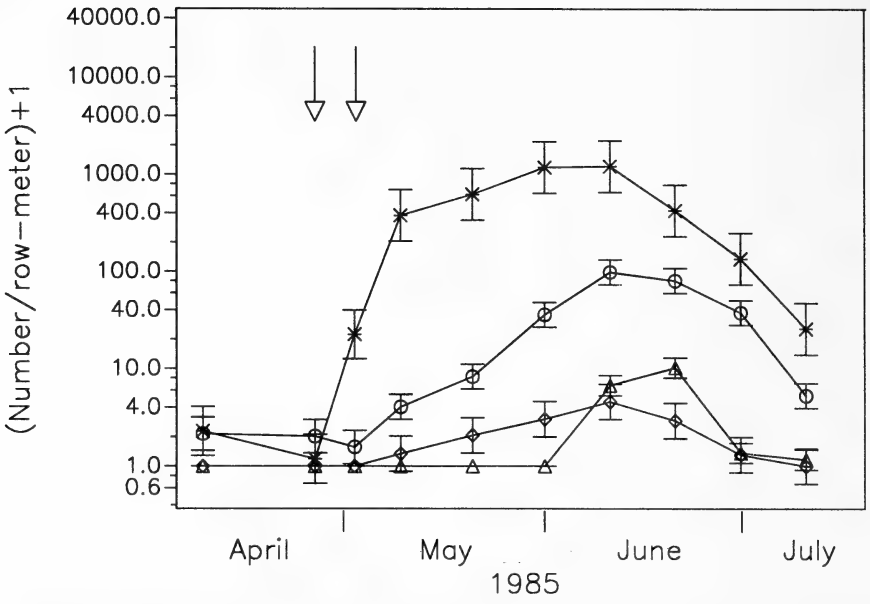

Fig. 6. Population trends of: *Tetranychus urticae*—asterisk; *Amblyseius fallacis*—circle; *Phytoseiulus persimilis*—diamond; and *Stethorus punctum picipes* larvae—triangle, in 1985. Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the introduction of twospotted mites and the right arrow, the introduction of *P. persimilis*.

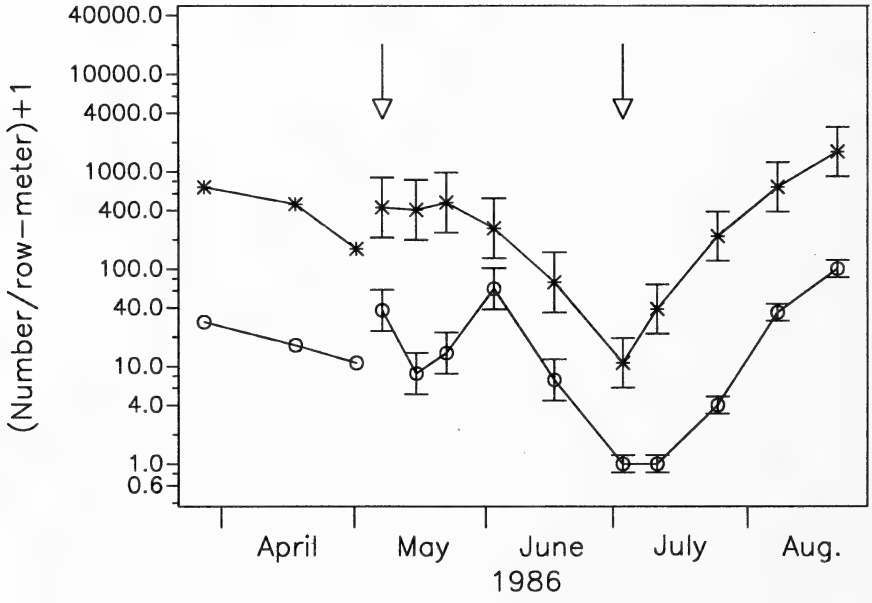

Fig. 7. Population trends of: *Tetranychus urticae*—asterisk; and *Amblyseius fallacis*—circle, in 1986. Vertical bars indicate ±1 SE of the geometric mean. The left arrow indicates the first introduction of twospotted mites and the right arrow, the second introduction.

twospotted mites by adults. Only *A. fallacis* was observed in the autumn samples. The response of *A. fallacis* in terms of accumulated predator-days at different levels of twospotted mites was significantly greater than that of the other two species (Fig.5). Twospotted mites overwintered in the field in 1985, and *A. fallacis* appeared in the samples before any other predator (Fig. 6). Analysis of the sample data prior to the introduction of the pest indicated that there was no carry-over effect of the 1984 treatments with respect to the prey or predator ($p > 0.05$). Analysis of the sample data after the introduction of the predator mite, *Phytoseiulus persimilis* Athias-Henriot, suggested that there were no detectable effects from its various introduction levels ($p > 0.05$). The numbers of twospotted mites and associated predators in the 16 plots were therefore pooled. Population levels of *A. fallacis* were much higher than those of *P. persimilis* and *S. punctum picipes* (Fig.6). Only one *Aphidoletes* sp. larva was seen on 560 leaflets on 10 June, and three on 30 June. The presence of eggs of the ladybird beetle indicated predation on twospotted mites by adult beetles from 20 May to 30 June. Active *A. fallacis* were collected in field samples as late as 15 November. *Phytoseiulus persimilis,* a tropical species, did not overwinter successfully to the spring of 1986.

In 1986, *A. fallacis* was collected in a field sample on 16 February. The average number per row-m in March-April, 17.2 ($+5.56$, -4.21) (Fig. 7), was higher than the number observed in April 1985 (Fig. 6). Introductions of twospotted mites in May and July failed to produce significantly different population trends relative to control plots ($p>0.05$), despite the fact that the release rates were equivalent to those of the medium-to-high density treatments of 1984 (Table 1). The data for the treatments and controls were therefore pooled (Fig. 7). Only four *S. punctum picipes* larvae were observed on 560 leaflets on 2 June, and three were observed on 16 June. However, the presence of eggs of the ladybird beetle indicated adult predation on the twospotted mites from 22 May to 7 August. One *Aphidoletes* sp. larva was observed on 16 June. The *A. fallacis* population trend followed that of the twospotted mites from April through August.

Amblyseius fallacis was the predominant predator of *T. urticae* over the 3 years. The rate of increase of *A. fallacis* in each treatment in 1984, and in each experiment in 1985–86 was determined as the slope of the regression of ln(mean number per row-m) against degree-days above 4°C (DD_4) (Table 4). Although there was a statistically significant relationship between the rate of increase of *A. fallacis* and the average density of twospotted mites during the time when *A. fallacis* was increasing in 1984, the data for 1985–86 did not support the relationship. The two lowest rates of increase were observed during August and September and these were significantly different from the rates observed during May, June and July ($p<0.05$). Based on an overall regression, the average rate of increase of *A. fallacis* per 100 DD_4 during spring and early summer was 1.0335 ± 0.0621, while that during late summer and early autumn was 0.5481 ± 0.0845. These rates were equivalent to a population increase of $2.1\times$ and $1.6\times$ per week $[e^{(bxtime/100)}]$: where 'b' is the slope of the regression line and 'time' is DD_4 per week (about 70 DD_4 per week from May to July and 85 from August to mid-September).

Resistance of the predatory mite, *A. fallacis* to Pesticides.

There were no differences in pesticide resistance with respect to the origin of *A. fallacis* ($p > 0.05$), but there were differences in resistance to the different pesticides (Table 2). Carbofuran, demeton, dicofol and dimethoate were very toxic, whereas cyhexatin, endosulfan, and malathion had little effect. Diazinon was intermediate. There did not appear to be any cross-resistance between pesticides within similar chemical groups.

Table 4
Rates of increase of *Amblyseius fallacis*, calculated as the slope of the regression of ln(mean per row-m) against degree-days above 4C (DD_4). The geometric mean density of twospotted mites during the period of *A. fallacis* increase was also determined

Year	Months	Treatment	Rate per 100 DD_4	(± SE)	Density of twospotted mites per row-m
1984	July - Sept.	Control	0.5299	0.1104	535
	June - July	Low	0.7822	0.2175	3861
	June - July	Medium	1.1128	0.2175	11555
	June - July	High	1.2597	0.2175	15589
1985	May - June	Pooled	1.0012	0.1967	376
1986	May	Pooled	0.9897	0.3780	373
	July - Aug.	Pooled	0.6048	0.1952	625

DISCUSSION

Several predator species were associated with twospotted mites on strawberry but one, *A. fallacis*, has a number of qualities that make it potentially useful as a biological control agent: it successfully overwinters; it may be found associated with its prey from early spring until late autumn; it responds numerically to population increases of twospotted mites, with a rate of increase equivalent to that of the prey in commercial fields (Raworth and Strong 1990); it is resistant to a number of pesticides; and it can be reared in the laboratory throughout the year. However, the data presented do not indicate how effective *A. fallacis* was at regulating twospotted mites because there were no controls in which predators were excluded. Experimental releases of mass-reared *A. fallacis* are needed. A basic problem with releasing predaceous mites to control *T. urticae* is that the predators are usually exposed to pesticides applied to control aphids. Aphids vector virus diseases that substantially reduce yields (Mellor and Krczal 1987) and are of great concern to growers. In the past, endosulfan, diazinon and malathion were used to control aphids. *Amblyseius fallacis* has some resistance to these compounds (Table 2), but recently, many growers have preferred to control aphids with a systemic such as demeton, which is highly toxic to *A. fallacis*. Integration of *A. fallacis* releases into the current cultural system may be possible by artificially selecting for resistance to specific pesticides (Hoy 1982). Alternatively, because aphid numbers increase most in the spring (Shanks 1965), systemic sprays could be used before harvest, and a spray-free period could be established after harvest to provide time for increase in the numbers of introduced predators. Given the activity of *A. fallacis* late in the autumn and early in the spring, its introduction would maximize the effective length of the spray-free 'window.' When it is necessary to spray for aphids in the autumn, one of the three pesticides that are not harmful to *A. fallacis* could be used.

Raworth and Strong (1990) developed and tested a management plan for twospotted mites. Sampling is recommended at intervals of 1-3 weeks when mite density is below five per leaflet and, above that level, sprays are recommended depending on the rate of population increase. However, neither the plan nor the binomial sampling methodology that is used to determine mite density is applicable when inundative predator releases are used for pest control. Given the current mass-rearing technology, a grower could afford to introduce 50,000 predators per ha at a cost of about $500 per ha. This release rate is equivalent to six predators per row-m when there are 8300 row-m of strawberries per ha. Although effective predator:prey ratios have not yet been determined, studies conducted with other mite systems (Collyer 1958; Hamai and Huffaker 1978; Waite 1988; and Wilson *et al.* 1984) suggest that a ratio of 1:20 (6:120) is a reasonable estimate. Leaflet densities increase through the season, but 120 twospotted mites per row-m is about 0.4 per leaflet in May (270 leaflets per row-m, 1984 data) and 0.3 per leaflet before mowing in

July (366 leaflets per row-m, 1984 data). As an action threshold, 0.4 pest mites per leaflet is an order of magnitude below the threshold for spray application, therefore the Raworth and Strong (1990) management plan is not valid when predators are released as a control measure. Furthermore, the sampling methodology becomes increasingly unreliable as mite density decreases below one mite per leaflet (Raworth 1986b). Sampling is still useful, however, not to determine if twospotted mite densities are high enough to warrant release of predators, but to determine whether the mite densities are low enough that the predators have a chance of being effective. A density of five pest mites per leaflet, for example, is equivalent to about 1500 per row-m. A release of 50,000 predators per ha at this density would result in a predator:prey ratio of 1:250. Under this circumstance, a grower should probably apply one spray to bring mite numbers down before releasing the predators. Alternatively, if the samples are examined closely for predators, the grower may find that there is little advantage in predator releases because there are substantially more predators in the field than the number being released. A predator density of 0.1 per leaflet is equivalent to about 40 per row-m, 7 × the 50,000 per ha release rate. Time and experience are required to work out the details of an integrated biocontrol plan, but the strategies must be considerably different from those in which pesticides are the only method of control.

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Notes on the longevity, fecundity and development of *Pissodes terminalis* Hopping (Coleoptera: Curculionidae) in the Interior of British Columbia, Canada

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ABSTRACT

The biology and life history of the lodgepole terminal weevil, *Pissodes terminalis,* was studied in the interior of British Columbia, Canada. Average longevity of females of *P. terminalis was 112.8 days at 20*°C. Mean lifetime fecundity was 115 eggs per female. The egg stage lasted 8 days, and pupation took 15 days. In the field, egg laying started at the beginning of June and all larvae reached the final instar by early September. Pupation began in mid-September and at the end of the month the first adult was ready to emerge.

INTRODUCTION

Large areas of mature lodgepole pine (*Pinus contorta* Doug. ex Loud) in the Interior of British Columbia have been infested during the last two decades by the mountain pine beetle, *Dendroctonus ponderosae* Hopk. These have been managed by salvage logging the infested forests and now there are large areas of young lodgepole pine forests. Such stands are vulnerable to attack by regeneration pests (Amman and Safranyik 1984) one of the most important of which is the lodgepole terminal weevil, *Pissodes terminalis* Hopping.

Adults typically emerge from the leaders in early summer and after some maturation feeding, the females lay eggs into the elongating terminal shoot of host trees. Newly hatched larvae mine just beneath the epidermis; later instars burrow into the pith and mine towards the apical bud. Pupation occurs in the pith. Most of the weevils overwinter as late instar larvae but pupae and adults may also overwinter in the terminal.

Larval feeding in the phloem-cambium region and in the pith results in the death of the terminal. Dead terminals are replaced by laterals, resulting in the formation of crooks, forks in the main stem, and in severe cases, in multi-leadered crowns (Stevenson and Petty 1968; Stevens and Knopf 1974; Duncan 1986). Beside deformities, the trees also suffer height growth loss (Maher 1982; Amman and Safranyik 1984).

Leader clipping trials for the lodgepole terminal weevil (MoF 1984), as an experimental control method, have been carried out to reduce weevil numbers. Knowledge of the biology and life history of the weevil can play an important role in the timing of leader clipping operations. Although the impact of *P. terminalis* on young lodgepole pine trees has been studied in the past (Maher 1982), no detailed information is available on this pest's biology in British Columbia. Our objectives were to investigate: the longevity and fecundity of adult female *P. terminalis;* the duration of egg and pupal stages; the development of the weevil from egg to adult in field conditions.

METHODS AND MATERIALS

Longevity and fecundity.

Ten pairs of *P. terminalis* adults were placed in 0.5 L jars covered with cheese cloth and kept at room temperature, 20 ± 2°C. Each day a 10-cm-long section of lodgepole pine terminal was placed in each jar from a supply of cut leaders that was kept refrigerated. Numbers of feeding punctures, oviposition sites and numbers of eggs per oviposition site were counted daily using a dissecting microscope.

Table 1
Longevity and ovipositional characteristics of ten female *Pissodes terminalis* reared at 20 ± 2°C.

Characteristics	Mean	+ S.D.	Range
Longevity (days)	112.8	74.9	32–226
Preoviposition period (days)	10.1	6.8	2–22
Total eggs/female	115.0	67.5	9–216
Eggs/oviposition site	0.94	*	0–2
Eggs/female/day**	1.57	1.34	0.39–4.62

* S.D. not calculated
** From first to last day of oviposition

Duration of the egg stage.
Sections of the current year's terminal growth with oviposition sites, obtained from the longevity and fecundity experiment, were placed on moist paper towels in closed paper boxes maintained at room temperature. Desiccation of the leaders was prevented by moistening the paper towels daily. The eggs were checked daily and hatching recorded. After each daily examination the oviposition sites were closed to prevent desiccation of the eggs.

Duration of the pupal period.
Twenty weevil larvae were obtained from dissections of one-year-old infested lodgepole pine leaders. Each larva was kept in a 3–4 cm long section of the leader which was placed in a separate petri dish at 20 ± 2°C. Dates of pupation and adult emergence were recorded for each larva.

Development of *P. terminalis* in the field.
Weekly collections at Ellis Creek, 25 km east of Penticton, B.C., were made between June 5, 1987 and September 30, 1987. Ten attacked leaders were clipped with a hand pruner and taken back to the laboratory where they were dissected. Numbers of all weevil developmental stages were recorded. To relate the weevil's life history with leader phenology, 25 lodgepole pine trees with unattacked terminals were randomly chosen and marked with red plastic ribbon. A number was assigned to each tree so that repeated measurements could be taken from the same tree. Elongation of the leaders was measured and recorded every 7 days.

RESULTS AND DISCUSSION

Longevity and fecundity.
Average longevity of the 10 female *P. terminalis* was 112.8 days after emergence from the puparia; one female lived for 226 days (Table 1). Fontaine and Foltz (1985) found that longevity of adult female deodar weevils, *Pissodes nemorensis* Germar, was 130.5 days (S.D. = ± 63.3; range = 1–198) under laboratory conditions of 25 ± 1°C. McMullen and Condrashoff (1973) reported that adults of *Pissodes strobi* (Peck) can live up to 4 years in the field.

We observed that female *P. terminalis* are able to lay eggs as early as 2 days following emergence and therefore they do not require a long maturation feeding. The preoviposition period averaged 10.1 days (Table 1). In contrast, the corresponding time for *P. nemorensis* was 36.6 days (S.D. = 6.1; range = 28–47) at 25 ± 1°C (Fontaine and Foltz 1985).

The first eggs were laid on the second day, after which oviposition increased until day 21 (Fig. 1). There was a sharp decline in the number of eggs laid between day 21 and day 28, but there was a resurgence of oviposition in the following 7 day period. A very similar pattern was observed by Fontaine and Foltz (1985): after a period of increasing oviposition by *P. nemorensis*, the number of eggs laid suddenly "declined to about one-half its peak value on day 90, and then increased again until day 130." They assumed that

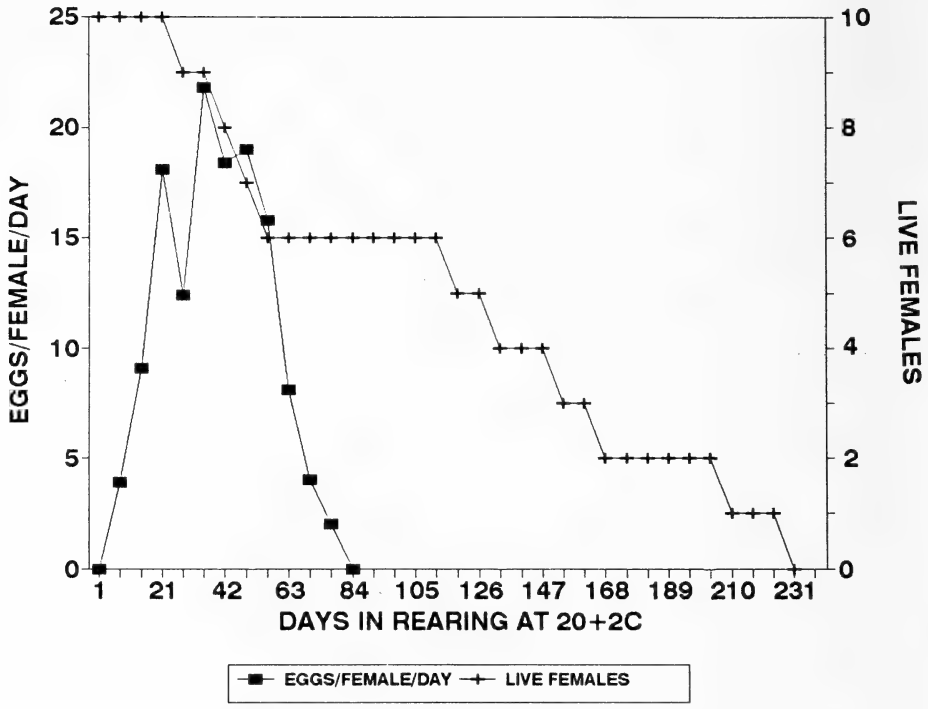

Fig. 1. Survival and fecundity of ten caged *Pissodes terminalis* females at 20 ± 2°C.

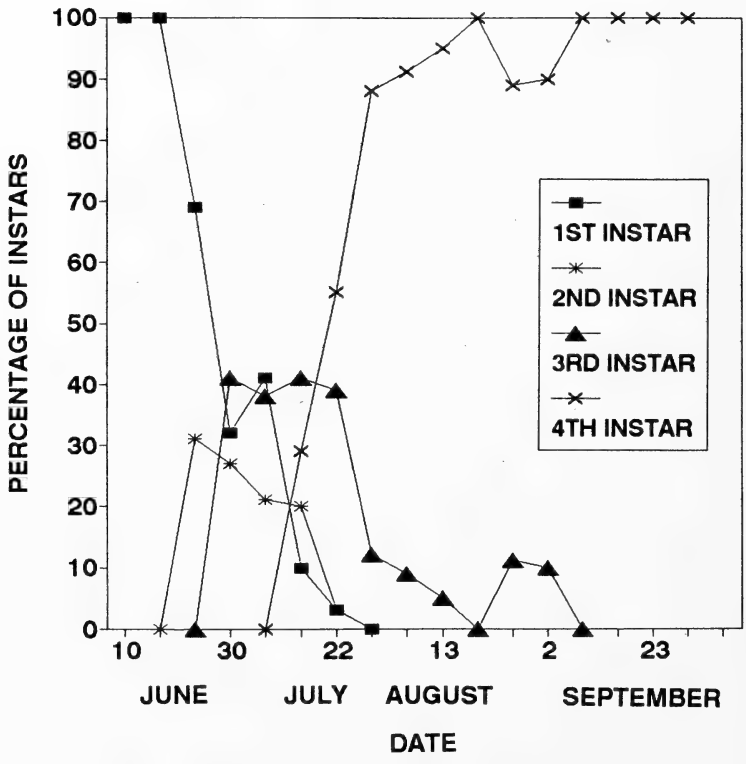

Fig. 2. Larval development of *Pissodes terminalis* at Ellis Creek, near Penticton, B.C. in the summer of 1987.

changing host quality caused the decline. Oviposition by *P. terminalis* reached its peak on day 35 and declined sharply afterwards, although more than half of the females were still alive. The last egg was laid on day 80.

The mean fecundity was 115 eggs per female, although one female laid 216 eggs (Table 1). Total numbers of eggs laid by *P. strobi* (Graham 1926) and *P. nemorensis* (Fontaine and Foltz 1985) averaged 115 and 284, respectively.

From the weekly field collections, a total of 1246 oviposition sites were counted and 1150 eggs were found, a mean of 0.94 eggs per oviposition site. This result is slightly smaller than the reported 1.19 eggs per site for *P. nemorensis* (Fontaine and Foltz 1985), and 1.4 eggs per site for *P. strobi* on Sitka spruce, *Picea sitchensis*. (Gara et al. 1971). Females of *P. terminalis* most often laid one egg per pit (91.6%), but sometimes they oviposited two eggs (0.5%) or none (7.5%). Sealed but empty oviposition pits were most often found towards the end of the oviposition period. Five eggs were laid directly on the bark surface (0.4%). These results support previous findings that generally only one egg is deposited in each pit (Drouin *et al.* 1963; Stark and Wood 1964). Females laid an average of 1.57 eggs per day.

Duration of the egg stage.

Observation of 54 eggs of *P. terminalis* revealed that the average duration of the egg stage was 8 days (S.D. = ±0.98; range = 5–18). This is in agreement with the findings of Stevens and Knopf (1974) who reported that eggs of *P. terminalis* hatch within 2 weeks. We observed that two eggs hatched 5 days after oviposition and 9 took 18 days to hatch.

Duration of the pupal period.

Observations of 20 *P. terminalis* pupae showed that on an average it took 15 days (S.D. = ±2.5; range = 11–20) from pupation to adult emergence at 20°C.

Observations of the development in the field.

The first adult *P. terminalis* was observed on a one-year-old attack on May 10, 1987. Neither an emergence hole nor fresh feeding punctures were observed on the terminal. Six more adults were observed on elongating leaders within the next ten days. The observations suggest that these weevils may have emerged in the previous fall and overwintered probably in the duff.

Daily examination of 50 dead leaders, attacked in 1986 revealed the first weevil emergence hole on June 19, 1987. However, the first current year's attack was recorded on June 3, 1987 suggesting that these eggs may have been laid by overwintering adults. The last eggs were observed on July 22, 1987.

Figure 2 shows the development of *P. terminalis* in the field at Ellis Creek, near Penticton, B.C. Prolonged egg laying by emerging adults and egg hatching resulted in first-instar larvae being present from the beginning of June through July 22, 1987. This is the date when the last second-instar larvae were recorded. In 1961, Stark and Wood (1964) found that in central Sierra Nevada, California, first- and second-instar larvae of *P. terminalis* were present until the end of July. In the present study, third-instar larvae were observed in the pith from the end of June through the beginning of September, 1987 (Fig. 2). Last-instar larvae were found on July 14, 1987 and by the end of the month they were commonly encountered. Ninety-five percent of the larvae were in the pith on Aug. 13, 1987. By September 9, 1987 all larvae reached the final instar. Stark and Wood (1964) reported that all larvae were in the last instar on September 6, 1961.

The first pupa was recorded on September 17, 1987 and two weeks later the first adult was ready to emerge. These observations suggest that, in this locality, *P. terminalis* overwinters as a fourth instar rather than a third instar larva. Pupae and adults also overwinter inside the terminal. Emerged weevils probably hibernate in the duff (Furniss and Carolin 1977).

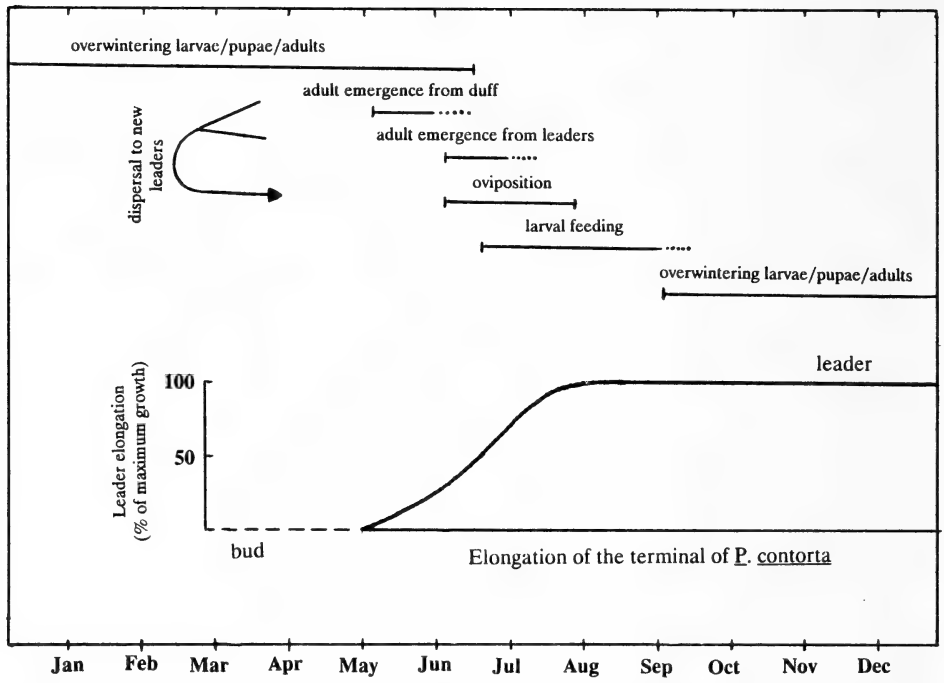

Fig. 3. Life cycle of *Pissodes terminalis* at Ellis Creek, near Penticton, B.C. in the summer of 1987.

On average, 3.4 larvae per tip (S.D. = ±2.79; range = 1–17; n = 160) were found. This number is slightly smaller than the 4.2 larvae per tip (range = 1–19; n = 305) found by Stark and Wood (1964) in California. Since adult females oviposit into the elongating terminal the coincidence of the greatest leader growth and ovipositional period is critical for successful oviposition. Figure 3 shows the relationship between oviposition and tip elongation at Ellis Creek in 1987. Leader growth started at the beginning of May and it was practically finished by the end of July. Only slight height growth was recorded in the first 2 weeks of August. Oviposition was restricted to the second half of the elongation period. Figure 3 also summarizes field observations on the life cycle of the lodgepole terminal weevil at Ellis Creek. Late-instar larvae, pupae and adults overwinter. Adult weevils start emerging in early May and egg laying begins early June. By mid-September all larvae reach the final instar and the first pupae are encountered in late September when some of the adults emerge. The life cycle of *P. terminalis* follows type 1, 2A, 2B and 2C life cycles described by Cameron and Stark (1989) from the Sierra Nevada.

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Note on the occurrence of *Paravespula germanica* (Hymenoptera: Vespidae) in the Lower Fraser Valley of British Columbia

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The German yellowjacket, *Paravespula germanica* (Fab.), was not known to occur in the Pacific Northwest prior to 1981. The first collections of this wasp were made in 1981 in Nampa, Idaho, and in 1982 in Puyallup, Washington (MacDonald and Akre, 1984). Buckell and Spencer (1950) did not include *P. germanica* in their list of vespid wasps of British Columbia. Akre *et al.* (1989) gave the range of this species in North America.

In the summers of 1984 and 1985, I netted yellowjacket workers in Cloverdale, B.C. and keyed them to *P. germanica* using the key in Akre *et al.* (1980). These wasps were sent to Akre, who confirmed their identity and retained them in the collection of the Washington State University, Pullman.

In 1986 an active nest of *P. germanica* was collected from a shed in Clearbrook. The nest was attached to the rafters and the lower tip touched a ceiling joist, measuring 91 cm long and 46 cm in diameter.

A small, globular (25 cm × 20 cm), active nest of *P. germanica* was collected from the inside of a storage cabinet of a sailboat in Richmond in early September, 1987. The boat had been built and moored there, eliminating the possibility that the nest might have been built while the boat was elsewhere.

Also in October of 1987, a farmer from Clearbrook contacted me concerning a large wasp nest in his barn. The nest was built between 5 cm × 30 cm ceiling joists on 40 cm centers and projected about 45 cm below them. It contained 11 combs, all situated between the ceiling joists. The mass of nesting material projecting below the ceiling joists contained no combs. Many dead wasps inside the nest keyed to *P. germanica*.

In 1988, 2 active nests measuring 25 cm × 25 cm were collected from crawl spaces under houses, 1 on 13 August from Aldergrove, and 1 on 30 August from White Rock. Specimens were also collected from 2 ground nests, on 3 September from North Langley, and on 30 September from Cloverdale. Further collections were made from 3 inaccessible nests: on 22 September from a hole in a wall of a mobile home in Rosedale; on 30 September from the attic of a home in south Langley; and on 5 October from the floor of a sundeck in Steveston.

On 18 July 1989, an active nest measuring 30 cm × 30 cm was taken from a large trunk in a storage shed in White Rock. Further collections were made from 3 inaccessible ground nests and 1 inaccessible nest in an attic as follows: 7 September—Vancouver, 11 and 28 September—Burnaby, and 3 October—south Langley. In addition to the collections reported above, Mr. M. Rabas collected *P. germanica* from Richmond on 10 September 1987 and deposited them in the Spencer Entomological Museum at the University of British Columbia.

P. germanica belongs to a group of wasps that includes *P. pensylvanica* and *P. vulgaris*. It resembles P. pensylvanica except that the continuous yellow genal band around the top of the compound eye is interrupted in *P. germanica*. In its behaviour it resembles *P. vulgaris*, being very aggressive and defensive around its nest. Nest and population size approach that of *P. vulgaris*, whereas external nest appearance and grey color resemble that of *P. pensylvanica*. Its scavenging feeding habits, and its selection of man-made structures for nesting sites brings this species in close contact with humans, thus increasing the potential for wasp stings, which are considered to be a nuisance or even a public health threat.

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Emergence patterns of terminal weevils (Coleoptera: Curculionidae) and their parasitoids from lodgepole pine in the Interior of British Columbia, Canada

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ABSTRACT

Three terminal weevil species emerged from 82 infested leaders collected at two locations in the Okanagan Valley. The most abundant species was *Pissodes terminalis* Hopping. *Magdalis gentilis* LeConte started to emerge at the beginning of May whereas *P. terminalis* and one species of *Cylindrocopturus* emerged a month later. Parasitoids reared from weevil infested terminals belonged to nine species in six families of the Order Hymenoptera. The most important species was the pteromalid *Rhopalichus pulchripennis* Crawford but two species of *Eurytoma* collectively ranked second in abundance. Emergence of the majority of the parasitoids preceded that of *P. terminalis* and *Cylindrocopturus* sp.

INTRODUCTION

Terminal weevils often cause serious damage to young coniferous trees by attacking terminal shoots (Keen 1952). According to Keen (1952) the three most important genera of twig weevils are *Pissodes, Magdalis* and *Cylindrocopturus.*

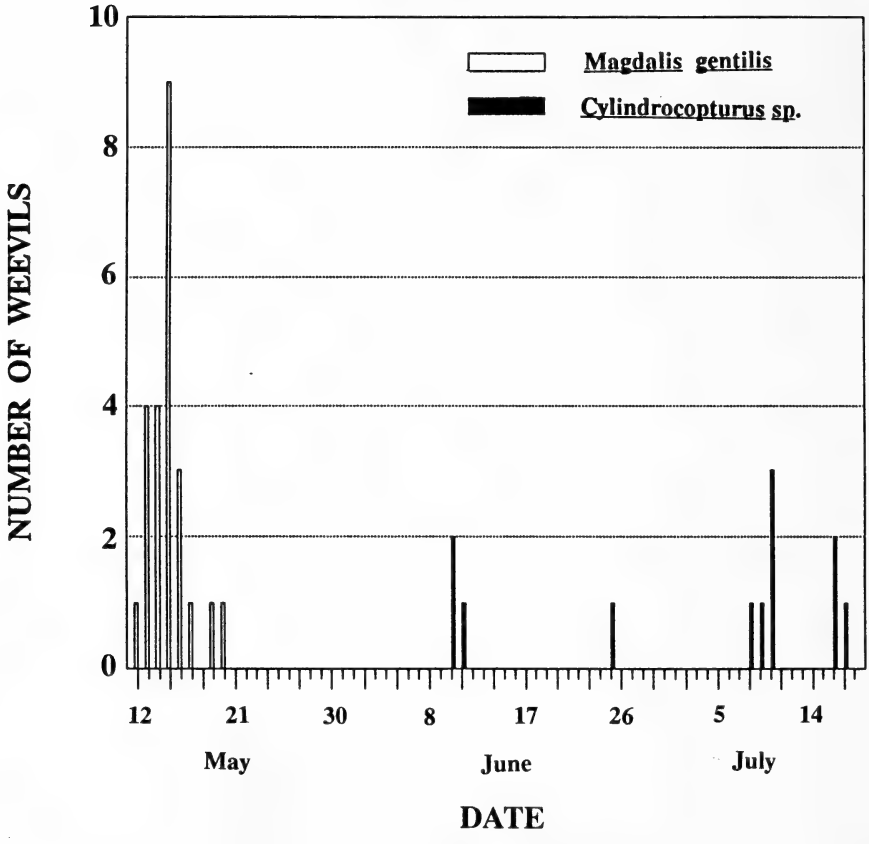
The lodgepole terminal weevil, *Pissodes terminalis* Hopping is the most important weevil species attacking leaders of lodgepole pine, *Pinus contorta* Doug. ex Loud., in British Columbia. The occurrence of Magdalis and *Cylindrocopturus* species in the province has been reported by Furniss and Carolin (1977) but the first damage caused by *M. gentilis* Lec. was observed and reported by the Forest Insect and Disease survey (FIDS) only in 1987 (Wood *et al.* 1987).

Fellin and Schmidt (1966) reported that the damage caused by *M. gentilis* "did not appear to be restricted to any particular portion of the crown." Adults puncture needles so that the distal portions desiccate and discolor (Fellin and Schmidt 1966), and are broken off by wind, rain or snow (Plumb 1950; Fellin 1973). Fellin (1973) stated that defoliation was the only type of damage he had observed. However, Kovacs' (1988) observations support the findings of Furniss and Carolin (1977) that larvae of *M. gentilis* mine branches as well as leaders. Damage caused by *Cylindrocopturus* spp. is similar to that of *M. gentilis.*

Leader clipping trials (MoF 1982, 1983, 1984) were carried out in the Cariboo Forest Region to reduce populations of *P. terminalis.* Leaders were clipped in July. Development of effective control methods requires they are consistent with the biology of the target species.

Losses caused by *M. gentilis* and *Cylindrocopturus* spp. are not considered important (Furniss 1942; Fellin 1973; Furniss and Carolin 1977) and therefore, no practical measures have been developed for their control. In the absence of effective control methods it seems that natural control will play the most important role in reduction of numbers of these pests.

Detailed studies have been carried out on insects associated with *Pissodes strobi* Peck. on eastern white pine, *Pinus strobus* L. (Harman and Kulman 1967), on Engelmann spruce (VanderSar 1978) and on Sitka spruce, *Picea sitchensis* Bong. (Carr.), (Stevenson 1967; Alfaro *et al.* 1985). However, no information is available on the parasite-predator complex of other leader weevils in British Columbia.



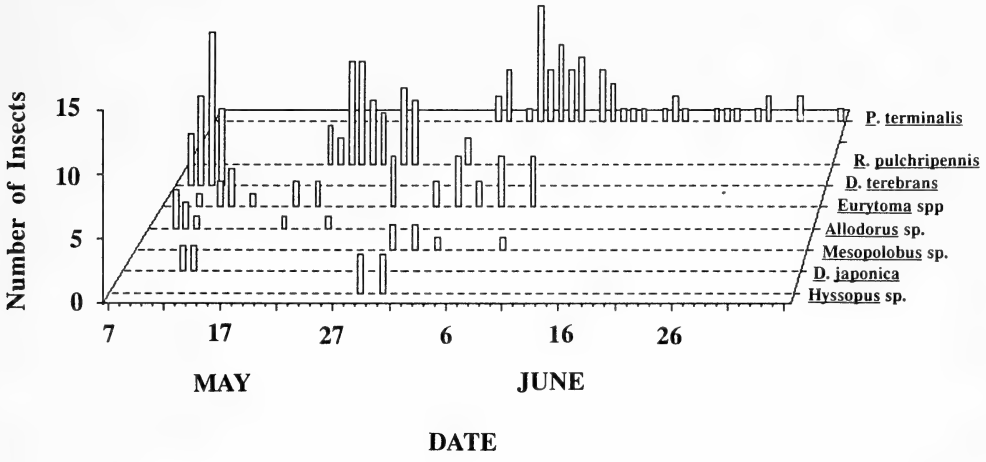
METHODS AND MATERIALS

In 1987, 737 dead leaders killed by terminal weevils were collected between May 7–11 in young spaced lodgepole pine stands in the southern Interior of British Columbia. Most of the leaders (641) were collected at Ellis Creek, 20 km east of Penticton and the rest (96) on the Big White Road, 30 km southeast of Kelowna. The terminals were incubated individually in cardboard mailing tubes. A small vial for trapping emerging weevils was inserted into the lower half of one of the end caps. The tubes were maintained at $20 \pm 2°C$. Emerging specimens were collected daily and either preserved in 70% alcohol or pinned. Specimens were submitted to the Biosystematic Research Institute in Ottawa for identification.

RESULTS AND DISCUSSION

Individual rearing, which started between May 7–11, 1987 revealed that in addition to *P. terminalis*, *M. gentilis* and *Cylindrocopturus* sp. were also present in the Penticton and Kelowna areas. Earlier rearings by Kovacs (1988) showed that *M. gentilis* can also be found in young lodgepole pine stands in the Cariboo Forest Region.

Weevils of all three species emerged from 82 lodgepole pine leaders (11.1%), whereas parasitoids emerged from 127 terminals (17.4%). The low emergence rate was probably the result of desiccation of the terminals in the mailing tubes which resulted in the death of larvae and pupae.



The first weevil species to emerge from dead leaders under laboratory conditions was *M. gentilis* which started emerging on May 12, 1987 and finished seven days later (Fig. 1). On June 3, 1987 (30 days in rearing) *P. terminalis* started to emerge and it reached its peak on June 7, 1987 (Fig. 2). Emergence continued until July 7, 1987. *Cylindrocopturus* sp. emerged between June 10, 1987 and July 16, 1987 (Fig. 1). The constant temperatures in the rearing regime meant that this material accumulated a thermal heat sum at a greater rate than was occurring under diurnal forest conditions. Reared material was approximately 12 days ahead by the end of June, calculated above a threshold temperature of 5°C. Enhanced heat sum accumulation needs to be considered when referencing the temporal sequences in Figs. 1, 2.

Many parasitoids were also reared from the terminals. They belonged to six families in the order Hymenoptera (Table 1). As leaders were attacked by a terminal weevil complex correct association between individual host species and parasitoids cannot be assured. In the course of this study neither predators nor entomophagous fungi were found in association with any of the weevils.

All samples were dominated by *Rhopalicus pulchripennis* Crawford (Hym.: Pteromalidae) and two species of *Eurytoma* (Hym.: Eurytomidae) collectively ranked second in abundance. *Dolichomitus terebrans nubilipennis* (Viereck) (Hym.: Ichneumonidae) was particularly abundant on one of the sites east of Penticton. These parasitoids have also been reported to attack *P. strobi* (VanderSar 1978; Alfaro *et al.* 1985). One *Mesopolobus* species has also been reported as a parasitoid of *P. terminalis* (Stevens and Knopf 1974).

Figure 2 shows emergence patterns of the parasitoids from infested lodgepole pine leaders in relation to that of *P. terminalis*. The parasitoid complex had a bimodal emergence pattern. Most of the parasitoids emerged earlier than *P. terminalis*. *D. terebrans* emerged between May 8–11 and the peak occurred on May 10, 1987. Stevenson (1967) reported that *D. terebrans* emerged in the field from late May to the third week of June with a peak about mid-June. The pteromalid *R. pulchripennis* started to emerge on May 20, 1987 and emergence was completed on June 2, 1987. Emergence of the two eurytomids lasted for a month and was fairly constant.

It was observed that one of the sites on a south facing slope had high numbers and a wide variety of parasitoids. This site supported an abundance of fireweed, *Epilobium angustifolium* L. and one species of lupin, *Lupinus*. Several adult parasitoids were observed feeding on nectar of these plants.

Table 1
Hymenopterous parasitoids found associated with terminal weevils in British Columbia, 1986-1987.

Family	Genus/Species	Location	Relationship to weevils	Time of emergence
Braconidae	*Allodorus* sp.	Kelowna Penticton Prince George Williams Lake	Endoparasitoid	Spring
	Coeloides rufavariegatus (Prov)	Kelowna	Ectoparasitoid	Spring
Eulophidae	*Hyssopus* sp.	Kelowna Penticton	Endoparasitoid	Summer
Eurytomidae	*Eurytoma* spp.	Kamloops Kelowna Merritt Penticton Prince George Williams Lake	Ectoparasitoid	Summer
Ichneumonidae	*Dolichomitus terebrans nubilipennis*	Penticton Williams Lake	Ectoparasitoid	Spring
	(Ratzeburg) *Delomerista japonica* Cushman	Penticton	Ectoparasitoid	Spring
Pteromalidae	*Rhopalichus pulchripennis* Cwfd.	Kamloops Kelowna Merritt Penticton Prince George Williams Lake	Ectoparasitoid	Summer
	Mesopolobus sp.	Kamloops Merritt Penticton	unknown	Summer
Scelionidae	*Telenomus* sp.	Kamloops Williams Lake	Endoparasitoid	Summer

MANAGEMENT IMPLICATIONS

Leader clipping trials near Prince George in the early 1980s (MoF 1984) failed to have any effect on the weevil population as clipping was done in July, a time when most weevils had probably already emerged. Therefore, knowledge of emergence patterns of the weevils is important in planning leader clipping projects. Early emergence of *Magdalis gentilis* suggests that clipping should be carried out by early spring.

Field observations indicated that the best time for clipping is February because almost all attacked leaders have already changed color to a dull brown by this time which facilitates recognition of infested terminals. Experience has also shown that the top of the snow is hard in February which facilitates easy walking in the stands. In addition, the depth of the snow helps the worker to reach the infested leaders and minimizes bending of the cold-brittle trees. The only disadvantage of February leader clipping is that many parasitoids would be removed in the leaders. Parasite enhancement techniques such as containing the clipped leaders in a mesh covered drum, as has been proposed for *P. strobi* (Hulme *et al.* 1987) might be successfully implemented for *P. terminalis.*

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Compatibility of the winter moth parasitoid *Cyzenis albicans* (Tachinidae) with pesticide use in the cultivation of blueberries in the Fraser Valley

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ABSTRACT

The potential for the use of the tachinid fly, *Cyzenis albicans* Fall., as an alternative control of winter moth, *Operophtera brumata* L. on blueberries was evaluated with respect to the flies' compatibility with late season clean-up insecticide sprays. Pupae of *Cyzenis* suffered no greater mortality when exposed to malathion sprays than did those not exposed to such sprays. Mechanisms of protection for the tachinid from insecticides and its potential for biological control in blueberries are discussed.

INTRODUCTION

One of the major problems associated with the introduction or conservation of natural enemies for the control of pests in agricultural crops, is the incompatibility of the control agents with the use of pesticides. Well established crops typically have a standard regimen of insecticide application; the success of biological control agents must then be evaluated within the context of pesticide use. This problem is exacerbated by the tendency for natural enemies to be affected more severely by insecticides than are their hosts (Bartlett, 1964).

An increasing problem in blueberry (*Vaccinium corymbosum*) cultivation in the Fraser Delta has been the spread of the introduced winter moth, *Operophtera brumata* (Geometridae), from Vancouver Island (Embree and Otvos, 1984). Two features of the biology of this insect makes control difficult: 1. early hatch (late March to early April) results in first- and second-instar larvae feeding inside unopened buds making detection difficult until heavy damage has occurred, and 2. feeding by larvae is greatest during the period of blueberry bloom when pesticides cannot be applied because of bee activity.

Commercial production of blueberries in the Lower Fraser Valley, British Columbia, utilizes a number of insecticidal sprays in spring for the control of lepidopterous larvae, especially geometrids and tortricids, and in summer for pre-harvest control of a wide variety of insects (British Columbia Ministry of Agriculture and Fisheries, 1988). The difficulty of winter moth control using insecticides could be potentially reduced by the use of natural enemies. The tachinid fly, *Cyzenis albicans* (Tachinidae), has contributed to control of winter moth in oakwoods (Embree, 1971, Roland, 1988, 1990). *Cyzenis* may be a useful addition to the current practice of blueberry cultivation reducing the need for spring application of insecticides, provided that the flies are not affected by the late-season (pre-harvest) insecticide sprays. This paper addresses the compatibility of *Cyzenis albicans* with late-season insecticide applications.

Insect phenology

Winter moth larvae feed on the foliage of many deciduous trees and shrubs until late May. *Cyzenis albicans* emerge from the soil in April, and oviposit on foliage on which host larvae are feeding. Parasitoid eggs are ingested by the feeding host caterpillars. Fully-fed, final instar caterpillars drop to the ground to pupate in late May and early June. Both the parasitized and unparasitized caterpillars pupate in the soil at a depth of 2–3 cm (Roland, 1986a). Within three to four weeks, in late June, *Cyzenis* maggots have completed feeding, and pupate inside the host's pupal case and cocoon. *Cyzenis* remain in the soil as pharate adults within their puparia until the following spring. Unparasitized winter moth pupae remain in the soil only until November or December when they emerge as adults. Both *Cyzenis* and its host would be present in the soil at the time of the pre-harvest clean-up spray.

MATERIALS AND METHODS

Cyzenis albicans were obtained in May 1988, by collecting parasitized hosts in an unsprayed apple orchard in Victoria, B.C. (sites described in Roland, 1986b). Twenty cocoons were placed in each of sixteen 15-cm diameter Petri dishes filled with damp peat soil collected from a commercial blueberry field (Richland Farms, Richmond, B.C.). Eight of the 16 dishes were exposed to Malathion spray in the field on June 26, by placing dishes under blueberry bushes, the normal location for winter moth pupation. Malathion 50 EC (500 g malathion/litre) was applied at the rate of 550 g a.i./ ha; the recommended rate for pre-harvest insect control on blueberries (British Columbia Ministry of Agriculture and Fisheries, 1988). The eight control dishes were similarly set out in the field, but were not exposed to insecticide spray. Dishes were collected after 1 h, and kept in separate cages inside a screened shade house. The proportion of *Cyzenis* flies emerging

the following spring was recorded for each replicate. The proportions surviving in the treatments and controls were compared with a one-way Analysis of Variance after transformation by arc-sine square-root.

RESULTS AND DISCUSSION

There was no effect from late-season malathion sprays on the survival of *Cyzenis* ($F = 1.08$, $df = 1$, $P = 0.32$). Over-all, 96% of *Cyzenis* survived in the control replicates, 97% survived in replicates which had been sprayed with malathion. Preharvest sprays with malathion appeared to have no effect on the survival of *Cyzenis*. Insecticides containing organochlorine, organophosphate and carbamate are known to be inactivated in soils high in organic matter probably because of adsorption. The mechanism of inactivation, however, is not clear. Harris (1964), demonstrated that in moist soils inactivation of insecticides such as heptachlor, DDT, diazinon, V-C 13 and parathion was proportional to the organic content of the soil. The absence of any impact of malathion on *Cyzenis* mortality may be due to the strong adsorption to, and inactivation in, the moist organic peat in which blueberries are typically grown. Another contributing factor may be the rapid degradation of malathion in soil. Malathion is known to be non-persistent in soils (Mulla et al., 1981). Under field conditions, 85% of malathion residues were lost from a silt loam during the first three days following application (Lichtenstein and Schulz, 1964). Malathion persisted least in moist soils (Lechtenstein and Schulz, 1964). Rapid disappearance ensures that malathion would have no residual effect on *Cyzenis* mortality. If *Cyzenis albicans* were to be used as an adjunct to current control of winter moth larvae in early spring, it appears that they will not suffer from clean-up sprays applied late in the summer. Biological control agents which pupate in damp organic soils, typical of blueberry production, may have enhanced suitability because they are not susceptibile to insecticides.

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Efficacy of the nematode, *Heterorhabditis heliothidis* (Rhabditida: Heterorhabditidae) against the peachtree borer, *Synanthedon exitiosa* (Lepidoptera: Sesiidae) in peach trees

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ABSTRACT

A suspension of *Heterorhabditis heliothidis* Khan, Brooks and Kirschmann, sprayed in mid-June onto the trunks of peach trees infested with peachtree borer (PTB) *Synanthedon exitiosa* (Say) larvae significantly ($P < .05$) reduced the numbers of PTB adults that eclosed from the feeding tunnels. Injections of nematode suspensions into and on the outside of active PTB tunnels did not reduce the number of emerging PTB adults to a level significantly ($P < .05$) lower than those emerging in the control cages. The study also confirms that the larvae of the peachtree borer require up to 2 years to complete development in stone fruit trees in the southern interior of British Columbia.

INTRODUCTION

The peachtree borer (PTB), *Synanthedon exitiosa* (Say) attacks most stone fruit trees and is a particularly serious problem on peaches, nectarines, apricots, prunes and plums in the southern interior of British Columbia. King and Morris (1956), as well as Madsen and Procter (1982), reported this species to have one generation per year in western North America in which adults are active through the summer. Female moths oviposit several hundred eggs on the trunks of stone fruit trees near the soil line (Anthon, 1949) and on the trunk bark up to a height of 60 cm above the soil line as well as on adjacent grass and weed foliage in stone fruit blocks with dense, deep cover crops (F.L. Banham, pers. commun.). The PTB larvae bore into the tree bark and feed by tunnelling in the cambium layer at or below the soil line. The tender bark and sapwood of nursery seedlings and young transplants makes them particularly vulnerable to larval attack. Young trees are frequently killed by the girdling injury. Severe feeding damage, even in older trees causes loss of vigor and increased vulnerability to secondary pests (Madsen and Procter, 1982). Chemical control of PTB is required to protect the trunks of stone fruit trees from larval feeding injury throughout the growing season. Once larvae have bored into the tree trunks they are protected from contact with conventional commercial control chemicals by the brown sawdust frass and sap gummosis exudate that plugs the feeding tunnels. Entomogenous nematodes have been shown to control boring insects in the family Sesiidae under field conditions (Simons 1978; Bedding and Miller 1981). The efficacy of the nematode, *Heterorhabditis heliothidis* Khan, Brooks and Hirschmann, was investigated as a possible biological alternative to chemical control of PTB larvae within their protected tunnels.

MATERIALS AND METHODS

A 0.12 ha block of Early Redhaven and Redhaven peach trees, located in an orchard in Osoyoos, British Columbia, was chosen for investigation. Grass, weeds and soil, to a depth of 5 cm, were pulled away from the bases of 40 PTB-infested trees 15 June, 1987. Frass at the entrance to PTB tunnels was scraped away and the number of active tunnels per tree assessed. The trees were irrigated at the trunk base by sprinklers on the day and evening prior to treatment.

Heterorhabditis heliothidis nematodes, provided by Phero Tech Inc. (Vancouver, B.C.), were applied to trees in the following treatments: a 200 ml spray of 200 nematodes per ml water around the base of the tree using a calibrated backpack sprayer; 2 ml

TABLE 1
Percentages of peach tree borer adults emerging from active feeding tunnels up to 90 days post-nematode treatment. 1987.

Treatment	% adults eclosing[1](n)
Control	20.14 a (52)
Syringed inside tunnel	7.19 ab (55)
Syringed outside tunnel	7.14 ab (51)
Sprayed at base of tree	3.97 b (43)

1. Percentages transformed before analysis using an arcsin transformation. Means followed by by the same letter are not significantly different ($P > .05$) as determined by Duncan's multiple range test.

injections of 500 nematodes per ml with a syringe into each active peachtree borer tunnel; and, applications of 2 ml of 500 nematodes per ml to the outside of each active tunnel. Each treatment was applied to 10 trees in a completely randomized design which included 10 control trees. On the day of treatment the humidity was 58% and the temperature 28°C.

Saran screen (32 mesh) trunk cages were fitted around the base of each of the 40 trees immediately after the numbers of active tunnels were determined and the treatments applied. Each cage formed a cone approximately 70 cm in diameter and 60 cm high with an 8 cm wide sponge rubber collar wrapped and tied tightly around the tree trunk. The edges of the screen were folded twice and stapled from the collar to below the soil. The bottom of each cage was buried in soil to a depth of at least 5 cm. Ten, fourth- and fifth-instar PTB larvae were removed from untreated peach trees and were exposed to *H. heterorhabditis* in the laboratory to establish survival.

From early July, after the first PTB adults were caught in Zoecon R PTB pheromone-baited traps within the test orchard, until the end of September, the trunk cages were lifted 4 times at 3-week intervals and the numbers of emerged PTB adults counted. Ten of the trunk cages were left on control trees and inspected at 6-week intervals the following year in late July and August. No evidence of rodents was found under the tents.

RESULTS AND DISCUSSION

Lower percentages of PTB emerged from *H. heliothidis* treated than from untreated trees (Table 1). The nematode spray around the base of the peach tree significantly ($P < .05$) reduced the percentage of emerging adults when compared to the emergence level from the control trees. Percentage PTB adult emergence was calculated based on the number of infested tunnels observed before treatment. Percentages were transformed using an arcsin transformation before analysis.

The soil-inhabiting entomogenous nematode *H. heliothidis* is capable of parasitizing a wide range of insects (Khan et al. 1976) including PTB larvae under laboratory conditions (pers. communication, T.A. Rutherford, Research Associate, Simon Fraser University, Burnaby, B.C.). All PTB larvae exposed to the nematode in the laboratory the day of the field release died in 7 to 14 days and nematodes were found within those sampled. In the second larval stage *H. heliothidis* penetrates host larvae through the mouth, spiracles and anus (Wouts 1979). Once inside a host the nematode releases a symbiont bacterium, *Xenorhabdus luminescens* Thomas and Poinar (Thomas and Poinar, 1979). Within 24 hours the bacterium multiplies and causes damage to all major internal host organs (Wouts, 1984). This restricts host feeding and movement and ultimately kills the insect while the nematode multiplies within. Nematodes are susceptible to ultra violet radiation and low humidity (Finney, 1981). Promising results in nematode field tests have followed nematode releases in damp environments and complete host control has been obtained with nematode application within the dark and

moist environment of wood-borers in the family Sesiidae (Bedding and Miller 1981; Simons 1978; Wouts 1984). The plugged, moist PTB tunnels located beneath the bark would theoretically provide a parasitic nematode with an ideal humid environment in which to move and multiply. Infective juvenile *H. heliothidis* are believed to find hosts by following host chemical attractants (Bedding and Akhurst 1975).

Suppression of PTB by *H. heliothidis* within infested peach trees shows promise as a potential control treatment that could decrease the need for routine protective chemical sprays. The importance of time, number and rate of application(s) of the nematode should be examined in future studies. Nematode treatment may be practical in an orchard setting as the trunk spray was equally successful as the more laborious and hence more expensive injections. Also, the tree trunk and surrounding soil can be easily moistened in most commercial orchards with irrigation systems. Peachtree borer survival and emergence within the control trees was only 20.1% by the end of the first summer test period (1987). When cages were removed from the 10 control trees the following summer (1988) they were found to contain 4 PTB moths and 15 uneclosed pupae. Three of the adult PTB found in the second year were alive indicating that they had emerged during the summer of 1988. Eclosed male and female PTB moths were not found co-existing in any of the control tents during the 1987 summer trials, eliminating the possibility of the second year PTB being a result of oviposition within the tents. The emergence of these adults substantiates previous observations that some PTB larvae require two growing seasons to complete development within stone fruit trees in British Columbia.

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A preliminary survey of Collembola in forest nurseries of British Columbia

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ABSTRACT

A survey of 24 forest nurseries in British Columbia yielded 22 collembolan taxa, 10 of which are reported for the first time in this province. The species most frequently encountered was *Sminthurinus quadrimaculatus,* which was represented in 13 of the nurseries. Only one of the species collected, *Bourletiella hortensis* is a known pest of conifer seedlings, but it is not an obligate phytophage. The presence of sarophagous Collembola and predatory actinedid mites in the samples suggests that pest collembolan species are being controlled naturally by competition for food and by mite predators.
KEY WORDS: Forest nursery, Pest management, Acari, Collembola, *Bourletiella hortensis, Isotomurus palustris.*

RÉSUMÉ

Au cours de l'inspection de 24 pépinières forestiéres en Colombie-Britannique, on a relevé la présence de 22 taxons de collemboles, dont 10 étaient signalés pour la première fois dans cette province. L'espèce la plus fréquemment observée a été *Sminthurinus quadrimaculatus,* qui était présente dans 13 pépinières. Une seule des espèces recueillies, *Bourletiella hortensis,* est un ravageur connu des semis de conifères, mais elle n'est pas un phytophage obligatoire. La présence de collemboles saprophages et d'acariens actinédides prédateurs dans les échantillons donne à penser que deux facteurs naturels interviennet dans la limitation des populations de collemboles ravageurs: la compétition pour la nourriture et les acariens prédateurs.

INTRODUCTION

This report deals with Collembola collected from three bareroot and 21 container nurseries in British Columbia. Bareroot nurseries are traditional nurseries where seeds are planted outdoors in the soil. In container nurseries, seedlings are grown in individual containers in greenhouses, shelterhouses, or outdoor compounds where growing media and environmental conditions are more rigorously controlled. Collembola occur in all nurseries in British Columbia, but so far few have been identified to species (Sutherland *et al.* 1989).

Collembola, or "springtails," are minute arthropods, usually less than 1 cm long. The largest species known, *Tetrodontophora bielanensis* (Waga), measures up to 8 mm (Wallwork 1970). The Collembola have traditionally been classified in the Apterygota or primitive, wingless insects. However, the relationship of Collembola to the Insecta is uncertain and Scudder *et al.* (1979) considered them a separate Class in the Superphylum Arthropoda. Collembola are known from Devonian fossils and have a number of unique characteristics (Richards 1979). These include six abdominal segments that bear three peculiar appendicular derivatives: a collophore, tenaculum and furcula (springing organ). The furcula might be reduced or absent in some taxa. Collembola may also have a postantennal organ. Pronounced sexual dimorphism is rare. All species moult throughout their life.

The classification of the Collembola is controversial, but two orders (Arthropleona and Symphypleona) are generally recognized (Kevan 1980). Ordinal division is based primarily on shape of the abdomen. The Symphypleona are characterized by a globular abdomen that lacks distinct segments; Arthropleona have an elongate abdomen that is usually divided into six distinct segments. About 4450 species and subspecies have been described world-wide (Salmon 1964) and at least 520 are estimated to occur in Canada (Richards 1979). These estimates are very conservative because hundreds more species have been described since Salmon's 1964 compendium and in Canada the Collembola have not been extensively studied (Danks 1988).

Members of both orders feed on a wide range of organic materials and springtails occur wherever plants grow, including Antarctic and Arctic Islands. Collembola may be present in large numbers in forest soils and during mass emergence or swarming, estimates of over 1 million per m^2 have been reported (Christiansen 1964).

METHODS

In 1987-88, Collembola were hand-collected from styroblocks of container nurseries. Fine camel's-hair brushes were used to sweep specimens directly into vials (2.5 cm diameter) to which 75% ethanol was then added. Specimens were generally numerous on the sides and upper surfaces of styroblocks and this method proved more successful than aspiration. Collections in bare root nurseries were made form the soil surface in 1971-72 by the grease-film method (Marshall and Ilnytzky 1976). Collembola in bareroot nurseries, such as Koksilah and Green Timbers, are a source of inoculum for container nurseries that are built on the same site or when the former are converted to container nurseries.

Collembola were cleared by the Hille Ris Lambers method (Spencer 1959) and mounted in a modified Swann medium (Rusek 1974). A minimum of six individuals from each representative group were prepared for mounting; where less than six individuals were available, all specimens were mounted.

Species identifications were made from Christiansen and Bellinger (1980), but the family and generic classification mainly follow Salmon (1964) in order to better relate the results to the world fauna. In many cases, subgeneric designations in Christiansen and Bellinger (1980) corresponded to genera in Salmon; where there was disagreement an annotation is given for the name used herein.

RESULTS AND DISCUSSION

Twenty-two Collembolan taxa were identified from the 24 nurseries (Table 1). Seventeen of these were identified to species; the other five could be identified only to genus because of poor specimen condition or inability to fit the description of North American species.

Ten of the identified species (** in Table 1) were recorded in British Columbia for the first time. The list contains many common species, but did not include members of the Onychiuridae nor five species reported by Beirne (1972) to cause damage in agricultural crops. *Sminthurinus quadrimaculatus* was the most frequently encountered species, occurring in 13 of the nurseries surveyed. The next most frequently encountered species, *Willowsia buski,* is a household pest (Scott 1954). These species, however, are not known to attack living plants.

Two recognized plant pests, *Bourletiella hortensis* and *Isotomurus palustris,* were also encountered. *B. hortensis* is regarded as cosmopolitan (Salmon 1964). In Canada, it has been reported from Nova Scotia, Quebec, Ontario, Manitoba and British Columbia (Christiansen and Bellinger 1980). It appears to be an indiscriminate feeder (Marshall 1978) and causes damage to many agricultural crops (Edwards and Heath 1964; Beirne 1972). It also feeds on seedlings of larch, pine, and Engelmann, Sitka and white spruce and western hemlock in bareroot nurseries (Bevan 1965; Marshall and Ilnytzky 1976). No damage has yet been reported in container nurseries (Sutherland *et al.* 1989).

Table 1
Collembola and Acari from British Columbia forest nurseries.

COLLEMBOLA	
BRACHYSTOMELLIDAE	
Brachystomella parvula (Schäffer) **	GC *
Brachystomella stachi Mills **	GC
ENTOMOBRYIDAE	
Entomobrya sp.	CN, CR, NU, TH
Lepidocyrtus sp.	NO
Lepidocyrtus sp.? *bipunctatus* Packard ** (a)	MB
Orchesella zebra Guthrie **	GC
Willowsia buski (Lubbock)	HN, HY, IF, MB, NO, RC, SU, SY, TH
Willowsia sp.	CR, HY
HYPOGASTRURIDAE	
Hypogastrura matura (Folsom) **	RR, TE
Hypogastrura trybomi (Schött) **	HY
ISOTOMIDAE	
Isotoma viridis Bourlet	GC
Parisotoma notabilis (Schäffer) (b)	GC
Isotoma sp.	RC
Isotomurus palustris (Müller)	GB, KN
Proistoma immersa (Folsom) **	GC
NEANURIDAE	
Morulodes serratus (Folsom) (c)	CN
Pseudachorutes sp.	NU
SMINTHURIDAE	
Bourletiella hortensis (Fitch)	EG, GB, HY, KN, NO, RC, SU, WN
Bourletiella sp.	IF, KN, WN
Eusminthurus sminthurinus (Mills) ** (d)	HY
Sminthurinus quadrimaculatus (Ryder) **	CN, CR, CF, EG, HE, HN, HY, IF, NO, RC, SK, SY, WN
Sphaeridia pumilis (Krausbauer) ** (e)	KN
ACARI	
BDELLIDAE	
Bdellodes sp. nr. *bisetosa* Atyeo	AG, HY, RC
ERYTHRAEIDAE	
? *Erythrites* sp.	WN
EUPODIDAE	
Eupodes voxencollinus Thor	EG, MB, NU, SU, VN
PENTHALODIDAE	
Penthalodes turneri Baker	KN

* Abbreviations, location and sampling dates of the 24 nurseries follow, with (BRR) standing for Bareroot and (CON) for Container nursery: 1. AG, Arbutus Grove, Sidney (CON) 88.06.08; 2. CN, Campbell River, Campbell River (CON) 87.11.01 and 88.08.26; 3. CR, Chilliwack River, Chilliwack (CON) 88.06.03; 4. CF, Crown Forest, Armstrong (CON) 88.06.15; 5. EG, Elmore Greenhouses, Nanoose (CON) 88.06.06; 6. GB, Green Timbers, Surrey (BRR) 71.05.19; 7. GC, Green Timbers, Surrey (CON) 87.11.24; 8. HE, Hammer Enterprises, Maple Ridge (CON) 88.04.27; 9. HN, Harrop, Nelson (CON) 88.06.18; 10. HY, Hybrid, Pitt Meadows (CON) 88.04.27 and 88.05.03; 11. IF, Industrial Forest Service, Prince George (CON) 88.06.21; 12. KN, Koksilah Canada, Duncan (BRR) 72.08.21; 13. MB, MacMillan Bloedel, Nanaimo (CON) 88.06.09 and 88.08.25; 14. NO, Northwood, Prince George (CON) 88.06.21; 15. NU, Nuu-chah-nulth, Port Alberni (CON) 88.06.09; 16. RR, Red Rock, Prince George (CON) 87.09.12; 17. RC, Reid Collins, Aldergrove (CON) 88.05.30; 18. SK, Skimikin, Tappen (CON) 88.10.04; 19. SU, Summit, Telkwa (CON) 88.06.23; 20. SY, Sylvan Vale, Black Creek (CON) 88.06.09; 21. TE, Telkwa, Telkwa (BRR) 71.10.12; 22. TH, Thornhill, Terrace (CON) 88.06.23; 23. VN, Vernon, Vernon (CON) 88.06.15; 24. WN, Woodmere, Smithers (CON) 88.06.23.

** Newly recorded in British Columbia.

(a) Listed in subgenus *Seira* by Christiansen and Bellinger (1980).

(b) Listed in the genus *Isotoma* by Christiansen and Bellinger (1980).

(c) Salmon (1964) listed this in the genus *Lathriopyga*, but more recent authors place it in *Morulodes* (Massoud 1967; Christiansen and Bellinger 1980; Fjellberg 1985).

(d), (e) Listed in the genera *Sminthurinus* and *Sminthurides*, respectively, by Christiansen and Bellinger (1980).

Isotomurus palustris is common in Europe and is probably cosmopolitan (Salmon 1964). In Canada, it has been recorded from the Arctic, Ontario and British Columbia (Salmon 1964). This species also appears to be an indiscriminate feeder and has attacked sugar beets, sugar cane and tobacco (Scott 1954; Paclt 1956).

Only a few numbers of species were collected in most nurseries, with the highest number of six species being present at Hybrid nurseries. No Collembola were collected at Arbutus Grove and Vernon nurseries. Failure to obtain specimens at these two nurseries is undoubtedly due to collection methods rather than a complete absence of Collembola. Except for Campbell River, Hybrid and MacMillan Bloedel nurseries, which were sampled twice, all other nurseries were sampled only once (Table 1). This limited sampling and omission of soil in styroblocks and other habitats on nursery floors were inadequate to give a representation of the entire collembolan fauna.

Both container and bareroot nurseries provide conditions that are conducive to the establishment and maintenance of numerous species of Collembola. Such conditions include high relative humidity, temperatures well within ranges tolerated by Collembola, and plentiful food in the form of pollen and decomposing organic matter. Therefore, the 22 species collected probably represents less than half of the total number of species present, considering the known distribution of North American Collembola (Christiansen and Bellinger 1980).

Although pest species are of special concern in nurseries, free-living Collembola could be beneficial in two important ways. Firstly, Collembola may aid in the reduction of inoculum of fungal diseases. Many species of Collembola consume fungi as a major component of their diet (Takeda and Ichimura 1983). *Onychiurus encarpatus* Denis and *Proisotoma minuta* (Tullberg), which occur throughout North America and are voracious feeders on some fungi, are being investigated as potential control agents for *Rhizoctonia solani* Kühn, a pathogen of cotton seedlings (Curl *et al.* 1988; Lartey *et al.* 1989) and other crops. Secondly, predators such as *I. viridis* might be helping to control phytophagous Collembola.

While no special attempt was made to sample mites (Acari), four actinedid species (*Bdellodes* sp. nr. *bisetosa* Atyeo, *?Erythrites* sp., *Eupodes voxencollinus* Thor and *Penthalodes turneri* Baker) were found among the Collembola (Table 1). Only *E. voxencollinus* was represented in many nurseries. *E. voxencollinus* and *P. turneri* are not known to feed on Collembola, although they are in families considered general predators (Krantz 1978). However, species in *Bdellodes* and *Erythrites* are potential natural control agents for Collembola (Hoy *et al.* 1983).

It is only under exceptional conditions of high populations and lack of alternative food supply are Collembolan pest species expected to sufficiently damage germinating seedlings to make chemical or other control necessary (Edwards 1962, Christiansen 1964). Since damage has not yet been reported in container nurseries, collembolan pests are apparently kept from reaching high numbers by competition with free-living collembolan species and by the presence of predators. Mites are considered to be the major predator controlling collembolan populations (Wallwork 1970). The sampling technique used in this study cannot give information on collembolan populations and their fluctuations relative to such predators. Therefore, further studies are required in order to determine the effect of collembolan species on germinating conifer seedlings and to determine when control measures would be warranted in British Columbian nurseries.

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ERRATA

Editor's Note

These extensive errata were caused by the combined failure of the printer to make the corrections noted by the author on the galley proofs and the editor for not picking up the mistake. I apologize to the author for any embarrassment that may have resulted.

Santiago-Blay, J.A. 1989. Chalcidoids (Hymenoptera) reared from *Artemisia tridentata* (Asteraceae) galls from British Columbia, Canada. J. Entomol. Soc. Brit. Columbia 86:80–81.

Page 80

Line 2:	"GALLS IN" should read "GALLS FROM"
Line 10:	"exit holes and wasp's" should read "exit holes, and wasps' "
Line 11:	"22 June" should be "11 July"
Line 14:	"temperature were" should read "temperature, were"

Page 81

Lines 1, 2:	"widths to it (= width)" should read "widths"
Line 3:	"9–18 . . . 7–12" should read "9–18 mm . . . 7–12 mm"
Line 4:	"collection; which" should read " collection which"
Line 6:	"tephridids were" should read "tephritids, were"
Line 13:	"Lifespan males . . . females three" should read "Lifespan: males . . . females, three"
Line 15:	"flies, *Euaresta*" should read "flies *Euaresta*"
Line 18:	"data as . . . apex, diameter" should read "data are as . . . apex; diameter"
Line 23:	"Lifespan, male" should read "Lifespan: male"
Line 24:	"females four . . . .LP *Eupelmus* (Eupelmidae)" should read "females, four to seven." **"Eupelmus (Eupelmidae)".**
Line 25:	Sample size should be indented as a normal paragraph.
Line 28:	"large, (" should read "large ("
Lines 40, 41:	"(Department of . . ." should read "(Central Florida Research and Education Center, Apopka, FL)"
Lines 42, 43:	The sentence beginning with "Julie Wolf (. . .) work." should be deleted because, upon recommendation of the editor, the plate was eliminated.
Line 51:	"Vol. 1 Symphyta" should read "Vol. 1. Symphyta"

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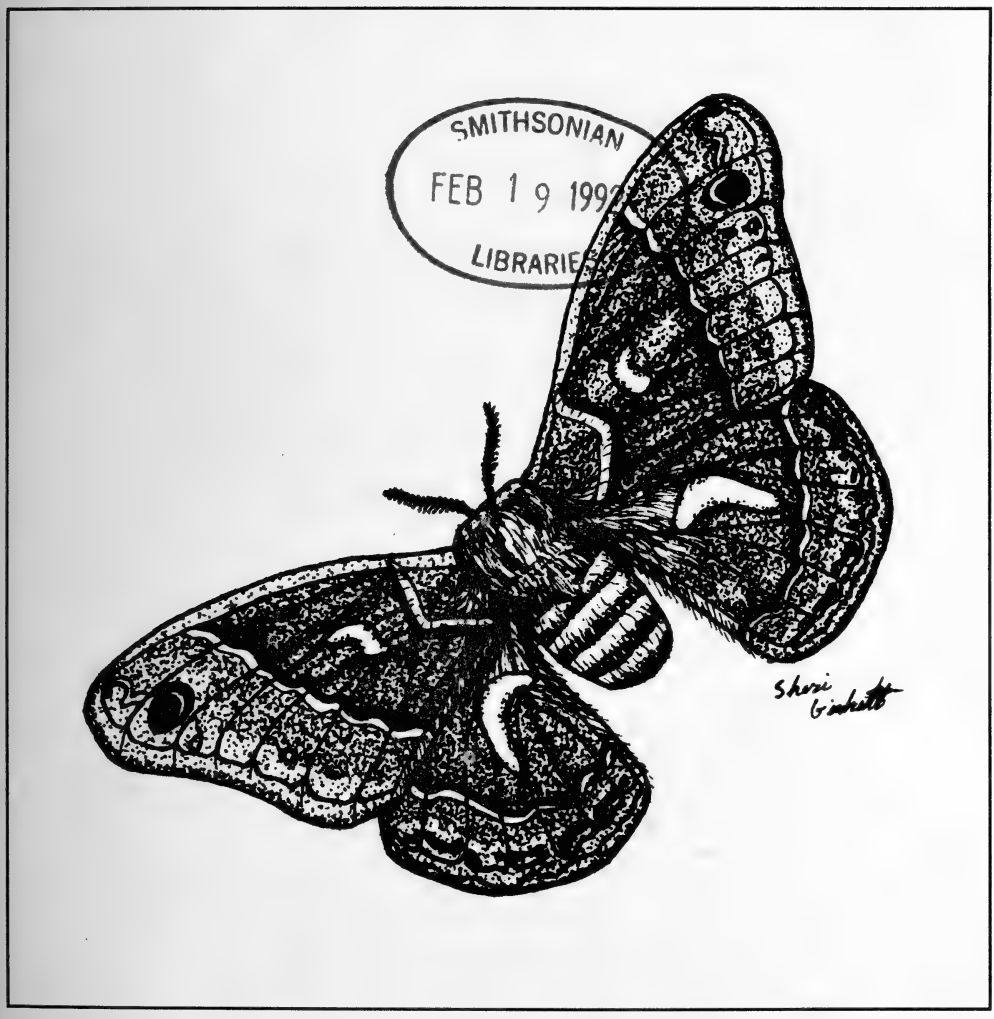

ESBC Entomological Society of British Columbia

COVER: An adult female *Hyalophora euryalus kasloensis* (Cockerell) (Lepidoptera: Saturniidae) drawn with pen and ink by Sheri Giesbrecht from specimens reared by Dean Morewood. The ceanothus silkmoth, *Hyalophora euryalus* (Boisduval), is native to the Pacific coast and western mountains of North America from Baja California to British Columbia. Despite any nominal preference for ceanothus, larvae of this species have been reported to feed on a wide variety of broad-leaved trees and shrubs and at least one conifer. In mid to late summer the larvae spin sturdy tear-drop shaped cocoons, usually attached at the side to twigs of their host plant, within which they spin a second cocoon. After overwintering as diapausing pupae, the large reddish brown moths emerge from their cocoons mainly in May and June, and dedicate their one week adult lifespan to reproduction. The form known as *H. e. kasloensis* is found in the interior of B.C. and northern Washington and Idaho and shows a distinct larval phenotype, but its taxonomic status has yet to be firmly established (see p. 31).

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Factors affecting the incidence of white pine weevil damage to white spruce in the Prince George Region of British Columbia

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ABSTRACT

A survey was conducted to study the incidence of attack by the white pine weevil, *Pissodes strobi* (Peck) on white spruce, *Picea glauca* (Moench) Voss., in the Prince George Region of British Columbia, in relation to biogeoclimatic subzone, site quality class and plantation age. The average percentage attack on the spruce component was 3.2% (range 0 to 26.6%). A general trend of increasing attack with increasing biogeoclimatic subzone moisture was found. No correlation was found between percentage attack and site quality or age. The implications of this survey for the Prince George Region are discussed.

INTRODUCTION

In British Columbia, the white pine weevil, *Pissodes strobi* (Peck) (Coleoptera; Curculionidae), causes serious damage to Sitka spruce, *Picea sitchensis* (Bong) Carr., white spruce, *Picea glauca* (Moench) Voss., and Engelmann spruce, *Picea engelmannii* Parry ex Engelm. (Alfaro 1982, Cozens 1983, McMullen 1976, McMullen and Condrashoff 1973, Stevenson 1967). Adult weevils overwinter in the duff and emerge in the spring to oviposit in year-old spruce leaders (Wood and McMullen 1971). Within about 10 days, the eggs hatch and the larvae begin to mine downward feeding on the phloem. The year-old leader is eventually killed through girdling which results in height growth loss. Greater losses occur if larvae mine past the year-old leader into the previous year's growth or if re-attack occurs below an attacked leader (Cozens 1987). Most adults emerge in late summer and fall, and, after feeding for a while, go to their overwintering sites. Depending on local climate, a portion of the larval population remains to overwinter within the leaders. Attacked trees usually develop stem defects (Alfaro 1989a) which affect the value of the logs obtained from the trees. Repeated attacks produce stunted and deformed trees.

McMullen (1976) studied the ecological factors which affect the distribution of *P. strobi* on Vancouver Island. Based on the minimum requirement for accumulated heat needed for brood development, McMullen concluded that low weevil hazard zones would occur on Northern Vancouver Island and along its extreme Western coastline. These findings were confirmed by Heppner and Wood (1984) who examined Sitka spruce plantations within the coastal Vancouver Forest Region of B.C., and concluded that these low hazard zones coincide closely with the Southern Hypermaritime Coastal Western Hemlock Biogeoclimatic Subzone Variant CWHvh. Past incidence surveys in the interior of B.C. (Lewis 1988) have yielded some results, but have never been stratified by biogeoclimatic units. This is important because ecological factors may influence the susceptibility of stands to weevil attack. In this study we report the results of a survey conducted in the Prince George Forest Region of B.C. to determine the incidence of *P. strobi* damage in white spruce in relation to biogeoclimatic zone, site quality and plantation age.

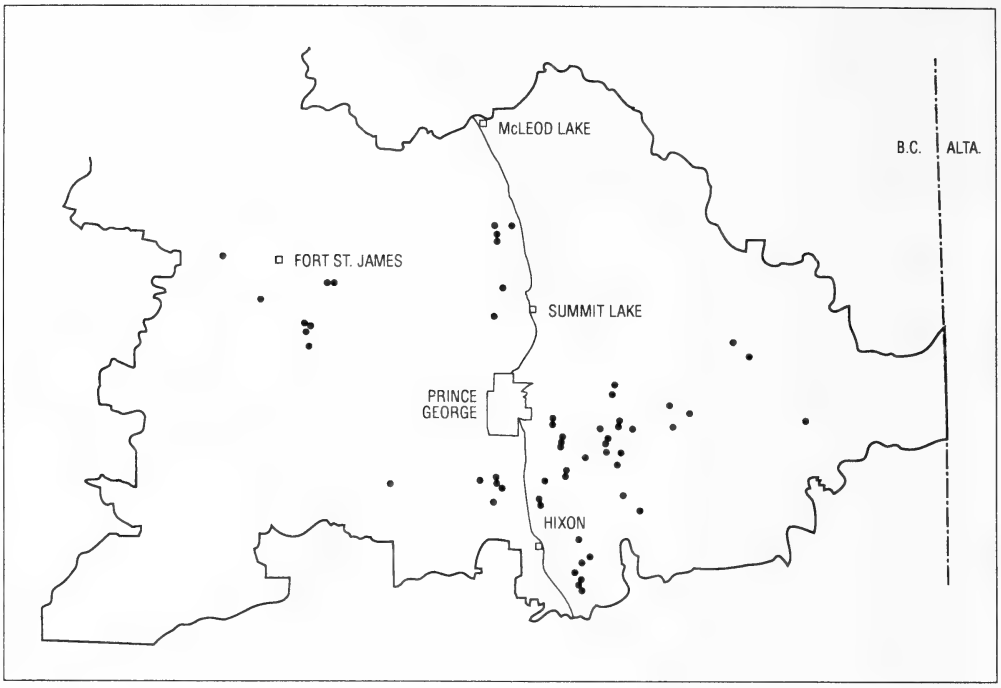

Figure 1. Location of the spruce plantations surveyed for *Pissodes strobi* incidence in the Prince George, Vanderhoof and Fort St. James Forest Districts, of the Prince George Timber Supply Area, in the Prince George Forest Region of British Columbia.

METHODS

Plantation selection

The survey was conducted in the Prince George Timber Supply Area (T.S.A.) of the Prince George Forest Region, which includes the Prince George, Vanderhoof and Fort St. James Forest Districts. A computer printout list of all second growth spruce plantations established in the T.S.A. since the 1960's was obtained from the B.C. Ministry of Forests Silviculture Branch. The plantation list included, among other attributes, the establishment date, site quality classification, and the biogeoclimatic zone and subzone of each plantation. Only plantations in which spruce was the dominant species and only those in the Sub-Boreal Spruce (SBS) biogeoclimatic zone (predominant in the Prince George T.S.A) were considered for examination of white pine weevil damage. The plantations were stratified based on biogeoclimatic subzone into groups which differed in soil moisture availability (Meidinger in press) as follows: DRY which included subzones dk, dw_2 and dw_3; MOIST, including subzones mw, mc_2, and mk1; and WET including subzones vk and wk1. The plantations were further stratified by site quality classification into good and medium sites, and by plantation age into three classes: 11-15, 16-20 and 21-25 years old.

Plantations which did not fall into one of these classes, were not considered in the study. No plantations were located in the SBS dry/good site 21-25 age class. Therefore, only 17 different categories were surveyed. The total number of plantations which fell into each category ranged from 1 to 200. In the categories which contained more than five plantations, five were randomly selected to be surveyed. If the category had five plantations or less, all plantations in that class were chosen. In all, 58 plantations were surveyed (Fig. 1).

Each plantation was identified on a 1:15,840 scale forest cover map provided by the forest district and on aerial photos. To estimate the percentage of *P. strobi* attack in a plantation, we used the systematic strip sampling method recommended by Fletcher (1986), who concluded that reasonably accurate estimates of weevil incidence could be obtained from sampling as few as five strips per plantation. In each plantation, a point of origin was established at random along the perimeter of the plantation. Then, starting at this point, five strips of equal length were established. The strips usually ran the approximate width of the plantation and were evenly spaced so that maximum coverage of the plantation was achieved. The length of each strip was determined using a topofil measuring meter. All planted spruce trees within 5.0 m of either side of the strip were examined for 1988 white pine weevil attack. Also recorded was the number of trees from species other than spruce which occurred as ingrowth on the plantation. For each plantation the percentage of spruce trees attacked was calculated with respect to the total number of trees and with respect to the spruce component.

The data were subjected to analysis of variance/covariance to test for significant differences in the percentage of white spruce trees attacked based on biogeoclimatic subzone, site quality and age. Stand density was used as a covariate. Attack percentages were transformed by the arcsin transformation before the analysis. The ANOVA procedures for unequal numbers of samples were used. Means were separated using the Student Newman-Keuls test.

RESULTS

The mean percent attack in the spruce component over all plantations was 3.2% (range 0 to 26.6%). The percentage spruce attacked with respect to all the trees in a stand averaged 2.5% (range of 0 to 23.7%) over all plantations.

The percentages of the spruce component attacked were sorted into 5% attack classes (Table 1). Nine of the 58 plots surveyed, or 15.5%, were free from weevil attack. Most plots (65.5%) had attack percentages of 0.1 to 5% (38% had 0.1 to 1% attack). Approximately 10 and 5% of the plots had attack intensities in the 5.1 to 10 and 10.1 to 15% classes, respectively. Only 2 plots (3.4%) had attack intensities higher than 15%.

A general trend to increasing attack with increasing site moisture (biogeoclimatic subzone class) was detected for both the percentage attack on the spruce component and the percentage attack on the total stand (Table 2). This relationship, however, was statistically significant only when percentage attack was calculated as a proportion of all trees in the plantation (ANOVA, $F = 4.5$, $P < 0.05$). The percentage of the spruce attacked was nearly three times higher on the Wet than on the Dry sites; similarly, the percentage of all plantation trees attacked was nearly 10 times higher on Wet than on Dry sites (Table 2). None of the other variables tested (site quality, plantation age or plantation density) had a significant relationship with the percentage of spruce trees attacked. This was true for the percentage calculated in relation to the spruce component or for the total number of trees in the stand.

DISCUSSION

Most reports of *P. strobi* damage come from the Sitka spruce literature where incidences of more than 50% trees attacked/year have been reported (Alfaro and Omule 1990). The incidence of *P. strobi* in the Prince George T.S.A. was generally low. However, the fact that individual plantations in this study had attack intensities as high as 26.6% indicates that white spruce is also highly susceptible to attack. The generally low incidence is probably due to the fact that most plantations in the Prince George area are young and are just entering their most susceptible stage. However, the lack of correlation of attack intensity with age may appear to contradict this statement. If plantations are more susceptible as they get older, a positive correlation of the attack with age was expected. The low correlation with age could be due to the fact that the older plantations are rare in this Region and

Table 1
Plantations surveyed in the Prince George Timber Supply Area tabulated by percentage attack by *P. strobi*.

Percentage* attack class	No. of plantations	Percentage of plantations
0	9	15.5
0.1- 5	38	65.5
5.1-10	6	10.3
10.1-15	3	5.3
15.1-20	0	0.0
20.1-25	1	1.7
25.1-30	1	1.7

* Percentage attack on the spruce component of the plantations.

Table 2
Mean percentage attack by *P. strobi* in 58 spruce plantations surveyed in the Prince George Forest Region, tabulated by moisture code, site and age class.

		Spruce trees attacked		Extent of total plantation attacked	
Code/Class	No. of plantations	%	Standard Deviation	%	Standard Deviation
Moisture					
Dry	13	1.7a	3.9	0.4ab	0.6
Moist	19	2.5a	4.1	2.0bc	3.7
Wet	26	4.6a	6.8	3.8c	5.9
Site					
Medium	31	3.4a	6.4	2.6a	5.6
Good	27	3.1a	3.9	2.3a	3.3
Age					
11-15 yrs	25	3.0a	5.7	2.3a	5.3
16-20 yrs	19	4.4a	6.3	3.3a	5.1
21-25 yrs	14	2.1a	2.9	1.6a	2.3

Means followed by the same letter were not statistically different (ANOVA and Student Newman-Keuls test P>0.05).

have until now escaped attack. Late invasion of older plantations after the weevil population reaches epidemic levels has been observed in the field by the authors. Whether interior spruce will ever show the elevated levels of attack reported for Sitka spruce (Alfaro 1982, Alfaro and Omule 1990) remains to be seen.

The high incidence of weevil damage in the wet habitats is probably due to fast growth in the spruces in response to high available moisture which produce long leaders and so favour weevil survival. In coastal Sitka spruce, *P. strobi* prefers to attack the trees with the longest leaders (Alfaro 1989b).

The results of this survey indicate that the white pine weevil has a generally low incidence in this Region and that, because a potential for higher populations does exist, foresters should continue to monitor this problem.

ACKNOWLEDGMENTS

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The Aphids (Homoptera:Aphididae) of British Columbia 20. Further additions

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ABSTRACT

Five species are added to the aphid fauna of British Columbia. Fifty-four of the 88 new aphid-host plant associations of plant species are new host plants.

INTRODUCTION

Four hundred species of aphids collected from 1124 hosts or in traps, and 2233 aphid-host plant associations were recorded in fifteen previous lists of the aphids of British Columbia (Forbes, Frazer and MacCarthy 1973; Forbes, Frazer and Chan 1974; Forbes and Chan 1976, 1978, 1980, 1981, 1983, 1984, 1985, 1986a, 1986b, 1987, 1988, 1989; Forbes, Chan and Foottit 1982). The present list adds 5 aphid species (indicated with an asterisk in the list) and 88 aphid-host plant associations to the previous lists. Fifty-four of the new aphid-host plant associations of plant species have not been recorded before. The additions bring the number of known aphid species in British Columbia to 405. Aphids have now been collected from 1178 different host plants and the total number of aphid-host plant associations is 2321.

Table 1
Collection sites of aphids, with airline distances from reference points

Locality	Reference Point	Dir	Distance km	Distance mi
Allison Pass	Kamloops	SW	174	109
Bijoux Falls	Prince George	NW	159	98
Blue River	Williams Lake	E	193	122
Burns Bog	Vancouver	SE	27	17
Castlegar	Creston	NW	88	55
Cedarvale	Prince Rupert	NE	149	93
Chemainus	Victoria	NW	51	32
Chetwynd	Prince George	NE	211	132
Christian Valley	Creston	NW	178	111
Christina Lake	Creston	W	123	77
Cinema	Prince George	S	63	39
Crowsnest Pass	Creston	NE	152	95
Eighty-three Mile House	Williams Lake	SE	86	54
Greenwood	Creston	W	162	101
Heffley Creek	Kamloops	N	26	16
Hixon	Prince George	S	50	31
Houston	Prince Rupert	E	242	151
Jaffray	Creston	NE	96	60
Lakelse Lake	Prince Rupert	E	117	73
Long Beach	Victoria	NW	186	116
Lost Lake	Vancouver	NE	102	64
Mayne Island	Victoria	N	46	28
McLeese Lake	Williams Lake	NW	34	21
McLeod Lake	Prince George	N	123	77
Moricetown	Prince Rupert	NE	206	129
Mount Robson	Williams Lake	NE	221	138
Mount Robson Provincial Park	Williams Lake	NE	221	138
Moyie Lake	Creston	NE	59	37
Nakusp	Creston	NW	160	100
Nanoose	Vancouver	W	99	62
Nechako	Prince Rupert	SE	106	66
New Hazelton	Prince Rupert	NE	206	129
Okanagan Lake Park	Kelowna	SW	34	21
Pavilion	Kamloops	NW	110	69
Rossland	Creston	W	96	60
Salmo	Creston	NW	58	36
Saltspring Island	Victoria	NW	40	25
Silver Star Mountain	Kamloops	SE	93	58
South Hazelton	Prince Rupert	NE	200	125
Sparwood	Creston	NE	144	90
Squilax	Kamloops	NE	59	37
Stagleap Provincial Park	Creston	W	35	22
Taylor	Prince George	NE	282	176
Tete Jaune	Williams Lake	NE	205	128
Topley	Prince Rupert	E	264	165
Trinity Valley	Kamloops	NE	123	77
Valemount	Williams Lake	NE	211	132
Whistler	Vancouver	NE	102	64
Whistler Village	Vancouver	NE	102	64
Widgeon Creek	Vancouver	NE	30	19
Yahk	Creston	E	34	21

The aphid names are in conformity with Eastop and Hille Ris Lambers (1976) and are listed alphabetically by species, except that *Aphis citricola* van der Goot has been restored to its former name, *Aphis spiraecola* Patch, based on the findings of Eastop and Blackman (1988). Names of native host plants are based on Anonymous (1982) and Taylor and MacBryde (1977). Names of cultivated host plants are based on Anonymous (1976). Fifty-one new collection sites are given in Table 1. The reference points are the same as those shown on the map which accompanies the basic list (Forbes, Frazer and MacCarthy 1973). Most of the aphids were collected by the authors except the *Cinara* spp. were Foottit's (1987) collections.

LIST OF SPECIES

AGATHONICA Hottes 1950, AMPHOROPHORA
Rubus idaeus 'Tulameen': Abbotsford, Jul9/90.
ALBIFRONS Essig 1911, MACROSIPHUM
Lupinus 'Russell Hybrid': Pemberton, Aug9/90.
*ALNIFOLIAE SSP FITCHII Baker & Davidson 1917, PROCIPHILUS
Pinus contorta var *latifolia*: Whistler, Sep15/90.
ANNULATUS (Hartig 1841), TUBERCULATUS
Quercus robur: Vancouver (UBC), Oct16/90.
ANTIRRHINII (Macchiati 1883), MYZUS
Brassica juncea 'Florida Broadleaf': Vancouver (CDA), May15/89.
Capsella bursa-pastoris: Vancouver, Jul1/89, Aug2/89.
Chlorophytum comosum 'Variegatum': Vancouver (CDA), Jul20/89.
Chlorophytum comosum 'Vitatum': Vancouver (CDA), Jun27/89.
Draba lindensii: Vancouver (UBC), Feb24/88.
Hoya carnosa: Vancouver (CDA), Dec14/89.
ASCALONICUS Doncaster 1946, MYZUS
Daucus carota: Vancouver (CDA), Jun7/89.
Senecio eremophilus var eremophilus: Vancouver (CDA), May16/89.
AVELLANAE (Schrank 1801), CORYLOBIUM
Corylus cornuta var californica: Vancouver, May15/90.
AVENAE (Fabricius 1775), SITOBION
Avena sativa 'Clintland': Abbotsford, Jun21/90.
Phleum pratense: Vancouver (CDA), Jul7/90.
BAKERI (Cowen 1895), NEARCTAPHIS
Crataegus viridis 'Winter King': Vancouver (UBC), Oct16/90.
BRASSICAE (Linnaeus 1758), BREVICORYNE
Brassica oleracea 'Purple Sprouting': Vancouver (UBC), Nov27/90.
Brassica oleracea 'White Sprouting Late': Vancouver (UBC), Nov27/90.
Isatis tinctoria: Vancouver (UBC), Aug8/89.
BREVISPINOSA (Gillette & Palmer 1924), CINARA
Pinus contorta: Allison Pass, Jul11/82; Beaverdell, Jul19/79; Bowser, Jul7/81; Burns Lake, Aug1/80; Campbell River, Sep26/41 ; Cascade, May28/57; Castlegar, Jul10/82 ; Cedarvale, Jun28/41; Christian Valley, Jun21/80; Cowichan Lake, May25/56; Creston, Jul10/82; Eighty-three Mile House, Jul29/80 Heffley Creek, Jun26/80; Hixon, Jul31/80; Houston, Aug4/80; Lac La Hache, Jul29/80; Long Beach, May13/79; Mackenzie, Aug6/80; McLeod Lake, Aug5/80; Mount Robson Provincial Park, Aug5/77 , Aug12/80; Moyie Lake, Jul10/82 ; Nakusp, Jun22/80; Nanaimo, May28/58, Jul7/81; Nechako, Jun4/59; New Hazelton, May22/41; Parksville, Jul7/81; Pitt Meadows, Jun27/81; Prince George, Jul31/80, Aug5/80 ; Princeton, Jun17/80, Jul1/81; Salmo, Jul10/82; Sayward, Jul8/81; Shuswap Lake, Jun11/59; Sparwood, Jul9/82; Stagleap Provincial Park , Jul10/82; Terrace, Aug3/80; Tofino, May26/62; Vernon, Jun16/56; Westbridge, Jun21/80, Jul27/77; Yahk, Jul10/82 (all Foottit 1987).

CANADENSE (Robinson 1968), DELPHINIOBIUM
Lonicera involucrata: Lost Lake, Jun26/90.
CAPILANOENSE Robinson 1969, AULACORTHUM
Rubus spectabilis: Shannon Falls, Jun26/90.
CARAGANAE (Cholodkovsky 1907), ACYRTHOSIPHON
Caragana arborescens: Vancouver (UBC), Jul20/90.
CARNOSUM (Buckton 1876), MICROLOPHIUM
Urtica dioica: Peace Arch Park, Jul2/90.
CERASI (Fabricius 1775), MYZUS
Galium odoratum: Vancouver (UBC), May16/89.
Prunus emarginata: Vancouver (UBC), Jul20/90.
CHANI Robinson 1985, UROLEUCON
Grindelia nana: Vancouver (UBC), Aug16/89.
CIRCUMFLEXUM (Buckton 1876), AULACORTHUM
Heliotropium arborescens: Vancouver (UBC), Aug20/89.
Pernettya mucronata 'Coccinea': Vancouver (UBC), Oct16/90.
*CONTORTAE Hottes 1958, CINARA
Pinus contorta: Bowser, Jul7/81; Burns Bog, Aug6/81 Oct2/81; Burns Lake, Aug4/80; Castlegar, Jul10/82; Christian Valley, Jun21/80, Jul1/81; Christina Lake, Jul29/59; Fraser Lake, Aug1/80; Houston, Aug4/80; Jaffray, Jul9/82; Lumby, Jun12/59; Mackenzie, Aug6/80; McLeese Lake, Jul29/80; Moricetown, Aug3/80 ; Moyie Lake, Jul10/82; Nanaimo, Jul7/81; Pitt Meadows, Jun27/81, Aug7/81; Port Coquitlam, Sep9/82, Oct11/82; Princeton, Jun17/80; Quesnel, Jul30/80, Jul31/80; Silver Star Mountain, Jun16/59; South Hazelton, Aug3/80; Summit Lake, Aug5/80; Terrace, Aug3/80; Westbridge, Jun21/80, Jul23/79 (all Foottit 1987).
CORYLI (Goeze 1778), MYZOCALLIS
Corylus cornuta: Vancouver (UBC), 0ct24/88.
COWENI (Cockerell 1905), TAMALIA
Arctostaphylos uva-ursi: Vancouver, Jul20/90.
CRYSTLEAE (Smith & Knowlton 1939), ILLINOIA
Lonicera involucrata: Cinema, Jul2/66.
CYPERI (Walker 1848), THRIPSAPHIS
Carex retrorsa: Vancouver (UBC), Aug25/89.
Scirpus americanus: Vancouver (UBC), Aug25/89.
DAPHNIDIS Borner 1950, MACROSIPHUM
Daphne laureola: Vancouver, Feb1/90; Vancouver (UBC), Nov22/89.
DIRHODUM (Walker 1849), METOPOLOPHIUM
Phleum pratense: Vancouver (CDA), Jul7/90.
Triticum x aestivum: Vancouver (CDA), Jun21/90.
ELEGANS del Guercio 1905, SIPHA
Triticum x aestivum: Creston, Nov28/88.
ERIOPHORI (Walker 1848), CERURAPHIS
Carex retrorsa: Vancouver (UBC), Aug25/89.
Catalpa speciosa: Vancouver, Oct25/88.
Viburnum carlesii: Vancouver, Jun2/88.
FABAE Scopoli 1763, APHIS
Dahlia sp: Victoria, Jul27/88.
Gleditsia triacanthos: Richmond, Jul14/88.
FAGI (Linnaeus 1767), PHYLLAPHIS
Fagus sylvatica: Vancouver (UBC), Nov22/89.
*FILIFOLIAE (Gillette & Palmer 1928), OBTUSICAUDA
Artemisia tridentata: Pavilion, May21/89.

FIMBRIATA Richards 1959, FIMBRIAPHIS
Capsella bursa-pastoris: Vancouver (CDA), Oct15/89.
Rosa 'Red Minimo': Vancouver (CDA), Oct15/89.
Rosa 'Rosy Minimo': Vancouver (CDA), Oct15/89
FOENICULI (Passerini 1860), HYADAPHIS
Lonicera tragophylla: Vancouver (UBC), Jul3/90, Sep13/89.
FRAGAEFOLII (Cockerell 1901), CHAETOSIPHON
Fragaria x ananassa 'Totem': Vancouver (UBC), Nov27/90.
FRAXINIFOLII (Riley 1879), PROCIPHILUS
Fraxinus excelsior: Vancouver (UBC), May31/89, Jun8/89.
GLYCERIAE (Kaltenbach 1843), SIPHA
Hordeum vulgare: Vancouver (CDA), Sep26/88.
GOSSYPII Glover 1877, APHIS
Capsella bursa-pastoris: Vancouver (CDA), Jun14/89.
Capsicum frutescens: Vancouver (UBC), Sep20/90.
Citrus limon: Vancouver, Mar16/90.
Cucumis sativus: Surrey, May29/89.
Solanum tuberosum: Vancouver (UBC), Sep10/90; Westham Island, Sep26/90.
HEDERAE Kaltenbach 1843, APHIS
Hedera helix: Mayne Island, Aug13/90; Saltspring Island, Aug14/90.
HELICHRYSI (Kaltenbach 1843), BRACHYCAUDUS
Myosotis rehsteineri: Vancouver (UBC), Jul27/88.
Spiraea douglasii ssp *douglasii*: Vancouver, Jun27/88.
JUGLANDIS (Goeze 1778), CALLAPHIS
Juglans regia: Langley, Jul27/90.
KIOWANEPUS (Hottes 1933), MACROSIPHUM
Zigadenus venenosus var *gramineus*: Kootenay Park, Jul12/88.
LACTUCAE (Passerini 1860), ACYRTHOSIPHON
Lactuca sativa 'Ithaca': Vancouver (UBC), Oct15/90.
Lactuca serriola: Saltspring Island, Aug14/90.
LONGICAUDA (Richards 1963), EOESSIGIA
Spiraea douglasii ssp *douglasii*: Vancouver, Jun9/90.
LONICERAE (Siebold 1839), RHOPALOMYZUS
Lonicera 'Dropmore Scarlet': Vancouver (UBC), Oct5/90.
LYTHRI (Schrank 1801), MYZUS
Prunus emarginata: Vancouver (UBC), May8/89, Jun9/90, Jul20/90.
MAXIMA (Mason 1925), ILLINOIA
Rubus parviflorus: Vancouver (UBC), Jun25/90.
MEDISPINOSA (Gillette & Palmer 1929), CINARA
Pinus contorta: Blue River, Aug13/80; Bowser, Jul7/81; Cascade, May23/57, Jul29/54; Chemainus, May24/62; Chetwynd, Aug6/80; Christina Lake, Jul29/59; Crowsnest Pass, Jul9/82; Duncan, Jul8/81; Grand Forks, May28/59; Greenwood, Jun3/59; Heffley Creek, Jun26/80; Hixon, Jul31/80; Houston, Aug4/80; Jaffray, Jul9/82; Lumby, Jun12/59, Jun16/62; McLeese Lake, Jul29/80; Mount Robson, Aug12/80; Moyie Lake, Jul10/82; Nanoose, May25/62; Princeton, Jun17/80, Jul1/81, Jul3/81; Qualicum Beach, May25/62; Quesnel, Jul30/80, Jul31/80; Rossland, May29/59; Shuswap Falls, Jun10/59; Squilax, Jun11/59; Stagleap Provincial Park, Jul10/82; Taylor, Aug7/80; Terrace, Aug3/80; Tofino, May26/62; Topley, Jul3/41; Trinity Valley, May14/59; Vernon, Jun16/56; Westbridge, Jul27/77; Williams Lake, Jul29/80 (all Foottit 1987).
MENZIESIAE (Robinson 1969), ILLINOIA
Menziesia ferruginea ssp *glabella*: Shannon Falls, Jun26/90.

MURRAYANAE (Gillette & Palmer 1924), CINARA
Pinus contorta: Burns Bog, Jul29/82, Aug6/81 , Oct2/81; Castlegar, Jul10/82; Chemainus, May24/62; Christian Valley, Jun21/80; Englishman River Falls Park, May20/62; Grand Forks, May28/62; Hixon, Jul31/80; Jaffray, Jul9/82; Mackenzie, Aug6/80; Mount Robson, Aug12/80; Moyie Lake, Jul10/82; Naramata, Jun17/79; Pitt Meadows, May29/79, Jun27/81 , Aug7/81, Sep18/81, Oct4/81; Qualicum Beach, May25/62; Salmon Arm, Jun14/55; Sparwood, Jul9/82; Valemount, Aug13/80 (all Foottit 1987).

NERVATA (Gillette 1908), WAHLGRENIELLA
Arbutus menziesii: Mayne Island, Aug13/90; Saltspring Island, Aug14/90.

NICOTIANAE Blackman 1987, MYZUS
Capsicum frutescens 'Midway': Sidney, Apr29/89.
Cynara scolymus: Sidney, Apr29/89.

NIGRA (Wilson 1919), CINARA
Pinus contorta: Chetwynd, Aug6/80; Eighty-three Mile House, Jul29/80; Fort St. John, Aug8/80; Heffley Creek, Jun26/80; Hixon, Aug31/80; Lakelse Lake, Aug3/80; Mackenzie, Aug6/80; Mount Robson Provincial Park, Aug12/80; Prince George, Jul31/80, Aug5/80; Quesnel, Jul30/80, Jul31/80; Smithers, Aug3/80; Sparwood, Jul9/82; Taylor, Aug7/80; Tete Jaune, Aug12/80; Valemount, Aug13/80 (all Foottit 1987).

NODULUS (Richards 1959), DIURAPHIS
Bromus tectorum: Summerland, Sep5/90.
Dactylis glomerata: Summerland, Sep6/55 (Richards 1959).

NOXIA (Mordvilko ex Kurdjumov 1913), DIURAPHIS
Hordeum vulgare: Creston, Oct17/89; Oliver, Oct18/89; Osoyoos, Oct18/89.
Triticum x aestivum: Creston, Oct17/89.

NYMPHAEAE (Linnaeus 1761), RHOPALOSIPHUM
Callitriche stagnalis: Vancouver (UBC), Jul18/90.
Nymphaea 'Gonnere': Vancouver, Aug15/90.

OBLIQUUS (Cholodkovsky 1896), MINDARUS
Picea glauca: Prince George, Sep18/87.
Picea sitchensis: Vancouver (UBC), Jun13/89.

*OENOTHERAE Oestlund 1887, APHIS
Epilobium ciliatum: Vancouver, Sep12/88.

ORNATUS Laing 1932, MYZUS
Anchusa azurea: Vancouver (UBC), Aug22/89.
Arctostaphylos uva-ursi: Vancouver (UBC), Jul2/90.
Callistemon viridiflorus: Vancouver (UBC), Jul3/90.
Cynara cardunculus: Vancouver (UBC), Aug8/89.
Euonymus hamiltoniana var *yedoensis*: Vancouver (UBC), May24/89.
Fragaria vesca var *semperflorens*: Vancouver (UBC), Nov3/90.
Gaultheria shallon: Vancouver (UBC), Sep28/90.
Gazania 'Mini Star Yellow': Vancouver (UBC), Aug8/89.
Liquidambar styraciflua: Vancouver (UBC), Jun21/90.
Lithodora diffusa: Vancouver (UBC), Aug8/89.
Rosa 'Beauty Secret': Vancouver (CDA), Feb15/90.
Salix lanata 'Stuartii': Vancouver (UBC), Aug8/89, Aug24/88.
Vaccinium corymbosum 'Bluecrop': Vancouver (UBC), Mar26/90.

PADI (Linnaeus 1758), RHOPALOSIPHUM
Bromus tectorum: Summerland, Sep5/90.
Zea mays: Chilliwack, Aug19/90.

*PARVICORNIS Hottes 1958, CINARA
Pinus contorta: Chetwynd, Aug6/80; Mount Robson, Aug12/80 (all Foottit 1987).

PASTINACAE (Linnaeus 1758), CAVARIELLA
Salix lasiandra: Widgeon Creek, Sep5/88.

PENDERUM Robinson 1986, UROLEUCON
Grindelia chiloensis: Vancouver (UBC), Oct16/90.
Grindelia nana: Vancouver (UBC), Aug16/89.
PERGANDEI (Wilson 1919), CINARA
Pinus contorta: Blue River, Aug13/80; Castlegar, Jul10/82; Christian Valley, Jun21/80; Mackenzie, Jul6/80; Nakusp, Jun22/80; Princeton, Jun17/80, Jul1/81; Quesnel, Jul30/80, Jul31/80; Vancouver, Jun23/75 (all Foottit 1987).
PERSICAE (Sulzer 1776), MYZUS
Euonymus hamiltoniana: Vancouver (UBC), May24/89.
Ilex macropoda: Vancouver (UBC), May24/89.
Phoenicaulis cherianthoides: Vancouver (UBC), May24/89.
Solanum tuberosum: Westham Island, Sep26/90.
PISUM (Harris 1776), ACYRTHOSIPHON
Lathyra odorata: Vancouver, Sep20/89.
Lotus pedunculatus: Vancouver (UBC), Aug22/89.
POMI de Geer 1773, APHIS
Cotoneaster gambeli: Vancouver (UBC), Jul3/90.
POPULIMONILIS (Riley 1879), THECABIUS
Populus trichocarpa: Lost Lake, Aug17/90.
PRUNI (Geoffroy 1762), HYALOPTERUS
Glyceria striata: Vancouver, Aug15/90.
PTERINIGRUM Richards 1972, AULACORTHUM
Vaccinium alaskaense: Mount Seymour, Jul9/88.
RIBISNIGRI (Mosley 1841), NASONOVIA
Lactuca sativa 'Ithaca': Vancouver (UBC), Oct15/90.
ROSAE (Linnaeus 1758), MACROSIPHUM
Lactuca sativa: Vancouver (UBC), Jul9/90.
Rosa spinosissima: Vancouver (UBC), Jul3/90.
ROSARUM (Kaltenbach 1843), MYZAPHIS
Potentilla fruticosa: Whistler Village, Jun26/90.
Rosa pendulina: Vancouver (UBC), Jul3/90.
Rosa rubrifolia: Vancouver (UBC), Jun16/89.
SOLANI (Kaltenbach 1843), AULACORTHUM
Citrus reticulata: Kamloops, Aug6/89.
Hypericum olympicum: Vancouver (UBC), May31/89.
Malva neglecta: Vancouver, May17/90.
Oxalis regnellii: Vancouver, Jan20/90.
Spiraea douglasii ssp *douglasii*: Vancouver, Jun27/88.
Taraxacum officinale: Vancouver, Apr26/90.
SPIRAEAE (MacGillivray 1958), ILLINOIA
Spiraea douglasii ssp *douglasii*: Vancouver, Jun27/88.
SPIRAECOLA Patch 1914, APHIS
Caragana arborescens var *crasseaculeata*: Vancouver (UBC), Aug24/88.
SPYROTHECAE Passerini 1856, PEMPHIGUS
Populus nigra 'Italica': Langley, Jul27/90; Saltspring Island, Aug14/90.
STANLEYI Wilson 1915, MACROSIPHUM
Sambucus racemosa ssp *pubens* var *arborescens*: Bijoux Falls, Aug26/90; Smithers, Aug26/90.
STELLARIAE Theobald 1913, MACROSIPHUM
Silene armeria: Vancouver, Jul2/90.
SYMPHORICARPI (Thomas 1878), APHTHARGELIA
Symphoricarpos x chenaultii: Vancouver (UBC), May24/90, Jun21/90.
TENUICAUDA Bartholomew 1932, MACROSIPHUM
Urtica dioica: Peace Arch Park, Jul2/90.

TESTUDINACEUS (Fernie 1852), PERIPHYLLUS
Acer saccharinum: Pemberton, Jun2/89.
TILIAE (Linnaeus 1758), EUCALLIPTERUS
Tilia cordata: Vancouver, Aug15/90.
TREMULAE (Linnaeus 1761), ASIPHUM
Picea engelmannii: Nelson, Nov20/87.
Picea glauca: Quesnel, Oct6/87.
ULMIFOLII (Monell 1879), TINOCALLIS
Ulmus americana: Okanagan Lake Park, Aug25/89.

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Honey bee foraging on dandelion and apple in apple orchards

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ABSTRACT

A four-year study was conducted to determine if honey bees foraging on dandelion switched to apple bloom when dandelion flowers closed in the afternoon. The number of honey bees foraging on dandelion decreased significantly in the afternoon with no significant increase of honey bee numbers on apple. Four thousand honey bees were marked while foraging on dandelion but only two were later observed working apple. Most honey bees foraging on dandelion for nectar do not switch to apple bloom after dandelions close.

Insecta, Honey bees, Pollinators, Dandelion, Apple

INTRODUCTION

'Delicious' apple requires cross-pollination and honey bees (*Apis mellifera* L.) are the primarily pollinators (Mayer, et al. 1986). Dandelions (*Taraxacum officinale*) are frequently found on the orchard floor of apple orchards in the Pacific Northwest and British Columbia. Dandelions bloom at the same time as apples and may compete with apple flowers for the limited number of bees available for foraging. On warm sunny days dandelion flowers mostly close by 1330 and remain closed for the day. Even on cloudy days most dandelions close in the afternoon. Kremer (1950) suggested that since dandelions closed at midday there was no competion and bees deserting the closed dandelion foraged on apple. Percival (1955) studied pollen presentation of dandelion and apple and pointed out that dandelion may not lure bees from fruit trees. Filmer (1941) found about equal numbers of bees foraging on apple and dandelion and supposed that dandelion was a major competitor to fruit. Free (1968) using pollen traps and marked honey bee pollen collectors found a great percentage of the pollen collected by colonies placed in fruit orchards was dandelion and marked pollen collectors seldom changed from dandelion to fruit. He concluded that dandelion was a serious competitor for apple. However, he worked only with pollen collectors although he reported that most bees visit dandelion for nectar rather than pollen. The purpose of this study was to determine if honey bees foraging on dandelion for nectar switched to apple bloom when dandelion flowers close.

MATERIALS AND METHODS

A 'Bisbee' Delicious apple orchard planted near Prosser, WA in 1976 on a 10 x 18 ft spacing was used. Experiments were conducted during late April when the trees were at full open bloom in 1986, 1987, 1988 and 1989. A nearly solid cover crop of blooming dandelions occurred on the orchard floor every year. Each year 1,000 honey bees foraging on dandelion between 0930 and 1000, were marked with a small cheesecloth bag containing orange fluorescent powder. The cheesecloth bag was gently tapped on the upper abdomen of individual bees as they collected nectar from dandelion. The same 0.25 acre plot in the orchard was used every year. Each year the total number of honey bees and number of marked bees per apple tree per minute (20 replications) and per square meter of dandelions per 30 seconds (20 replications) were recorded at 0900, 1130 and 1430 on the same day the bees were marked and at 0900, 1130 and 1430 on the following day. The first count on the first day was prior to marking honey bees. In all years, all or nearly 100% of the dandelion flowers closed between 1200 and 1300 and remained closed for the day. Data were analyzed by ANOVA using Tukey's multiple mean comparison test (Steel and Torrie, 1980).

Table 1

Mean number of honey bees per apple tree per minute and per square meter of dandelion per 30 seconds. Prosser, WA.

	1986		1987		1988		1989	
Time	Apple	Dande-lion	Apple	Dande-lion	Apple	Dande-lion	Apple	Dande-lion
Day 1								
0900	4a	14a	5a	24a	4a	28a	15a	16a
1130	10b	21a	4a	30a	7a	35a	22a	20a
1430	12b	1b	4a	0b	6a	3b	17a	2b
Day 2								
0900	5a	16a	6a	7a	6a	29a	9a	7a
1130	12b	22a	8a	7a	5a	30a	13a	21b
1430	14b	0b	8a	1b	6a	7b	11a	1c

Means within a column and day followed by the same letter are not significantly different (Tukey's multiple mean comparison test, P=0.5).

Table 2

Mean percent of honey bees observed at each time period on apple bloom and dandelion flowers with orange flourescent powder on their bodies. One-thousand honey bees foraging on dandelion were marked between 0930 and 1000 after taking the 0900 counts on day 1. Prosser, WA.

	1986		1987		1988		1989	
Time	Apple	Dande-lion	Apple	Dande-lion	Apple	Dande-lion	Apple	Dande-lion
Day 1								
0900	0	0	0	0	0	0	0	0
1130	0	48	0	53	0	46	0	35
1430	0	0	0	0	0	40	0.5	63
Day 2								
0900	0	28	0	10	0	27	0	33
1130	0	32	0	20	0	28	0	30
1430	0	0	0	0	0	21	0	23

RESULTS & DISCUSSION

As expected, honey bee foraging on dandelion decreased significantly in the afternoon when dandelion flowers closed (Table 1). However, there was no significant increase in honey bee foraging on apple flowers at 1430 when dandelion blooms were closed as compared to 1130 when they were open (Table 1). Higher numbers of honey bees foraging on apple after dandelion closed would indicate that bees foraging on dandelion did switch to apple. This was not the case in any of the four years. During 1986-1988, none of the 3,000 honey bees marked with orange powder while collecting nectar from dandelion was observed foraging on apple either on the day of marking or the following day (Table 2). In 1989, 2 bees out of the 1,000 marked were observed working apple at 1430 after dandelions closed (Table 2). Clearly, most honey bees do not switch to apple after dandelions close. Of the bees marked on dandelion at 0900, 35% to 63% were observed working dandelion at 1130 or 1430 on the day of marking and 10 to 33% on the next day (Table 2). The marking technique proved to be a good method for tracking individual bees. For example, at 1130 on day 1 in 1987, of 600 bees recorded on dandelion 318 were marked bees. Free (1970) suggested that an individual bee's foraging area is limited. We found that many marked bees continue foraging in our 0.25 acre test plot indicating that most

bees work a limited area. Honey bees foraging dandelion for nectar do not switch to apple bloom after dandelions close in the afternoon. Dandelions are beneficial to the bee colonies in providing pollen and nectar, but they appear to be a serious drain on the numbers of available pollinators for apple.

ACKNOWLEDGEMENT

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Unseasonably low fall and winter temperatures affecting mountain pine beetle and pine engraver beetle populations and damage in the British Columbia Chilcotin Region

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ABSTRACT

Unseasonably low temperatures in the fall and winter of 1984 and the fall of 1985 resulted in the decline and termination by 1987 of a major mountain pine beetle infestation which had been in progress since the late 60's. Following the winter of 1984-85, brood survival on lodgepole pine trees in plots near Tsuh Lake in the west-central Chilcotin area of British Columbia was restricted to the lower 0.5 m of infested boles, and the estimated average emergence of female beetles per tree was about 10% of the number required for replacement of the parent generation. Pine engraver beetle populations which built up during the mountain pine beetle epidemic killed many trees in 1985 and 1986, but collapsed by 1987, due mainly to tree resistance and other natural factors. The rise and fall of tree mortality from the pine engraver within the plots paralleled that in the rest of the central Chilcotin following the collapse of the mountain pine beetle outbreak.

INTRODUCTION

Mortality from cold is one of the major factors determining the distribution and abundance of the mountain pine beetle (*Dendroctonus ponderosae* Hopk.)(Safranyik 1978; Amman and Cole 1983). Mountain pine beetles normally overwinter as late-instar larvae, the stage at which they are the most cold-hardy (Safranyik 1978; Amman and Cole 1983). Cold-hardiness of mountain pine beetle increases with the accumulation of glycerol in body fluids in response to gradually decreasing temperatures in the fall and early winter

Table 1
Selected minimum daily temperatures* and month-end snow depths at Alexis Creek B.C. in 1984 and 1985.
(Source: Monthly records of Meteorological Observations in Canada 1984, 1985.
Environment Canada, Atmospheric and Environment Service.)

	Date	Minimum daily temp. (°C)	Snow depth (cm)
1984			
	Oct. 30	-23.0	
	Oct. 31	-31.0	7
	Nov. 1	-21.0	
	Dec. 29	-40.0	
	Dec. 30	-43.0	
	Dec. 31	-38.0	36
1985			
	Nov. 11	-27.5	
	Nov. 12	-20.0	
	Nov. 22	-31.0	
	Nov. 23	-35.0	
	Nov. 24	-23.5	
	Nov. 25	-26.0	
	Nov. 26	-39.0	
	Nov. 27	-43.0	
	Nov. 28	-39.0	
	Nov. 29	-36.0	
	Nov. 30	-29.0	16
	Dec. 1	-34.5	
	Dec. 2	-32.0	

* The estimated lethal low temperature threshold for larvae during the winter period is near -38°C; during the late October-early November period it is near -26°C. (Safranyik *et al.* 1974, Fig.25)

(Somme 1964). Maximum cold-hardiness is attained by December-January, and some large larvae can survive short exposures to -38°C during this period. During the fall before maximum hardiness is attained and as it wanes in the spring, the insects are susceptible to extreme cold, so that unseasonably low temperatures (less than -26°C) can cause widespread mortality (Safranyik *et al.* 1974; Safranyik 1978).

Unseasonably low temperatures in late October and late December of 1984, and again for several days in November of 1985, provided an opportunity to observe their effect on mountain pine beetle populations, tree mortality, and the incidence of attacks by some associated species of bark beetles. The plots had been established in June 1985 to investigate the dispersal of mountain pine beetle within stands. In this paper we present data which describe the infestation trends of mountain pine beetle and *Ips pini* Swaine (pine engraver beetle) between 1984 and 1987, and some characteristics of the infested trees.

MATERIALS AND METHODS

The plot area was established in a stand of mature lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) near Tsuh lake, about 80 km west of Williams Lake, British Columbia, within a massive epizootic of mountain pine beetle which began in the late 1960s (Wood and Van Sickle 1987). The study area was generally flat, 5.6 ha in area with about 2 ha of esker-like ridges 2-3 m in height in the southeast portion. It was surrounded on three sides by open meadows 10 to 40 m wide, and on the fourth by a stand of lodgepole pine less than 40 years old containing a few veteran Douglas-firs (*Pseudotsuga menziesii* (Mirb.) Franco). Within the study area, the tree cover averaged 592.3 stems per ha with diameter at breast height (dbh) greater than 5 cm, consisting of 83% lodgepole pine, 11% engelmann spruce (*Picea engelmannii* Parry)(mainly in depressions) and the balance scattered

Douglas-fir and aspen (*Populus tremuloides* Michx.). The average age of the lodgepole pines was 102 years in 1985.

In 1985 all trees over 5cm dbh were counted by species, and the dbh of trees attacked by mountain pine beetle or pine engravers in 1984 and 1985 were tallied. In the years 1986 and 1987 the dbh of all newly infested lodgepole pine trees were recorded. Tree heights and maximum height of attack were estimated for a random sample of infested trees using an Abney level; binoculars were used to determine the location of the highest attacks where necessary.

Mountain pine beetle attack and brood densities and totals per tree were estimated for trees infested in 1983 and 1984 only and were multiplied by the total infested bark surface area to estimate total population within the study area annually. Emergence in 1984 was estimated based on counts of emergence holes on 15 x 15 cm areas of bark at breast height on trees attacked in 1983. In 1985, the density of emergence of mountain pine beetle was estimated using total counts of beetles which emerged from caged infested bolts and counts of emergence holes on bark areas painted with light colored latex paint to enhance the visibility of the holes (Safranyik and Linton 1985). Brood and attack totals per tree were estimated based on measurements of dbh, total or infested tree height, and attack and brood densities at breast height (Safranyik 1988).

Minimum daily temperature and snow accumulation for the years 1984-85 (Table 1) were obtained using Environment Canada records from Alexis Creek, about 30 km west of the study area.

RESULTS AND DISCUSSION

The effect of unseasonable cold on mountain pine beetle

Trees attacked in 1984 are described by the data in Table 2. The mean mountain pine beetle attack height (11.36 m) was about 60% of total tree height, which is considered normal for the dbh and height of the attacked trees (Safranyik, 1969). The maximum height at which live mountain pine beetle brood were found, however, was only 63 cm (mean 53 cm)-less than 5% of the infested height. Normally, some beetles mature near the top of the infested bole region. Careful examination of infested trees in mid-May of 1985 indicated that survival was confined to the bark areas which were probably below snow during the winter. Recorded snow accumulation at Alexis Creek (Table 1) was less than the average height of live brood. It is, however, likely that snow depth inside the stand was greater than in the open area where the weather station is located. Dead larvae found beneath the bark higher up the stems were dark grey to black, and stretched out; both of these symptoms are indicative of winter mortality.

Temperature records (Table 1) show that temperatures near or below the lethal early winter threshold of about -26°C (Safranyik *et al.* 1974) occurred during 3 days at the end of October and during 2 days at the end of December in 1984. On October 31 and December 30 and 31, even the mean daily temperatures were as low as or lower than the fall lethal threshold of ca -26°C or the late-winter lethal threshold of ca -38°C. In 1985, minimum daily temperatures near or below the -26°C threshold were recorded for 13 days between November 10 and December 2; the last 11 of these occurred in an unbroken sequence. In contrast, the records for the years 1975-1983 show no periods when the temperatures fell below the estimated lethal minima for more than two consecutive days.

In 1985 the estimated mean number of potential emerging mountain pine beetle females per tree (1192, Table 2) Represented a static or increasing population over the previous generation (the mean number of attacks per tree in 1984 was 458), even after allowing for loss of beetles during dispersal and host colonization (Cole and Amman 1969). The mean actual emergence per tree (119, Table 2) was about 10% of the potential (i.e. the expected emergence without complete above-snow mortality). Considering a female:male ratio of 2:1 and a flight-establishment loss of 40% (Cole and Amman, 1969), the average of 119 emergents per tree represents 79 females, or 47 attacks. This is about 10% of the average attacks per tree made by the parent generation.

Table 2
Statistics describing lodgepole pine at Tsuh Lake infested in 1984 by mountain pine beetle.

Variables	Mean ± S.D.	N
Diameter (dbh, cm)	25.0 ± 5.7	35
Total height (m)	18.8 ± 2.0	12
Attack height (m)	11.3 ± 3.6	10
Brood height (m)	0.5 ± 0.1	17
Attacks/m^2 at dbh	133.3 ± 47.5	13
Attacks/tree *	458.3 ± 158.7	13
Emergence/m^2	212.7 ± 151.6	10
Emergence/tree **	119.5 ± 85.2	10
Estimated emergence /tree for 1985***	1192.4 ± 850.3	10

* Estimated as in Safranyik 1988 (eq. 13).
** Based on emergence data from caged bolts and emergence holes on infested bolts (Safranyik and Linton 1985).
*** Assumes the usual distribution of brood adults over the total infested bole. Based on mean no. of emerged beetles/tree (see footnote **), mean height of live brood on the bole and a cumulative function for brood on infested bole height (Safranyik 1988, eq. 16).

The mean number of trees per ha attacked by mountain pine beetle in 1985 was 10.23, or about 9% of the 1984 mean (Table 3). This agrees well with the corresponding estimate of 10% based on brood survival. This comparison assumes, however, that mean surface area attacked per tree and mean attack density did not change over the two years. These variables were not estimated for 1985 attacks. Numbers of trees attacked by mountain pine beetle further declined in 1986, and by 1987 no new attacks were found on the plot.

Response of pine engraver beetle population to decline of mountain pine beetle

No trees were killed in 1984 by the pine engraver beetle, a major associate of the mountain pine beetle (Sartwell *et al.* 1971). From 1985 to 1987, the mean numbers of engraver-attacked trees per ha were 15.02, 21.51, and 2.05, respectively. The mean dbh was smaller than that of trees killed by mountain pine beetle, but the difference was not statistically significant ($p>0.05$). The pine engraver normally attacks the uninfested tops and lightly infested areas of trees killed by mountain pine beetle. Consequently, during large outbreaks of mountain pine beetle, large engraver populations can build up. Because these insects overwinter in the duff, populations are not affected appreciably by severe winter temperatures. In 1985 and 1986 large engraver populations (which developed in trees killed by mountain pine beetle) attacked live trees in the absence of trees killed by mountain pine beetle. Many trees colonized by the pine engraver also bore a few mountain pine beetle attacks, and some from *Pityogenes plagiatus knechteli* Swaine, another common associate.

This study is the first to present data on the collapse of a mountain pine beetle outbreak due to cold temperatures, and the subsequent infestation by the pine engraver. After the collapse of the massive Mountain pine beetle infestations in the Chilcotin during 1985-86, pine engraver killed large numbers of the residual trees, mainly along the edges of cut blocks and rights-of-way (Wood and Van Sickle 1986, 1987). As expected, these infestations invariably declined in 2-3 years as populations suffered heavy mortality, apparently from host resistance, intraspecific competition and natural enemies (Sartwell *et al.* 1971).

Table 3
Numbers/ha and mean dbh of lodgepole pine trees attacked by the mountain pine beetle (MPB) and pine engraver beetle (*Ips*) from 1984 to 1987

Year of Attack	Beetle species	Trees/ha	Mean dbh. (cm) ± S.D.	N
1984	MPB	109.4	25.02 ± 5.74	35
	Ips	0	-	-
1985	MPB	10.23	21.48 ± 3.44	60
	Ips	15.02	18.77 ± 4.88	88
1986	MPB	7.68	23.17 ± 5.44	45
	Ips	21.51	18.58 ± 4.00	126
1987	MPB	0	-	-
	Ips	2.05	17.23 ± 6.53	12

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An improved system for mass-rearing codling moths[1]

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ABSTRACT

Various modifications were made to a system for mass-rearing the codling moth, *Cydia pomonella* (L.), on formulated diets and immature apples to improve production efficiency and to reduce exposure of workers to formaldehyde and moth scales. The modifications included: an improved oviposition cage, an oviposition cabinet, an apparatus to surface-sterilize eggs with formaldehyde fumes, a moth scale removal system in the adult collection room, and disposable adult eclosion containers. This system is suitable for research requiring large numbers of selected stages of the codling moth.

INTRODUCTION

The codling moth, *Cydia pomonella* (L.), a serious pest of several deciduous fruits and walnuts, has been mass-reared at the USDA, ARS research facility at Yakima for over 20 years. In the past, it was reared primarily for use in studies of the sterile insect technique, population movement and suppression, and pheromones (Hamilton and Hathaway 1966). Current programs in postharvest quarantine treatment research require large numbers of selected stages of the codling moth for use in studies to evaluate the efficacy of proposed treatments, such as fumigation, irradiation, and cold or controlled atmosphere storage. For example, in order to have a 99.9% confidence level in quarantine security, 93,616 insects are needed per treatment (Chew and Ouye 1985). Through the years, many changes have been made in codling moth diet (Howell 1967, 1970, 1971, 1972) and rearing procedures (Hathaway 1967, Hathaway *et al.* 1972, Hutt *et al.* 1972) to meet the need for more safe, efficient and cost-effective rearing.

This paper describes further modifications made to the rearing system, particularly to reduce worker exposure to hazardous materials, such as moth scales and formaldehyde, and the current procedures used to mass rear the codling moth at this location.

EGG COLLECTION AND HANDLING

Eggs are obtained using the oviposition cage of Hathaway *et al.* (1972) with one change; the muslin cloth liner in the top portion is replaced with 16-mesh wire screen. The oviposition substrate is either waxed paper or polystyrene pellets (Dow Chemical Co., granulation number 451-27-35). Waxed paper sheets are first crumpled, then flattened, before they are fitted into the bottom of the cages. Moths prefer to oviposit on crease lines in the sheets rather than on flat, smooth surfaces. In the use of pellets, 250 g are placed in each cage. Adults are transferred from collection containers to oviposition cages in a hood located in the adult collection room maintained at about 3°C (see below). Each cage holds 250-300 unsexed moths, which produce about 6000 eggs.

The prepared oviposition cages are held in a plywood cabinet, which was designed to control environmental conditions and remove moth scales (Fig. 1). The cabinet measures 2.9 m wide, 0.6 m deep, and 2.0 m high, and houses a heater, air filters (5W512-D Extended Surface Air Filter 50.8 x 63.5 x 2.5 cm, Dayton Electric Mfg. Co., Chicago, IL), a blower, and humidifiers. Sliding glass doors give access to two sets of five open metal wire shelves, 25 cm apart, each shelf with a 30-watt fluorescent light overhead. Air from the room, which is maintained at 23 ± 3°C, enters the plenum through the blower, passes

Footnote

1. Mention of a proprietary product does not constitute an endorsement by the USDA.

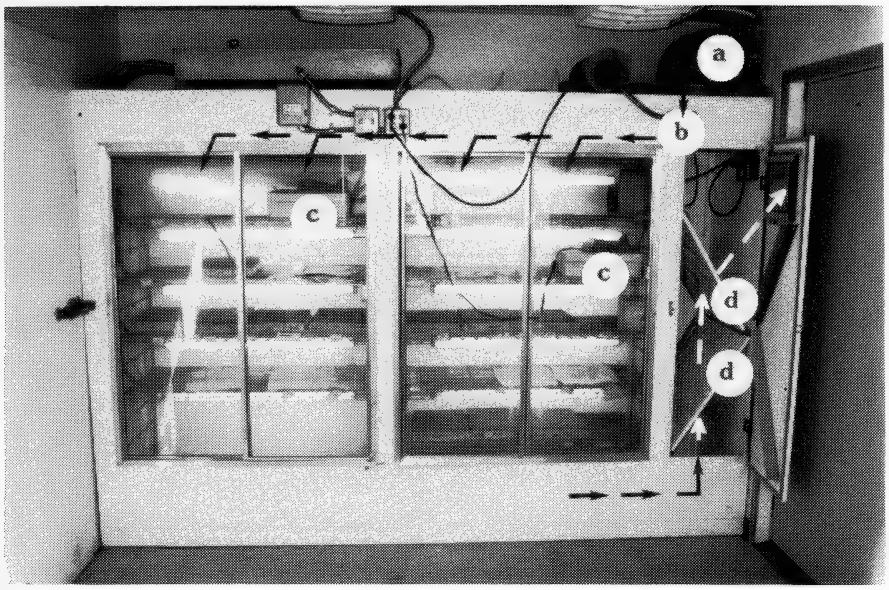

Fig. 1. Codling moth oviposition cabinet: (a) blower, (b) heater (hidden), (c) humidifier, (d) filters. Direction of air flow indicated by arrows.

over the heater, and enters the cabinet at the top, circulating in the cabinet at a rate of 0.15 m^3 per min. The air then enters the plenum at the bottom, passes through the air filters and is exhausted into the room. The cabinet is maintained at 24 ± 3°C, 62 ± 10% RH, and 16:8 (L:D) photophase.

After a 5-day oviposition period the cages are removed from the cabinet and transferred to the hood described above. After about 15 min in the cold room the adults become inactive, and are collected by vacuum and discarded.

Eggs used in mass-rearing need to be surface sterilized to eliminate surface contamination by pathogenic and non-pathogenic microorganisms. In the past, waxed paper sheets or pellets with codling moth eggs were dipped in a 0.1% sodium hypochlorite solution for 2 min (Hamilton and Hathaway 1966, Hathaway *et al.* 1972) or in formaldehyde solution (Howell 1970). These methods were time-consuming and hazardous. Furthermore, pellets tended to clump together when wet, and some eggs dislodged from waxed paper. We found that eggs tolerated formaldehyde vapor for 120 min without effect on hatching or the ability of neonate larvae to enter fruit. Tests showed that there were no codling moth larval deaths due to granulosis virus when eggs were fumigated with formaldehyde for 45 min (J. S. Tebbets and P. V. Vail, ARS Stored Products Research Laboratory, Fresno, CA, personal communication). Our procedure for the past 7 years to surface-sterilize eggs has been to fumigate them with formaldehyde vapor for 90 min at room temperature (23°C).

The fumigation apparatus, constructed of Plexiglas® and located in a fume hood, measures 41 cm deep, 26 cm wide, and 80 cm high (Fig. 2). It holds four removable wooden-framed trays of 0.36-cm mesh hardware cloth spaced 13 cm from the top of the chamber to the top tray and 13 cm between trays. A 10-cm diam exhaust fan is located at the top of the apparatus. Three 2.2-cm diam ventilation holes are located on each side, 5 cm from the bottom, for air to enter the apparatus during evacuation of formaldehyde fumes before the hinged door in front is opened. A 28 x 15 x 10 cm stainless steel container, with a lid, containing the undiluted formaldehyde sits on the floor of the chamber.

For fumigation, egg-laden pellets held on 18 x 16 mesh saran screen are placed on the trays in the fumigation chamber. Egg-laden waxed papers are placed directly on the trays. The lid to the formaldehyde container is removed and the door closed. At the end of the

Fig. 2. Fumigation apparatus in fume hood for surface-sterilizing codling moth eggs with formaldehyde fumes: (a) exhaust fan, (b) empty tray, (c) tray with egg-laden waxed paper, (d) tray with egg-laden polystyrene pellets, (e) stainless-steel container for formaldehyde.

fumigation period, the exhaust fan is turned on and formaldehyde fumes evacuated for 2-3 min. The formaldehyde tank lid is then replaced and the eggs removed.

LARVAL REARING

Formulated diet

Various formulated diets have been used to mass-rear the codling moth at this laboratory (Hamilton and Hathaway 1966; Howell 1967, 1970, 1971, 1972). However, we have been using a diet developed by Howell and Toba (unpublished) for the past 7 years because it has been the most satisfactory one for our purpose. To infest trays of diet a waxed paper sheet with eggs is cut into 20 equal squares, each generally having about 300 eggs. Five squares are placed on the diet in each stainless steel tray (45 x 26 x 7 cm) and the tray is covered with a muslin cloth lid with a wood frame. The weight of the frame, which hangsover the edge of the tray, holds the cloth snug against the lip of the tray to prevent larvae from escaping and to help control dehydration of the diet. The trays are placed on wheeled metal racks and maintained at 23 $\pm$ 2°C, 50 $\pm$ 10% RH, and 16:8 (L:D) photophase. Seven days later the waxed paper squares are removed. Fifteen days after egg infestation, 40.5 x 1.9 cm fluted fiberboard strips are placed in each tray to serve as cocooning sites for mature larvae. The strips are placed in spaces between the diet and the sides of the tray, plus three to four on the surface of the diet.

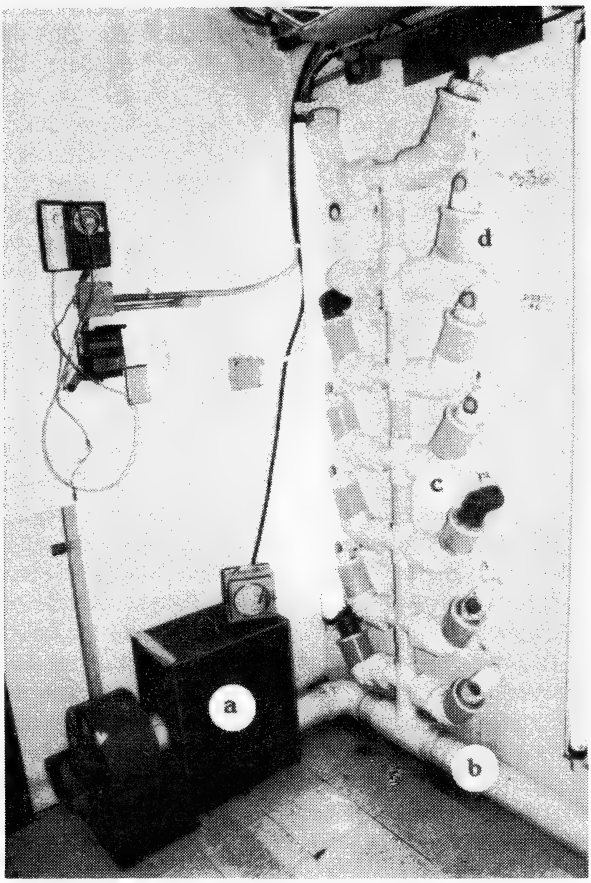

Fig. 3. Scale removal system in codling moth adult collection room: (a) filtering apparatus, (b) polyvinyl chloride tubing, (c) dryer duct sleeve, (d) moth collection container.

Immature apples

When rearing codling moths on apples, one layer of immature, thinning apples previously washed in water is placed in each disposable fiberboard tray (Hathaway 1967). Because water does not remove pesticides that are harmful to codling moths, apple samples are analyzed for residue before using. Each tray is inoculated with about 1500 eggs by sprinkling a given volume (usually 25 ml) of egg-laden pellets. The number of eggs is based on counts in a sample of pellets. The trays are then covered with 18 x 16 mesh saran screen, fitted with tops, and placed on wheeled metal racks. If mature cocooning larvae, pupae or adults are desired, fiberboard pupation strips are placed on the apples. The trays are maintained at 23 ± 2°C, 60 ± 10% RH, and 16:8 (L:D) photophase.

COCOON AND ADULT COLLECTION AND HANDLING

Fiberboard strips with cocooned larvae are harvested from trays of diet or immature apples. A system developed by Hutt *et al.* (1972) to automatically collect emerged moths utilizes two adjoining rooms: an unlighted eclosion room maintained at 24 ± 2°C and 70 ± 10% RH, and a lighted room maintained at about 3°C where the moths are collected. Moths emerging in the dark eclosion containers are attracted to light in the cold room through tubes attached to adult collection containers. Various modifications have been made to this system, primarily to control moth scales.

Eclosion containers made of galvanized sheet metal (Hutt *et al.* 1972) have been replaced with disposable fiberboard containers of the same dimensions. Cocooning strips

are loosely stacked criss-cross in the fiberboard containers instead of on racks used in the metal containers. The fiberboard containers are disposed of after use, thereby eliminating the need to clean and sterilize them and reducing worker exposure to moth scales and microbial contamination.

The problem of moth scales in the cold room where the moths are collected and handled has been decreased with a scale removal system (Fig. 3). One end of polyvinyl chloride tubing is attached to a box housing a blower and an air filter (TA Pinch Pleat 25.4 x 50.8 x 2.5 cm, Environmental Filter Corp., Santa Rosa, CA). Moth collection containers with screen bottoms are connected to the tubing by means of short pieces of flexible dryer duct sleeves. A small hood in the cold room used to transfer moths is also connected to the scale removal system by polyvinyl chloride tubing. The hood is not vented outdoors to conserve cold air in the room.

SANITATION

When mass-rearing insects, sanitation is essential to control contamination of diet, equipment and insect by microorganisms. Certain measures have been taken to minimize these problems in rearing the codling moth. After each use, moth collection containers and oviposition cages are cleaned in a dishwasher. Used diet trays are held in a freezer at about -18°C for 2 days to kill any insects present, then cleaned and autoclaved at 115.5°C and 18-20 psi for 1 hr. Diet tray covers are similarly cleaned and autoclaved for 0.5 hr. The autoclave opens at both ends, each end opening into a separate room. Dirty trays and covers are cleaned and placed in the autoclave in one room (dirty room), and removed and stored in the other room (clean room) after autoclaving. Used apple rearing trays and adult eclosion containers with cocooning strips are held in a room at about 49°C for 12 hr to kill any insects present before discarding them. Walls and floors are cleaned weekly with household ammonia or detergent.

Scavenger mites (family Ascaidae) sometimes become a problem when larvae are reared on immature apples. To prevent mite contamination, the rearing rooms are emptied after each use, cleaned with household ammonia, and heated to about 49°C for 2 days to kill the mites.

DISCUSSION

Various modifications made to improve on a system to mass-rear the codling moth at Yakima has resulted in improved production efficiency. The desired environmental conditions in the oviposition cabinet can now be controlled and maintained, and the moth scale hazard has been removed. The advantages of surface-sterilizing eggs with formaldehyde fumes over dipping them in sodium hypochorite or formaldehyde include not only a reduction of worker exposure to these hazardous chemicals, but also about a 50% reduction in handling time. Further reduction in worker exposure to moth scales has been achieved with the scale removal system in the adult collection room, and the use of disposable adult eclosion containers. The cost of disposable adult eclosion containers is about 35% of the cost of cleaning and sterilizing metal containers, resulting in about a 65% saving.

This system is suitable for obtaining large numbers of selected stages of the codling moth required for such research as quarantine treatments and studies on pheromones, attractants, biological control, and pesticides. Eggs can be readily obtained from egg-laden waxed paper or polystyrene pellets, larvae from the formulated diet, mature cocooning larvae or pupae from the pupation strips, and adults from collection containers. Large numbers of infested immature apples can also be produced by this system. Since 1983, we have successfully produced up to 32,000 larvae per week on the formulated diet.

ACKNOWLEDGEMENTS

We thank Lee Fox, Eric Halfhill (retired), John Turner and Pat Wilson of this laboratory for their technical assistance. This study was funded in part by the Washington State Tree Fruit Research Commission.

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Compound eye of male *Stylops pacifica* (Strepsiptera; Stylopidae)

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INTRODUCTION

Few insect groups have greater sexual dimorphism than the Strepsiptera. With the exception of a single family (Mengeidae), the female is a completely passive endoparasite in a much larger insect, and nearly without the ususal external features of other insects (Gehrhardt 1939). These are reduced to a hint of segmentation on the abdomen and a few indeterminate pits and sutures on the sclerotized cephalothorax (Fig. 1). Copulation is said to be achieved *in situ* (Bohart 1941).

The male develops in a larval capsule similar to that of the female, but upon emergence is a small, unusually active, winged insect, about 3 mm long, already well sclerotized, short-lived and nervous, having many of its structures much modified. The antennae show development and variation between species and are well provided with large sensoria (Fig. 2).

The compound eyes of adult males appear to be somewhat primitive and are possibly of secondary importance to the insect. They resemble the eyes of thrips, collembolans, male coccids or the pupal eyes of some beetles (Pankrath 1890). There are no ocelli. Strohm (1910) suggested that each facet represents a lateral ocellus (ocellare komplexaugen), but Bohart (1941) pointed out that they may equally well have been reduced to their present form from normal compound eyes. Each optic unit resembles an ocellus rather than an ommatidium.

METHODS AND MATERIALS

Dr. J.W. McSwain, Instructor in Entomology at the University of California, Berkeley, caught and identified the insects as *Stylops pacifica* Bohart. He allowed me to accompany him into the hills above and behind the town on a fine afternoon in mid-March, 1951. We took eight bees (*Andrena complexa* Vier.) feeding on *Ranunculus*. All were parasitized with Strepsiptera, five with females including one bee with two, and three with males. One male was in the act of emerging. The material for study was put alive into Petrunkevitch fixer and held for a few weeks. The emergent male was the principal subject.

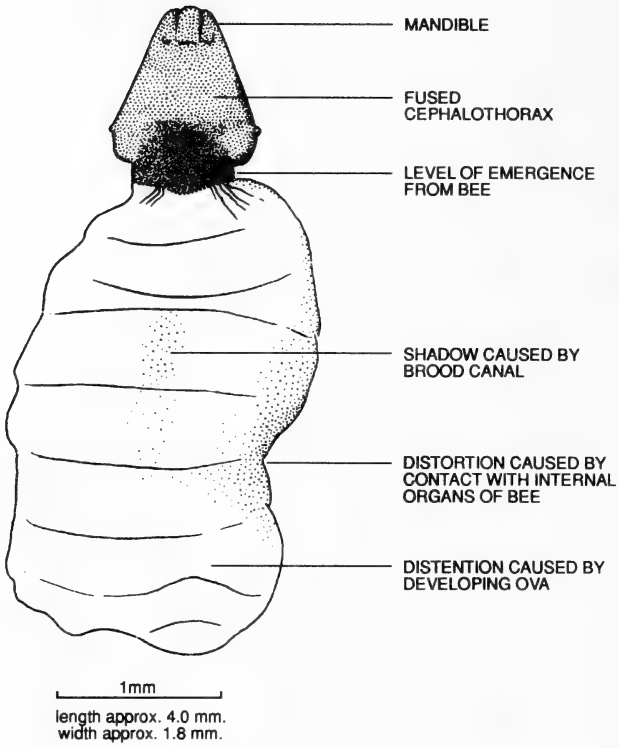

Figure 1. Adult female *S. pacificia*. Ventral aspect.

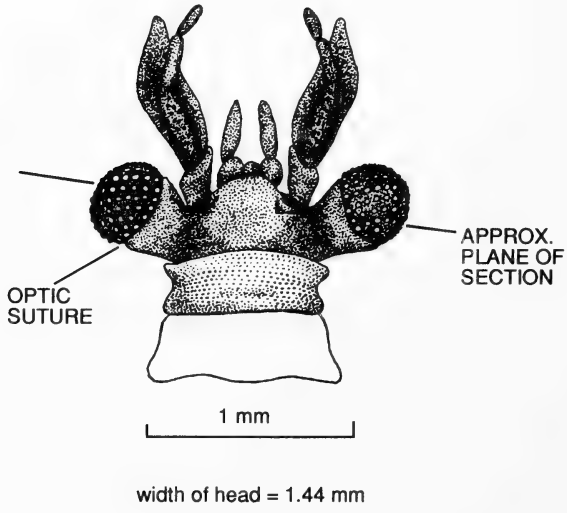

Figure 2. Head of adult male *S. pacifica*, showing compound eyes and antennae with sensoria.

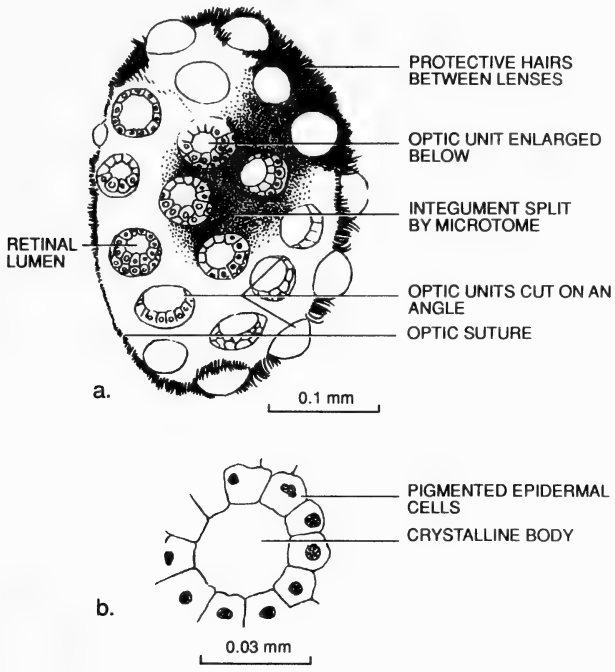

Figure 3. Compound eye of adult male *S. pacifica,* showing the separation of optic units (a) and detail of a single unit (b).

The histological treatment was unspecialized, designed to stain and counterstain as many cell types as possible. Dehydration and embedding started with ethyl alcohol from 70%, increased in five stages to 100%, each stage for 4 h, followed by three changes of xylene at various intervals. Paraffin was added to semi-fluidity and heated to 70°C for 4 h, then infiltrated further fresh paraffin for 2 h at 70°C in a vacuum chamber. The sections were cut transversely from the tip of the abdomen forward. Tests showed that haemotoxylin of pH 1.5 in 80% alcohol gave good results. The eosin stain was in 95% alcohol, at pH 7.0. The sections were never hydrated below 80% alcohol, and were mounted in Canada balsam.

RESULTS AND DISCUSSION

The head of the male *S. pacifica* is so wide in proportion to its length that the hemispherical compound eyes appear to be stalked (Fig. 2). Each eye has a deeply inflected optic suture (Figs. 2, 3, & 4). There are between 50 and 80 lenses per eye, which are not hexagonal but circular, glabrous, protuberant and well separated from one another by thickly pilose, heavily-pigmented integument (Fig. 4). The irregular biconvex shape of the lens suggests that these coarse hairs may play some part in shading it from oblique light rays (Figs. 3a & 5a,b), on the assumption that axial rays are the most important.

Within the lens a number of striae can be seen, a result of its laminar construction (Snodgrass 1935). These probably alter the refractive index of the lens, thus making it more difficult to work out a reliable optical scheme. A thick lens of this shape would have two principal points, the distances of which from their associated surfaces would depend upon the lens thickness, refractive index and both radii of curvature (Hausmann and Slack 1939). Using a single focal point a hypothetical optical system is proposed (Fig. 5b), which agrees with the interpretations of the tissues and their apparent functions.

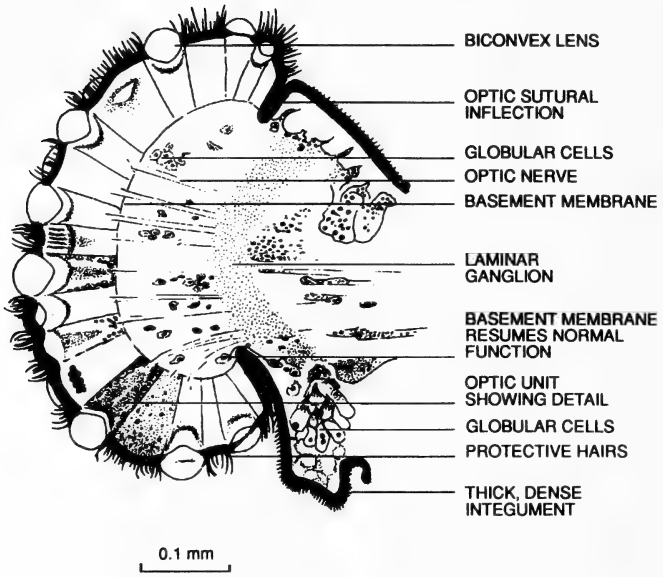

Figure 4. Compound eye of adult male *S. pacifica,* in lateral cross-section.

According to the lens formula, $1/p + 1/q = 1/f$ (where p = object distance, q = image distance, and f = focal length) and substituting values taken from the drawings, the object distance is found to be short. Male *S. pacifica* appear to be short-sighted.

Immediately beneath the integument in the specimen studied, each otic unit was surrounded by about 11 pigmented epidermal cells to a depth of three or four cells, or 30-40 cells per optic unit (Figs. 3a, b). At this level the units abut on one another in conventional, slightly irregular, hexagons. Beneath the lens and surrounded by the epidermal cells is a transparent crystalline body, apparently non-cellular, which may be formed as a secretion product of other cells (Snodgrass 1935). Below this again is a circle of granular, pigmented, corneagenous epithelium, without cell boundaries (Fig. 5a).

From this point proximally around the base of the unit, the cells change to rhabdomeres, or optic sense cells, with processes passing into the brain. There appear to be about 50 rhabdomeres per unit. There was not enough resolution to observe any neurofibrillae on the walls of the cells facing the retinal lumen (Hesse 1901). The lumen is nonnuclear with a fine-textured and variable darkening in the centre (Figs. 4 and 5a). The proximal processes of the rhabdomeres, or optic nerves, are prominent, each converging upon and passing through the basement membrance by way of a large opening. Around the base of each optic unit are apparently unspecialized mantle cells which may have no more than a nutritive or parenchymatous role.

The essentially epidermal nature of the eye is shown where the basement membrance (Figs. 4 and 5) passes directly to the integument at the optic sutural inflection (Fig. 4), there to resume its normal function underlying the epidermis. Within the brain there is a wide zone lying immediately beneath the basement membrane and traversed by the optic nerves, interspersed with large globular cells (Fig. 4). A laminar ganglion follows proximally, succeeded by other brain tracts. No optic chiasma was seen.

NOTES

This study was an individual assignment in a course on morphology, given by Prof. Roderick Craig, when I was a student at the University of California at Berkeley, in 1951. It has been slightly edited and shortened.

According to the late Prof. G.J. Spencer (Proc. Ent. Soc. B.C. 48: 38, 1951), the late Hugh Leech "found stylopized bees freely in the arboretum" on the UBC campus. I know of no other mention in this province of these extraordinary insects.

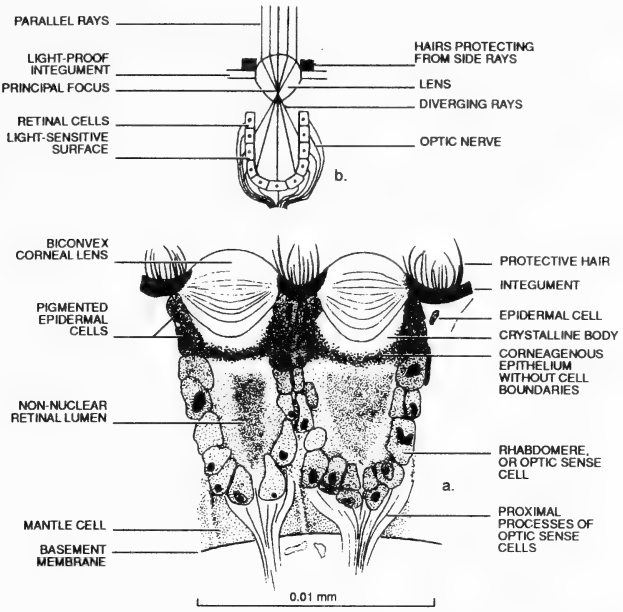

Figure 5. Compound eye of adult male *S. pacifica*. Longitudinal sections of two adjacent optic units (a) and theoretical optical system (b).

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Larvae of *Hyalophora euryalus kasloensis* (Lepidoptera: Saturniidae)

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There are no currently recognized subspecies of the ceanothus silkmoth, *Hyalophora euryalus* (Boisduval) (cf. Ferguson 1972, Lemaire 1978; see Packard 1914, McDunnough 1921 for discussion of specific synonyms); however, the status of *H. e. kasloensis* (Cockerell) has been debated for many years. The subspecific name *kasloensis* was published by T.D.A. Cockerell in Packard's (1914) monograph and was described as representing "a local [submelanic] race occurring in the interior of British Columbia" which was originally described, but not named, by Cockle (1908). Based on surveys of wild

moths and some very limited hybridization studies, Sweadner (1937) concluded that *H. e. kasloensis* represented an intergrade population between *H. euryalus*, native to the Pacific coast and western mountains, and *H. gloveri* (Strecker), native to the Rocky Mountain region. It has since been well-established that interspecific crosses in the genus *Hyalophora* Duncan produce hybrids consisting of fertile males and sterile females (Collins 1973). This fact, combined with the apparently intermediate characters of adult *H. e. kasloensis*, led Ferguson (1972) to speculate that *H. e. kasloensis* arose through a period of hybridization between *H. euryalus* and *H. gloveri* with extensive backcrossing of hybrid males to *H. euryalus* females, resulting in a population that is essentially *H. euryalus* but that retains enough of the *H. gloveri* gene pool to produce a distinct form. He concluded by reducing the name *kasloensis* to the status of a synonym of *H. euryalus*, but not before noting that the larva of *H. e. kasloensis* "has never been adequately described". The existence of a distinct larval phenotype in *H. e. kasloensis* has long been suspected (Sweadner 1937, Collins and Weast 1961, Collins 1984) but has never been documented.

In May 1988 a small colony of *H. e. kasloensis* was established from an adult female collected at Kelowna, B.C., and larvae were reared on cuttings of redstem ceanothus, *Ceanothus sanguineus* Pursh (Rhamnaceae), under ambient conditions in the Okanagan Valley. The colony was maintained and enlarged by mating several reared females with wild males at Kelowna in 1989 and at OK Falls in 1990 using mating cages constructed from coffee cans, as described by Miller and Cooper (1976). Larvae were reared on *C. sanguineus* cuttings in the Okanagan during the summer of 1989 and on cuttings of cascara, *Rhamnus purshiana* DC. (Rhamnaceae), and Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*, in Victoria during the summer of 1990. Cascara was chosen as an alternate food plant because of its relationship to ceanothus and because it is quite common around Victoria whereas ceanothus is very scarce on Vancouver Island. Douglas-fir was offered as a food plant because *H. euryalus* larvae have been found locally in Douglas-fir seed orchards. A series of specimens (eggs and neonate through 5th instar larvae) from the 1990 generation was deposited at the Royal British Columbia Museum [catalogue numbers ENT991-64042 through ENT991-64051].

The species was initially identified as *H. euryalus* based on the collection locality, the wing patterns of the adults, and the apparent preference of the larvae for ceanothus as a food plant. Eventually, however, it became obvious that the larvae did not match published descriptions for larvae of *H. euryalus*, in which all of the dorsal scoli in 4th and 5th instars are bright yellow (cf. Arnett and Jacques 1981). The reared larvae had red-orange dorsal scoli (Plate 1), with no discernable variation in this character among any of the ca. 250 larvae reared during the past three years. This larval phenotype is distinct from both *H. euryalus*, in which the dorsal scoli are yellow, and *H. gloveri*, in which the dorsal scoli are red-orange in 4th instar but yellow in 5th instar larvae (Ferguson 1972). It is also noteworthy that the form of the dorsal scoli in 5th instar larvae resembles more closely that of *H. euryalus* than that of *H. gloveri* (cf. Tuskes 1976).

H. e. kasloensis shows many characters that are intermediate between *H. euryalus* and *H. gloveri*, particularly in adult wing patterns, and may well have originally arisen through hybridization between these two species as proposed by Ferguson (1972). However, the fact that the larvae show a phenotype that is different from both of the supposed parental species suggests that this form should be considered distinct, particularly when dorsal scoli colouration is used as the primary diagnostic character for distinguishing species in larvae of *Hyalophora* (cf. Ferguson 1972). The name *H. e. kasloensis* seems appropriate because of its apparent affinities with *H. euryalus* and the fact that the specimen designated as lectotype was collected at Kaslo, B.C. (Ferguson 1972). Further studies, involving cross-breeding with *H. euryalus* and *H. gloveri* as well as surveys of the geographic range of the *H. e. kasloensis* phenotype, are required to firmly establish the taxonomic status of this distinct form of *Hyalophora*.

Plate 1. Late 4th (top) and early 5th (bottom) instar larvae of *Hyalophora euryalus kasloensis* (Cockerell) (Lepidoptera: Saturniidae) on *Ceanothus sanguineus* Pursh (Rhamnaceae), July 1989.

ACKNOWLEDGEMENTS

Thanks to T.J. Simonson for invaluable assistance in collecting adults and rearing larvae in 1988 and 1989, and to M. Gardiner for mating adults and collecting their eggs in the spring of 1990. Special thanks to H.W. Morewood for providing financial support for this publication.

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cis-Verbenol: An aggregation pheromone for the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae)

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ABSTRACT

cis-Verbenol increased catches of male mountain pine beetles, *Dendroctonus ponderosae* Hopkins, to multiple-funnel traps baited with myrcene and *exo*-brevicomin. *cis*-Verbenol had no effect on the response of males to traps baited with myrcene, *exo*-brevicomin and *trans*-verbenol. In contrast, *cis*-verbenol increased catches of female *D. ponderosae* to semiochemical-baited traps irrespective of the absence or presence of *trans*-verbenol. Our results demonstrate that *cis*-verbenol is an aggregation pheromone for *D. ponderosae* and that the combination of *cis*- and *trans*-verbenol elicits sex-specific responses.

Additional keywords: *trans*-verbenol, myrcene, *exo*-brevicomin, sex-specificity.

INTRODUCTION

Various studies on the use of semiochemicals by the mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae), including some that were specifically aimed at determining the effect of *trans*-verbenol, inadvertantly used *trans*-verbenol contaminated with 6-20 % *cis*-verbenol (Pitman 1971; Billings *et al.* 1976; Ryker and Rudinsky 1982; Borden *et al.* 1983; Conn *et al.* 1983). The role of *trans*-verbenol as a pheromone for *D. ponderosae* has subsequently been verified with chemical purities >97% (Ryker and Rudinsky 1982; Libbey *et al.* 1985; Borden *et al.* 1987).

However, no attempt has been made to discern the role of *cis*-verbenol in the chemical ecology of *D. ponderosae* and interpretation of studies using contaminated *trans*-verbenol must therefore be suspect. The issue is of economical importance since *D. ponderosae* is a major pest of lodgepole pine in the Pacific northwest (Safranyik *et al.* 1974; Furniss and Carolin 1980). Semiochemical-based manipulation of *D. ponderosae* has become a major component of lodgepole pine silviculture in British Columbia (Borden and Lacey 1985) Due to production costs, the tree bait most commonly used against *D. ponderosae* contains a 13:87 mix of *cis*- and *trans*-verbenol (Phero Tech Inc., Delta BC), together with myrcene and *exo*-brevicomin. *Dendroctonus ponderosae* uses myrcene as a kairomone (Billings *et al.* 1976; Conn *et al.* 1983; Libbey *et al.* 1985; Borden *et al.* 1987) and both enantiomers of *exo*-brevicomin as male-produced pheromones (Pitman *et al.* 1969; Rudinsky *et al.* 1974; Pitman *et al.* 1978; Borden *et al.* 1983; Libbey *et al.* 1985; Borden *et al.* 1987).

Our objective was to demonstrate that *cis*-verbenol is an aggregation pheromone for *D. ponderosae* in stands of lodgepole pine. *cis*-Verbenol is produced by *D. ponderosae* (Pitman *et al.* 1969; Hughes 1973; Ryker and Rudinsky 1982; Libbey *et al.* 1985; Pierce *et al.* 1987; Hunt *et al.* 1989). Antennae of both sexes of *D. ponderosae* are sensitive to *cis*- and *trans*-verbenol equally (Whitehead 1986; Whitehead *et al.* 1989). It is quite probable, therefore, that *cis*-verbenol is a pheromone for *D. ponderosae*. We tested the

two following hypotheses: 1) *cis*-verbenol should increase attraction of *D. ponderosae* to traps baited with myrcene and *exo*-brevicomin; and 2) *cis*- and *trans*-verbenol should have an additive effect on the attraction of *D. ponderosae*.

MATERIALS AND METHODS

cis-Verbenol was prepared by reduction of *S*-(-)-verbenone by the alkoxy-substituted lithium aluminum hydride method (Brown and Deck 1965) and concentrated *in vacuo*. *trans*-Verbenol was prepared by subjecting *cis*-verbenol to acid-catalysed isomerisation at 23 °C (Cooper *et al.* 1967) and purified by flash chromatography on silica gel (Still *et al.* 1978). Chemical and optical purities of verbenols were determined by split, capillary, gas chromatography (Hewlett Packard HP 5890 using a 30-m X 0.32-mm ID DB-1 fused silica column), before and after derivatisation to acetyl lactate diastereomers (Slessor *et al.* 1985). The chemical purities of *cis*- and *trans*-verbenol were 97 and 99%, respectively, while the chiral ratios were identical at 83% *S*-(-): 17% *R*-(+).

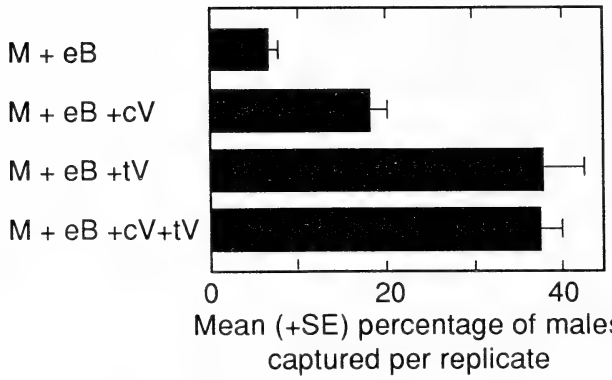
Verbenol lures consisted of polyethylene, bubble-cap devices (Phero Tech Inc., Delta BC) containing 1,3-butanediol solutions of *cis*- and *trans*-verbenol, respectively. The release rates of *cis*- and *trans*-verbenol were approximately 3.38 and 2.58 mg/day at 24-27 °C (determined by weight loss). Phero Tech Inc. (Delta BC) supplied the following additional lures: 1) (±)-*exo*-brevicomin (chemical purity, 98%) laminar lures ; and 2) ß-myrcene (chemical purity, 98%) in closed, polyethylene, screw-cap bottles (15 mL). The release rates of *exo*-brevicomin and myrcene were approximately 0.01 and 281 mg/day, respectively, at 24 °C (determined by collection of volatiles on Porapak-Q for *exo*-brevicomin and by weight loss for myrcene).

Forty, 8-unit, multiple-funnel traps (Lindgren 1983) (Phero Tech Inc., Delta BC) were set in 10 replicate grids of 2 x 2 in stands of mature lodgepole pine near Princeton BC. Grids were spaced at least 100 m apart, and traps were set 10-15 m apart within each replicate. Each trap was suspended between trees by rope so that the top funnel of the trap was 1.3-1.5 m above ground. No trap was within 2 m of any tree. All traps were set during the period of 2 to 26 September 1989. Treatments were randomly assigned within each replicate. The control treatment consisted of myrcene and *exo*-brevicomin while the remainder consisted of myrcene, *exo*-brevicomin and one of the following: 1) *cis*-verbenol; 2) *trans*-verbenol; 3) *cis*- and *trans*-verbenol. Sexes in subsamples (N=20) of tured *D. ponderosae* were determined by dissection and internal examination of genitalia.

The data were analysed using the SAS statistical package ver. 5.0 (SAS Institute Inc., Cary NC). For each sex, trap catch data, transformed by ln(Y+1), were subjected to 3-way ANOVA, using replicate, *cis*-verbenol, *trans*-verbenol, and the interaction of *cis*- and *trans*-verbenol, as model factors. Two orthogonal contrasts were performed on each data set, comparing catches in traps baited with myrcene and *exo*-brevicomin against catches to traps baited with myrcene, *exo*-brevicomin and *cis*-verbenol and catches to the combination of myrcene, *exo*-brevicomin and *trans*-verbenol against catches to traps baited with all four components.

RESULTS AND DISCUSSION

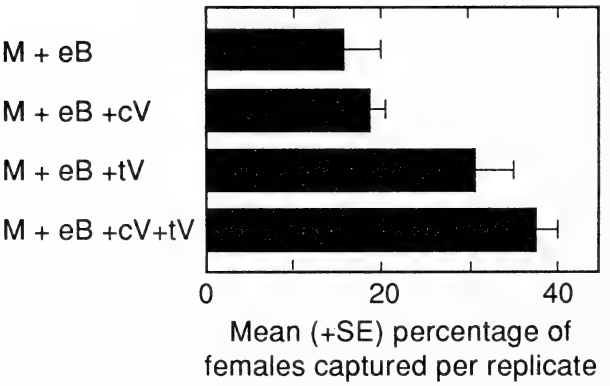
Both *cis*- and *trans*-verbenol significantly increased the catches of *D. ponderosae* to semiochemical-baited funnel traps (Figs. 1 and 2), although the effect of *cis*-verbenol on females was only weakly significant. There was a significant interaction between *cis*- and *trans*-verbenol on the capture of male *D. ponderosae* (Fig. 1). Catches of males in traps baited with myrcene, *exo*-brevicomin and *trans*-verbenol were not significantly different from catches in traps baited with all four components (orthogonal contrast, F(1,35), P=0.750). Catches of males in traps baited with myrcene, *exo*-brevicomin and *cis*-verbenol were significantly higher than those in traps baited with myrcene and *exo*-brevicomin alone (orthogonal contrast, F(1,35), P=0.004). In contrast, there was no interaction between *cis*- and *trans*-verbenol on the catches of female *D. ponderosae* (Fig. 2).



ANOVA

Source	df	P
A	9	0.651
B	1	< 0.001
C	1	0.058
B*C	1	0.018
Error	26	

Figure 1. The effects of *cis*- (cV) and *trans*-verbenol (tV) on the attraction of male *D. ponderosae* to multiple-funnel traps baited with myrcene (M) and *exo*-brevicomin (eB) near Princeton BC from 2 to 26 September 1989 (n=10). Data were transformed by ln(Y+1) and subjected to ANOVA using the following model factors: replicate (A), *cis*-verbenol treatment (B), *trans*-verbenol treatment (C), and the interaction between *cis*- and *trans*-verbenol treatments (B*C). The total number of males caught was 2303.



ANOVA

Source	df	P
A	9	0.001
B	1	< 0.001
C	1	0.089
B*C	1	0.984
Error	26	

Figure 2. The effects of *cis*- (cV) and *trans*-verbenol (tV) on the attraction of female *D. ponderosae* to mutiple-funnel traps baited with myrcene (M) and *exo*-brevicomin (eB) near Princeton BC from 2 to 26 September 1989 (n=10). Data were transformed by ln(Y+1) and subjected to ANOVA using the following model factors: replicate (A), *cis*-verbenol treatment (B), *trans*-verbenol treatment (C), and the interaction between *cis*- and *trans*-verbenol treatments (B*C). The total number of females caught was 5303.

Our results demonstrate that *cis*-verbenol is an aggregation pheromone for *D. ponderosae*. It is produced by female *D. ponderosae* (Pitman *et al.* 1969; Hughes 1973; Ryker and Rudinsky 1982; Libbey *et al.* 1985; Pierce *et al.* 1987) and is attractive to both sexes (Figs. 1 and 2). Interpretations of results from previous studies that used *trans*-verbenol, with chemical purities less than 97%, should consider the effect of *cis*-verbenol, and the possible interactions of *cis*-verbenol with other treatments.

Our results further show that *cis*- and *trans*-verbenol have an additive effect on the attraction of female *D. ponderosae* but not on male *D. ponderosae*. The interaction

between the verbenols resulted in sex-specific responses; males and females responded differently to *cis*- and *trans*-verbenol separately than to the combination of verbenols (Figs. 1 and 2). These sex-specific responses may be a function of either the presence of both verbenols together or of the ratio of verbenols. The ratio of *cis*- and *trans*-verbenol following autoxidation of α-pinene ranges from 29:71 to 20:80 (Hunt *et al.* 1989). Axenically-reared *D. ponderosae* produce verbenol with a *cis:trans* ratio of 14:86 when exposed to α-pinene odors while wild beetles produce a ratio of 2:98 (Hunt *et al.* 1989).

Regardless of the mode of specificity, both *cis*- and *trans*-verbenol are required to maximise the attraction of female *D. ponderosae*. Since females initiate attacks on trees (Safranyik *et al.* 1974), it is critical that tree baits used in silvicultural practices to control populations of *D. ponderosae* contain both pheromones . Fortunately the bait currently employed operationally for controlling *D. ponderosae* contains both *cis*- and *trans*-verbenol at a ratio of 13:87 (Phero Tech Inc., Delta BC), well within the range of observed production ratios.

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Melanchra picta (Harris) (Lepidoptera: Noctuidae), a cutworm new to British Columbia

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Here we report the occurrence of the zebra caterpillar, *Melanchra picta* (Harris) as a minor pest of commercial cranberries, *Vaccinium macrocarpon* Ait., in Langley and Pitt Meadows, British Columbia, during the summer of 1991. In the field, zebra caterpillars ate the growing tips of cranberry runners and uprights. In the laboratory, larvae preferred succulent cranberry tissue, consuming mature leaves only if no new growth remained. In the field and laboratory, larvae also consumed the foliage of dicotyledonous weeds such as cutleaf blackberry, *Rubus laciniatus* Willd., western St. John's wort, *Hypericum formosum* Humboldt, marsh St. John's wort, *Triadenum virginicum* L., and Watson's willow herb, *Epilobium watsonii* Barbey. In eastern Canada, zebra caterpillars have been reported to feed on a wide variety of fruit, vegetable, and leguminous forage crops (Beirne, 1971).

Early records of zebra caterpillar infestations in British Columbia (Cockle, 1911; Middleton, 1913) actually referred to *Mamestra canadensis* Smith, now considered a synonym of *Lacanobia nevadae* (Grote). In Canada, the zebra caterpillar, *M. picta*, occurs from the Atlantic coast, west to the foothills of the Rocky Mountains, whereas in the U.S.A. its range extends further west into California, Oregon, and Washington. There are no specimens of *M. picta* from B.C. in the Canadian National Collection, the Royal British Columbia Museum, or the Spencer Collection, University of British Columbia, nor does *M. picta* appear on lists of B. C. fauna (*e.g.* Llewellyn Jones, 1951). Recent reports of *M. picta* on strawberries, *Fragaria* x *ananassa* Duch., in 1981, highbush blueberries, *Vaccinium corymbosum L.*, in 1983 (Belton, 1988), and corn, *Zea mays* L., in 1990 (Philip, 1991) in B. C. probably refer to this species. Since the zebra caterpillar has previously been found very close to the B.C. border in Washington State, (Tonasket, 40 km south of Osoyoos, B.C.; Puyallup, 55 km south of Seattle), we believe that its presence in B. C. represents a recent range extension rather than an introduction.

The zebra caterpillar is not usually a significant pest, but local outbreaks have been recorded from eastern Canada (Beirne, 1971). The larva has a red head capsule and a black stripe running down its back. On each side of its body, a black longitudinal stripe, broken with narrow, white, vertical lines, runs between two bright yellow stripes. *M. picta* is bivoltine, with larvae present during late June and July and again in September in the Fraser Valley. Its presence on cranberries, an economically important crop in B. C., bears watching.

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Distribution of European winter moth, *Operophtera brumata* (L.)[1], and Bruce spanworm, *O. bruceata* (Hulst), in the lower Fraser Valley, British Columbia

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ABSTRACT

Sixteen pheromone traps, baited with (Z,Z,Z)-1,3,6,9-nonadecatetraene, were placed in commercial blueberry and raspberryfields, and at one woodland site in the lower Fraser Valley. Traps were monitored weekly from early November, 1990 until late January, 1991. Winter moth males were recovered from all but the eastern-most trap in Mission. Four traps in blueberry fields in Richmond caught a total of 2,928 winter moths, and 198 were caught in two traps in Delta and Surrey, whereas only 74 came to the ten traps north and east of Surrey. A total of 1,306 Bruce spanworm males were trapped. Although spanworm moths were recovered from traps in all areas, there was no correlation between trap location and number of spanworms caught. Thirteen males with characters intermediate between the two species were trapped in Richmond and Surrey. Males of both species were more numerous in raspberries than in nearby blueberry fields. Spanworm males came to the traps later in the fall than winter moths. East of Richmond, most spanworm males were trapped during November whereas, in Richmond, very few were attracted until the first week of December.

INTRODUCTION

The polyphagous European winter moth, *Operophtera brumata* (L.), was first detected in British Columbia in the mid-1970's (Gillespie *et al.*, 1978) and has become a serious pest of highbush blueberries, *Vaccinium corymbosum* L., in Richmond, B.C. (Sheppard *et al.*, 1990). In 1988, the B.C. Blueberry Co-operative Association was forced to cancel over 1.36 million kg in sales (Whaley, 1989) because larval damage to blossoms prevented entire plantings from producing fruit.

Fruit growers in the lower Fraser Valley east of Richmond are concerned that winter moths will spread undetected into their area and damage their crops. Although the female moths are flightless, larvae may be carried by the wind (Edland, 1971) and eggs and larvae can be inadvertently transported on nursery stock. To provide growers east of Richmond with an early warning system, we used pheromone traps to map the distribution of the winter moth in the lower Fraser Valley. We were able to detect the Bruce spanworm as well as the winter moth, because the pheromone isolated from winter moth females (Roelofs *et al.*, 1982) has also been isolated from spanworm females (Underhill *et al.*, 1987) and attracts males of both species (Roelofs *et al.*, 1982; Underhill *et al.*, 1987). Here we report the numbers of males of both species attracted to pheromone traps during November, 1990, to January, 1991, in blueberry-and raspberry-growing areas of the lower Fraser Valley.

METHODS AND MATERIALS

Pheromone trapping

Sixteen double-cone orifice traps (Hara traps; Hara Products Ltd., Swift Current, Sask.) were baited with rubber septa impregnated with 100 µg of (Z,Z,Z)-1,3,6,9-nonadecatetraene, the winter moth pheromone, and placed at field sites on October 31, 1990. Aninsecticide-containing strip (S.W.A.T. Insect Strip; Green Cross, Ltd.) was placed in each trap and the trap cones were covered with fine screening to keep birds from eating dead moths. Single traps were placed in four commercial blueberry fields in the municipality of Richmond (Fig. 1: 1-4), eight commercial blueberry fields from Delta to the eastern-most site in the municipality of Mission (Fig. 1: 5-9, 14-16) and in three commercial raspberry fields from Langley to Matsqui (Fig. 1: 11-13). One trap was placed in a mixed coniferous/deciduous forest at least 1 km away from cultivated land in Langley (Fig. 1: 10). Traps were emptied weekly from November 6 to December 18, 1990, and then on January 23 and 30, 1991. Very bad weather prevented us from reaching some of the sites between late December and mid-January.

Moth identification

Several authors have described external characters (Brown, 1962; Cuming, 1961; Pivnick, 1988) and genitalic characters (Eidt *et al.*, 1966; Ferguson, 1978; Wolff, 1964) of the two moths. To identify specimens accurately, we found it necessary to use a synthesis of these characters plus some previously unreported ones, and to quantify the dimensions of genitalic characters (Table 1).

Data analysis

Where appropriate, the data were analyzed by Spearman rank correlation or t-test.

Table 1
Characters used to separate males of the Bruce spanworm, *Operophtera bruceata* (Hulst), from males of the European winter moth, *Operophtera brumata* (L.)

Type of Character	Spanworm	Winter moth
External		
Wings	distinct lines and bands on dorsal surfaces	lines on dorsal forewing are obscure; often no lines on dorsal hindwing
Forewing	pale yellow-orange ventral costal margin[1]	yellow-orange colour faint to absent
Hindwing*	dark dorsal discal dot	dot absent
Abdomen*	golden brown[2]	brown
Genitalic[3]		
Uncus	narrow (< 0.12 mm); nearly parallel-sided; not spatulate	wider (*ca.* 0.14 mm); slightly spatulate
Juxta	shallow medial notch at base; dorsal process wide (*ca.* 0.25 mm) at base	divided at base by a medial cleft; dorsal process narrowed (ca. 0.16 mm) at base
Saccus	long (*ca.* 0.63 mm); as long as or longer than width at base of valva	short (*ca.* 0.40 mm); shorter than width at base of valva

* Previously unreported characters
1, 2 True only of Bruce spanworms in B.C.
3 Genitalic characters are illustrated in Eidt *et al.* (1966).

RESULTS

A total of 3,200 winter moths, 1,306 spanworms and 13 moths with characters intermediate between the two species were trapped during the 13-week period. Most (2,928) of the winter moths were recovered from the four blueberry fields in Richmond (Fig. 1: 1-4; Spearman rank correlation coefficient = 0.8294, $p < 0.001$, $n = 16$). A total of 198 winter moths were captured in Delta and Surrey (Fig. 1: 5 and 6), and 74 came to the ten traps north and east of Surrey (Fig. 1: 7-16). More winter moths were trapped in the three raspberry fields (Fig. 1: 11-13; $\bar{X} \pm S.D. = 10.0 \pm 11.27$ per trap) than in three nearby blueberry fields (Fig. 1: 9, 14 and 15; $\bar{X} \pm S.D. = 3.33 \pm 4.04$ per trap; $t = 2.95$, $p = 0.042$). No winter moths were recovered from the trap in Mission (Fig. 1: 16).

Spanworms were recovered from all sites, but there was no correlation between trap location and number of spanworms caught (Spearman rank correlation coefficient = -0.0106, $p \geq 0.05$, $n = 16$). More spanworms were found in the three raspberry fields (Fig. 1: 11-13; $\bar{X} \pm S.D. = 90.33 \pm 101.5$ per trap) than in three nearby blueberry fields (Fig. 1: 9, 14 and 15; $\bar{X} \pm S.D. = 42 \pm 45.18$ per trap; $t = 6.912$, $p = 0.0023$).

Eleven of the 13 moths with characters intermediate between the two species were trapped in Richmond (Fig. 1: 1-4); two were trapped in Surrey (Fig. 1: 5).

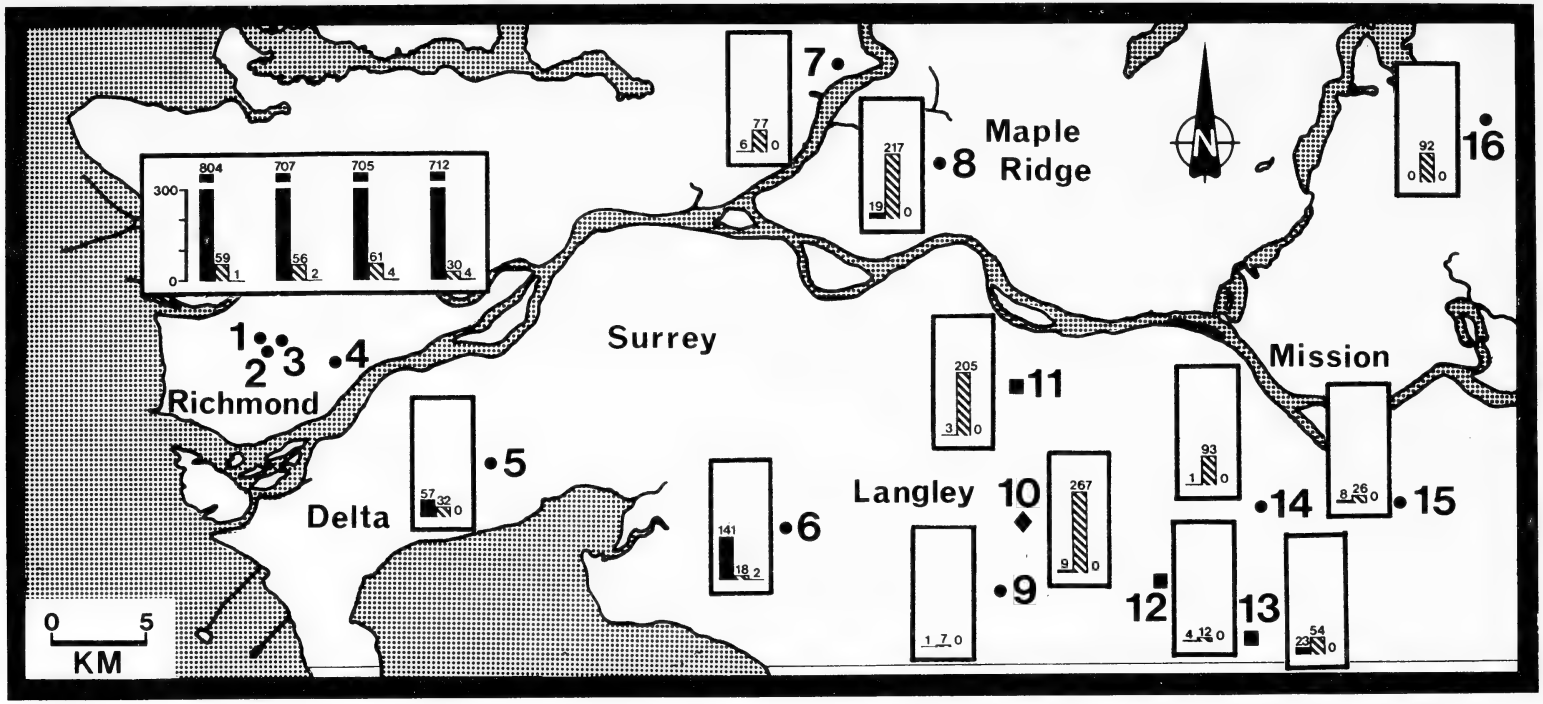

Figure 1. The lower Fraser Valley of British Columbia showing the location of pheromone traps for the European winter moth, *Operophtera brumata* (L.), and Bruce spanworm, *O. bruceata* (Hulst). Traps in blueberry fields are represented by circles, those in raspberry fields by squares, and the one in coniferous/deciduous woodland by a diamond. Traps 13, 14 and 15 lie within the municipality of Matsqui. Total numbers of winter moths (first column, solid bars), spanworms (second column, hatched bars) and moths with characters intermediate between the two species (third column) are indicated near each trap site.

Table 2
Numbers (#) and cumulative percentages (%) of Bruce spanworm, *Operophtera bruceata* (Hulst), males collected from four pheromone traps in Richmond and 12 traps east of Richmond during November, 1990, to January, 1991.

Date	Richmond (4 traps) #	%	East of Richmond (12 traps) #	%
Nov. 6	0	0	13	1.2
Nov. 13	3	1.5	151	15.0
Nov. 20	2	2.5	135	27.2
Nov. 28	15	9.7	328	57.0
Dec. 3	57	47.1	251	79.8
Dec. 11	46	69.4	162	94.5
Dec. 18	52	94.7	55	99.6
Jan. 23	11	100	5	100

Most winter moths were trapped earlier in the fall than most spanworms (Fig. 2). By the fourth week of November, 86% of the total number of winter moths had been recovered from the traps, whereas only 50% of the spanworm males had been caught. The mothswith intermediate characters were trapped during the first, second and third weeks of November, and the second week of December.

In Richmond, very few spanworms (< 10% of the total number caught) were trapped until the first week of December but, further east, most (57%) had come to the traps by the last week of November (Table 2).

DISCUSSION

The European winter moth is well established on blueberries in Richmond, and is present in blueberry and raspberry plantings as far east as Matsqui (Fig. 1). We found winter moths at one coniferous/deciduous site east of Richmond and suspect that they may be established at other wooded sites in the Valley. We recommend that growers east of Richmond, especially those in Delta and Surrey, monitor their plants closely in late March and early April when winter moth eggs hatch.

The Bruce spanworm is also present throughout the lower Fraser Valley (Fig. 1), but there is no correlation between location and number of spanworms trapped. Although spanworms were numerous in Maple Ridge and Langley (Fig. 1: 8, 11), there is no history of economic damage to fruit crops in these areas.

Both species were more numerous on raspberries than on nearby blueberries, suggesting that they may prefer, or have a higher fitness on, raspberries. A more extensive survey and developmental studies are needed to test this hypothesis.

Spanworm adults generally emerge later in the fall than winter moths (Hale, 1989), so the pheromone trap counts (Fig. 2) probably reflect the flight periods of the two species except, perhaps, in Richmond, where spanworms were trapped even later than at sites further east (Table 1). We suspect that spanworm males emerging in Richmond in November may have been attracted to calling winter moth females rather than to pheromone traps. Several facts support this hypothesis. The pheromone (Z,Z,Z)-1,3,6,9-nonadecatetraene has been isolated from winter moth (Roelofs *et al.* 1982) and spanworm (Underhill *et al.* 1987). Spanworm males can mate successfully with winter moth females, but pairings between winter moth males and spanworm females rarely succeed (Hale, 1989). We recovered several possible hybrids from traps in Richmond and Surrey,

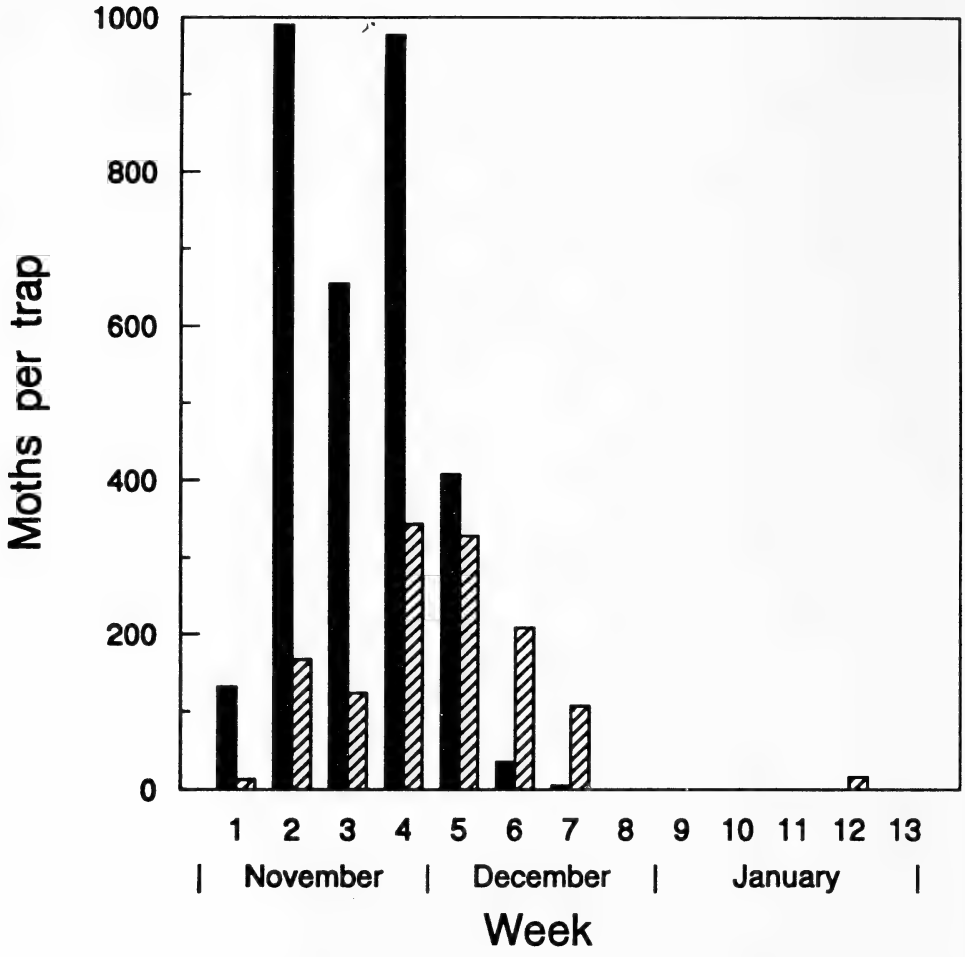

Figure 2. Total numbers of the European winter moth, *Operophtera brumata* (L.), (solid bars) and the Bruce spanworm, *O. bruceata* (Hulst), (hatched bars) caught in pheromone traps in the lower Fraser Valley during the fall and winter of 1990-91. The spanworms recovered from traps during week 12 were probably attracted during the preceding four weeks, when traps were not emptied.

suggesting that interspecific mating may be occurring in the field. An alternative explanation for the delayed spanworm catch in Richmond is that hybridization problems (Hale, 1989) may have resulted in natural selection for late-emerging spanworm.

Our results show that monitoring with pheromone traps can be used to indicate the presence of adult winter moths, and to identify regions where the risk of winter moth damage to crops is high. A pheromone-trap survey of the Okanagan Valley would provide an early warning system for this pest in that area.

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Cuticular metal hardening of mouthparts and claws of some forest insects of British Columbia.

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ABSTRACT

The presence of metals in mouthparts and claws of some forest insects associated with British Columbia conifers, particularly cone and seed pests, were detected and mapped by energy dispersive X-ray microanalysis. Zinc was concentrated in the mandibular cutting edges and claw tips of larval lepidopterans (but not in adult mouthparts), in the mandibles and claws of larval and adult coleopterans and in the mandibles of the hymenopteran, *Megastigmus spermatotrophus*. Calcium was the predominant metal in the mouth hooks of dipteran larvae, but minor peaks of zinc or manganese were present additionally in two species. Manganese occurred in the stylets of the hemipteran, *Leptoglossus occidentalis*, in the mandibles and claws of one coleopteran species, and with zinc in the mandibles of a clerid predator. The function of metal concentrations in specific areas of these structures is probably related to hardening of cuticular regions in some instances and to some other biomechanical aspect of cuticular strengthening in other cases.

INTRODUCTION

Forest insect pests, especially those that feed on developing cones and seeds or damage potential seed-bearing branches, have a major economic impact on coniferous forest productivity and regeneration in British Columbia (Ruth, 1980; Wood and Van Sickle, 1987). It is of interest to forest entomologists, therefore, to know that mouthparts and claws of some of these herbivorous pests appear to be hardened by cuticular metal deposits that may affect abrasive wear or confer strength biomechanically. We have surveyed some B.C. forest insects, emphasizing seed and cone pests, for evidence of cuticular metal hardening using energy dispersive X-ray microanalysis (EDXa) to detect metals, and X-ray mapping to show their morphological distribution. The information presented here has implications in the ecology of forest insect pests and is a base for studies on the interrelationship between hardening of insect mouthparts, particularly during development, and insect feeding strategies.

Use of metals, such as iron, zinc, copper, manganese or silicon, to harden mouthparts and other structures as an adaptation against excessive wear is widespread among both aquatic and terrestrial invertebrates (Simkiss and Wilbur, 1989). This adaptation also occurs in insects, though its extent is not particularly well known. Concentration of zinc in the mandibles of two locust species, the original accounts of cuticular metal hardening in insects, was related to resistance to wear in relation to feeding on tough plant material (Hillerton and Vincent, 1982; Hillerton, Reynolds and Vincent, 1982). Hillerton and Vincent (1982) also used EDXa and X-ray mapping to demonstrate the specific location of zinc or manganese along the cutting edge of chewing structures in 36 herbivorous species from 5 orders; five omnivores from 2 orders did not have metals in their mouthparts. Subsequently Hillerton, Robertson and Vincent (1984) demonstrated zinc or manganese in the mandibles of 54 (out of 57) species of stored-product beetles, thus emphasizing the major role of these metals in increasing the hardness of chewing structures. Co-occurrence of metals, i.e., two metals occurring in the same structure, has been reported in some species, but its significance is not well understood. For example, ion microprobe techniques have demonstrated concentrations of both zinc (about 4%) and manganese (about 0.4%) in the mandibular teeth of ants (Lefevre *et al.*, 1987; Schofield *et al.*, 1988).

Calcium, the only other metal commonly found in insect cuticle, is prominent in Diptera, notably in muscid flies where its presence has been related functionally to stabilization of the puparial cuticle as an alternative to sclerotization, not as a hardening mechanism to resist abrasion (Grodowitz and Broce, 1983; Roseland *et al*, 1985).

MATERIALS AND METHODS

Specimens of insect larvae and adults (Table 1) were obtained from culture stocks and collections of the Pacific Forestry Centre, Victoria, B.C., through the assistance of Mr. D. S. Ruth. Usually they were received preserved in 70% ethanol after previous fixation, but some live specimens were fixed by us in 2.5% glutaraldehyde in phosphate buffer, pH 7.4.

The appropriate mouthparts (mandibles, stylets, or mouth hooks) and claws were removed, dehydrated in a graded ethanol series and air dried; alternatively they were removed after dehydration and critical point drying. Dried structures were mounted on carbon boats using carbon paste, then lightly sputter coated with gold. Although artifactual gold peaks were thus introduced, gold-coating reduced the extreme charging problems encountered in carbon-mounted specimens. EDXa was performed with a Tracor Northern 5500 EDXa system mounted on a JEOL 1200EX scanning transmission electron microscope operated in the scanning electron microscope (SEM) mode. X-ray spectra were typically acquired from specimens tilted to 30° for 100 seconds over the energy range 0-20 keV, at an accelerating voltage of 40 kV, beam current 15 mA. Digital video images of the specimens and corresponding X-ray maps, with appropriate controls, were acquired and processed using Tracor Northern software. Some SEM morphology was carried out

Table 1
Taxonomic list of the forest insects surveyed, including stage of development and collection data.

Species	Common name	stage of life cycle	Collection data
LEPIDOPTERA			
Barbara colfaxiana (Kearfott)	Douglas fir cone moth	eggs instars 1-4 adult females	Keremeos B.C. 18/5/87 cone collection 28/6/84
Cydia strobilella (L.)	Spruce seed moth	instar 1 instar 4	Tappen, B.C. 26/5/87 White spruce cones, Smithers, B.C. 6/8/68
Dioryctria abietivorella (Grote)	Fir coneworm	larva	Mesachie Lake, B.C. 18/8/80
Dioryctria reniculelloides Muutura and Munroe	Spruce coneworm	larva	Oliver, B.C. 26/5/87
Holocera immaculella McDermott	Douglas fir fall coneworm	larva	Hedley, B.C. 2/6/87
DIPTERA			
Contarinia oregonensis Foote	Douglas fir cone gall midge	larva	Mesachie Lake, B.C. 15/8/86
Delia anthracina (Czerny)	Spiral spruce cone maggot	instars 1-4 eggs	White spruce cones, Prince George, B.C. 11/6/87 Tappen, B.C. 26/5/87
Earomyia abietum McAlpine	Fir cone maggot	larva	Grand fir cones, Ladysmith, B.C. 6/8/68
Earomyia barbara McAlpine	Fir cone maggot	larva	Douglas fir cones, Ladysmith, B.C. 28/8/72
HEMIPTERA			
Leptoglossus occidentalis Heidemann	Seed bug	instars 1, 2 adult	lab rearings 22/5/87 lab rearings 8/5/87
HYMENOPTERA			
Megastigmus spermatotrophus Wachtl	Douglas fir seed chalcid	larva	Douglas fir cone seed, Courtney, B.C. 19/9/71
COLEOPTERA			
Dendroctonus ponderosae Hopkins	Mountain pine beetle	instars 3, 4; adults	from Lodgepole pine held in cold storage. 15/7/87
Enoclerus schaefferi Barr	Checkered beetle, predator upon *B. colfaxiana*	larva	cone collection, Keremeos, B.C. 14/5/87
Neacanthocinus obliquus Le Conte	Long-horned wood borer	adult	lab rearings 15/7/87

Table 2
Metals in the feeding structures and claws of forest insects demonstrated by EDXa.

Species	Stage	Structure	Metals
LEPIDOPTERA			
Barbara colfaxiana	eggs		none
	instars 1-4	mandibles	Zn
		claws	Zn
	adult	mouthparts	none
Cydia strobilella	instar 1	mandibles	Zn
		claws	Zn
	instar 2	mandibles	Zn
		claws	Zn
Dioryctria abietivorella	larva	mandibles	Zn
		claws	Zn
Dioryctria reniculelloides	larva	mandibles	Zn
		claws	Zn
Holocera immaculella	larva	mandibles	Zn
		claws	Zn
DIPTERA			
Contarinia oregonensis	larva	spatula	none
Delia anthracina	eggs		none
	instar 2	mouth hooks	Ca, Mn
	instar 3	cuticle	none
		mouth hooks	Ca, Mn
	instar 4	mouth hooks	Ca, Mn
Earomyia abietum	larva	mouth hooks	Ca
Earomyia barbara	larva	cuticle	Ca
		mouth hooks	Ca, Zn
HEMIPTERA			
Leptoglossus occidentalis	instar 1	proboscis	none
		claws	none
	instar 2	proboscis	Mn
		claws	none
	adult	proboscis	Mn
		claws	none
HYMENOPTERA			
Megastigmus spermatotrophus	larva	mandibles	Zn
COLEOPTERA			
Dendroctonus ponderosae	instar 3	mandibles	Zn
	instar 4	mandibles	Zn
	adult	mandibles	Zn
		claws	Zn
Enoclerus schaefferi	larva	mandibles	Zn, Mn
		claws	Zn
		anal hooks	Zn, Mn
Neacanthocinus obliquus	adult	mandibles	Mn
		claws	Mn

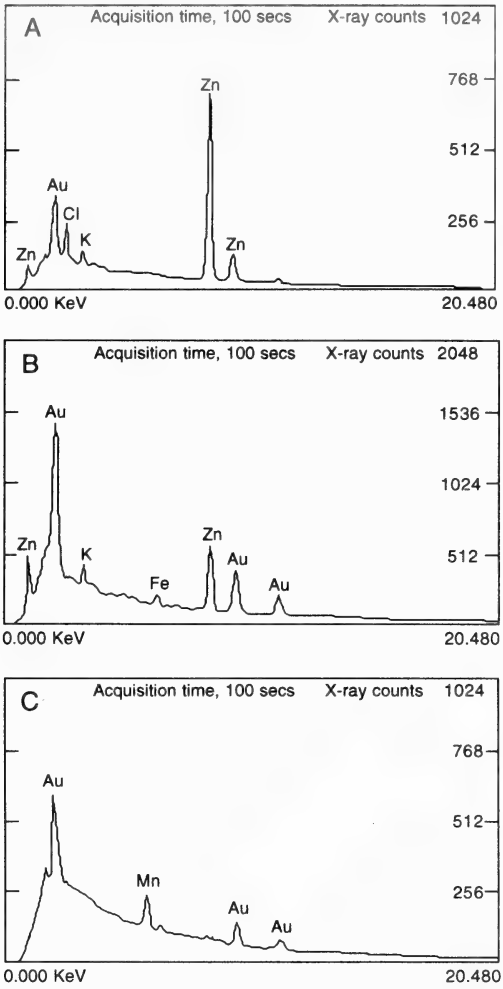

Fig. 1. Representative EDXa spectra. Gold peaks are artifacts as explained in the text. A. From the mandibular cutting edge of *B. colfaxiana*, instar 4, showing prominence of zinc peaks. A chlorine peak is also evident. B. From a claw tip of *B. colfaxiana*, instar 4, showing the presence of zinc. C. From a stylet of an *L. occidentalis* adult, showing a relatively weak manganese peak.

on conventionally prepared specimens using a JEOL JSM-35 scanning electron microscope.

RESULTS

A synopsis of metals detected is shown in Table 2. Each report of a metal finding is based on analysis of at least 3 specimens. Spectra were typically replicated three times for each sample point.

Among lepidopteran species, larvae showed a consistent pattern of zinc accumulations along the cutting edge of the mandibles and in claw tips. Zinc or other metals were not detectable in the cuticle of the body generally except in these areas. Most information on zinc distribution in the lepidopterans available to us is from *B. colfaxiana* for which we had a full range of stages. In that species, zinc is found along the cutting edge of the mandibles in all instars (Figs. 1A, 3) but it is not present in the mouth structures of the adult. We did not attempt accurate quantification but, estimated from X-ray counts for the Zn Kα peaks and comparison of X-ray images, the relative amount of zinc along the mandibular cutting edge apparently increases in each successive instar. Zinc is also precisely localized in the larval claw tips (Figs. 1B, 4). Again each instar shows relatively

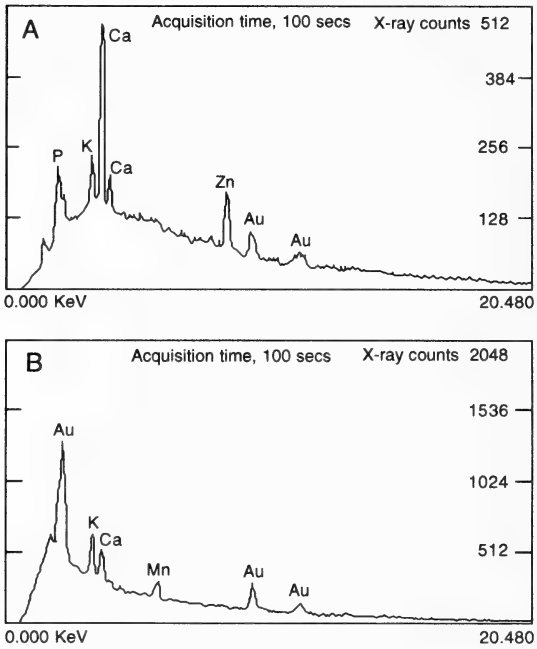

Fig. 2. Representative EDXa spectra from dipteran mouth hooks.. Gold peaks are artefacts as explained in the text. A. From the base of a mouth hook of *Earomyia barbara* showing the co-occurrence of calcium and zinc. B. From the tip of a mouth hook of *Delia anthracina* showing the co-occurrence of calcium and manganese.

greater zinc concentrations, but it is absent from adult claw tips. A chlorine peak accompanies the zinc peak in the mandibles, but chlorine is distributed more widely throughout the mandibular cuticle. Chlorine appears to be in highest concentrations along mandibular cutting edges where zinc is localized. Minor chlorine peaks are inconsistently present in claws, but not generally over the body surface. A potassium peak is common over the entire body surface. Gold peaks are, of course, artifacts of gold-coating.

Although the material available for analysis was not so extensive, the larvae of four other lepidopteran species showed a similar pattern of zinc distribution, accompanied by chlorine as described above. Zinc X-ray images show the spatial distribution of zinc in the mandibles and claw tips of the Douglas fir fall cone worm, *H. immaculella*, for example (Fig. 5, 6), and demonstrate the consistency of the pattern of metal distribution in these lepidopteran species.

Zinc was found in the small mandibles of the larvae of the hymenopteran, *M. spermatotrophus*, but X-ray maps were not successfully obtained because their small size proved difficult to work with. The larvae lack claws.

The coleopteran species did not show a consistent pattern of metal accumulation. The mountain pine beetle, *D. ponderosae*, had major accumulations of zinc in the cutting edges of the mandible of larvae and adults. Small amounts of manganese accompanied zinc in the mandibles of the larval checkered beetle, E. *schaefferi*, and zinc alone occurred in the larval claw tips. The long-horned wood borer, *N. obliquus*, had small accumulations of manganese in adult mandibles and claw tips.

The seed bug, *L. occidentalis*, had small amounts of manganese (Fig. 1C) in stylets of the second instar nymph and adult, but none was detected in the first instar nor in the claws of any of the stages examined. Where manganese occurred, it was not restricted to the tip but was distributed uniformly throughout the stylet.

Dipteran species had complex patterns of metal accumulations, but calcium was typically prominent. Calcium was found widely distributed throughout the cuticle of mouth

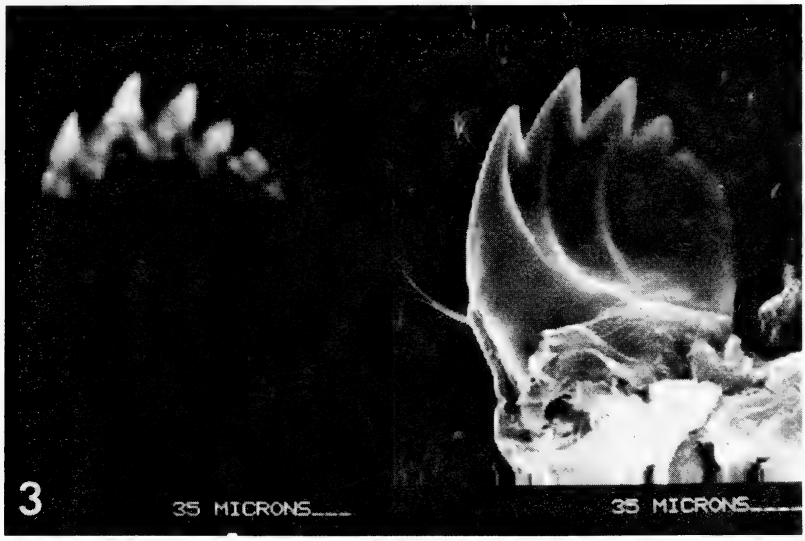

Fig. 3. SEM and zinc X-ray images of the mandible of *Barbara colfaxiana*, instar 3. Right, digitized SEM image of the left mandible, inner surface. Left, zinc X-ray image indicating the morphological distribution of zinc within that mandible

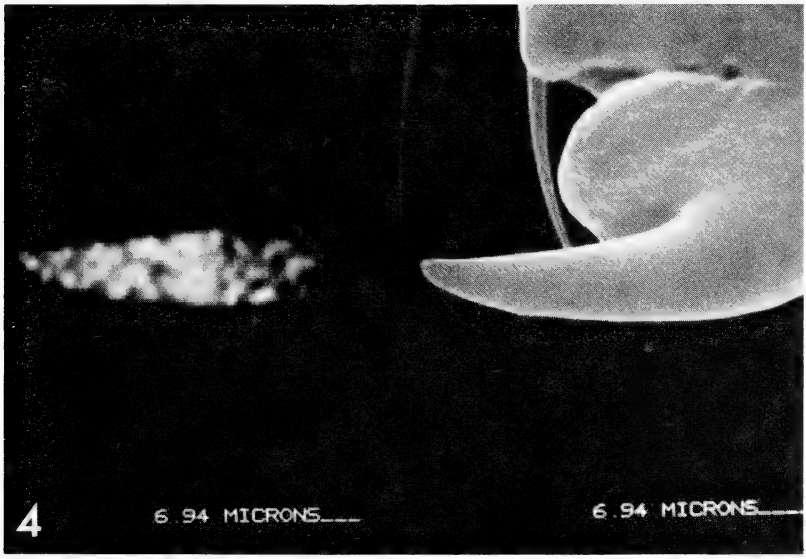

Fig. 4. SEM and zinc X-ray images of a claw of *Barbara colfaxiana*, instar 3. Right, digitized SEM image. Left, zinc X-ray image showing the distribution of zinc in the claw tip.

hooks of all species, with the exception of *C. oregonensis*. Additionally, zinc was detected together with calcium in the mouth hooks of *E. barbara* (Fig 2A) and manganese along with calcium in *D. anthracina* (Fig. 2B). Low levels of calcium were also present throughout much of the larval cuticle of *E. barbara*.

Fig. 5. SEM and zinc X-ray images of the mandible of a larval *Holocera immaculella*. Right, SEM image, left mandible, inner face. Left, zinc X-ray image showing the distribution of zinc in that mandible.

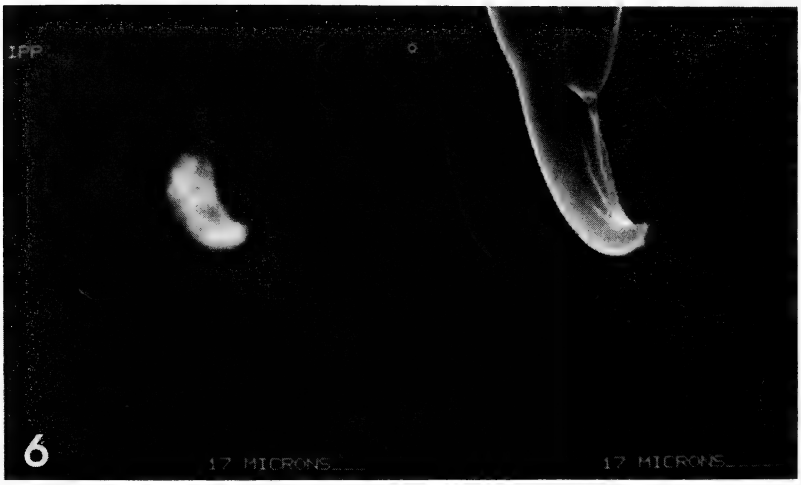

Fig. 6. SEM and zinc X-ray images of a claw of a larval *Holocera immaculella*. Right, SEM image of a claw. Left, zinc X-ray image showing the distribution of zinc in the claw tip.

DISCUSSION

In discussing cuticular metal hardening in arthropods, we are considering non-crystalline, amorphous metal deposits within cuticular substance (Hillerton and Vincent, 1982; Schofield and Lefevre, 1989), a situation distinct from better known hardening mechanisms based on highly ordered biominerals, as in ferric mineral capping of chiton or fish teeth (Sparks *et al.*, 1990).

Cuticular metal hardening in insects appears to have at least two aspects, probably related to differing biomechanical mechanisms. In one case, much metal is deposited in association with a well-defined area subject to wear; for example, zinc deposits along the cutting edge of coleopteran mandibles. In the other situation, relatively little metal is distributed uniformly throughout a structure; for example, manganese in the proboscis of the seed bug where there is too little metal to believe that its mere physical presence confers hardness. However, in a situation like this, a little metal could significantly affect stiffness or some other biomechanical property via promotion of secondary bonding of cuticular proteins (Hillerton and Vincent, 1982; Schofield and Lefevre, 1989). In our view, which of these alternative metal-based adaptations is employed appears to be related to the feeding biology of the insect. In some species, two metals co-occur in a structure, suggesting to us cases where the function and biomechanics of the structure require simultaneous employment of both adaptations.

Our evidence shows that zinc concentrations along mandibular cutting edges and in claw tips are common in herbivorous forest insects, particularly where feeding requires mining through bark or cone scales or prolonged tunneling within inner bark or developing cones (Ruth, 1980; Wood and Van Sickle, 1987). The lepidopteran species examined share a similar feeding strategy, mining as larvae into cones to feed on developing seeds. Zinc is prominent in mandibles and claws of adult and larval mountain pine beetles, *D. ponderosae*, which tunnel through bark as adults and as larvae mine tissues of inner bark. Zinc is found in the mandibles and claws of the checkered beetle, *E. schaefferi*, which, although a predator upon *B. colfaxiana* larvae, mines through bark or cones to find them (Moeck and Safranyik, 1984). The Douglas fir seed wasp, *M. spermatotrophus*, oviposits through cone scales into developing seeds on which its larvae feed (Ruth, 1980; Wood and Van Sickle, 1987) using zinc-hardened mandibles.

Development of toughness in plants is a defensive adaptation known to affect morphology, feeding behaviour and distribution patterns of some herbivorous insects (Feeny, 1970; Djamin and Pathak, 1979; Raupp, 1985). Such relationships are likely to exist in the mouthpart and claw tip adaptations of herbivorous forest insects, particularly cone and seed insects.

Zinc is the metal typically accumulated by terrestrial arthropods for cuticular hardening of the kind described above. For example, zinc occurs in the cheliceral fangs of several spiders (Schofield and Lefevre, 1989), in the tips of chelicerae and pedipalps of a scorpion and in the mouthparts of a mite (Fontaine and Pedersen, unpublished observations). Metals accumulated by aquatic organisms for cuticular hardening are more diverse. Some examples include zinc or copper in marine polychaete jaws (Gibbs and Bryan, 1980), silicon in chaetognath teeth (Bone *et al.* 1983), and silicon and zinc in copepod mandibles (Perry *et al.*, 1983).

The alternative pattern for metal deposition is that the metal occurs in small quantities distributed diffusely within a structure. As suggested above, metals in these situations may have biomechanical roles (e.g., stiffness, resistance to fracture) via metal biochemistry but their function is unlikely to be metal hardening as such. Manganese has this sort of distribution in the species we surveyed. In contrast to the herbivorous insects, the manganese-accumulating species do not mine or chew continually and employ diverse feeding strategies as in, for example, the seed bug, *L. occidentalis*, and the long-horned wood borer, *N. obliquus*. In the seed bug, manganese occurred in the stylets of the second instar and adult which feed on cone seeds by inserting the stylet through the tough seed coat, enzymatically digesting and then ingesting the endosperm (Ruth, 1980). The first instar nymph feeds on foliage rather than on seeds and lacked any metal in the stylets. In contrast to the herbivorous chewing insects, mouthparts like these must have different biomechanical requirements which, in our opinion, are reflected in the metal distribution pattern.

Major amounts of calcium deposits in insect cuticle seem to be restricted to dipteran species, according to our results and others (Grodowitz and Broce, 1983; Roseland *et al*, 1985). Calcium may be functionally analogous to manganese since it also occurs in small

quantities with a diffuse distribution. However, it is interesting to note that calcium co-occurs with manganese in *D. anthracina* mouth hooks and with zinc in *E. barbara* mouth hooks.

Co-occurring metals (calcium/manganese in *D. anthracina*; calcium/zinc in *Earomyia barbara*; manganese/zinc in *Enoclerus schaefferi*) suggest structures where interaction of two distinct biomechanical mechanisms is required and is accomplished by using different metal hardening processes (Schofield et al., 1988; Schofield and Lefevre, 1989). Once again, these differences may reflect adaptive requirements based on feeding or dietary differences, such as relative abrasiveness of food. Among the fir cone maggots, for example, *Earomyia barbara* (calcium/zinc) uses its mouth hooks to feed on Douglas fir cones which are tougher than the balsam fir cones fed on by *E. abietum* (calcium alone) (D. S. Ruth, personal communication).

Hillerton, Robertson and Vincent (1984) considered the occurrence of zinc or manganese in mandibles of coleopteran species to be correlated with taxonomy and to be a reflection of evolutionary history of the group, despite some paradoxes of metal distribution within some sub-taxa. In our view, the metal or metals that occur in a species are more likely to be correlated with biomechanical adaptations of feeding structures. Since species groups within a family often employ a similar feeding strategy, they are likely to share similar biomechanical adaptations and similar uses for a metal. By contrast, calcium accumulation is apparently unique to Diptera and in that taxon may well be the result of phylogenetic conservatism.

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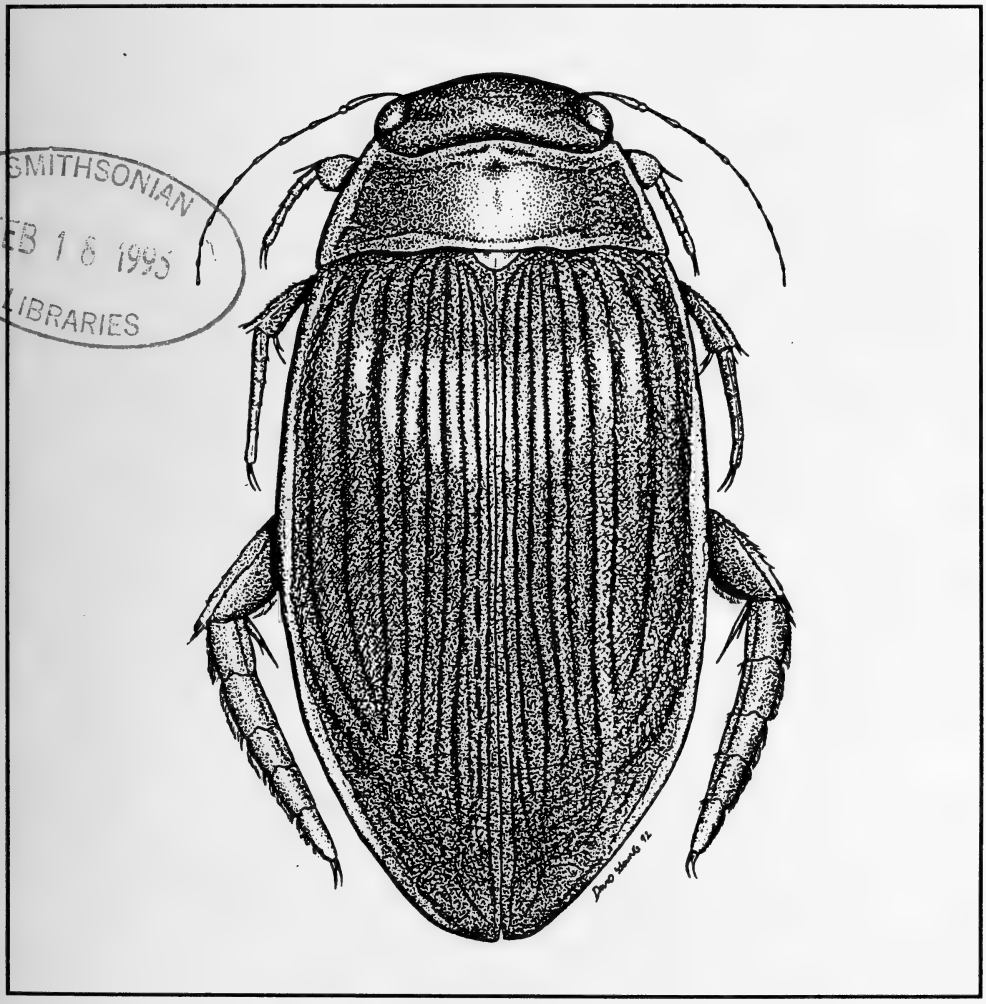

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COVER: An adult female *Dytiscus dauricus* Gebler (Dytiscidae: Coleoptera) drawn with pen and ink by David Young from specimens collected by Adrian de Bruyn. The specimen is 33 mm long. The species is Holarctic in distribution and can be collected along the margins of ponds, slow brown water streams and bush- or tree-ringed permanent ponds and lakes in British Columbia.

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Some ants (Hymenoptera: Formicidae) from Southern Vancouver Island, British Columbia

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ABSTRACT

A study of the ants collected in and around Victoria and on Thetis Island during the Autumn of 1987 and the Spring of 1988 is described. Twenty-four species were found, and the locations and habitats have been noted. Two of the *Leptothorax* species are believed to be new records for Canada and another remains unidentified. Some myrmecophiles were also recorded.

INTRODUCTION

Little has been published on the ant fauna of British Columbia. According to Buckell (1932), Muesebeck (1951), and Ayre (in Sharplin, 1966), between 45 and 55 species, subspecies and varieties have been recorded, although the taxonomic status of some is uncertain. The Victoria region, at the southern tip of Vancouver Island, has an equable climate, and this, combined with a considerable diversity of habitats, would be expected to make an investigation of its ant fauna worthwhile.

The west coast of British Columbia is well known for its heavy rainfall. The highlands west of Victoria receive about 54″ (137 cm) of rain annually, but Victoria itself is in their rain shadow and so receives only half of this amount, most of which falls during the winter. As a result, Victoria has the lowest midsummer rainfall in Canada (Kerr, 1951), and drought often withers the vegetation, even though temperatures are not particularly high. This is significant as ants are influenced by soil surface temperatures rather than the overall meteorological climate. Thus, summer sunshine is very important and mild winter weather is largely irrelevant.

The rainfall gradient also increases habitat diversity by creating a series of vegetation zones, the effect being amplified by variations in relief. Several ecological classifications have been proposed (Hagmeier, 1965; Roemer, 1972; McMinn, 1976; and Pavlick, 1986). The major vegetation types listed in order of increasing moisture are:

(A) Grass balds/Garry oak woodland. This consists of rock outcrops with grass and mosses and scattered oaks (*Quercus garryana*).

(B) Douglas fir forest. Douglas fir (*Pseudotsuga menziesii*) often with scattered *Arbutus menziesii* and an understory of mosses and, in moister sites, Oregon grape (*Berberis* spp.).

(C) Western red cedar forest. Dense stands of cedar (*Thuja plicata*) often with western swordfern (*Polystichum munitum*) beneath.

(D) Coastal western hemlock forest (*Tsuga heterophylla*). Absent from the immediate Victoria area.

There is also a number of types which are either of localised occurrence or are due to human activities:

(E) Wet deciduous forests

(F) Meadows (dry and wet)

(G) Bogs

(H) Beaches, sand dunes

(I) Urban and suburban.

Table 1
Ants of Southern Vancouver Island

		Locality												
	Species	x	a	b	c	d	e	f	g	h	i	j	k	l
(1)	*Myrmica emeryana* group sp.						■	s	■		s			
(2)	*M. incompleta*			■	s		s	■		■				
(3)	*Stenamma diecki*		■					s				s		
(4)	*Aphaenogaster subterranea occidentalis*	■	s		■	■		s	■			■		
(5)	*Solenopsis molesta*	■												
(6)	*Leptothorax muscorum*		s		■									
(7)	*L. muscorum* group sp. "*uvicensis*"				■									
(8)	*L. rugatulus*		■			■			■					
(9)	*L. melanderi* (?)	■	■			■								
(10)	*L. nevadensis* (?)								■					
(11)	*Tapinoma sessile*		■			■		■						
(12)	*Brachymyrmex depilis*					■								
(13)	*Lasius pallitarsis*	■	■		s	s		s	■			s		
(14)	*L. alienus*	■				s		■			s	s		
(15)	*Camponotus modoc*	■		s	■			s			s			
(16)	*C. laevigatus*	■												
(17)	*C. vicinus*	■				■		■						
(18)	*Formica subnuda*				s	■			s		s			
(19)	*F. obscuripes*			■	s	s								
(20)	*F. accreta*	■	■		s	■	s	■	■	s	s	s	s	s
(20a)	*F.* sp. "*fuliginothorax*"		■		■		s	■	s					■
(21)	*F. pacifica*						s				s		■	■
(22)	*F. neorufibarbis*				■									
(23)	*F. subpolita*													■
(24)	*F. lasioides*		■		■	■			■		s			■
	Site Total n =	9	10	3	12	12	5	11	9	2	7	5	2	5

Locality	**Habitat type (see text)**
x Pilkey Pt area (Thetis Is.)	B
a Mt Douglas	A, B, C
b Blenkinsop Rd and Lake	F
c UVic Campus	A, C, F, I
d Mt Tolmie	A
e Cedar Hill Crossroads	I
f Cadboro Pt Peninsula	B, I
g Uplands Park	A
h Oak Bay	H, I
i Shelbourne St	I
j Pembroke St	I
k Stanley Ave area	I
l Coast, Clover Pt westwards	F

■ Specimen taken
s Sight Record

MATERIALS AND METHODS

Specimens were collected by hand and preserved in 25% isopropyl alcohol containing traces of copper sulphate. 70% ethyl alcohol can also be used. Foraging workers were mostly taken from the soil surface and from tree trunks. Nests were located under stones and in or under fallen logs and tree stumps. No excavations were carried out, so highly subterranean species and those that nest only in the soil are likely to be under-represented in, or absent from, the collection.

RESULTS AND DISCUSSION

The results are based on collections made in September/October 1987 and May 1988, and are summarised in Table 1. The collection sites mentioned are shown on Figures 1a and 1b. The survey was not comprehensive—only habitats of six types were investigated—so there is enormous scope for future work.

Twenty-four definite species were found, several on a single occasion only. The *Formicinae* is the dominant subfamily with 13 species, followed by the *Myrmicinae* with 10 species and a single member of the *Dolichoderinae* (Table 2).

A number of the identifications are tentative because the taxonomy of many groups of North American ants is uncertain, and synonyms exist for many species. Because of this, all *Myrmica* and *Leptothorax* species are illustrated and the latter are also briefly described.

Subfamily *Myrmicinae*

A large subfamily, the members are characterised by a sting and a two-segmented petiolus. Pupae are never enclosed in cocoons. Tropical genera display a great diversity of form, but the species listed here are all rather conservative in appearance and behaviour, being well armoured and slow moving. Body surfaces are usually sculptured except for the gaster. Only *Myrmica* (with two species) and *Leptothorax* (with five) were represented by more than one species. This is a surprisingly small number in the former case. Two of the *Leptothorax, L. melanderi* and *L. nevadensis*, are believed to be new records for Canada and another has not been identified. Additional species could occur.

(1) *Myrmica emeryana* group sp. (Fig. 2a)

A typical *Myrmica* species, length 4-4.5 mm with foreparts reddish-brown, gaster slightly darker. Head and thorax coarsely rugose. Antennal scapes sharply angled near base. Widespread rather than abundant in short turf. Both this and the next species were more in evidence in May 1988 than in the hot, dry autumn of 1987. A small alate female of about 5 mm was taken in mid-September 1987 near Uplands Park. It is assumed to be of this species although the ventral surface of the petiole is not obviously convex.

(2) *Myrmica incompleta* Provancher (Fig. 2b)

Slightly larger than the previous species (about 4.5 mm) with both head and gaster normally dark. Head and thorax with coarse sulcations. Antennal scapes evenly curved from base. It was first taken on the beach at Oak Bay, otherwise its occurrence was similar to that of the previous species, but with some preference for damper, more thickly vegetated sites. *Myrmica* colonies typically contain 500-1500 workers.

(3) *Stenamma diecki* Emery

The workers of this species are small (3.5 mm), slender and dark reddish-brown. When foraging they are slow moving and inconspicuous. Colonies contain approximately 100 workers and typically occur under stones in shaded sites. Careful searching in red cedar forest usually reveals one or two. Alates were present in the nests in September and October 1987.

(4) *Aphaenogaster subterranea occidentalis* Emery

Workers of this common species may initially be mistaken for *Myrmica* but are more slender and shiny—somewhat similar in shape to *Stenamma*, although larger. They are most often seen above ground in the evening. Colonies are found under large stones in Garry oak woodland, Douglas fir forest, and gardens. They are similar in size to those of *Myrmica* species (4-5 mm).

(5) *Solenopsis molesta* Say

This tiny (1.5 mm) yellow, thief ant was taken only once. About 20 workers and pupae were found under a small stone in a shaded area of Douglas fir forest on Thetis Island, a few feet from a *Lasius alienus* colony. It is probably widespread, but is easily overlooked due to its subterranean habits. Mature *Solenopsis* colonies can be very populous.

Table 2
Relative abundance of the ant fauna in the vicinity of Victoria, B.C. by habitat type

	Habitat Types					
	A	B	C	F	H	I
(1) *Myrmica emeryana* group sp.				C		C
(2) *M. incompleta*				C	C	C
(3) *Stenamma diecki*		?	S			S
(4) *Aphaenogaster subterranea occidentalis*	V	V				C
(5) *Solenopsis molesta*		S				
(6) *Leptothorax muscorum*		?				S
(7) *L. muscorum* group sp. "*uvicensis*"						S
(8) *L. rugatulus*	C					
(9) *L. melanderi* (?)	S	C	S			
(10) *L. nevadensis* (?)	S					
(11) *Tapinoma sessile*	S	S				
(12) *Brachymyrmex depilis*	S					
(13) *Lasius pallitarsis*	V	V	V	?		V
(14) *L. alienus*		C				S
(15) *Camponotus modoc*		S				C
(16) *C. laevigatus*		S				
(17) *C. vicinus*	S	C				
(18) *Formica subnuda*	C					C
(19) *F. obscuripes*	S			S		
(20) *F. accreta*	V	V	S	?	V	V
(20a) *F.* sp. "*fuliginothorax*"	S					S
(21) *F. pacifica*						C
(22) *F. neorufibarbis*						S
(23) *F. subpolita*				S		
(24) *F. lasioides*	V			V		V
	13	10	4	5	2	15

Habitat Types A–I (see text)

V = Very common or locally abundant
C = Fairly or locally common
S = Scarce to very rare
? = Status uncertain

(6) *Leptothorax muscorum* (Nylander) (Fig. 2c)

Workers of this species resemble a small (3.5 mm) short legged *Myrmica*, reddish-brown with head and gaster darker. Female castes of this and the next two species have 11-segmented antennae. Clypeus with slight but distinct trough. Mesopropodeal suture distinct from above. Tibiae and scapes may have some sub-erect hairs, looped on the latter. Antennal clubs dark. Funiculus segments 2-6 only marginally longer than broad. Coarse sculpture defining a deep, rounded well for antennal insertions. Gaster slightly convex at junction with postpetiole. *Leptothorax* colonies are usually small, with 50-200 workers. Several were found in stumps in the University Gardens. Also seen on Mt. Douglas and perhaps also on Mt. Tolmie, but no specimens were taken at these sites.

Note—The European *L. muscorum* has not been recorded east of the Urals (Collingwood, 1979). If the North American species is truly identical this presents an interesting biogeographical puzzle.

(7) *Leptothorax muscorum* group sp. "*uvicensis*" (Fig 2d)

This species is blackish in colour and less strongly sculptured than the previous species. Clypeal trough indistinct. Mesopropodeal suture less distinct from above. Antennal well also less sharply defined and more oval in shape. The thorax of this species is slightly flatter and more slender in profile than the previous species, but broader in dorsal view. Dorsal surface of petiole rises to a distinctive peak. A single colony was found nesting in a stump in the University Gardens, very close to, but completely separate from, a *L. muscorum* colony. It is possible that *L.m.* "*uvicensis*" is an extreme variant of *L. muscorum*, but the differences are sufficient for it to be tentatively regarded as distinct, allied to species such as *L. wilsoni* and *L. crassipilis*. More specimens, including alates, are needed.

(8) *Leptothorax rugatulus* Emery (Fig. 2e)

Despite having 11-segmented antennae *L. rugatulus* is quite distinct from the previous two species and more like the following two in general appearance. Workers are 2.5-3.0 mm long, reddish-brown, with head and gaster darker. It is solidly built, with a somewhat box-shaped thorax. Mesopropodeal suture indistinct. Propodeal spines of moderate length and divergent. Appendage hairs mostly sub-erect or decumbent. Antennal clubs pale. Funiculus segments 2-6 distinctly longer than broad. Gaster concave at junction with postpetiole, in contrast to the previous two species. This species nests under stones in dry, grassy sites.

(9) *Leptothorax melanderi* Wheeler (Fig 2f)

This is a yellowish-brown species, length about 2.5 mm. Antennae 12-segmented, clubs pale. First funiculus segment about as long as the next two. Head and thorax punctate reticulate. Propodeal spines characteristically upright. It is tentatively identified as *L. melanderi* after examination of species from Montana held in the British Museum (Natural History) in London. The Montana species are, however, larger and have relatively shorter propodeal spines than those described above. Similar species which could occur in the province include *L. ambiguus* (which has 11-segmented antennae) and *L. nitens*. This is the most widespread *Leptothorax* species, usually nesting under stones in mossy, semi-shaded sites. When the nest stone is lifted the workers often remain motionless for several seconds, then simultaneously start running about, presumably triggered by the release of an alarm pheromone.

(10) *Leptothorax nevadensis* Wheeler (Fig. 2g)

This species is blackish, length about 2.5 mm. Antennae 12-segmented with dark clubs. First funiculus segment distinctly longer than next two. Head and thorax more densely and evenly punctate reticulate than the previous species and propodeal spines flatter. The high, rounded petiole is distinctive. The specimen described here compares well with those in the British Museum collection although it is again slightly smaller in size. From the material examined it is difficult to understand why Creighton (1950) treats *L. melanderi* as a subspecies of *L. nevadensis*. They appear to be quite distinct, particularly if due weight is given to the morphology of the petiolus region, rather than to sculpture. A single worker was taken in Uplands Park. It was captured in late afternoon in a very dry, stony area with very short grass. To the author's knowledge, no *Leptothorax* with 12-segmented antennae have previously been recorded from British Columbia.

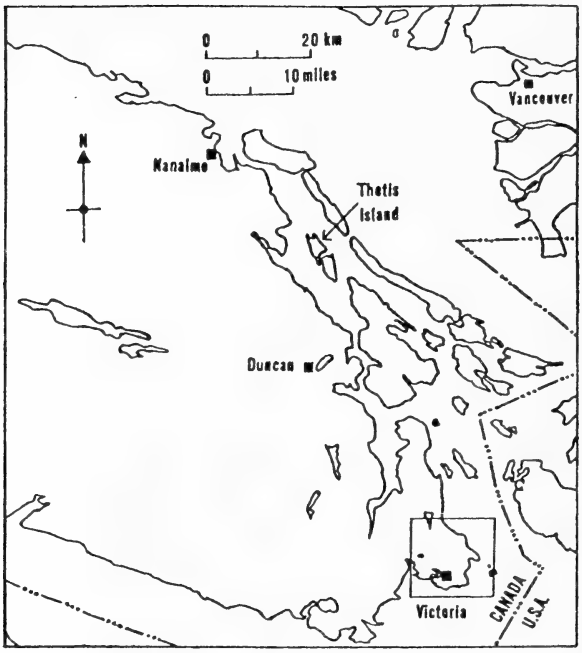


Figure 1a. Collection area, with Thetis Island indicated and Victoria region enclosed.

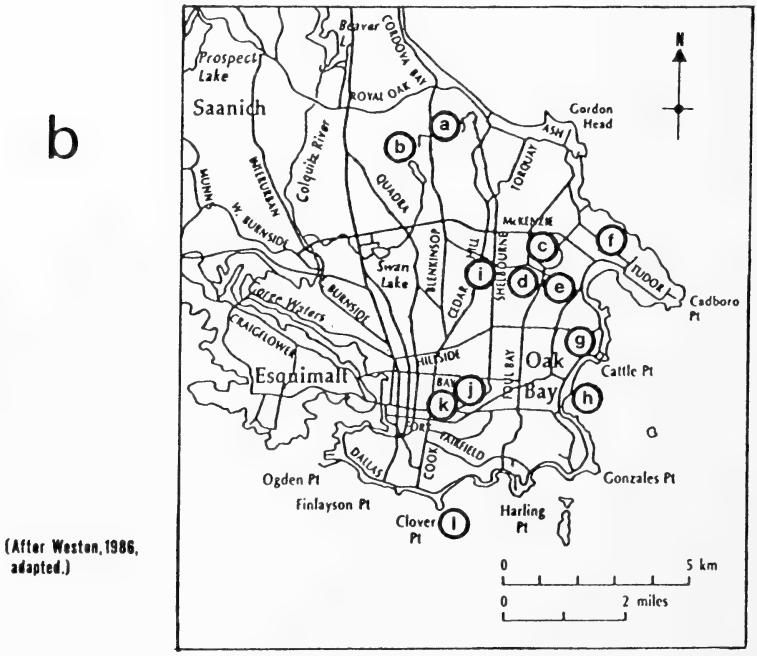


Figure 1b. Location of collection sites in the Victoria region.

Subfamily *Dolichoderinae*

Members of this subfamily are mostly monotonous in appearance. They are lightly amoured and have only a single petiole segment. The sting is vestigial or absent but the poison glands produce effective repellents. Pupae are naked. A single species was found.

(11) *Tapinoma sessile* Say

The workers of this species are small (2.5 mm), blackish and very agile. It is adaptable and can occur in a variety of habitats. It was taken at several scattered sites, a few hundred workers at most.

Subfamily *Formicinae*

Ants of this subfamily are similar to the *Dolichoderinae* in general appearance. The petiole consists of a single scale and the poison glands produce formic acid, which some genera, particularly *Formica*, can squirt a considerable distance. In many *Formica* species naked pupae are common while in other genera they are normally enclosed in cocoons. *Formica* is the dominant genus with seven definite species. Three *Camponotus*, two *Lasius* and one *Brachymyrmex* species were also recorded.

(12) *Brachymyrmex depilis* Emery

This minute (c 1.5 mm), pale brown species was taken once on Mt. Tolmie under a small piece of wood and an adjacent stone. It may be quite widespread, but like *Solenopsis molesta* it is easily overlooked because of its small size and subterranean habits.

(13) *Lasius pallitarsis* Provancher (syn. *L. sitkaensis* Pergande)

A relatively robust species. Workers are about 3.5 mm long and pale brown in colour. It is widespread, and most often found under stones in semi-shaded or shaded habitats. Workers sometimes forage above ground and even up small trees. Alates were seen in September.

(14) *Lasius alienus* Förster

This small (2.5-3.0 mm), brown species was found two or three times in partially shaded situations. It is probably widespread. Its behaviour in North America contrasts with that in Western Europe where it favours an open heathland habitat. Mature *Lasius* colonies are usually populous, with several thousand workers.

(15) *Camponotus modoc* Wheeler

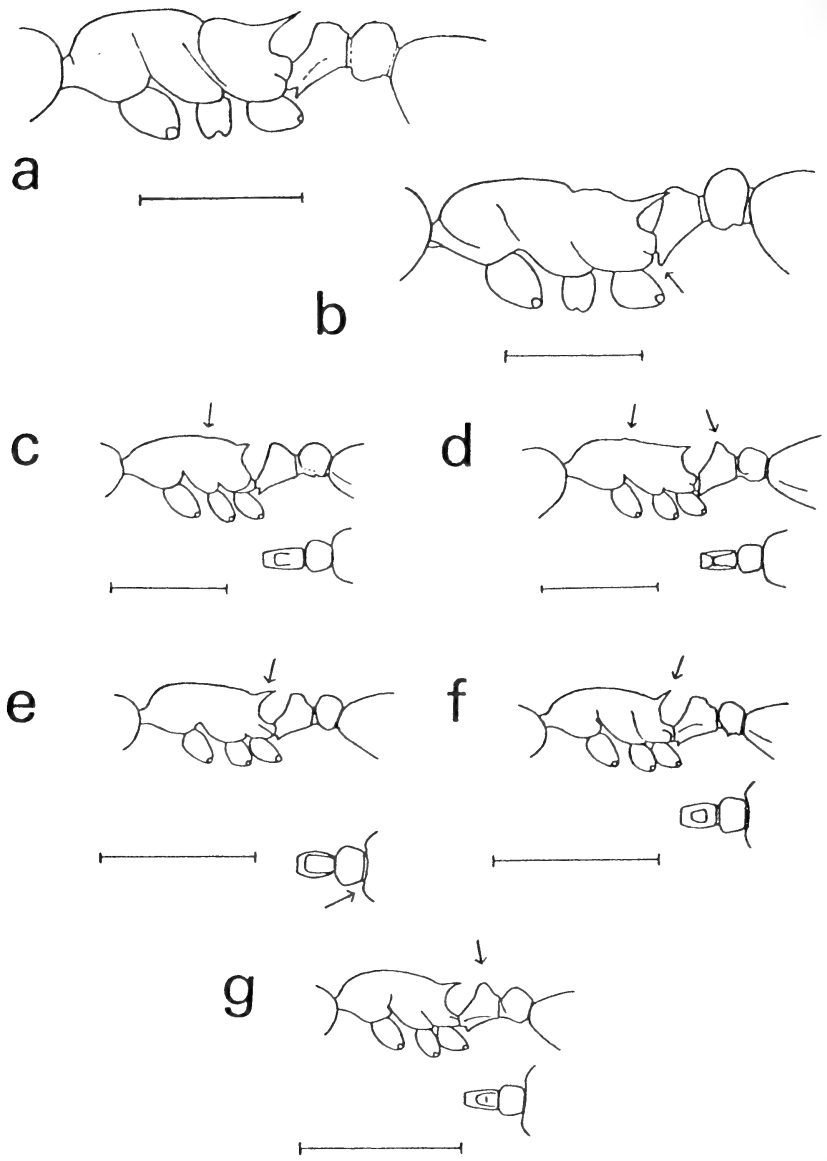
The western equivalent of the carpenter ant, *C.* pennyslvanicus. Workers are up to 13 mm long, and dull black with reddish legs. It is probably the commonest *Camponotus* species in Victoria itself, sometimes occuring in gardens. It is uncommon by the roadside in the Pilkey Point area of Thetis Island. Nests are usually situated in or under wood. They are fairly populous, estimated to contain from several hundred to over a thousand workers. Workers were often observed climbing trees, probably to tend aphids. On 11th May, 1988, a nuptial flight took place on the University of Victoria campus. Most colonies released only a few dozen alates, but one produced at least 1000 (quite possibly more than that number), an impressive sight as they covered at least 20 square yards of vegetation in their attempts to get airborne.

(16) *Camponotus laevigatus* F. Smith

The workers of this shining black species are smaller, faster and more agile than those of *C. modoc*. Two or three colonies of moderate size were found in clearings in Douglas fir forest on Thetis Island. The nests occur in fallen logs.

(17) *Camponotus vicinus* Mayr

Another very large species, the workers display a more marked polymorphism than those of *C. modoc*. They are normally bicolored, the red thorax contrasting with the dark head and dull black gaster, but the workers of a small colony from a shaded site on Thetis Island were entirely dark. As these were otherwise not separable from other specimens they are likely to belong to this species. Nests are normally located beneath logs or stones and are of moderate size. It was common in Douglas fir forest on Thetis Island but the colony found on Mt. Tolmie was well away from trees. It appears to be largely nocturnal which makes it much less conspicuous than *C. modoc*. Alates were present in Thetis Island nests in early September, and these possibly over-winter and fly in early summer.



Figures 2a-b. Alitrunk in profile of workers of *Myrmica*.
Figure 2a. *Myrmica emeryana* group sp.
Figure 2b. *Myrmica incompleta*.
Figures 2c-g. Alitrunk in profile and dorsal view of petiolus of workers of *Leptothorax*.
Figure 2c. *Leptothorax muscorum*
Figure 2d. *Leptothorax muscorum* group sp. "*uvicensis*"
Figure 2e. *Leptothorax rugatulus*
Figure 2f. *Leptothorax melanderi* (?)
Figure 2g. *Leptothorax nevadensis* (?)
Scale: 1 mm; arrows = important diagnostic characters.

Note—Two other very large *Camponotus* species could potentially occur in the Victoria region. *C. herculeanus* and *C. noveboracensis* are closely allied to *C. modoc*, all worker castes sharing the very robust form of that species, but being bicolored they are more likely to be confused with *C. vicinus*. *C. herculeanus* tends to be the darker of the two. It has a pubescent gaster, like *C. vicinus*. *C. noveboracensis* usually resembles typical *C. vicinus* in having a brighter red thorax but with a shining gaster.

(18) *Formica subnuda* Emery

A conspicuous species, typically 6-8 mm long with head and thorax blood-red, gaster black. Like most members of the *F. sanguinea* species group it is a facultative slave raider. *F. accreta* and *F. neorufibarbis* slaves were seen, and these occasionally accompanied the *F. subnuda* workers up trees to tend aphids. One colony had slaves of both species. It is fairly common in suburban areas and Garry oak woodland, usually nesting in sunny situations in stumps or under stones. Most colonies contained at least a few hundred workers.

(19) *Formica obscuripes* Forel

The only member of the *F. rufa* group seen. Workers are quite large, about 5-8 mm. Majors have orange heads, but minors are darker, being almost a uniform blackish-brown. It is very sparsely distributed in Victoria itself, building typical "wood ant" heaps of vegetable debris in grassy areas around woodland borders. These contain tens of thousands of workers.

(20) *Formica accreta* Francoeur

A fairly large (4-7 mm) black species, it is very like the European *F. fusca* but more aggressive. Colonies of this and all the following species vary in size from several hundred to a thousand or more workers. It is easily the most conspicuous ant in Victoria, being abundant and almost universally distributed. The type locality is Royal Oak, a suburb of Victoria. Several de-alate females were seen wandering over the ground in early September. A pterergate was also collected.

(20a) *Formica* sp. "*fuliginothorax*"

This "species" may be synonymous with *F. accreta* as the only clear distinction is the dark brown colour of *F.* "*fuliginothorax*". Francoeur (1973) describes *F. accreta* as being black or dark brown. *F.* "*fuliginothorax*" was not, however, seen to associate with *F. accreta* and no mixed colonies were found. It is much more sparsely distributed and seems to favour different habitats—normally short turf or crumbling banks. More specimens are needed, including alates.

(21) *Formica pacifica* Francoeur

A distinctly coloured species, with fine but dense bronze pubescence on the thorax and a darker head and gaster. It has an interesting distribution, being almost entirely restricted to urban areas. Nests normally occur between cracks in concrete, so it is commonest by roadsides and in car parks. The only record from an even semi-natural habitat was at Clover Point.

(22) *Formica neorufibarbis* Emery

This species is characteristically bicolored, with a blackish head and gaster, and red thorax. Despite its robust build it is rather timid and it was taken only in the gardens of the University of Victoria, where a couple of nests were found in stumps.

(23) *Formica subpolita* Mayr

Another robust species. It is darker in colour than *F. neorufibarbis* and has a characteristically convex dorsal surface to the propodeum. Two workers were taken on short turf above the cliffs near Beacon Hill Park.

(24) *Formica lasioides* Emery

The only member of the *F. neogagates* species group to be found. It is rather variable in size, colour and pilosity but is always shining, with at least a few erect hairs on its antennal scapes. It is widespread in grassy habitats, including open oak woodland.

Myrmecophiles

The ant cricket, *Myrmecophila oregonensis* Bruner, was observed on several occasions near nests of *F. obscuripes* and *F. subnuda*. Two ant mimics were also found. A bug (*Nabis* sp.) was taken on Thetis Island, and an unidentified spider mimic of *F. subnuda* was seen on Mt. Tolmie.

CONCLUSIONS

This study attempts to relate the ant fauna to habitat type. While it is provisional due to the small number of sites visited and the influence of human perturbances, it should have some predictive value for a more comprehensive survey. Of the natural habitats, the grass balds—Garry oak woodland appears to have the richest fauna (13 species). This is not surprising because of the high insolation at the soil surface, but it should be noted that this habitat was by far the most intensively searched. South-facing clearings in Douglas fir forests are probably comparable. The cooler red cedar forest has a much more limited ant fauna but is notable for the presence of *Stenamma diecki*. Culivated and urban areas increase habitat diversity and are of interest because of the presence of a number of species recorded from truly "wild" areas, particularly *Formica pacifica*.

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Attraction of Douglas-fir beetle, spruce beetle and a bark beetle predator (Coleoptera: Scolytidae and Cleridae) to enantiomers of frontalin

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ABSTRACT

In three separate experiments, Douglas-fir beetles, *Dendroctonus pseudotsugae* Hopkins, preferred traps baited with either (*S*)-(-)- or racemic (*R,S*)-(±)-frontalin over those baited with the (*R*)-(+)-enantiomer. Spruce beetles, *D. rufipennis* (Kirby), appeared to be attracted equally to both the (*S*)-(-)- and (*R*)-(+)-enantiomers, but low catches and high variance made interpretation of the data tenuous. For both species racemic frontalin was as attractive as the preferred enantiomer alone. The bark beetle predator, *Thanasimus undatulus* (Say), was attracted preferentially to (*S*)-(-)-frontalin over (*R*)-(+)- or (*R,S*)-(±)-frontalin in a Douglas-fir stand, while both enantiomers were equally attractive in a spruce stand.

Additional keywords: *Dendroctonus pseudotsugae*, *Dendroctonus rufipennis*, semiochemical, kairomones, *Thanasimus undatulus*, predator, trapping

INTRODUCTION

Biological activity of semiochemicals on insects may be maximal to particular enantiomeric blends or restricted to single enantiomers. For example, the ambrosia beetle, *Gnathotrichus retusus* (LeConte), responds to (*S*)-(+)-sulcatol, whereas the presence of (*R*)-(-)-sulcatol is inhibitory (Borden et al. 1980a). Similarly the pine engraver, *Ips pini* (Say), is attracted by (*R*)-(-)-ipsdienol, but inhibited by (*S*)-(+)- ipsdienol in California (Birch et al. 1980). The striped ambrosia beetle, *Trypodendron lineatum* (Olivier), produces and responds to 1(*R*),4(*S*),5(*R*),7(*R*)-(+)-lineatin, whereas the 1(*S*),4(*R*),5(*S*),7(*S*)-(-)-enantiomer is inert (Borden et al. 1980b).

Numerous studies on the chemical ecology of the Douglas-fir beetle, *Dendroctonus pseudotsugae* Hopkins, and the spruce beetle, *D. rufipennis* (Kirby), have been conducted over the last two decades. Both species produce 1-methylcyclohex-2-en-1- ol (MCOL) and 3-methylcyclohex-2-en-1-one (MCH), and 1,5-dimethyl-6,8- dioxabicyclo[3.2.1]octane (frontalin) (Kinzer et al. 1971; Libbey et al. 1983; Gries et al. 1988; G. Gries[1], pers. comm.). Both species also exhibit enantiospecific response to MCOL (Lindgren et al. 1992; J.H. Borden[1], pers. comm.) However, there is no published information on the response by these beetles to enantiomers of frontalin. Thus, the objective of this study was to determine the response of Douglas-fir beetles and spruce beetles to the two frontalin enantiomers alone and in combination.

MATERIALS AND METHODS

Enantiomers of frontalin (chemical purity >97 %; optical purity 97 % for both enantiomers) were purchased from Simon Fraser University. Lures consisted of frontalin-filled capillaries (45 × 1 mm i.d.) placed in 400 µl polyethylene Eppendorf centrifuge tubes. A 4 mm-diameter hole was cut in the side of each Eppendorf, and the devices suspended in Lindgren funnel traps so that the hole faced downward. In this manner entry of rainwater into the Eppendorf tubes was minimized. The release rate of each enantiomer was estimated at 0.5 mg/24 h @ 24 °C by measuring the drop of the meniscus.

Treatments in all experiments consisted of: (1) (*R*)-(-)-frontalin, (2) (*S*)-(+)-frontalin, and (3) (*R*)-(-)- and (*S*)-(+)-frontalin (one capillary each). In this manner the release rate of each enantiomer was held constant among treatments. In the first experiment, an unbaited control was also included as a fourth treatment. All experiments utilized 8-unit multiple-

funnel traps (Lindgren 1983) (Phero Tech Inc. Delta, B.C.). A 2 × 2 cm piece of dichlorvos-impregnated wax bar was placed in the collection jar of each trap to prevent predatory beetles and ants from destroying the captured bark beetles.

Douglas-fir beetle.

The first of three experiments was conducted at the University of British Columbia Research Forest, Maple Ridge, B.C., as a three-block, randomized complete block design experiment, with two time replicates, May 4-11, and May 11-18, 1984. Treatment positions were rerandomized for the second time replicate. The second experiment was conducted at the Manning Creek Forest Road, about 30 km NW of Merritt, B.C., as a seven-block, randomized complete block design experiment May 7-20, 1985. The third experiment was conducted at the Manning Creek Forest Road as a four-block, randomized complete block design experiment, with two time replicates, May 24-27 and May 27-June 4, 1985. Treatment positions were rerandomized for the second time replicate. Captured insects were collected and stored in a freezer until counted and their sex determined (Jantz and Johnsey 1964; Lyon 1958).

Spruce beetle.

Two seven-block randomized complete block design experiments were conducted along the Miner Creek Forest Road, about 30 km SW of Merritt, B.C., June 7-18, and June 18-21, 1985. Captured insects were collected, stored and their sex determined as described above.

Statistical Analyses.

The data were subjected to analysis of variance ($\alpha = 0.05$), and the means separated by Tukey's Test ($\alpha = 0.05$). All data were transformed as $x' = \log_{10}(x + 1)$ to remove heterogeneity of variances before analysis. Proportion data in the third Douglas-fir beetle experiment were transformed as $x' = \arcsin\sqrt{p}$, where p is a proportion, and 0 was replaced by $^1/_4n$ and 1 by $1-(^1/_4n)$ (Zar 1984). The first and third Douglas-fir beetle experiments, and the spruce beetle experiments, were analyzed as replicated randomized complete blocks.

Table 1

Response by Douglas-fir beetles to Lindgren funnel traps baited with enantiomers of frontalin. Malcolm Knapp Research Forest, Maple Ridge, B.C., 1984 (n = 6).

TREATMENT	MEAN NUMBER (± SD) DOUGLAS-FIR BEETLES CAPTURED[a]
UNBAITED CONTROL	0.0 (±0.0)a
(*R*)-(+)-FRONTALIN	0.2 (±0.4)ab
(*S*)-(-)-FRONTALIN	2.0 (±2.1)b
(R,S)-(±)-FRONTALIN	1.8 (±1.8)b

[a]Means followed by the same letter not significantly different, analysis of variance and Tukey's test ($\alpha = 0.05$)

RESULTS AND DISCUSSION

Douglas-fir beetle. The data analyses from the first experiment, which was conducted in the coastal Douglas-fir zone, indicated that (*R*)-(-)-frontalin is the attractive enantiomer (Table 1). Although the (*S*)-(+)-enantiomer was not significantly different at the stated probability level from any other treatment in this experiment, the Tukey HSD probability was $p = 0.051$ and $p = 0.055$ when comparing (*S*)-(+)-frontalin to (*R*)- (-)- and (R,S)-(±)-frontalin, respectively. The two experiments conducted in the interior Douglas-fir zone showed clearly that (*R*)-(-)-frontalin is the attractive enantiomer for male Douglas-fir beetles, while the (*S*)-(+)-enantiomer appears to be relatively inactive (Tables 2-3). Thus, male Douglas-fir beetles in both the coastal and interior Douglas-fir zones responded similarly to frontalin enantiomers. Female Douglas-fir beetles were attracted mainly to the (*R*)-(-)-enantiomer in both the second and third experiment (Tables 2-3). The treatment effect for female catch in the second experiment approached significance ($p = 0.079$), and was highly significant in the

third experiment. There was no treatment effect on sex ratio, expressed as proportion of females, in the third experiment (Table 3). Only two females were captured in the first experiment, both of which responded to traps baited with both enantiomers. Traps baited with both enantiomers tended to capture the highest numbers of beetles of both sexes in all three experiments, indicating that (*S*)-(+)-frontalin may have some activity.

Table 2

Response by Douglas-fir beetles and the clerid predator *Thanasimus undatulus* to Lindgren funnel traps baited with enantiomers of frontalin. Manning Creek Road, Merritt Forest District, B.C., May 7-20, 1985 (n = 7).

	MEAN NUMBER (±SD) DOUGLAS-FIR BEETLES AND CLERIDS CAPTURED[a]			
TREATMENT	**MALES**	**FEMALES**	**TOTAL**	**CLERIDS**
(*R*)-(+)-FRONTALIN	1.0a (±1.2)	0.1a (±0.4)	1.1a (±1.2)	0.1a (±0.4)
(*S*)-(-)-FRONTALIN	16.7b (±21.2)	3.3a (±5.7)	20.0b (±26.7)	2.9b (±2.6)
(R,S)-(±)-FRONTALIN	12.0b (±11.5)	4.1a (±4.2)	16.1b (±15.6)	0.6a (±0.8)

[a]Means followed by the same letter not significantly different, analysis of variance and Tukey's test ($\alpha = 0.05$).

Table 3

Response by Douglas-fir beetles to Lindgren funnel traps baited with enantiomers of frontalin. Manning Creek Road, Merritt Forest District, B.C., May 20-27, 1985 (n = 8).

	MEAN NUMBER (±SD) DOUGLAS-FIR BEETLES CAPTURED[a]			PERCENT
TREATMENT	**MALES**	**FEMALES**	**TOTAL**	**FEMALES**
(*R*)-(+)-FRONTALIN	7.5a (±6.0)	3.8a (±3.2)	11.3a (±8.1)	37.4a (±31.8)
(*S*)-(-)-FRONTALIN	32.6b (±39.8)	15.9b (±19.3)	48.5b (±59.0)	32.6a (±8.1)
(R,S)-(±)-FRONTALIN	43.6b (±30.3)	21.1b (±20.7)	64.8b (±50.3)	28.9a (±6.7)

[a]Means followed by the same letter not significantly different, analysis of variance and Tukey's test ($\alpha = 0.05$)

Spruce beetle. Catches of spruce beetles were extremely low and variable (Table 4). Very few insects were captured by any treatment, although one trap baited with (*S*)-(+)-frontalin captured 54 beetles in the first experiment. There were no significant treatment effects, and no interactions, in these experiments. Based on these limited data, it appears that spruce beetles respond to both enantiomers. Further experiments are needed to confirm this, as well as to determine geographic variation in the response.

Clerid beetles, *Thanasimus undatulus* (Say), were captured in sufficient numbers for statistical analysis in the second Douglas-fir beetle experiment and in the spruce beetle experiment. Significantly more clerids were captured in the traps baited with (*R*)-(-)-frontalin than to either of the treatments containing (*S*)-(+)-frontalin in the Douglas-fir beetle experiment (Table 2), whereas there were no significant differences among the treatments in the spruce beetle experiments. This may indicate some level of behavioral or physiological adaptation, or possibly genetic selection, in clerids predominantly responding to kairomones from a single prey species. Herms et al. (1991) suggested that the related *Thanasimus dubius* (F.) may select for changes in the pheromone system of its prey, *Ips pini*

(Say), which both exhibited considerable inter- and intrapopulational variation in their response to enantiomers of ipsdienol. However, in the experiments reported here the numbers of clerids captured were low, so that additional experiments would be needed to be certain that clerid response to their prey kairomones are enantiospecific, and if such specificity is tied to the pheromone production of its prey.

Table 4

Response by spruce beetles and the clerid predator *Thanasimus undatulus* to Lindgren funnel traps baited with enantiomers of frontalin. Miner Creek Road, Merritt Forest District, B.C., June 7-21, 1985 (n = 14).

	MEAN NUMBER (±SD) SPRUCE BEETLES AND CLERIDS CAPTURED[a]			
TREATMENT	**MALES**	**FEMALES**	**TOTAL**	**CLERIDS**
(*R*)-(+)-FRONTALIN	2.9 (±7.6)	2.7 (±6.6)	5.6 (±14.1)	2.0 (±3.0)
(*S*)-(-)-FRONTALIN	0.8 (±1.0)	1.1 (±1.7)	1.9 (±2.3)	1.6 (±1.8)
(R,S)-(±)-FRONTALIN	1.5 (±2.1)	1.5 (±2.7)	3.0 (±4.6)	4.3 (±6.8)

[a]There were no significant differences among treatments, analysis of variance ($\alpha = 0.05$)

If the lack of treatment effects in the spruce beetle experiments is real, enantiospecific responses to frontalin may be one of the mechanisms whereby these bark beetles maintain species segregation. However, interspecific cross attraction to semiochemicals produced from infested logs has been demonstrated for these species (Chapman and Dyer 1969). For both species, synthetic racemic frontalin can be used in management applications, since it is equally attractive as either enantiomer.

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NOTE

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Establishment of *Phyllonorycter mespilella* (Hübner) (Lepidoptera:Gracillariidae) and its parasitoid, *Pnigalio flavipes* (Hymenoptera:Eulophidae), in fruit orchards in the Okanagan and Similkameen Valleys of British Columbia

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ABSTRACT

In 1988, a leafminer, *Phyllonorycter mespilella* (Hübner) (Lepidoptera:Gracillariidae) was found for the first time in commercial fruit orchards in the Okanagan and Similkameen valleys of British Columbia after apparently moving across the international border from Washington State. Leafminer infestations and parasitoid-induced-leafminer-mortalities were assessed in widespread surveys in the two orcharding areas from 1988 to 1990. *Pnigalio flavipes* (Hymenoptera:Eulophidae) was the primary parasitoid of the leafminer pest. Three additional parasitoid species associated with the leafminer host in 1990 were: a *Sympiesis* species, an *Eulophus* species and a *Cirrospilus* species (Hymenoptera:Eulophidae). Parasitism reduced intraseasonal leafminer population increase as parasitoid-induced-mortality in the first leafminer generation of 1989 and 1990 was negatively correlated with leafminer density in both the second and third generations of the same year.

Key words: Insecta, *Phyllonorycter mespilella*, leafminer, parasitism.

INTRODUCTION

The leafminer pest of several economically important tree fruit-crops in western North America, previously misidentified as *Phyllonorycter elmaella* Doğanlar & Mutuura (Lepidoptera:Gracillariidae), has been identified as *Phyllonorycter mespilella* (Hübner) by J.-F. Landry (Centre for Land and Biological Resources Research, Ottawa) and D. Wagner (University of Connecticut, Storrs). Although low infestations of this leafminer cause minimal apple damage, severe infestations in apple orchards can result in premature ripening, leaf and fruit drop, reductions in apple firmness, size, color and storage life, and reduced foliar absorption of growth regulators (Hoyt 1983).

This leafminer was a minor orchard pest throughout the Pacific Northwest of the United States until the species developed resistance to commonly used organophosphate and chlorinated-hydrocarbon orchard chemical sprays (Hoyt 1983). The only chemical currently registered for successful control of the resistant pest species on apple in the United States is a carbamate; a chemical that is toxic to predaceous mites and therefore disrupts established nonchemical integrated mite management programs.

Parasitism has been reported to cause major mortality in *Phyllonorycter* spp. (Barrett 1988, Doğanlar and Beirne 1980, Pottinger and LeRoux 1971). *Pnigalio flavipes* (Ashmead) (Hymenoptera:Eulophidae), the key parasitoid of the leafminer pest in Washington State (Barrett 1988), has been shown to have the potential to reduce the leafminers' intraseasonal population increase and to keep its host's density below treatment levels (Barrett and Brunner 1990).

Phyllonorycter elmaella was described in British Columbia on apples in the Vancouver area (Doğanlar and Mutuura 1980), however the species has not been recorded in areas of commercial orcharding in the Okanagan and Similkameen valleys. This study reports surveys conducted from 1988 to 1990 to verify the establishment and spread of *P. mespilella* and its associated parasitoids, into apple orchards in the interior of British Columbia.

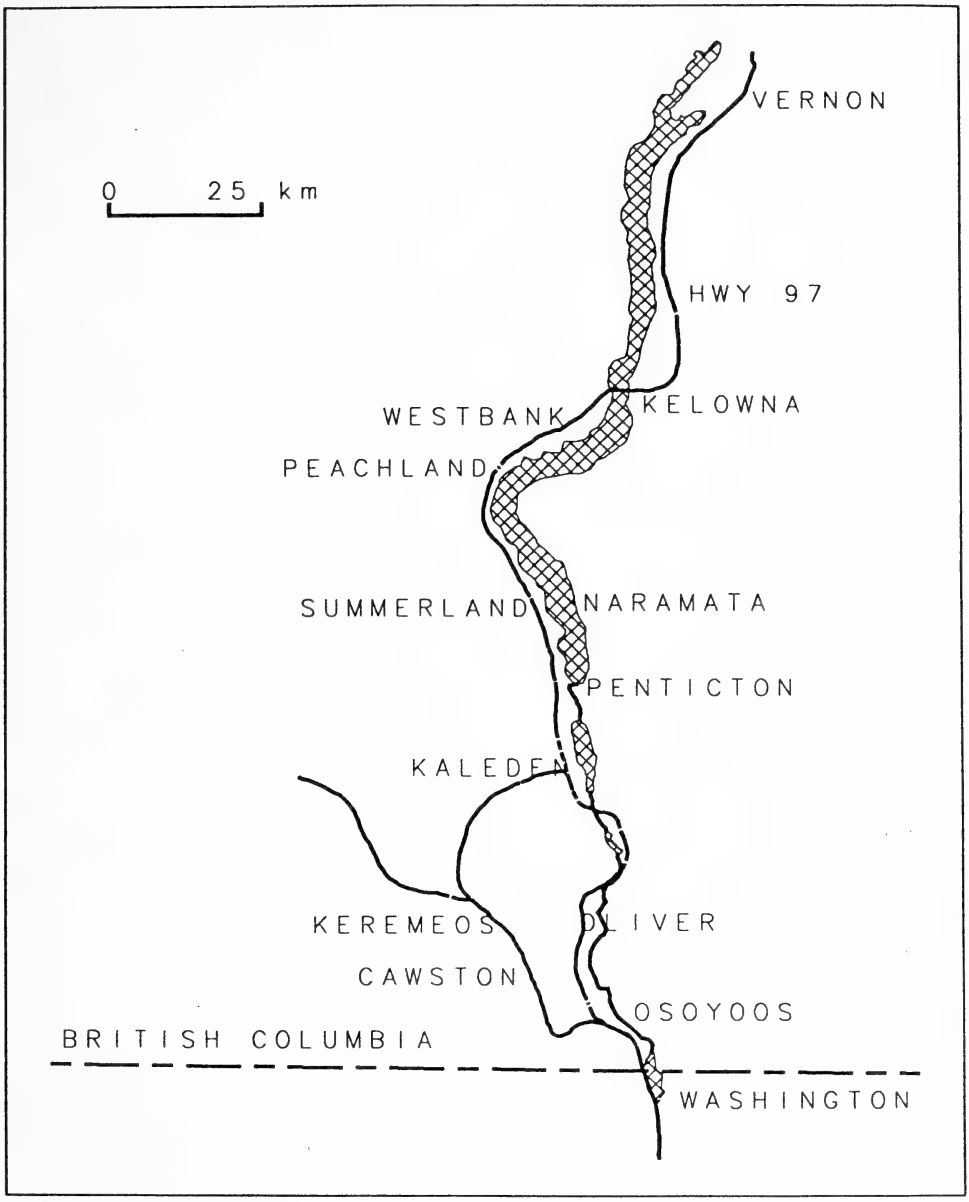

Figure 1. Area of the Okanagan and Similkameen valleys included in the leafminer survey.

MATERIALS AND METHODS

In the first *P. mespilella* generation of 1988, three orchards in Osoyoos, where the original infestation was found, and in the second generation, 13 orchards from Osoyoos to Kaleden were surveyed. In the third generation of 1988, 33 orchards from Osoyoos to Vernon (Okanagan Valley) as well as eight orchards in Keremeos and Cawston (Similkameen Valley) were surveyed in a similar fashion (Fig. 1). In 1989 and 1990 from 28 to 42 of the same orchards in the two valleys were surveyed in each of the three leafminer generations (Table 1). Surveys were conducted during the tissue-feeding stage of each leafminer generation. All orchard sites, save one in each of the Okanagan and Similkameen Valleys, were exposed to azinphosmethyl treatments for summer codling moth control.

Table 1

Mean leafminers found per minute of searching time in orchards in the Similkameen and Okanagan Valleys of British Columbia, 1988-1990.

Orchard Area (km north)[a]	Gen[b]	Mean mines found per minute[c] ± sd		
		1988 (n)[d]	1989 (n)	1990 (n)
Keremeos	1	—[e]	1.43 ± 1.82 (8)	1.72 ± 1.58 (8)
(20 km)	2	—	1.33 ± 1.32 (8)	5.19 ± 4.35 (8)
	3	3.49 ± 4.79 (8)	2.55 ± 2.48 (8)	61.91 ± 24.91 (8)
Osoyoos	1	0.10 ± 0.00 (3)	0.99 ± 1.07 (6)	1.29 ± 0.52 (5)
(0 km)	2	1.21 ± 0.73 (6)	0.43 ± 0.42 (6)	2.33 ± 1.52 (5)
	3	6.59 ± 4.10 (6)	5.84 ± 6.40 (6)	30.25 ± 23.77 (5)
Oliver	1	—	0.18 ± 0.11 (6)	0.75 ± 0.38 (5)
(20 km)	2	0.14 ± 0.16 (5)	0.07 ± 0.08 (6)	1.60 ± 0.83 (5)
	3	0.45 ± 0.37 (5)	1.52 ± 0.94 (6)	23.25 ± 16.22 (5)
Vaseux Lake	1	—	1.22 ± 1.85 (3)	0.07 ± 0.08 (3)
to Kaleden	2	0.28 ± 0.25 (2)	0.15 ± na[f] (1)	0.43 ± 0.33 (3)
(31-43 km)	3	0.30 ± 0.30 (3)	1.50 ± 0.85 (3)	10.08 ± 11.04 (3)
Penticton	1	—	0.08 ± 0.15 (4)	0.49 ± 0.78 (4)
(49 km)	2	—	0.14 ± 0.21 (4)	9.24 ± 5.95 (4)
	3	0.03 ± 0.05 (4)	1.05 ± 1.38 (4)	43.44 ± 47.84 (4)
Naramata	1	—	0.42 ± 0.72 (3)	5.62 ± 6.59 (3)
(64 km)	2	—	0.50 ± 0.74 (3)	27.62 ± 26.84 (3)
	3	0.02 ± 0.05 (3)	1.08 ± 0.88 (3)	129.50 ± 69.68 (3)
Summerland	1	—	—	0.13 ± 0.14 (3)
(67 km)	2	—	—	1.07 ± 1.11 (3)
	3	0.00 ± 0.00 (3)	0.08 ± 0.08 (3)	12.83 ± 11.58 (3)
Peachland to	1	—	—	0.00 ± 0.00 (2)
Westbank	2	—	—	0.40 ± 0.57 (2)
(87-92 km)	3	0.00 ± 0.00 (2)	0.00 ± 0.00 (2)	4.73 ± 2.86 (2)
Kelowna	1	—	—	0.00 ± 0.00 (3)
(92 km)	2	—	—	0.00 ± 0.00 (3)
	3	0.00 ± 0.00 (3)	0.00 ± 0.00 (3)	1.10 ± 0.43 (3)
Vernon	1	—	—	0.01 ± 0.03 (4)
(137 km)	2	—	—	0.21 ± 0.39 (4)
	3	0.00 ± 0.00 (4)	0.00 ± 0.00 (4)	11.26 ± 20.36 (4)

[a] Kilometers north of Canada/United States border
[b] Leafminer generation
[c] Derived from 10 minute visual search
[d] Number of orchards included in mean
[e] Unrecorded
[f] Only one orchard surveyed therefore no standard deviation of mean

An orchard survey involved a ten-minute visual search by two individuals experienced in mine recognition. In 1990, the survey time was reduced to two-minutes in orchards where more than 50 mines were counted per minute. Leaves in the orchards were examined continuously during the time period, both on the upper and lower surfaces because sapfeeders (the early feeding stage of the leafminer) are visible only on the underside of the leaf. All leafminer-infested leaves observed were collected and taken to the laboratory. Each mine was examined under a stereomicroscope and the stages of leafminers and parasitoids present were recorded. Empty mines, whose previous occupants could not be determined, were included in total mine counts in the first generation only.

Leafminers were recorded as parasitized when an ectoparasitoid egg, larva, pupa, or adult was found in the mine. A round parasitoid exit hole on the surface of the mine was recorded as parasitized in the first generation count only. Dead leafminers were considered to have been host fed or stung.

Table 2

Mean percent parasitism of leafminers in the Similkameen and Okanagan Valleys, 1988-1990.

Orchard Area (km north)[a]	Gen[b]	Mean percent parasitism ± sd		
		1988 (n)[c]	1989 (n)	1990 (n)
Keremeos	1	—[d]	41.36 ± 15.46 (8)	26.19 ± 16.66 (8)
(20 km)	2	—	31.25 ± 24.15 (8)	25.56 ± 13.59 (8)
	3	17.10 ± 11.53 (8)	16.43 ± 10.78 (8)	30.11 ± 13.58 (8)
Osoyoos	1	0.00 ± 0.00 (2)	64.39 ± 29.02 (6)	40.52 ± 16.44 (5)
(0 km)	2	38.36 ± 28.27 (6)	11.10 ± 12.31 (6)	22.91 ± 15.39 (5)
	3	61.23 ± 20.99 (6)	23.09 ± 10.30 (6)	21.71 ± 2.69 (5)
Oliver	1	—	37.22 ± 37.14 (6)	33.96 ± 16.59 (5)
(20 km)	2	4.17 ± 7.21 (3)	5.00 ± 10.00 (6)	17.50 ± 6.53 (5)
	3	37.14 ± 18.42 (5)	33.94 ± 20.38 (6)	25.67 ± 13.38 (5)
Vaseux Lake	1	—	32.09 ± 27.85 (3)	16.67 ± 23.57 (2)
to Kaleden	2	na[e]	0.00 ± na (1)	50.00 ± 16.67 (3)
(31-43 km)	3	na	25.84 ± 17.36 (3)	35.26 ± 13.09 (3)
Penticton	1	—	16.67 ± na (1)	1.52 ± 3.03 (4)
(49 km)	2	—	5.56 ± 7.86 (2)	37.08 ± 10.38 (4)
	3	0.00 ± na (1)	34.28 ± 16.79 (2)	14.30 ± 7.15 (4)
Naramata	1	—	36.00 ± na (1)	6.32 ± 7.17 (3)
(64 km)	2	—	5.56 ± 7.86 (2)	18.12 ± 12.36 (3)
	3	0.00 ± na (1)	17.33 ± 20.17 (3)	16.54 ± 2.45 (3)
Summerland	1	—	d	22.22 ± 38.49 (3)
(67 km)	2	—	d	39.39 ± 17.91 (3)
	3	na	0.01 ± 0.00 (2)	31.02 ± 16.07 (3)
Peachland to	1	—	d	na
Westbank	2	—	d	37.50 ± na (1)
(87-92 km)	3	na	na	9.26 ± 7.86 (2)
Kelowna	1	—	d 0.00 ± na (1)	
(92 km)	2	—	d	6.25 ± na (1)
	3	na	na	3.44 ± 6.89 (4)
Vernon	1	—	d 0.00 ± na (1)	
(137 km)	2	—	d	0.00 ± na (1)
	3	na	na	4.46 ± 6.31 (2)

[a] Kilometers north of Canada/United States border

[b] Leafminer generation

[c] Total orchards included in mean[d]Unrecorded

[e] Only one orchard surveyed or no leafminer found, therefore percent parasitism irrelevant

To compare the estimate of leafminer density using timed mine surveys with that obtained by randomly collecting 100 leaves (Barrett and Brunner 1990, Hoyt 1983), both techniques were carried out at 34 orchard sites in the two valleys in the third generation of 1989 as well as the first generation of 1990. The percentage of mines per 100 leaves was compared with the number of mines found per 10 min per person using a Spearman correlation (SAS 1985).

Pheromone traps baited with spotted tentiform leafminer, *Phyllonorycter blancardella* (Fabricius), pheromone were hung in sample orchards where the leafminer had not previously been recorded. Samples of adult parasitoids were fixed in alcohol and sent to the Biosystematics laboratory in Ottawa for identification.

Table 3

Mean percent dead leafminers in orchards of the Similkameen and Okanagan Valleys, 1988-1990.

Orchard Area (km north)[a]	Gen[b]	Mean percent dead leafminers ± sd		
		1988 (n)[c]	1989 (n)	1990 (n)
Keremeos	1	—[d]	8.92 ± 11.40 (8)	11.93 ± 9.15 (8)
(20 km)	2	—	10.82 ± 10.08 (8)	12.60 ± 7.08 (8)
	3	—	51.21 ± 13.25 (8)	38.82 ± 7.67 (8)
Osoyoos	1	0.00 ± 0.00 (8)	10.68 ± 13.90 (6)	17.59 ± 10.83 (5)
(0 km)	2	9.04 ± 4.69 (6)	35.56 ± 24.75 (6)	10.14 ± 2.82 (5)
	3	—	50.94 ± 14.05 (6)	47.47 ± 9.11 (5)
Oliver	1	—	40.56 ± 41.11 (6)	13.52 ± 7.83 (5)
(20 km)	2	0.00 ± 0.00 (3)	55.00 ± 52.60 (4)	18.47 ± 10.10 (5)
	3	—	44.11 ± 17.69 (6)	43.75 ± 1.44 (5)
Vaseux Lake	1	—	45.15 ± 48.06 (3)	33.33 ± 47.14 (2)
to Kaleden	2	0.00 ± na[e] (1)	66.67 ± na[e] (1)	8.15 ± 7.14 (3)
(31-43 km)	3	—	27.88 ± 8.20 (3)	31.32 ± 18.57 (3)
Penticton	1	—	0.00 ± 0.00 (1)	3.03 ± 6.06 (4)
(49 km)	2	—	0.00 ± 0.00 (2)	28.15 ± 4.01 (4)
	3	—	25.13 ± 8.35 (2)	37.37 ± 17.35 (4)
Naramata	1	—	16.00 ± na (1)	7.91 ± 6.03 (3)
(64 km)	2	—	3.70 ± 5.24 (2)	12.58 ± 4.15 (3)
	3	—	13.45 ± 12.17 (3)	36.66 ± 5.38 (3)
Summerland	1	—	—	0.00 ± 0.00 (3)
(67 km)	2	—	—	9.73 ± 8.43 (3)
	3	na	58.33 ± 11.79 (2)	21.47 ± 10.02 (3)
Peachland to	1	—	—	na
Westbank	2	—	—	0.00 ± na (1)
(87-92 km)	3	na	na	14.82 ± 5.24 (2)
Kelowna	1	—	—	0.00 ± na (1)
(92 km)	2	—	—	0.00 ± na (1)
	3	na	na	4.49 ± 8.98 (4)
Vernon	1	—	—	0.00 ± na (1)
(137 km)	2	—	—	0.00 ± na (1)
	3	na	na	3.57 ± 5.05 (2)

[a] Kilometers north of Canada/United States border
[b] Leafminer generation
[c] Total orchards included in mean
[d] Unrecorded
[e] Only one orchard surveyed or no leafminer found therefore percent parasitism irrelevant

RESULTS AND DISCUSSION

A visual inspection of a defined number of randomly sampled leaves per orchard site (Barrett and Brunner 1990, Hoyt 1983) was not used as a survey technique because very low infestations could easily be left unrecorded using this method. The timed mine count used in the survey was significantly correlated with the mine count in randomly collected leaves ($R = 0.82$, $P = 0.0001$, $n = 67$). Therefore, we conclude that the timed survey was realistic both in terms of finding extremely low infestations as well as estimating mine density.

In 1988, low infestations of the *P. mespilella* were widespread in surveyed orchards in Keremeos and Cawston in the southern Similkameen Valleys, and from Osoyoos to Naramata in the Okanagan Valley (approximately 20 to 23 km and 0 to 64 km N of the international border respectively) (Table 1). The leafminer was found in two of the three Osoyoos orchards surveyed in the first generation of 1988, suggesting that the species may have been present in the Okanagan valley by the Fall of 1987. Leafminer infestations decreased in density in orchards from the S to N of the Okanagan Valley (Table 1), suggesting that the species crossed the international border in the interior of the province.

Pnigalio flavipes, the primary tentiform leafminer parasitoid species in Washington State (Barrett 1988) and the second most dominant *Phyllonorycter* parasitoid in Utah (Barrett and Jorgensen 1986) was found in 87% ($n = 101$ mines) of the leafminer hosts in the southernmost orchard surveyed in the Okanagan Valley in 1988. *Pnigalio flavipes* was not listed as one of the 12 parasitoid species reared from the *P. elmaella* in the Vancouver area of British Columbia from 1976 to 1977 (Doğanlar and Beirne 1980) indicating that this species also crossed the international border from Washington State orchards. No parasitism was found N of Oliver in 1988 (Table 2), however leafminer infestations were so low from Oliver to Summerland that it is possible that the parasitoid was present but not intercepted.

In 1989, leafminers were not found in pheromone or visual orchard surveys north of Summerland and Naramata. The density of leafminer infestations, as determined by mines found per minute, remained low throughout the south Okanagan and Similkameen Valleys (Table 1) even though parasitism in these regions was as high as 64.39 ± 29.02 percent (Table 2). Multiparasitism rather than superparasitism may have been what was evident in orchards with high rates of parasitism.

In 1990, low numbers of the *P. mespilella* were found as far N as Vernon (approximately 137 km north of the international border) (Table 1). The highest leafminer counts were found in the Naramata survey area, however even these numbers had not reached the treatment threshold of one, two or five mines per leaf in the first, second or third leafminer generations respectively, as recommended for control of *P. mespilella* for Washington State growers (Hoyt 1983).

Three additional parasitoid species were identified in survey orchards from Osoyoos to Summerland in 1990. The second most abundant parasitoid was identified as a *Sympiesis* sp. (Hymenoptera: Eulophidae) and the remaining two parasitoids as *Eulophus* sp. and *Cirrospilus* sp. (Hymenoptera:Eulophidae). Percent parasitism per species was not determined as not all of the parasitoids survived after the survey mines had been opened and inspected.

The percentage of dead leafminers in the 1989 and 1990 surveys was generally high in infested areas (Table 3) (3.57 to 51.21% in the third generation). Adult *Pnigalio* species can kill host larvae by stinging the host while ovipositing, as well as by feeding on the larvae. Van Driesche and Taub (1983) also recorded death induced by *Sympiesis marylandensis* stinging host larvae without oviposition. Percent parasitism combined with percent dead leafminers (parasitoid-induced-mortality) is probably most indicative of the total impact that the *Pnigalio* parasitoid is having on the leafminer host (Barrett 1988).

Phyllonorycter mespilella density in both the second and third generations in 1989 and 1990 was significantly ($P = 0.0001$) and negatively correlated with parasitoid-induced-mortality in the first generation of the same years ($r = -0.68$ and $r = -0.63$ respectively, $n = 39$). Parasitoid-induced-mortality in the second generation did not correlate significantly ($P > .05$) with host density in the first, second or third generation. Parasitoid-induced-mortality in the third generation was significantly negatively correlated with host density in

the second ($r = -0.40$, $P = 0.01$, $n = 39$) and third generations ($r = -0.34$, $P = 0.03$, $n = 39$). *Pnigalio flavipes* in Washington State was found to respond to its tentiform leafminer host in a density dependent manner (Barrett 1988) and to reduce the leafminer's intraseasonal population increase.

The *P. flavipes* and its host survived the azinphosmethyl codling moth treatments applied in all but two of the orchards in this survey. Resistance of the parasitoid to commonly used orchard pesticides and the parasitoid's ability to reduce leafminer density in the second and third generation supports parasitism as a realistic integrated strategem against leafminers that is preferable to a carbamate-insecticide alternative.

High standard deviation of mean leafminer counts, percent parasitism and mortality throughout the survey is indicative of the high variation between orchards even within a given region. This variation should subside with time as the new pest and its parasitoid complex become established throughout the orcharding area.

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Wireworm (Coleoptera: Elateridae) survey in wheat-growing areas of northcentral and northeastern Oregon[1]

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ABSTRACT

A wireworm survey was conducted at 34 sites in wheat-growing areas of northcentral and northeastern Oregon using a baiting technique. The highest mean number of wireworms found at any site was 4.4 per bait of corn-wheat mixture. When wireworm numbers at each site were used to estimate the population density, some sites had densities high enough to cause yield reduction in spring wheat but not winter wheat. The species were predominantly *Ctenicera pruinina* (Horn), *Limonius californicus* (Mannerheim), and *Melanotus longulus oregonensis* (LeConte), with lesser numbers of *Limonius infuscatus* Motschulsky, *Ctenicera glauca* (Germar), *Aeolus mellillus* (Say), and *Dalopius* sp. False wireworms (Tenebrionidae) were also found at 10 sites, but their influence is uncertain.

INTRODUCTION

Wireworms, the larvae of click beetles, are destructive pests of cereal grain crops, feeding on seeds, roots, and underground stems. In the Pacific Northwest, they include members of the genera *Aeolus*, *Agriotes*, *Ctenicera*, *Dalopius*, *Limonius*, *and Melanotus* (Hyslop 1915, Lane 1935). Much research has gone into developing treatment of seeds with pesticides for protecting the crops and determining the short-term benefits derived from its use, such as reduction in stand loss and increase in yield. Yet, because no long-term study has been conducted, one can only assume that continued use of treated seeds suppresses wireworm populations.

Many of the pesticides used for seed treatment in the past are no longer available, and the availability of safe, effective and economical products in the future is uncertain. The necessity of using treated seeds to control wireworms depends upon whether or not damaging populations are present, for which the data are limited (Toba et al. 1985, 1988). Soil sampling can be used to estimate wireworm densities (Jones and Shirck 1942, Onsager 1969). However, such sampling is laborious and time consuming, whereas baiting is less demanding. Ward and Keaster (1977) developed a method of baiting by covering a buried mixture of corn and wheat with a polyethylene sheet, resulting in significantly higher attractancy to corn-infesting wireworms than did uncovered baits. Because such a baiting technique merely indicates the absence or presence and relative abundance of wireworms, Toba and Turner (1983) developed a method whereby a population density could be estimated from the number of wireworms found at the baits.

This report documents the density of wireworm populations in various wheat-growing areas of nine counties in northcentral and northeastern Oregon using a baiting technique.

MATERIALS AND METHODS

The survey was conducted in July and August 1981 at 34 sites. Each site was selected with the advice and consent of individual ranchers who all practiced dryland farming, primarily of wheat. The number of sites selected in each county was generally based on 1980 wheat acreage as compiled by the Extension Economic Information Office, Oregon State University. Ranchers were also asked about the field history, particularly in regards to the use of

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treated seeds for wireworm control. In several cases, the test sites were located in zones believed to be affected by wireworms within the recent past. Fallow fields were favored over planted fields. In the latter, an area of the field was left unplanted for the test sites.

Each study plot usually consisted of 16 bait spots in a 4-by-4 array, 15.2 m apart, except at three locations in Union County; 2 m apart at location 39E,1S,9 and 4 m apart at the other two locations. The baiting technique was similar to that of Toba and Turner (1983). At each spot, a 20-cm-deep hole was dug with a 5-cm-diameter steel pipe driven into the ground with a heavy hammer. Soil temperature readings were made about 5 cm below the bottom of each of four holes with a YSI Model 42SC Tele-Thermometer (Yellow Springs Instrument Co., Yellow Springs, Ohio) fitted with a soil probe. About 50 ml of a 1:1 mixture of presoaked whole wheat and corn was placed in each hole and covered with the same soil that had been removed. The seeds were untreated except for a fungicide (Vitavax) applied to wheat. The spot was then covered with a 0.6-m^2 polyethylene sheet (4 mil thick) centered over the spot, and the edges of the sheet were covered with soil.

About 21 d later, the baits, along with surrounding soil, were recovered with a 16-cm-diam posthole digger to a depth of about 25 cm. The soil was sieved through two screens (8 and 10 mesh per 2.5 cm), and the wireworms discovered were counted and placed in bottles. The bottles, along with the baits, were brought back to the laboratory for further examination, counts and identification of wireworms. Soil below 25 cm (usually as deep as 50-60 cm) was also removed and cursorily examined for wireworms. The total number of wireworms found at each site included the field counts plus any additional wireworms found in the baits during laboratory examination. The mean number of wireworms per bait per site was calculated based on the total number of baits recovered because some baits were not recoverable. Wireworm species were determined based on keys and descriptions in Glen et al. (1943) and Wilkinson (1963).

RESULTS AND DISCUSSION

The mean number of wireworms per bait per site varied from 0 to 4.4 (Table 1). The wireworm species, number of sites they were found at, and percentage of the total were as follows:

Species	No. sites	%
Ctenicera pruinina (Horn)	16	38.6
Melanotus longulus oregonensis (LeConte)	10	19.1
Limonius californicus (Mannerheim)	5	25.5
Limonius infuscatus Motschulsky	2	9.6
Dalopius sp.	1	5.6
Ctenicera glauca (Germar)	1	1.2
Aeolus mellillus (Say)	1	0.4

Umatilla County was represented by three species and had the highest mean number of wireworms per bait per site (2.23), followed by Union County with 1.19 wireworms, predominately *L. californicus*. The wireworms (0.67/bait/site) in Gilliam County were comprised of a mixture of four species, although only *C. pruinina* was present in three of the four sites with wireworms, whereas all of the wireworms (0.40/bait/site) in Morrow County were *C. pruinina*. Sherman County had 0.30 wireworms per bait per site (a mixture of four species), Baker County had 0.31 wireworms (all *M. longulus oregonensis*), Wasco County had 0.20 wireworms, and Wallowa and Jefferson Counties had none. No wireworms were found in soil below the baits.

A baiting technique indicates whether or not wireworms are actively present, and their relative abundance. It does not, however, give a measure of wireworm density as soil sampling does. Because no soil samples were taken in this study, the wireworm density at each site was estimated based on results of Toba and Turner (1983). They found that after 3 wk exposure of baits in June, the ratio of wireworms per bait:wireworms per 929 cm^2 (1 ft^2)

of soil sample was 0.59:1. Although climate and soil type were similar in both studies, we considered that room for error existed in using their data because of differences in time of study (June vs. July and August), location, and other factors. However, no other published reports could be found regarding the relationship between bait and soil sample, and soil temperatures recorded at our study sites (mean of 20.9°C) corresponded to that for June (22°C) in Toba and Turner's study. Thus, after calculating the estimated number of wireworms/929 cm^2 of soil at each site (Table 1), the highest density was found at location 28E,3N,24 with 7.45 wireworms.

Information is also lacking on damaging threshold populations of wireworms in wheat. However, Toba et al. (1985) have presented data that may be helpful in providing such information. When winter wheat was planted in plots treated with 4.5 kg a.i./ha fonofos and incorporated 10-15 cm deep, to provide the best possible treatment as an indication of potential yield in the absence of wireworms, yields in treated plots did not differ from those in untreated control plots even when the population density was as high as 6.87 wireworms/929 cm^2 of soil. With spring wheat, a density as low as 4.84 wireworms/929 cm^2 was capable of significantly reducing yields in the control plots compared to the fonofos-treated plots. Similar results were obtained by Toba et al. (1988) in which spring wheat yields in plots of untreated seeds were significantly lower than those in plots having seeds treated with carbosulfan, lindane or fonofos. In the present study, only one site had more than 6.87 wireworms/929 cm^2 (Table 1), but it would be questionable whether even this density would cause a yield reduction in winter wheat. However, there were three sites with densities greater than 4.84 wireworms/929 cm^2. Therefore, it appears that damaging populations can be found in wheat-growing areas of northcentral and northeastern Oregon, at least to spring wheat.

False wireworms, the larvae of certain genera of Tenebrionidae, are also important because they cause damage similar to that of wireworms in wheat crops (Calkins and Kirk 1975). We found false wireworms, primarily *Eleodus*, as follows:

Site location (County)	No./site
28E,3N,33a (Umatilla)	11
20E,2N,32 (Gilliam)	10
26E,1N,20 (Morrow)	7
27E,3N,25 (Umatilla)	5
16E,8S,28 (Wasco)	3
28E,3N,33b (Umatilla); 17E,3S,7 (Sherman); 21E,1N,24 (Gilliam)	2
13E,1S,9 (Wasco); 17E,7S,27 (Wasco)	1

When they were included in calculations for estimating density of wireworms and false wireworms per 929 cm^2 of soil, they did not add materially to the density of wireworms shown in Table 1; i.e., no additional sites had densities higher than 4.48 larvae/929 cm^2. However, no information is available on the attractancy of false wireworms to the bait we used or on the relationship between the number found at baits and the density per 929 cm^2 of soil.

Despite the apparent lack of damaging populations, it is possible that our estimates were conservative. Toba and Turner (1983) showed that the number of wireworms found at baits decreased from April to June, which in all likelihood was directly related to decrease in soil moisture. Because our study was conducted in July and August, one would expect soil moisture, and consequently the number of wireworms at the baits, to be lower than they would have been in June.

There appears to be no correlation between wireworm density and ranchers' practice of using seeds treated for wireworm control. Even if a damaging population was found in a field where treated seeds had been in use, one would expect such a treatment to exert pressure on the population, thereby preventing the development of an even higher population. On the

Table 1

Results of baiting for wireworms in wheat-growing areas of northcentral and northeastern Oregon.

Site location[a]	Soil name[b]	Seed treated[c]	No. baits[d]	No. wireworm	$\bar{X}$ No. wireworm/ bait	Est. $\bar{X}$ No. wireworm/ ft^{2}[e]	Wireworm species (%)[f]
UMATILLA COUNTY (323,000 Acres)							
28E,3N,24	Sagehill FSL	Yes	5/16	22	4.40	7.45	Lc(10), Cp(90)
27E,2N,25	Burke SL	Yes	2/16	6	3.00	5.08	Mo(67), Cp(33)
28E,3N,33a	Sagehill FSL	No[g]	16/16	27	1.69	2.86	Mo(83), Cp(17)
28E,3N,33b	Adkins FSL	Yes	13/16	22	1.69	2.86	Lc(100)
27E,3N,25	Shano SL	Yes	16/16	6	0.38	0.64	Mo(17), Cp(83)
GILLIAM COUNTY (135,000 Acres)							
21E,6S,5	Morrow SL	Yes	16/16	52	3.25	5.51	Mo(32), Cg(8), Li(60)
20E,3S,21	Condon & Valby SL	No	16/16	6	0.38	0.64	Cp(100)
20E,2N,32	Ritzville SL	Yes	16/16	4	0.25	0.42	Cp(100)
21E,3S,12	Condon & Valby SL	Yes	16/16	2	0.12	0.20	Cp(100)
21E,1N,24	Warden SL	Yes	16/16	0	0.00	0.00	
19E,2S,28	Mikkalo SL	Yes	16/16	0	0.00	0.00	
UNION COUNTY (52,000 Acres)							
39E,1S,9	Palouse SL	No[g]	16/16	32	2.00	3.39	Lc(100)
39E,3S,8	La Grande SCL	No	16/16	24	1.50	2.54	Lc(36), Da(64)
40E,3S,18	Hot Lake SL	No	16/16	1	0.06	0.10	Lc(100)
MORROW COUNTY (213,000 Acres)							
27E,2N,19	Ritzville SL	No	16/16	15	0.94	1.59	Cp(100)
26E,1N,20	Willis SL	Yes	16/16	12	0.75	1.27	Cp(100)
25E,1S,15	Ritzville SL	No	12/16	8	0.67	1.14	Cp(100)
26E,1N,4	Warden SL	Yes	16/16	4	0.25	0.42	Cp(100)
27E,2N,30	Ritzville SL	No	24/24	4	0.17	0.29	Cp(100)
24E,2S,30	Rhea SL	Yes	16/16	0	0.00	0.00	
23E,1N,28	Ritzville SL	Yes	16/16	0	0.00	0.00	
SHERMAN COUNTY (142,000 Acres)							
16E,4S,23	Condon SL	No	16/16	11	0.69	1.17	Mo(90), Cp(10)

Table 1 continued

Site location[a]	Soil name[b]	Seed treated[c]	No. baits[d]	No. wireworm	$\bar{X}$ No. wireworm/ bait	Est. $\bar{X}$ No. wireworm/ ft^{2}[e]	Wireworm species (%)[f]
18E,1S,7	Walla Walla SL	No	16/16	9	0.56	0.95	Cp(100)
17E,3S,7	Condon SL	No	16/16	2	0.12	0.20	Cp(100)
16E,2N,26	Walla Walla SL	Yes	16/16	0	0.00	0.00	
WASCO COUNTY (86,700 Acres)							
16E,8S,28	McMeen SL	No	16/16	8	0.50	0.85	Mo(43), Cp(43), Am(14)
13E,1S,9	Dufur SL	Yes	16/16	2	0.12	0.20	Mo(50), Li(50)
17E,7S,27	Tub GSCL	Yes	16/16	2	0.12	0.20	Mo(100)
13E,1S,13	Duart SL	No	16/16	1	0.06	0.10	Mo(100)
BAKER COUNTY (12,000 Acres)							
43E,8S,26	Brownscombe SL	No	16/16	5	0.31	0.52	Mo(100)
WALLOWA COUNTY (20,700 Acres)							
44E,5N,16	Cowsly SL	Yes	16/16	0	0.00	0.00	
43E,1S,15	Redmount GSL	Yes	16/16	0	0.00	0.00	
43E,1N,7	Snow SL	Yes	16/16	0	0.00	0.00	
JEFFERSON COUNTY (28,000 Acres)							
14E,10S,9	Cullius loam	No	2/2	0	0.00	0.00	

[a] Range, Township, Section of Public Land Survey System.
[b] GSL = gravelly silt loam, GSCL = gravelly silty clay loam, FSL = fine sandy loam, SL = silt loam, SCL = silty clay loam.
[c] Ranchers' response as to whether or not seeds were treated with pesticides for wireworm control (includes sometimes).
[d] Number recovered/number set.
[e] Calculations based on ratio of 0.59 wireworms/bait:1 wireworm/929 cm^{2} (1 ft^{2}) of soil sample (Toba and Turner 1983).
[f] Abbreviations used: Am = *Aeolus mellillus*, Cg = *Ctenicera glauca*, Cp = *C. pruinina*, Da = *Dalopius* sp., Lc = *Limonius californicus*, Li = *L. infuscatus*, Mo = *Melanotus longulus oregonensis*.
[g] Sites have never been farmed.

other hand, lack of damaging populations in fields where no treated seeds had been in use is no assurance that damaging populations will not develop in the future.

Our results, along with those of Toba and Turner (1983) and Toba et al. (1985, 1988), indicated that the population densities of wireworms found in the wheat-growing areas studied apparently were not high enough to cause yield reduction in winter wheat, although they could cause stand reduction. The reason for this is that yield may not be affected despite a 20% reduction in plant stand (Harwood et al. 1957), whereby stand reduction is compensated by increased tillering by the remaining plants. On the other hand, population densities do exist that can reduce yields in spring wheat.

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Biology of the black vine weevil *Otiorhynchus sulcatus* on hop in Idaho (Coleoptera: Curculionidae)[1]

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ABSTRACT

The black vine weevil, *Otiorhynchus sulcatus* (Fabricius), is an important pest of hop, *Humulus lupulus* L., in Idaho. Although some adults survived winter conditions, *O. sulcatus* overwintered primarily as developing larvae associated with hop root systems 5-50 cm deep in the soil. Primary damage occurred as nearly mature larvae girdled small roots and rhizomes during spring feeding. Pupation began in mid-April with soil temperatures of 15-17°C and concluded in mid- to late May. Adult emergence began in early May and was complete by late May to early June during 1986-1988. The preoviposition period averaged 26 days in the field. The mean number of eggs laid per adult female was 290 (22-1230). Eggs hatched in 12-22 days at 21°C.

INTRODUCTION

The black vine weevil, *Otiorhynchus sulcatus* (Fabricius), is an important pest of commercially grown hop (*Humulus lupulus* L.) in the Pacific Northwest. Nearly 1000 acres of infested hop have been removed from production in Idaho within the last 10 years because of this pest. Selective replanting of infested areas has enabled some yards to remain productive for several additional years. In Washington, *O. sulcatus* is also an important hop pest (Mayer and Cone 1985), although damage is not as extensive as in Idaho.

Nearly 200 plant species are listed as hosts of *O. sulcatus* (Smith 1927, Essig 1933, Warner and Negley 1976 and Masaki et al. 1984), yet this is the first published record of hop being infested at economically important levels in the United States. The biology of *O. sulcatus* on this perennial plant is poorly understood and no information is available in the literature on this host-pest relationship.

There are no natural agents effecting significant control in Idaho hop yards. Efforts have been directed at controlling adult weevils with foliar sprays after emergence but before oviposition (Baird and Nyberg 1987). More recently, several nematode parasites have demonstrated control in the field (Dorschner et al. 1989). This paper reports on a multi-year study of the biology of black vine weevil on hop in Idaho.

METHODS AND MATERIALS

Root weevil adults and larvae were collected in soil samples from hop yards in the Notus, Wilder and Greenleaf areas about 35 mi (55 km) W of Boise, near the Oregon border in Canyon County (Elev = 700 m), Idaho between 1977 and 1989. Larvae were reared to adults in 100 × 15 mm petri dishes containing slightly moistened soil. Adult identifications were confirmed by W.F. Barr, University of Idaho, and D.H. Whitehead, United States National Museum. Voucher specimens are deposited at each location.

Soil sampling consisted of removing soil from around hop roots and crowns to a depth of 18-50 cm, screening the soil through 4 mesh/cm metal screen, removing root weevil life stages, and replacing the soil around the hop root system. To determine developmental events in field populations, soil sampling was completed semi-weekly from March through September in infested hop yards (N = 50 BVW specimens). Soil temperatures were recorded at 10 cm depth at time of sampling, usually between 1000 and 1400 hr. Soil type was sandy with pH 7.5.

Internal egg development was monitored by dissecting newly emerged adults (20 per week) and examining them for reproductive tract condition and egg development. When newly emerged adults indicated egg maturity, close observations were begun on adult

weevils in the field to observe oviposition behavior, sites and timing. Egg production was determined by placing newly emerged adults in petri dishes with slightly moistened filter paper and a new hop leaf daily for food (Penman & Scott 1976). Adults in petri dishes were maintained in shade at outdoor temperature and photoperiod.

To determine the sequence of developmental changes through the pupal stage, 100 mature larvae were collected in early March and placed in individual plastic cups ($3 \times 3 \times 3$ cm) filled with soil from the collection site. Sufficient moisture was provided to prevent desiccation. Cups were maintained at outdoor temperature (12–16°C) and photoperiod by placing them in shaded areas protected from severe weather. Specimens were observed daily while larvae, then twice daily after pupation. As rapid changes in pupal development occurred, hourly observations were made. Teneral adults were observed twice daily during the tanning period (17–19°C).

To determine the ability of adults to overwinter, 250 adults were placed in screened cages ($91 \times 61 \times 61$ cm) filled with soil and young, cutback hop plants. The cages were maintained outdoors under field conditions from September to April. Evaluations were then made by carefully screening the soil and counting the living adult weevils in each cage.

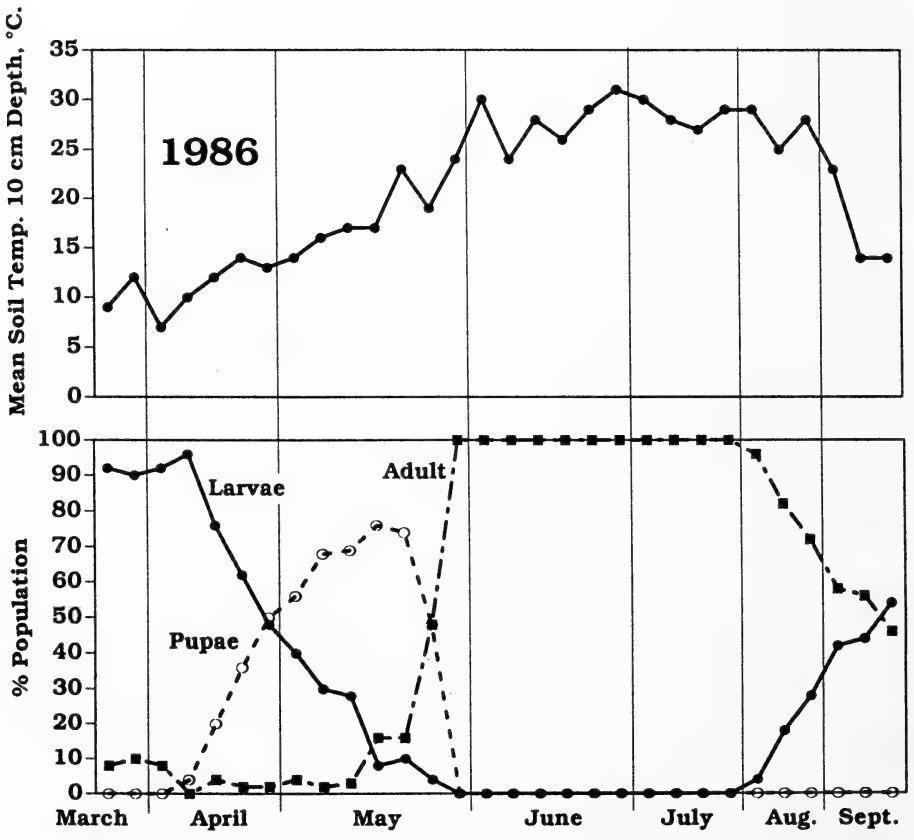

Figure 1. Percent larvae, pupae, adult black vine weevil and mean soil temperature in semi-weekly soil samples (1986).

RESULTS

Species of root weevils present. Soil and plant debris sampling of 36 hop yards in Canyon County, Idaho revealed low infestation levels overall. Certain varieties, i.e. Cascade and L-8, had high root weevil numbers in at least some portion of the yard whereas most other varieties were lightly-infested. Black vine weevil, *O. sulcatus*, was the dominant species found (94.2 %) with strawberry root weevil, *O. ovatus*, (4.8%), rough strawberry root weevil, *O. rugosostriatus*, (0.8%), and *O. meridionalis* (0.2%) occurring at lower levels. Two hop yards, var L-8 and Cascade, had *O. ovatus* as the dominant species (83%) and *O. sulcatus* (17%) during initial investigations during 1978, but the percentage reversed within two years and *O. sulcatus* remained the dominant species. No males of any *Otiorhynchus* species were found while examining over 1500 specimens.

General life history. Root weevils overwintered in the soil primarily in the larval stages, although a small percentage of adults also survived the winter in the soil. Overwintering larvae pupated beginning the second week of April, and the earliest adult emergence occurred in early May (Figs. 1,2,3). In most years, adults emerged by 27-30 May, but late emergence extended into mid-June. Oviposition by new adults began in late June, peaked by late July and concluded by early September (Fig. 4). Overwintered adults began oviposition in late May to early June and concluded by early July.

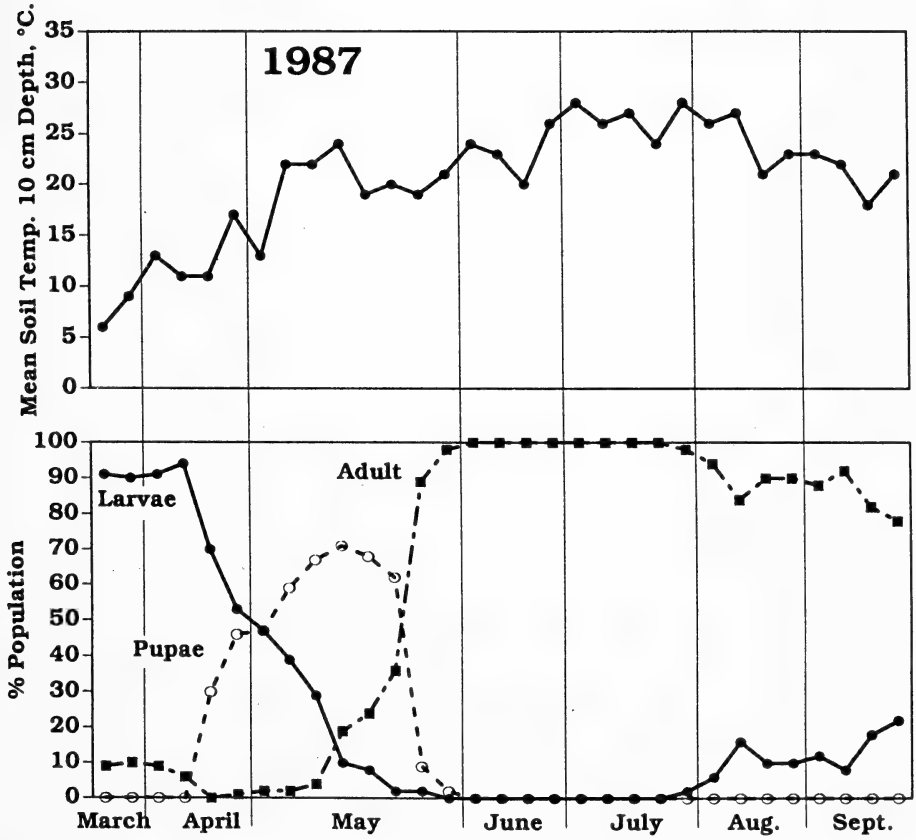

Figure 2. Percent larvae, pupae, adult black vine weevil and mean soil temperature in semi-weekly soil samples (1987).

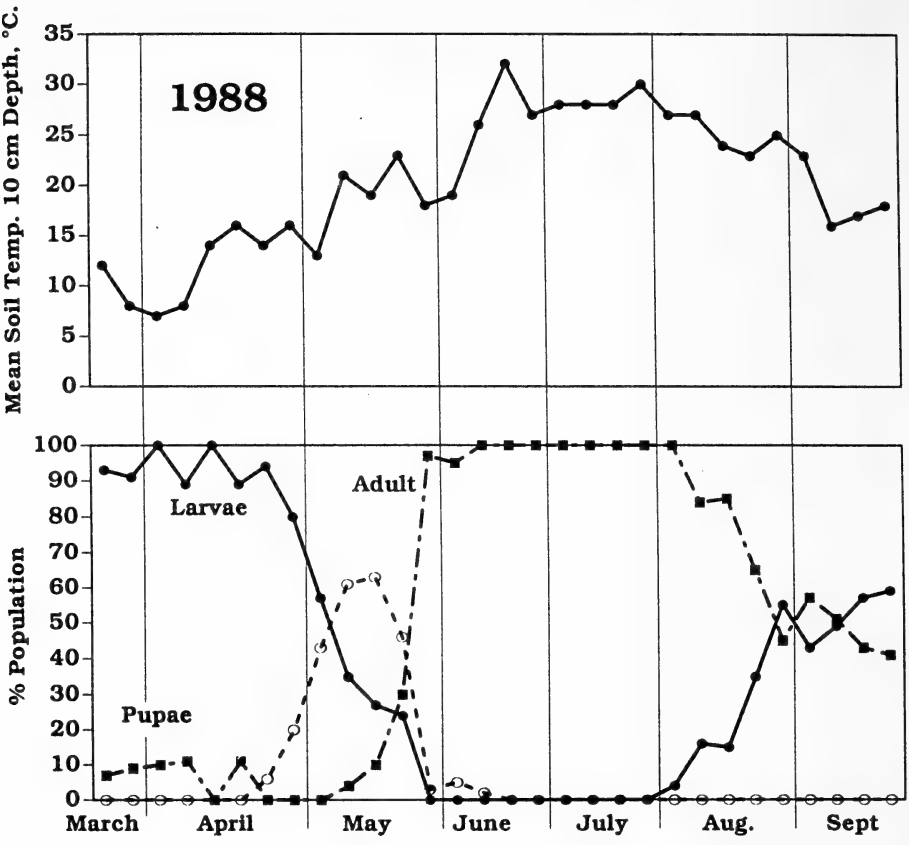

Figure 3. Percent larvae, pupae, adult black vine weevil and mean soil temperature in semi-weekly soil samples (1988).

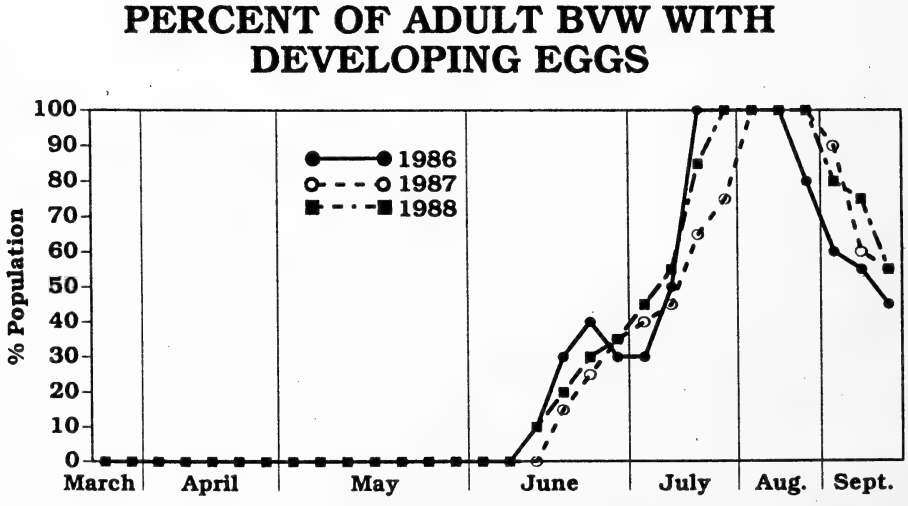

Figure 4. Percent of adult black vine weevil with developing eggs (1986-88).

Larval and adult feeding and damage. Larval feeding extended from late summer into the following spring with the primary damage being caused by larvae scoring and girdling 3-20 mm diameter hop roots. The most visible damage resulted from late instar feeding in early to late spring. During the coldest months, larvae were found 30-50 cm deep in the soil closely associated with the woody hop crown with little damage evident. Within a few hours after emerging from the soil, adults began feeding intermittently on hop leaves, but the defoliation was slight (<2%) and has not been demonstrated to be important. Adults were also observed feeding on several weed species including pigweed and lambsquarter and ornamental shrubs (lilacs) in the Ada and Canyon County areas.

Table 1
Developmental Changes During Black Vine Weevil Pupal Stage (12–16°C).

Elapsed Time	Developmental Events
0.0-1.0 days	Mature larva (prepupa). Feeding ceases, thoracic segments swell, integument splits along dorsal line; Pupa emerges.
1.0-2.0 days	Pupa translucent white, spine tips light brown.
4.0-6.0 days	Pupa milky white.
8.0-10.0 days	Pupa yellowish-white; compound eyes dark red top half, light red bottom half; antennae bases light brown; tarsal claws tan distally.
10.0-12.0 days	Dorsum of head medium brown; femora-tibiae joint medium brown; compound eye uniformly red; tarsal claws light brown; mandibles visible, dark brown; antennae bases dark brown.
12.0-13.0 days	Dorsum of head dark brown; snout dorsum dark brown; antennae bases black, other segments light brown; tarsal claws black; mandibles black; sclerite margins light brown; elytra separated slightly, tan lines visible.
13.0-13.5 days	First visible signs of molt, liquid droplets on pupal body. Ecdysis occurs. Cuticle splits at leg base, peels off distally; antennae cuticle splits at base, peels off distally; cuticle splits at vertex of head, peels off to snout, mandibles; elytra folds into position on dorsum; molt complete in 3-6 hr.

Developmental events in field populations. During 1986-88, five to ten percent of the *O. sulcatus* field population overwintered as adults in the soil. In separate tests of caged adults maintained outdoors during these same winters, 11 to 14 percent survived.

In early March, late instar larvae were found in close proximity to hop roots from 2 to 30 cm deep in the soil. Fresh girdling and scoring on roots indicated recent feeding. By mid March, most larvae were mature and had moved higher in the soil profile away from the root system. By late March, mature larvae in prepupal cells were found 2-6 cm deep in the soil.

During 1986 through 1988, the earliest pupae were found from 11-21 April reaching a peak of 62-70% in pupal stage by 15 May. The average pupal period was 18 days, however, this varied from 15 to 30 days. New, teneral adults were first found 2 May reaching a peak adult (98-100%) emergence by 27-30 May. Teneral adults were found in soil samples until 7 June (1986-87) and until 21 June in 1988.

Newly emerged adults taken in field samples showed little evidence of internal egg development until 21-26 June when 30% were gravid (Fig. 4). An increasing prevalence of gravid females occurred through early July reaching 100% of the weevil population by July 22-29. The earliest egg deposition in field populations was on 20 June 1986 and 24 June 1987. Most adult weevils were gravid and ovipositing by early July and had completed oviposition by mid August, however, a few eggs were laid in early September. Overwintered adults, being a very small portion of the population, were difficult to observe. However, limited observations indicate early onset of oviposition (late May) and completion by early July. In commercial hop yards, eggs hatched in 14-18 days.

Observations in laboratory populations. The sequence of morphological and color changes in pupae transforming to adults is described in Table 1. Adult tanning and color changes following eclosion are described in Table 2.

Feeding on hop leaves began within 24 hr of adult emergence from the soil. Caged adults fed readily on hop leaves usually notching the leaves but at times feeding on the inner leaf portions thus skeletonizing the leaf. As in the field observations, all feeding was at night.

The preoviposition period (eclosion to oviposition) averaged 26 days (14-75 days) for adults from field populations. Maximum egg production occurred in weevils with a preoviposition period of 17-23 days and dropped off sharply after 25 days. Weevils with onset of oviposition delayed beyond 30 days had very low egg counts.

Table 2
Tanning Sequence of Teneral Adult Black Vine Weevils (17–19°C).

Elapsed time	Developmental events
0–10 hr	Newly emerged adult; antennae and snout dorsum light brown; distal femora, proximal tibiae light brown; dorsal thorax, ventral snout, sternites light tan; mandibles and antennae bases black.
16–24 hr	Distal femora and proximal tibiae dark brown; remainder of legs light brown; snout dorsum anterior $^2/_3$ black; elytra tan.
2–4 days	Distal femora and proximal tibiae black; snout dorsum anterior $^3/_4$ black; snout venter anterior $^1/_2$ black; coxae light brown.
4–8 days	Ventral and dorsal head and snout black; legs except coxae black; coxae reddish brown; elytra and thorax dorsum dark brown; thorax venter reddish brown.
8–10 days	Thoracic sternites dark brown; coxae dark brown; other head, thorax, abdomen areas black; yellow tufts visible on elytra.
10–21 days	All areas black except for yellow tufts on elytra.

During oviposition, the female lowered the terminal abdominal segment and extended the ovipositor about 1.5 mm. Individual eggs were then forced down the egg tube and deposited singly or in small, unevenly spaced groups. They were laid on the soil surface, in soil crevices, and on leaves. The mean number of eggs laid per day per ovipositing adult was 10 with a maximum of 45 (20–21°C). The mean oviposition period for 113 weevils was 33 days with oviposition being frequently interrupted by feeding intervals of 2-6 days. The average number of eggs laid by a single adult in one season was 290 (22-1230). Eggs laid under laboratory conditions hatched in 12-22 days (21°C).

DISCUSSION

Black vine weevil (*O. sulcatus*) was the most common root weevil species found in Idaho hop yards, although strawberry root weevil (*O. ovatus*) was found in dominant numbers in two yards and occasionally in other yards throughout the study. *Otiorhynchus rugosostriatus* and *O. meridionalis* were rare in collections from hop yards but were occasionally collected from ornamental hosts in the area. Essig (1933) reported *O. sulcatus* as a hop pest in Great Britain but not in the United States. He further indicated *O. sulcatus* is the most widely distributed *Otiorhynchus* species in North America but did not list hop among its host plants. Warner and Negley (1976) listed *O. ovatus* from hop in the United States but did not record *O. sulcatus* and *O. rugosostriatus* on hop as we found in this study. Cone (Pers. Comm. 1991) indicated *O. sulcatus* is a significant pest in Washington hop yards.

Based on specimens in museums (University of Idaho, Moscow and Albertson College of Idaho, Caldwell), the next most frequent collection site for *O. sulcatus* in Idaho is lilac and for *O. ovatus*, caneberries and as a transient pest in homes and yards. Interestingly, *O. ovatus* is rare in commercial peppermint in Idaho, even in fields adjacent to infested hop yards, yet it is an important pest of mint (*Mentha* spp.) in Oregon.

Black vine weevil not only has a wide host range but has adapted to widely differing conditions in the Pacific Northwest and elsewhere. Adult emergence in Idaho hop yards began earlier (2 May) than in western Washington strawberries (31 May) (Garth and Shanks 1978) or south central Washington grapes (17 June) (Cone 1963).

There was considerable variation in the preoviposition period observed in various locations and host plants. According to most authors, *O. sulcatus* oviposition is dependent upon the food source and quality resulting in a shorter preoviposition period and more eggs when adults fed on optimal host plant tissue (Cram and Pearson 1965). Shanks and Finnigan (1973) stated the preoviposition period for *O. sulcatus* on strawberries in western Washington to be 3-4 weeks. Garth and Shanks (1978) found the interval to be 7 weeks during a cooler than average season. Ambient temperature and water availability (plant succulence) also affect the length of the preoviposition period and egg production (Cram 1970, Shanks 1980). Our findings of 3-4 weeks on Idaho hop are within the range reported by other workers. The number of eggs laid per day and per season on hop was highly variable but within the range found on other crops (Cram 1970, 1980, Shanks 1980, Doss and Shanks, 1985).

Egg development time at 12-22 days was quite variable whether in the laboratory or under field conditions but was within the range reported by other workers (Smith 1927).

Changes in *O. sulcatus* pupae and teneral adults during the developmental processes have not been described by other workers. Although there was variation among the 200 weevils observed, the elapsed times recorded in Tables 1 and 2 represent the timing of most of the individuals observed and provide a reference for determining age and stage of development for future researchers.

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The distribution and life cycle of *Reduvius personatus* (L.) (Hemiptera: Reduviidae) in Canada

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ABSTRACT

The distribution of *Reduvius personatus* in Canada is mapped, and is recorded for the first time from New Brunswick. It is shown that this species has a two-year life cycle in this country, overwintering as larvae in both the third and fifth instars. Most adult emergence occurs from May to early October, with a peak in June-July.

INTRODUCTION

Reduvius personatus (L.) known popularly as the "kissing bug", the "masked bug" or the "masked bed-bug hunter", is a cosmopolitan species that occurs widely in North America, ranging from Quebec and New England west to Kansas and south to Florida (Blatchley 1926; Slater and Baranowski 1978; Froeschner 1988). In Canada it has been recorded from Ontario and Quebec in the east and British Columbia in the west (Moore 1950; Larochelle 1984; Scudder 1961; Froeschner 1988).

Both adults and immatures cover themselves with lint and dirt (Blatchley 1926; Harz 1952; Immel 1954), and hide in corners and crevices waiting for prey, which usually consists of flies and other soft-bodied insects such as silverfish, booklice, bedbugs and harvestmen (Harz 1952). Leconte (1855) reports that *R. personatus* can bite humans, and that the pain caused is almost equal to that of a snake bite, the swelling and irritation sometimes lasting for a week.

Reduvius personatus is reported as typically having one generation a year and overwintering as a fourth or fifth instar larva in England, Germany and the Ukraine (Puchkov 1986). However, Puchkov (1986) notes that in the USA and Germany, cases are known where the life cycle lasts two years, and larvae spend the first winter in the third instar. Readio (1931) found that larvae that pass the first winter in the third instar take two years for development, entering diapause again in the fifth instar and passing the second winter in that stadium.

This paper reports on the occurrence of a two year life cycle in Canada, and summarizes the distribution and phenology in this country.

MATERIAL AND METHODS

Previous published records were summarized and specimens in the Canadian National Collection, and various other collections across Canada were studied to document the distribution. Seasonal occurrence of adults was determined from specimen labels and graphed according to the methods of Soós (1958).

Evidence for a two year life cycle in British Columbia was obtained by recording the occurrence of immature stages at Osoyoos in October 1989, and in April and October 1990. Evidence for a two year life cycle in Ontario was obtained by rearing a specimen through two years.

On March 1, 1988, while I was working on the Canadian National Collection in Ottawa, a Mr. Vernon Alexander brought in a live third instar larva of *R. personatus* collected in a house in that city. This specimen was brought to Vancouver and reared. The larva was kept in a small plastic container in my home and fed various insects, mostly Diptera. For the most part these were adult Syrphidae, *Calliphora* spp., and *Pollenia rudis* (Fabr.). Fresh food was presented once every week. Occasionally adult clay-coloured weevils (*Brachyrhinus singularis* (L.)) were offered as food, but these were rarely accepted. Third instar locusts (*Schistocerca gregaria* Forskal) were offered during cold spells in winter when no other

insects were readily available but no feeding was observed. Temperature was maintained between 18.5°C (0700-2300 H) and 16.5°C (2300-0700 H) in winter, but at times was as high as 26.5°C in the summer during the day. The larva of *R. personatus* was examined for evidence of molting, when the food was changed each week.

RESULTS AND DISCUSSION

A total of 186 specimens of adults of *R. personatus* from British Columbia, Ontario and Quebec were examined. Place and dates of capture were recorded. Figure 1 records the distribution of the species in Canada, based on the museum specimens studied, and previously published records. The species here is recorded from New Brunswick for the first time (Fredericton, 30 June 1933 (C.E. Atwood)) [Royal Ontario Museum]. It is clearly restricted to the southern areas of the country.

Both adults and larvae of *R. personatus* typically live in houses and outhouses (Blatchley 1926; Southwood and Leston 1959), and in British Columbia have been recorded as abundant in dockside warehouses in Vancouver (Scudder 1961), and inside and outside houses and garden sheds in Osoyoos (Scudder, unpublished). In spite of living in such a habitat, *R. personatus* is not so widely distributed as some other insects that live in homes in Canada. For example, Vickery and Kevan (1986) document that the cosmopolitan American cockroach (*Periplaneta americana* (L.)) occurs in buildings from British Columbia to Newfoundland, and the cosmopolitan German cockroach (*Blattella germanica* (L.)) which occurs in stores, warehouses, bakeries, food-processing and storage buildings and dwellings, occurs in Alaska, Yukon, Northern Quebec and across the southern half of Canada. Southwood and Leston (1959) found that *R. personatus* was restricted to the southern part of the British Isles, occurring north only to Lancashire, but being absent from Ireland, Scotland and Wales.

Figure 2 diagrams the frequency of occurrence of adult *R. personatus* collected in Canada. Most emergence occurs from May to early October, with a peak in June-July. The time of occurrence of adults in Canada, is thus similar to that in the USA. Blatchley (1926) reports their occurrence from June 11 to July 9 in Indiana, and August 15 in Alabama, and Readio (1931) records that adults occur from May to September at Lawrence, Kansas. The time of occurrence of adults of *R. personatus* in the southern Ukraine is also similar to that in North America (Puchkov 1986).

Most records of insects attracted to light are in June and July in both British Columbia and Ontario. Similarly, Blatchley (1926) reported that in Indiana, adults are most common flying to light at dusk in June.

A total of two second instar, five third instar, eight fourth and three fifth instar larvae of *R. personatus* were captured at Osoyoos in October 1989 and 1990. These data suggest that in this locality the species overwinters for two years as reported in the USA by Readio (1931): the first winter is spent in the third instar and the second as a fifth instar. This was confirmed by the capture of only third and fifth instar larvae at Osoyoos in April 1990.

Rearing of the single larva captured as a third instar in Ottawa during March 1988 confirms this two-year life cycle in Ontario. This insect reached the fifth instar in October 1989, overwintered in this stage, and emerged as an adult on May 15, 1989. It did not feed during the winter, although food was always available and temperature was maintained between 16.5°C and 18.5°C. Unlike many other insects with long life cycles (Danks 1992), dormancy in *R. personatus* is evidently inherent and not induced by environmental temperature or humidity (Readio 1931).

It would seem that the life cycle of *R. personatus* in Canada is similar to that reported for this species in the USA and Germany, where two-year life cycles are recorded (Readio 1931; Puchkov 1986). Whether or not this species in North America also has populations with a single generation a year as in England, Germany and the Ukraine (Puchkov 1986) is still unknown. It will be necessary to undertake many more rearing experiments before this is clarified.

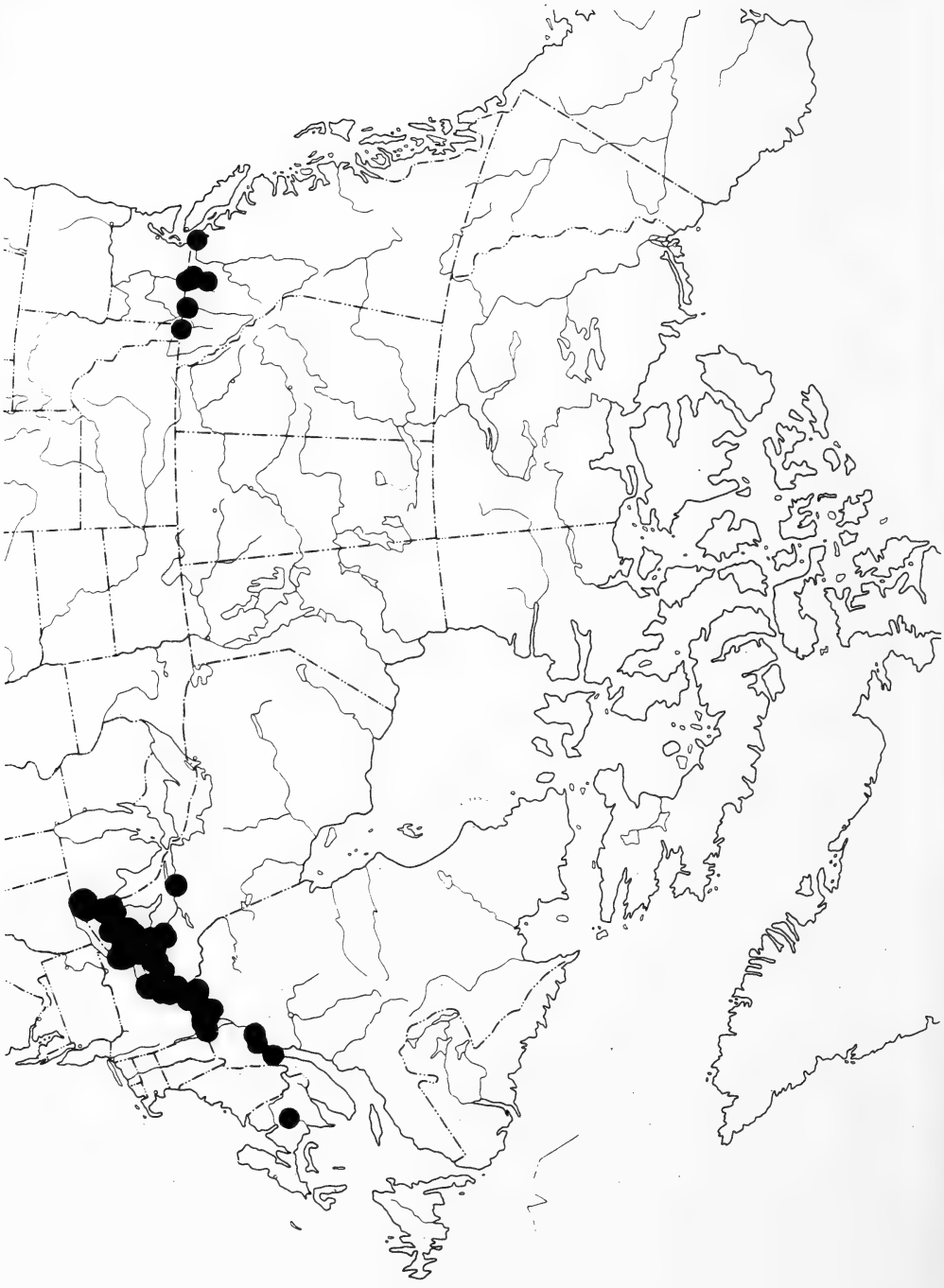

Figure 1. Distribution of *Reduvius personatus* in Canada.

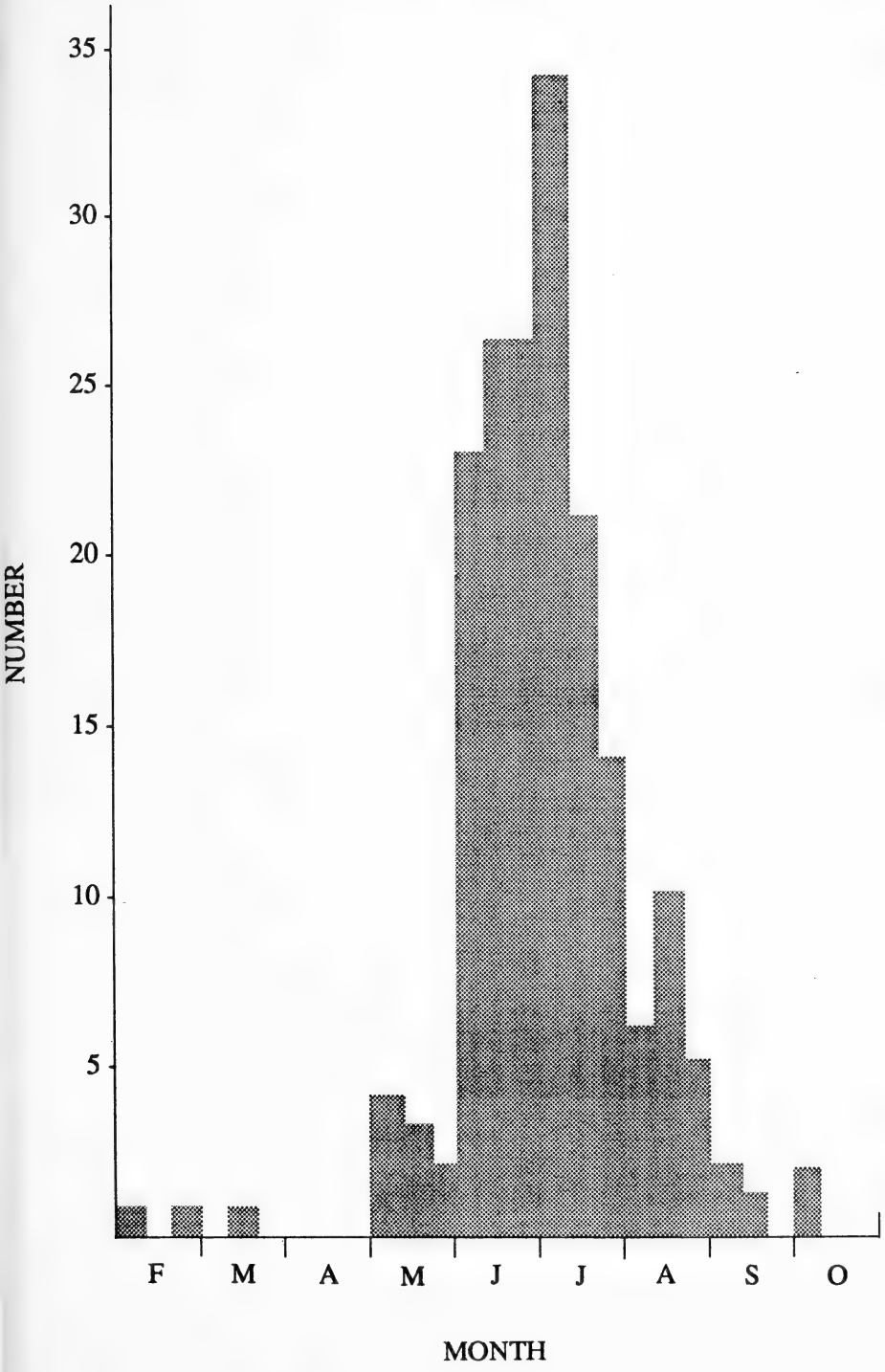

Figure 2. Frequency of adult *Reduvius personatus* occurrence throughout year in Canada.

ACKNOWLEDGMENTS

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A life stage development index for *Trypodendron lineatum* (Oliv.) in a spruce boom on the Alberni Canal, Vancouver Island

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ABSTRACT

Development of *Trypodendron lineatum* Oliv. was monitored in a high-grade log boom of Sitka spruce, *Picea sitchensis*, stored in the Alberni Canal, B.C. in 1991. Twenty-eight logs were surveyed at weekly intervals from April 19 to September 13, 1991. By the sixth week all 28 logs had been attacked. Every week, chunks of wood were cut from each attacked log and total of all life stages were recorded. Changes in insect development and the presence or absence of stain were noted. The ratio of brood adults to parental adults was 10:1 and it was determined that the timing of both parental and brood adult emergence coincided in the "sister" flight. An insect development profile was constructed from these data, and an index was produced for estimating the minimum number of days required to reach specific stages in development. When combined with logging and transportation information, the index provided an estimate of where and when the logs had been attacked. With this information, modifications in management strategies can be reviewed and steps taken to avoid pest populations being transported to storage areas.

Key words: *Trypodendron lineatum*, ambrosia beetle, life stages, stain, insect development index.

INTRODUCTION

The ambrosia beetle, *Trypodendron lineatum* (Olivier.), is a serious pest to the forest industry and has caused extensive degrade to high-grade logs in coastal British Columbia (Kinghorn and Chapman 1959; Dyer 1963; Gray and Borden 1985; McLean 1985). The clear outer part of the log is the preferred habitat for shelter and brood production of the ambrosia beetle (Shore 1985; Borden 1988). Degrade results when the valuable outer portion of these logs has darkly stained pinholes as a result of ambrosia beetle activity. The lumber is downgraded or rejected from specific markets.

In mid-April ambrosia beetles fly from their overwintering sites in the duff on the forest floor. Host volatiles arrest the emerging beetles at felled or stored log inventories where they colonize the sapwood (Borden 1988). Once the wood has been penetrated by the beetles it becomes stained by the action of symbiotic dark staining fungi. The larvae and parental adults feed on the ambrosia fungus while the brood develops. The adult beetles tend the brood inside the log by keeping the galleries clear of frass and by cropping the growth of the fungus in the galleries. In late summer, after a short maturation period, parental and brood adults leave the logs and fly to the forest margin to overwinter.

Considerable efforts have been invested in the development of control strategies involving insecticides (Richmond 1969), trapping studies using pheromones (McLean and Borden 1975; Shore and McLean 1984, 1985; Lindgren 1990) and other methods of integrated pest management (Richmond and Nijholt 1972; Nijholt 1978; Borden 1988; McLean and Stokkink 1988). In spite of this knowledge, logs are still being attacked in the forest and insects are being spread extensively throughout the transportation system (McLean 1991).

In coastal B.C., log inventories accumulate in booming grounds and storage areas prior to processing. In some cases, depending on supply and demand of certain sorts, this wood can remain in storage for a considerable length of time. If infested logs are left in storage areas and sorting grounds at the time of brood emergence in summer, they become the

source of the following season's spring attack flight beetles. Teneral adults will emerge, and overwinter in adjacent forested margins.

As early as 1950, Graham et al. (1950) researched the use of indices to measure and assess the degrade caused by ambrosia beetles. The issues of breeding sites and population estimates were explored by Chapman (1974) and Von Popo and Thalenhorst (1974). There is a need to know where and when ambrosia beetles attack high value logs. Identification of high hazard areas can assist in the development of strategies to direct log inventory flow. Log inventory control can be implemented in the forest, in the sorting areas and the log storage areas in order to reduce the chances of ambrosia beetle attack on high value saw logs.

Studies were carried out in the Alberni Canal on Vancouver Island to develop a method where life stages could be used as indicators to estimate the timing of the original attack on a log. There were two main objectives: first to observe the life stage development of *Trypodendron lineatum* over time and to identify key changes in insect development and conditions in attacked logs; and second to prepare a life stage development index to estimate where and when the attacks occurred.

METHODS AND MATERIALS

On April 3 1991, sawlogs of Sitka spruce, *Picea sitchensis* (Bong.) Carr., were transported by barge from the west coast of Vancouver Island into the Alberni Canal. Timber marks and inventory information indicated that the logs had been cut between February and March 1991. These logs were sorted in the Alberni Canal. Both bundles and large loose logs were put into the boom. After the boom was completed on April 18 1991, it was towed out for storage along the shore of the Alberni Canal, some 2 km south of Port Alberni.

The first survey of the boom was conducted on April 19, at which time all of the non-submerged logs were surveyed. A total of 28 logs were tallied and numbered for further survey. Between April 19 and September 13 1991, each of the 28 logs were searched at weekly intervals for signs of infestation as indicated by the presence of white boring dust initially and later, entry holes. Most logs were sampled each week as long as the galleries were accessible. If a log had been attacked, a chunk of wood containing the entrance hole to a gallery was chopped from the log. The chunk measured approximately 20 cm. square, and was cut as deep as the insects had penetrated.

TABLE 1

Insect Development Index for *Trypodendron lineatum* constructed from data generated during a 22 week survey of a spruce boom in the Alberni Canal from April 19 to September 13, 1991.

Life stages and visible symptoms	Estimated time since attack (days)
Adults only present (no niches)	0-10
Adults; evidence of gallery construction (egg niches present; some light staining)	11-20
Adults and eggs; niches present (some dark staining)	21-28
Adults, eggs and early instar larvae (wood darkly stained)	29-35
Adults, eggs, late instar larvae and pupae	36-48
Adults, eggs, larvae, pupae and teneral adults	49-84
Adults larvae, pupae, teneral adults present; empty pupal niches	85-105
Attacked, stained with empty pupal niches and no life stages	>105 days

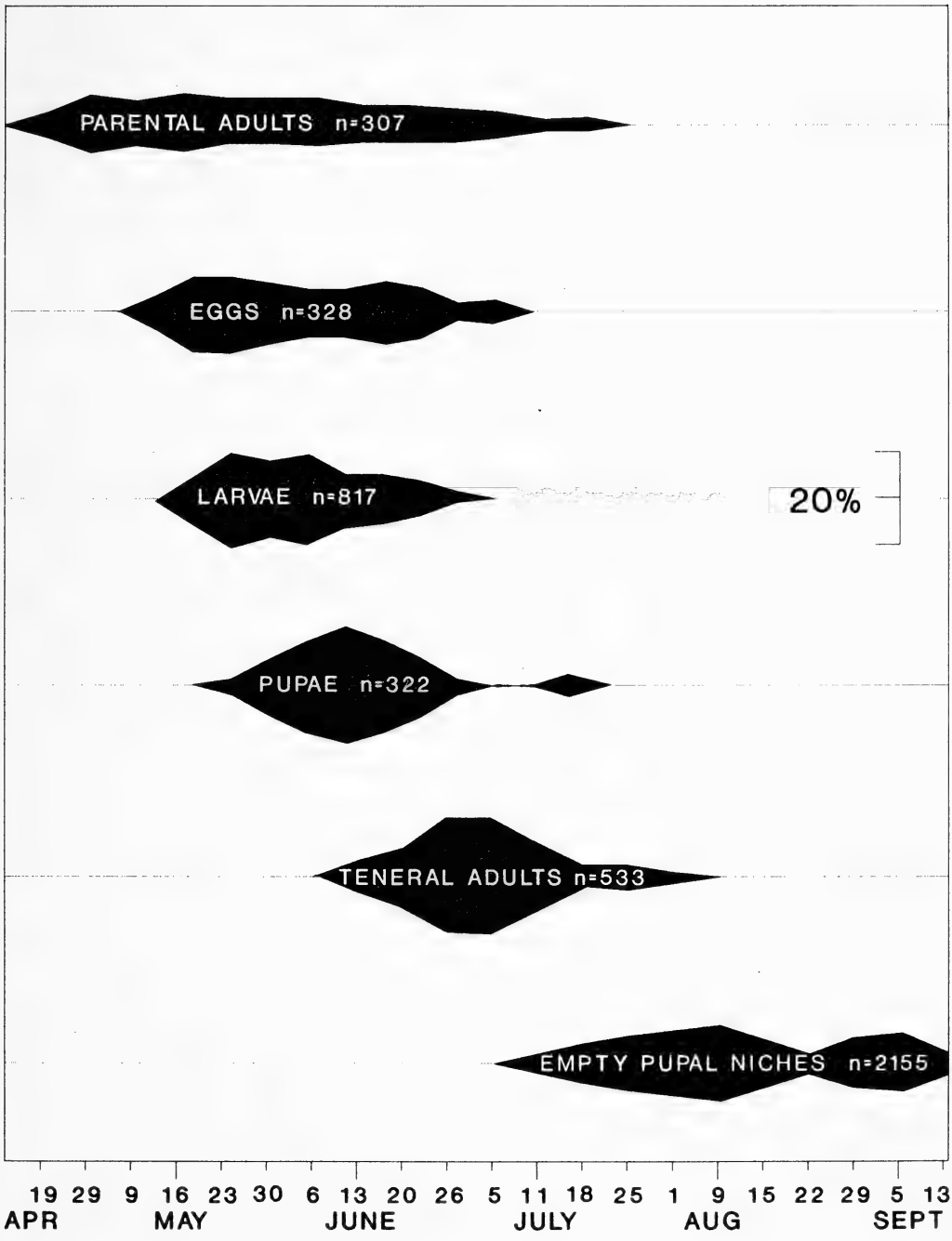

Figure 1. Kite diagrams to show the relative abundance of the life stages of the ambrosia beetle *Trypodendron lineatum* (Oliv.) over time in a log boom of Sitka spruce, *Picea sitchensis*, in the Alberni Canal, during the summer of 1991.

The chunk of wood was then carefully dissected with a pocket knife to expose all insect life stages. Counts of all parental adults, eggs, larvae, pupae and teneral adults were recorded as well as the sex of parental adult(s), depth of penetration, presence of niches, and presence and development of stain.

The total numbers of each of the life stages found at every time interval were summed. From this information, an insect development profile was constructed to trace the number of each life stage present in the logs over time. Since there was so much variability in attacks both within and between logs and because the survey required destructive sampling, this information was best represented in a "kite" chart to show the relative abundance of each life stage over time.

RESULTS AND DISCUSSION

The development profile for each life stage in time and the overlap between life stages is shown in Figure 1. It is particularly interesting to note that the number of parental adults present in the galleries declined at about the same time the teneral adults reach their peak. The ratio of teneral to parental adults was calculated as 10:1. The decline in the number of teneral adults from July 5-18 corresponded with the first empty pupal niches. This indicated that the teneral adults were leaving the niches but were still active in the galleries. Finally, the parental and teneral adults left the logs at about the same time around the middle of July.

The profiles were then used to construct the life stage development index. The premise of this index is that all time increments are minimum estimates. The estimated time since attack represents the minimum time leading to the presence of substantial numbers of each specific life stage or other gallery phenomena.

For the first 10 days of the survey only adults were present. Activity at this time suggests that the adults had located a potentially suitable habitat and had initiated "aggregation". At the time of the first survey, the mean penetration by adults was 8.4 mm. which, from our observations suggested that the attack was no more than two days old. The initial attack date was April 18, 1991. In this establishment phase, there was a period of at least ten days when only adults were present before any signs of niches or staining were found. This was the first of the components of the insect development index (Table 1).

Between the first and second surveys, the attacking insects had mated and begun to excavate the galleries. At this time there were no lateral galleries found. By the time of the second survey, 70% of the beetles were paired. In all cases, the female was at the head of the gallery while the male was actively clearing boring dust from the gallery. Many of the females were found in the lateral galleries and one egg niche was found indicating active brood gallery construction. At this time there was evidence of light staining around the gallery walls. Thus, from 11 days and up to 20 days, after the initial attack the presence of adults, gallery construction, egg niches (but no eggs), and some light staining was seen.

Between the second and the third surveys egg niches were constructed and oviposition had occurred. The first sign of eggs occurred 21 days after the initial attack and dark staining was present in the galleries. Although by May 16, 28 days after the initial attack, adults and eggs were present and there was still no evidence of larvae.

In the period between May 16 and May 23, 29 and 35 days respectively after the estimated initial attack, eggs had hatched and by the 23 May a total of 83 larvae were found. Therefore, there was a period of 14 days after the first eggs were seen before larvae were found. Nijholt (1978) estimated that eggs require 8-10 days to hatch. In this case, our data support that estimate, if egg hatch had started shortly after the survey on May 16.

Larval development was evident 29 days after the initial attack, and by May 30 (after 36 days), the number of larvae present had reached a peak, and late instar larvae were present. In addition, a few of the more advanced larval instars had developed into pupae. By June 6, 49 days after initial attack, parental adults and eggs were present and some of the pupae had developed into teneral adults. The first empty pupal niches were found on July 11 after 84 days. At this time, larval stages were still present. In early August, 105 days after the first signs of attack, there were no life stages present. There was an abundance of empty pupal niches and the wood was heavily stained.

This index can be combined with harvesting and transportation data to estimate where and when the attack could have occurred, and more importantly to predict when the adults will emerge to overwinter. If an estimate of the time of emergence is known, decisions can be made as to the storage location of booms to protect storage and sorting areas; or schedule processing to use the higher risk booms at this critical time.

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Seasonal abundance and distribution of ambrosia beetles on the North Arm of the Fraser River, British Columbia[1]

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ABSTRACT

Pheromone-baited multiple funnel traps were set up on a transect to determine the abundance and occurrence of ambrosia beetles over water and land in the Point Grey log boom storage locations on the North Arm of the Fraser River. Beetle collections made from April to September 1991, showed the proportion of *Trypodendron lineatum, Gnathotrichus sulcatus* and *G. retusus* beetles were in ratio of 1,054:24:1, respectively.

Most of the ambrosia beetles were collected in the forested margin close to the shoreline. Although there is no active logging in the adjacent Foreshore and Pacific Spirit Parks, these areas still provide an overwintering refuge to a large number of ambrosia beetles. The transportation of infested log booms to the North Arm of the Fraser and local wind patterns are factors that lead to the build up of beetle numbers in the area.

INTRODUCTION

Sawmill managers detest the presence of ambrosia beetles in their sawlogs because the dark staining galleries show up as "pinhole" defects in lumber. This damage reduces the value of the lumber recovered from infested logs. Most of the lumber with pinholes does not end up in lumber yards, but rather is consigned to the chipper and thence to pulp. Lumber degrade and value losses caused by ambrosia beetles have been documented by McBride and Kinghorn (1960). More recently, McLean (1985) suggested that the damage incurred from ambrosia beetles infestations results in annual losses of $63.7 million in British Columbia (B.C.).

The biology of ambrosia beetles has been described by Nijholt (1978), Shore (1985), Borden (1988) and Lindgren (1990). The three common species of ambrosia beetles found in B.C. are *Trypodendron lineatum* (Olivier), *Gnathotrichus sulcatus* (LeConte) and *G. retusus* (LeConte). All three species make their homes in the fallen branches, boles and stumps of coniferous trees (Dyer 1963; McLean and Borden 1975a). The flight of *T. lineatum* begins in the spring. Overwintering beetles leave the duff when temperatures exceed 16°C (Kinghorn and Chapman 1959). The beetles will hawk through the forest until arrested by suitable host material (Moeck 1970). Although *T. lineatum* adults are able to fly short distances unaided, beetle dispersal by the wind may be as far as 1.9 km from flight origin within 24 h (Salom and McLean 1990). In the forest, the major host is the valuable old-growth sawlog. Once a suitable host is found and the attacks initiated, the pioneering sex releases an aggregation pheromone that attracts other beetles to the site. The first population aggregation pheromone identified was that for *G. sulcatus* and it was given the trivial name, sulcatol (Borden and Stokkink 1973). The aggregation pheromones for the other two ambrosia beetles have also been identified and synthesized: lineatin for *T. lineatum* (MacConnell *et al.* 1977) and retusol for *G. retusus* (Borden *et al.* 1980).

Soon after the beetles enter into a log, eggs are laid in small niches along the galleries. The galleries are also the growing fields for symbiotic fungi which are inoculated on to the wood when the beetles first enter the log. The depth of gallery penetration varies among beetle and host species. Most of the activity is confined to the moist sapwood. The developing larvae feed solely on the fungus and remain in their niche throughout development. The *T. lineatin* larva is walled off behind a frass plug and as the larva grows, the niche is extended. Frass is extruded through a tiny hole in the plug (Borden, 1988). The development from egg to adult is estimated to take 70 days and the population may multiply 8-fold (Shore *et al.* 1987; McIntosh and McLean 1992). *Gnathotrichus sulcatus* and *G.*

retusus differ slightly from *T. lineatum* in that the male is the pioneering sex. The larval niches remain open throughout larval development but the pupa seals the niche before pupating. The overwintering site for *Gnathotrichus spp* is normally within a log but it may also successfully develop in sawn lumber (McLean and Borden 1975b). *T. lineatum* teneral adults leave the log in the summer and are blown to the nearest forest margin where they overwinter in the duff on the forest floor. At this time the teneral adults are unresponsive to pheromones (Borden 1988).

The Point Grey booming ground is located at the mouth of the North Arm of the Fraser River in B.C. It is an important storage area for forest companies which tow their log booms from the northern coast to the mills in the Vancouver area. The booming ground includes two large areas: the North Arm Jetty (NAJ) where groups of booms are tied up after arriving from the north coast, and the Coast Mill Export (CME) ground, that covers 20 km^2 adjacent to the Foreshore Park, where log booms are stored on tidal flats. These two areas, as well as the shores of the Fraser River, are used to store booms of sawlogs in fresh water. Log booms towed to the NAJ are moved up the river for freshwater storage, to the mills located beside the river, or to the CME ground for resale. To the north of the main river channel and the CME ground are the Foreshore and Pacific Spirit Parks. Both parks are mainly second growth forest that followed harvesting in the 1930's. Deciduous trees, shrubs and ferns blanket the understory.

A study in spring of 1991 was conducted across the NAJ, CME grounds and into the Parks to determine: a) the incidence of ambrosia beetles in the boom storage area and adjacent forest foreshore area; and b) the seasonal abundance of *T. lineatum, G. sulcatus* and *G. retusus* at the North Arm of the Fraser.

MATERIAL AND METHODS

A trapping transect was set out across the North Arm Jetty, the CME storage area, the forested Foreshore Park area and into the Pacific Spirit Park (Fig. 1). Twenty-four multiple-funnel traps were placed in 8 rows of three traps. The three traps within each row were baited with ethanol and alpha-pinene. The aggregation pheromones lineatin, sulcatol and retusol were assigned randomly to one of the three traps in each row. Traps within each row were at least 50m apart.

The first row of traps was placed on the sandy banks of the North Arm Jetty. The second through fifth rows of traps were placed on dolphins (groups of 4 pilings to which booms are tied) standing between alleys in the CME ground. Access to traps on the NAJ and CME ground was by boat. The sixth row of traps was set out half way up the foreshore cliffs while the seventh row was set out at the top of the cliffs. Traps in row 8 were placed in Pacific Spirit Park on the north side of Marine Drive (Fig. 1).

Traps were checked every week from April through September 1991. Twenty two collections were brought back to the laboratory for counting and identification. The daily maximum temperature, wind direction and wind speed data for the Vancouver Airport were obtained from the Environment Canada office in Vancouver.

RESULTS AND DISCUSSION

Many previous studies have shown that abiotic factors influence the flight of ambrosia beetles during emergence in the spring and selection of overwintering locations in the late summer. Temperature is a major factor that stimulates beetle activity after winter diapause. Results from our study and others (Chapman 1962; Daterman et al. 1965; Shore and McLean 1985) show that significant *T. lineatum* flights occur when temperatures in the spring are above 15.6°C (Chapman and Kinghorn 1958). This initial peak flight is often sudden and correlates with the adult emergence from the forest litter on the first warm days of spring. These adults are sensitive to host odours and pheromones.

In our study, a total of 48,540 *T. lineatum* beetles were collected in the lineatin funnel traps. The major *T. lineatum* flight started in the third week of April (Fig. 2). Very few beetles were caught in the first week of April and the highest catches were recorded in the

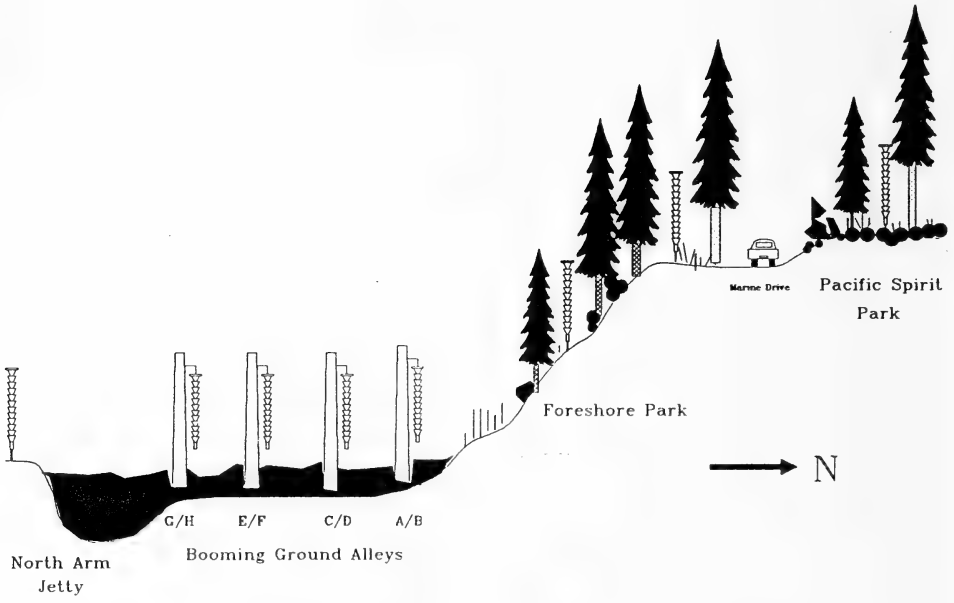

Figure 1. Diagrammatic cross-section of the Point Grey log boom storage area showing the relative positions of the 8 trap lines. Each trap line consisted of three traps set out 50 m apart in an east-west direction. See text for baiting regimes.

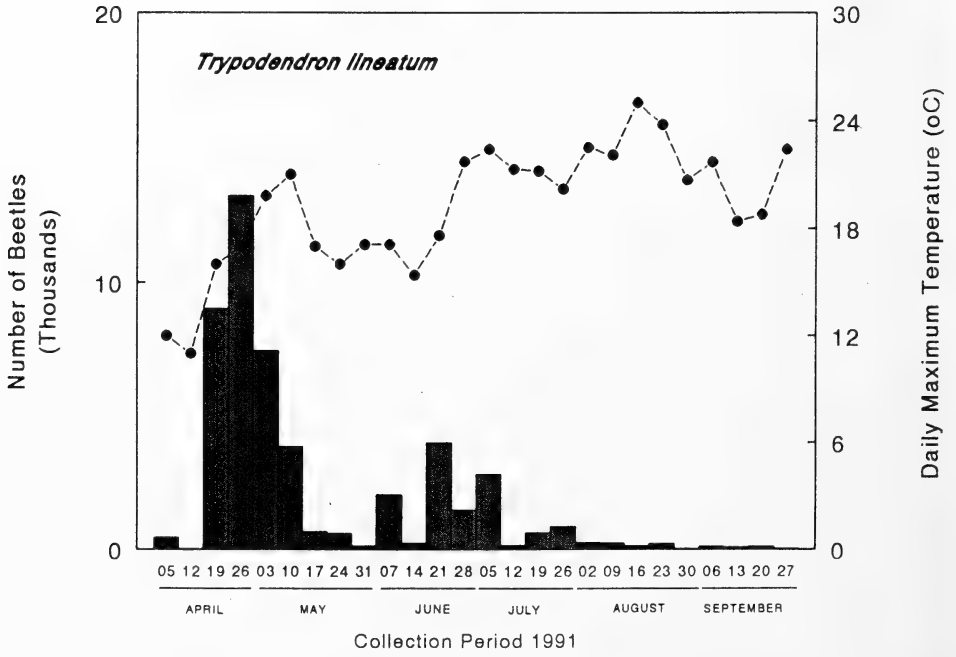

Figure 2. Weekly total catches of *Trypodendron lineatum* in the Point Grey log boom storage area.

last week of April. In the third week of collection, the daily maximum temperature during April 12 to 18, exceeded the required temperature for flight on 2 of the 7 days. The beetle catch increased from 20 to 9,016 *T. lineatum* beetles in two weeks. Beetle emergence from the forest litter continued into the second week of May and finally ended in the same month. A second, but smaller *T. lineatum* peak ("sister flight") was observed in June and July; these beetles represented 21% of the total beetle catch from April to September 1991. This second peak of beetles is thought to be mainly pheromone-sensitive parent beetles that leave infested logs at the same time as their offspring (McIntosh and McLean 1992). A few teneral adults, which are considered to be pheromone insensitive until they have overwintered (Borden 1988), were also caught. A proportion of the parental adults collected in the traps could possibly establish a second brood that would emerge before year's end. We observed some mid-summer attack of logs by *T. lineatum* but have no data on the success of these galleries. Vigorous parents may reattack and raise a second late summer brood (Nijholt 1978).

Gnathotrichus sulcatus catches were consistently lower than *T. lineatum* catches (Fig. 3). Again most of the beetles were caught in the first two months of collection. There was one major flight of *G. sulcatus* beetles that occurred in early May. This peak emergence was 2 or more weeks after the peak *T. lineatum* flight. A major second *G. sulcatus* flight was expected in late August (McLean and Borden 1975b), however this did not occur. One reason for the low number of *Gnathotrichus* beetles in the area may have been the lack of infested logs. No suitable host or infested material was seen within the parks. A total of 1,121 *G. sulcatus* and 47 *G. retusus* beetles were collected in the sulcatol and retusol traps, respectively.

Significantly greater numbers of *T. lineatum* and *G. sulcatus* beetles were caught in the two trap rows in Foreshore Park, than in Pacific Spirit Park ($X^2 < 0.001$ in both cases). Very few beetles were caught on the NAJ and CME dolphins (Fig. 4). Only 300 *T. lineatum* beetles, half of which came from one collection on July 7th, were caught in the lineatin traps on the row 5 dolphins of alley A/B. Total *T. lineatum* and *G. sulcatus* catches on the NAJ and CME ground were 1% and 4%, respectively of the total catch.

It is likely that the beetles caught in the parks originated from infested logs in storage during June and July of the previous summer at the NAJ and in the CME booming ground. The parental and brood adults that emerged in June, July and August were displaced by the prevailing winds to the forested Foreshore Park area. Daterman *et al.* (1965) have shown that *T. lineatum* and *Gnathotrichus* beetles are in flight between 1100 to 1700 hours. Wind direction analysis for this time in April/May and July through September showed that for 89% of the time, the wind blew from the NAJ and CME ground towards the land. Furthermore, wind tunnel studies have shown that ambrosia beetles are unable to maintain directional flight at winds speeds over 1.8 km/hour (Salom and McLean 1991). Average wind speed recorded at the airport weather station between July through September, during the time that the beetles are thought to be in flight was 12 km/hour. The station is less than 10 km distant.

Wind speeds of this magnitude during the dispersal flight periods support the hypothesis that the number of beetles caught in the traps in the forested margin in 1991 are a direct result of previous summer's wind patterns which displaced a number of the beetles emerging from infested log booms over the water and into the forest margins. Beetles then emerged in the subsequent spring and flew in search of suitable new host material within the forested area where they were captured in traps. Wind patterns were suitable for flight towards the log booms for only 10% of the time.

There is a nine month delay between the flight of brood beetles to overwintering sites in forested areas and their reemergence the following spring to attack any suitable host material in the area. Loggers who fall trees in the fall one year will not see signs of beetle attack on the logs until the following spring. Managers of coastal tie-up areas must recognize that booms stored against a forested foreshore are in a high ambrosia beetle hazard zone (Fig. 4). High value booms would be best stored in areas that are as far as possible from forested foreshores to prevent ambrosia beetles from attacking the floating sawlogs. The Ambrosia Beetle Task Force that conducted a year long study on MacMillan Bloedel's inventory in 1990/1991 found

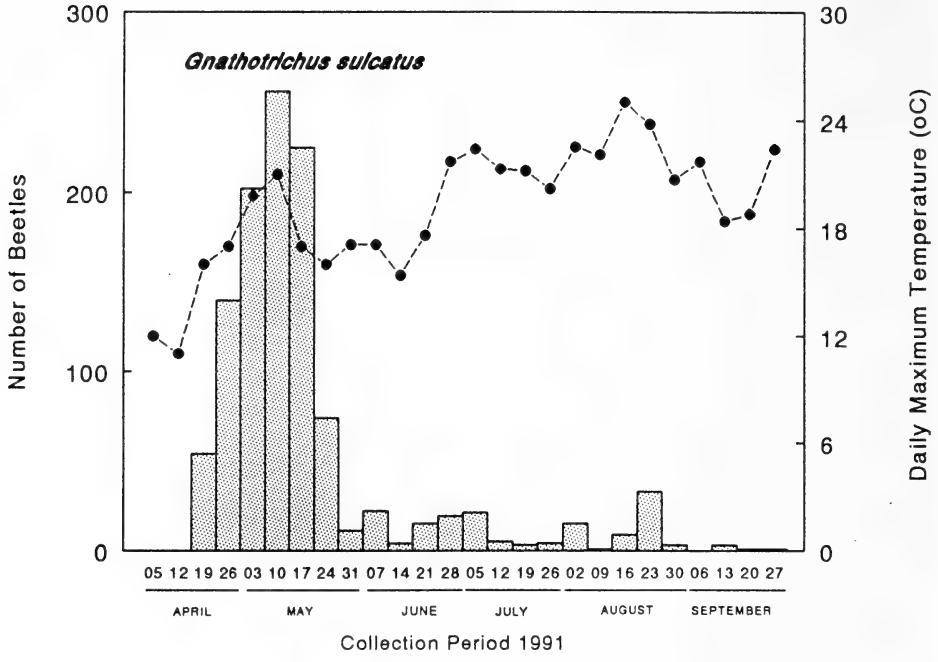

Figure 3. Weekly total catches of *Gnathotrichus sulcatus* in the Point Grey log boom storage area.

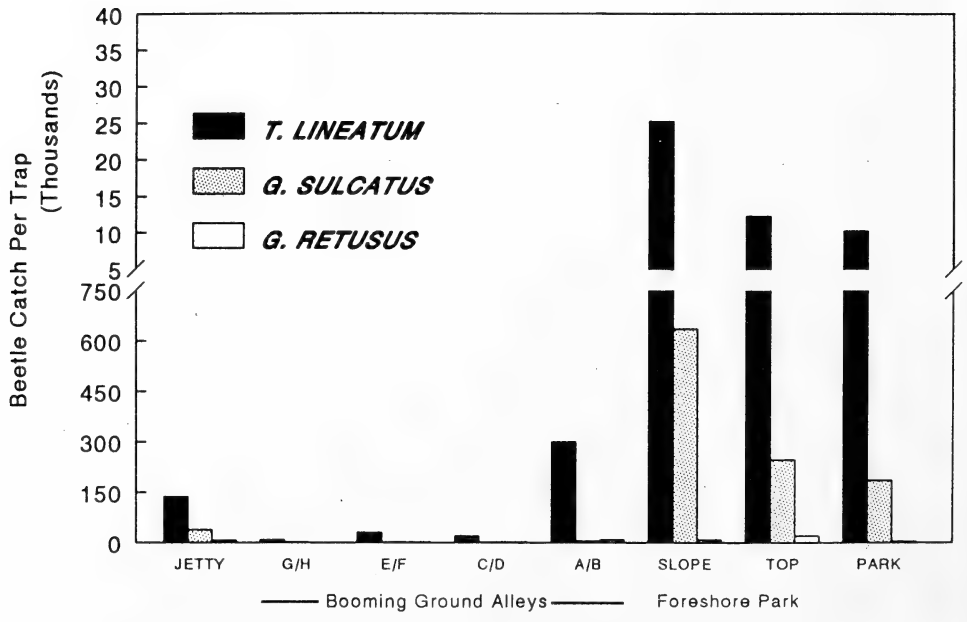

Figure 4. Total seasonal catch of three species of ambrosia beetles across the Point Grey log boom storage area and the forested foreshore area (see Fig. 1).

some degree of attack on log booms stored against forested foreshore areas while more remote locations such as the Nanaimo River flats and the outer alleys of the Point Grey booming ground had few fresh attacks. In this study on the North Arm of the Fraser, it is possible that ambrosia beetles blown into the forested margin may be able to disperse out to the beach tie up areas when the onshore winds abate. Hence, valuable sawlog booms should be stored away from the forested margin and alley A/B during the April and May beetle flight period.

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Potential insect vectors of the black stain root disease pathogen on Southern Vancouver Island

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ABSTRACT

Three species of beetles suspected of vectoring the black stain root disease pathogen (*Leptographium wageneri)* were found at two locations on Vancouver Island, British Columbia. The most commonly trapped specie was *Hylastes nigrinus* (Scolytidae) (691) followed by *Steremnius carinatus* (Curculionidae) (64) and *Pissodes fasciatus* (Curculionidae) (31). These insects may be vectors of the fungus that induces black stain root disease but confirmatory studies are needed. Douglas-fir resin at 1% or 10% in 95% ethanol attracted the most insects, whereas 95% ethanol or resin alone attracted the fewest. Pitfall traps captured significantly more of all three species than window traps, and were easier to maintain.

INTRODUCTION

Black stain root disease of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) caused by the fungus *Leptographium wageneri* var. *pseudotsugae* Harrington & Cobb, is a serious problem in the western U.S.A.(Cobb and Platt 1967; Harrington et al. 1983). The disease also causes pockets of mortality on Vancouver Island and the adjacent coastal mainland of British Columbia, although the total regional damage so far appears low. The fungus spreads by root-to-root contacts (Hessburg and Hansen 1986) and is vectored by a root-feeding beetle (*Hylastes nigrinus* Mann.) and weevils (*Steremnius carinatus* (Boh.), and *Pissodes fasciatus* (LeC.)) that attack stressed trees (Hansen et al. 1988).

Recent studies on resistance and mortality rates of black stain root disease, raised questions as to the occurrence of vectors at study sites on Vancouver Island (Jacobi, unpublished data). *Steremnius carinatus* and *Pseudohylesinus nebulosus* LeConte were found previously in black stain affected stands on the Island but the pathogen was not found on these insects (Morrison and Hunt 1988). No previous record appears to exist of *Pissodes* or *Hylastes* activity in areas affected by black stain.

Thus the two objectives of this study were to determine how most efficiently to attract and trap these insect species and to determine if potential vectors of the pathogen were present at two black stain disease centers on Vancouver Island.

MATERIALS AND METHODS

The two study plots were near Sooke and Port Renfrew B.C. on southern Vancouver Island. The Sooke plot was in a naturally regenerated Douglas-fir stand, 18 yr old, 13 km north of route 14 and 0.2 km west of the Butler Main line. The Port Renfrew plot was in a 21 yr old planted Douglas-fir provenance trial about 7 km east of Port Renfrew off the Lens Creek main line. Both plots were active centers of black stain root disease with trees showing a range of symptoms from near healthy to dead. Black stains, diagnostic of black stain root disease, were found on roots and root collar of declining trees.

Twelve insect traps were placed at each plot from April to June 1990 to determine which potential insect vectors were present. Four traps, located around an affected tree, were placed at three sites within each plot. Three traps were nondirectional window types, consisting of two 30 × 30 cm clear plastic "windows", a collecting funnel and a jar containing 10% antifreeze solution. Plastic tops were placed on the traps to exclude rain. The traps were suspended 0.8 m above the ground from posts driven into the ground at an angle.

Table 1
Occurrence of Potential Vectors of Black Stain Root Disease at Sooke and Port Renfrew, B.C. 1990.

		Collection Date							
Insect[a]/Trap	**Location[b]**	**4/18**	**4/28**	**5/10**	**5/24**	**6/5**	**6/21**	**Total**	**Total[c]**
100% Resin-Window									
Hylastes	S	—	1	21	0	0	4	26	76 c
	P	0	0	25	0	4	21	50	
Pissodes	S	—	0	3	0	0	0	3	4 b
	P	0	0	0	0	0	1	1	
Steremnius	S	0	0	0	0	0	0	0	0 b
	P	0	0	0	0	0	0	0	
1% Resin-Window									
Hylastes	S	—	32	20	0	11	46	109	220 b
	P	8	0	38	2	6	57	111	
Pissodes	S	—	0	0	0	0	0	0	5 b
	P	2	0	3	0	0	0	5	
Steremnius	S	—	1	0	0	0	0	1	1 b
	P	0	0	0	0	0	0	0	
95% Ethanol-Window									
Hylastes	S	—	3	4	0	2	4	13	40 d
	P	0	0	8	0	2	17	27	
Pissodes	S	—	0	1	0	0	0	1	4 b
	P	1	0	1	1	0	0	3	
Steremnius	S	—	0	0	0	0	0	0	0 b
	P	0	0	0	0	0	0	0	
10% Resin-Pit Fall									
Hylastes	S	—	0	37	18	30	85	170	375 a
	P	9	5	46	47	32	66	205	
Pissodes	S	—	0	10	0	0	3	13	18 a
	P	0	0	4	1	0	0	5	
Steremnius	S	—	0	4	3	1	1	9	63 a
	P	18	4	10	11	5	6	54	

[a]Insects are *Hylastes nigrinus*, *Pissodes fasciatus* and *Steremnius carinatus*. Baits were 100% Douglas-fir resin or resin dissolved in 95% ethanol. Insect counts are totals from 3 traps.
[b]Locations are (S) Sooke and (P) Port Renfrew on southern Vancouver Island, B.C.
[c]Totals of insect counts over both locations. Counts by insect type followed by the same letter are not significantly different ($P > 0.01$) based on Chi-square tests.

Baits for the three window traps consisted of 95% ethanol, 1% Douglas-fir resin in 95% ethanol, or 100% resin. The resin was collected previously from a cut stump and used because turpentine is a good attractant (Payne et al. 1978). One pitfall trap was placed at each of the three sites. The trap was a plastic Multipher(R) trap (Biocontrol Services, Ste Foy, Quebec, Canada) placed in the ground with a jar filled with 10% antifreeze inside to collect the insects. Bait for the pitfall traps was 10% resin in 95% ethanol. The baits were placed in 35 mm plastic film canisters with four 2 mm holes in each lid. Elution rates of the baits were 20-30 ml of 95% ethanol per 14 days. Baits were suspended half way down the "windows" and on the under side of the pit trap lids.

Collections were made every 10-14 days and the numbers of *Hylastes*, *Pissodes* and *Steremnius* were recorded. Insects were identified by H. A. Moeck and R. Duncan, entomologists at the Pacific Forestry Centre, Victoria B.C.. A Chi-square analysis tested for uniform distribution of insect counts by species collected among four baits in both trap types and among three bait types in window traps.

RESULTS AND DISCUSSION

Three insect species suspected of vectoring *Leptographium wageneri* were found at both locations (Table 1). The most commonly trapped insect species was *Hylastes nigrinus* (691) whereas *Steremnius carinatus* (64) and *Pissodes fasciatus* (31)were found less often. Only seven *Pseudohylesinus nebulosus* were trapped in window traps and one in a pitfall trap. Morrison and Hunt (1988) captured *P. nebulosus* in trap log sections which may be more attractive than the resin bait used in this study.

Window traps collected both flying insects, *Hylastes* and *Pissodes*, but only one of the flightless *Steremnius*. Pitfall traps collected significantly ($P = 0.01$) more of all three insect species than the window traps (Table 1). All baits attracted insects, but in the window traps 1% resin attracted significantly ($P = 0.01$) more *Hylastes* than 100% resin or 95% ethanol. Few *Pissodes* and *Steremnius* were collected by window traps and there were no significant differences in numbers of these species attracted by the three baits. Pitfall traps are adequate to monitor these three insects and are much easier to maintain than window traps.

Although the presence of these insect species in black stain root disease centers is now confirmed, no isolations for *L. wageneri* were attempted to establish that these potential vectors were indeed vectoring the black stain root disease pathogen. Further studies are needed to address the relative importance of insect vectoring versus root contact as means for infecting regenerating Douglas-fir in black stain disease areas.

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Distribution of economically important, wood-infesting anobiid beetles in the Pacific Northwest

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ABSTRACT

Structure-infesting anobiid beetles were surveyed in Washington State homes and outbuildings during 1987-91. *Hemicoelus* (=*Hadrobregmus*) *gibbicollis* (LeConte) was found in virtually all of the 90 structures inspected and is the predominant species infesting building timbers. This anobiid is known primarily from coastal areas of western North America. *Hadrobregmus quadrulus* (LeConte) was discovered in 5.5% of infested structures while *Xestobium affine* LeConte and *Priobium punctatum* (LeConte) were found in only 2% of infested buildings. The curculionid, *Rhyncolus brunneus* Mannerheim, also infests structural timbers and was present in 8% of buildings examined in this study.

INTRODUCTION

Wood-infesting beetles in the family Anobiidae are serious structural pests in many areas of the world. Larvae cause extensive damage by feeding and tunneling within timbers resulting in weakened structures. Considerable resources are often expended for wood replacement and/or chemical controls. Unfortunately, little is known about most species despite the extensive damage they cause. Long life cycles and extreme difficulty in rearing the beetles has resulted in this dearth of information.

Certain anobiid species are well known, and many notable infestations have been recorded from wooden structures during the 20th century. Baines (1914) reported a serious infestation of the deathwatch beetle, *Xestobium rufovillosum* (De Geer), in oak timbers supporting the slate roof of Westminster Hall in London. The widespread damage resulted in extensive replacement of wood with steel supports and provided a major impetus to conduct the first biological studies on anobiid beetles. Prior to that time anobiids were mostly considered to be a curiosity. While in dry dock for repairs, H.M.S. Victory, an 18th century wooden ship of the British Navy, was found to be infested by the same beetle species (Fisher 1940). In order to address damage caused to oak timbers and furniture in England by *X. rufovillosum*, the Forest Products Research Laboratory was created (Fisher 1938). An attack by this insect on oak timbers in the Old South Meeting House in Boston, Massachusetts was reported by Muirhead (1941). Engineers assessing the damage to tower supports noted that the hurricane of 1938 would probably have destroyed them if the building had not undergone earlier repairs.

Another anobiid, *Euvrilletta peltata* (Harris) [=*Xyletinus peltatus* (Harris)], was identified as infesting a home in North Carolina (Wright 1959) and stimulated interest in wood-destroying species in the United States. Moore (1968, 1970), Williams (1977, 1983), Williams and Mauldin (1974, 1981), and Williams and Waldrop (1978) conducted research projects on *E. peltata*, including life cycle studies, types of wood infested, and control options. Earlier work by Simeone (1960) found *Hemicoelus carinatus* (Say) to be the most frequently encountered wood-infesting anobiid in northeastern North America. Doane et al. (1936) cited examples of structures in the western states being damaged by various anobiid beetles, including *Hadrobregmus quadrulus* (LeConte), *Hemicoelus* (=*Hadrobregmus*) *gibbicollis* (LeConte), and *Priobium punctatum* (LeConte).

The furniture beetle, *Anobium punctatum* (De Geer), is probably the best known wood-infesting anobiid. Various researchers (Becker 1940; Kelsey et al. 1945; Hickin 1949, 1960, 1981; Bletchly 1952, 1957; Spiller 1952; Fisher 1958; Berry 1976) have published on this species. This is the most serious wood-destroying pest throughout England and much of

northern Europe, far more damaging than termites or any other group of insects (Hickin 1975). Additionally, Denne et al. (1944) noted that the furniture beetle was a widespread problem in New Zealand. Antique furniture shipped to the United States from Europe has typically been fumigated with methyl bromide to prevent the beetle's spread.

Anobiid beetles in the Pacific Northwest (PNW) are largely unidentified (Hatch 1962). However, infestations of these insects are regularly reported to various agencies throughout the region. An initial goal of this research was to identify those species causing structural damage in the PNW.

MATERIALS AND METHODS

Collection data.

Anobiid beetles are difficult to collect (White 1969). Cryptic coloration and a tendency to remain immobile, except when seeking a mate, contribute to this difficulty. Therefore, efforts were initially concentrated on reviewing collection specimen data from researchers and coleopterists who had made anobiid collections in the PNW. Entomologists from seven major collections were contacted, and the most prevalent beetle species were then tallied. In addition, pest control operators and extension specialists submitted specimens to us from 1987 to 1991.

Collection and rearing of beetles.

Ninety anobiid-infested structures were examined, primarily in western Washington, although collections were also made in eastern Washington, western Oregon, and Oakland, California. Infested wood was removed from crawl spaces and basements, transported to the laboratory at Washington State University, Pullman, and stored in 33 gal emergence containers where environmental conditions simulated the moderate temperatures and high relative humidity found in western Washington. Emergence containers remained under constant temperature and relative humidity (18 ± 1°C and 65 ± 3% RH). Certain containers were placed out-of-doors from 1987-91 to observe the effects of extreme heat and cold (as found in eastern Washington) on beetle survival. Maximum and minimum temperatures attained within the containers were recorded during 1987-90. Emerging beetle adults were collected throughout the year and identified. A standard size sweep net (38 cm diam) was used during summer months to sample forested areas for beetle adults in western Washington and Oregon.

RESULTS AND DISCUSSION

Primary, structure-infesting anobiid beetles.

After much correspondence, analyses of various insect collections, and visits to anobiid-infested structures, it became apparent that one species predominated over all others combined. *Hemicoelus gibbicollis*, the most common species, was recovered from all 90 study sites and is known to infest structures from Alaska to California (Linsley 1943). This anobiid has caused extensive damage in subfloor areas of buildings (Doane et al. 1936). Nevertheless, Furniss and Carolin noted in 1977 that the biology of *H. gibbicollis* was still incompletely recorded. Thus, when the overall importance of this species was studied, efforts were also focused on its distribution.

Hemicoelus gibbicollis was initially described from collections made in California by LeConte (1859), and in succeeding years the records became more widespread. Doane et al. (1936) first reported this anobiid as vigorously attacking beams of Douglas-fir, *Pseudotsuga menziesii* (Mirbel), in old bridges, barns, and basement timbers in the San Francisco area. Linsley (1943) referred to this species as the California deathwatch beetle and documented a number of infested structures in California and Oregon. Hatch (1946) produced the first evidence of this insect attacking wooden timbers in Washington. Spruce boards in the porch of a residence on the Olympic Peninsula were badly infested and required replacement. This beetle is probably the primary wood-infesting anobiid in California, Oregon, and Washington. Building inspections conducted during 1984 by Jan and Red Butler, Angeles Pest Control, showed *H. gibbicollis* to be the only species collected in Port Angeles and Sequim,

Clallam County, Washington (Suomi 1992: appendix 1). These localities are within some of the most heavily infested areas of the state.

Melville H. Hatch, the preeminent coleopterist in the Pacific Northwest, collected a significant number of *H. gibbicollis* near the Long Beach Peninsula of southwestern Washington (Hatch and Kincaid 1958). His records do not indicate whether these insects were captured while sweeping forested areas, or if he gathered infested wood and later collected emerging adults. In our experience it is extremely difficult to sweep heavily forested areas for these beetles, so beating trays or other collecting methods may have been utilized. The greatest collecting successes result when wood from infested structures is obtained, and emerging adults are captured under controlled conditions.

Most collections of *H. gibbicollis* have been made along coastal areas of the western United States, Canada, and Alaska (Suomi 1992: appendix 2). No collections have been reported from coastal areas south of California probably because the climatic conditions are too dry to favor larval survival. Two unusual sites were reported from Glacier National Park, Montana and Yellowstone National Park, Wyoming (Fig. 1). These probably represent atypical records, and the native range for this insect is along the Pacific Coast of North America. One other noteworthy collection site was in Yakima County, Washington, near Mt. Rainier National Park. Although *H. gibbicollis* can survive the extreme climatic conditions found in eastern Washington (Table 1), most collections were made in the milder climatic zones along coastal areas (Fig. 2, Suomi 1992: appendix 3).

Table 1

Temperature extremes (°C) in emergence containers and numbers of *H. gibbicollis* that emerged in eastern Washington.

Year	Maximum	Minimum	No. Emerged
1987	35.0	−19.0	4
1988	34.5	−20.5	14
1989	39.5	−27.0	16
1990	36.5	−18.0	82

Secondary, structure-infesting anobiid beetles.

Linsley (1943) and White (1982) described a number of anobiid species as capable of causing structural damage in the western states. However, during the building inspections conducted, only three anobiid species, in addition to *H. gibbicollis*, were recovered. *Hadrobregmus quadrulus* is a known wood-infesting species but was only found in 5.5% of infested structures. This beetle is commonly associated with the wood-destroying fungus, *Meruliporia incrassata* (Berkeley and Curtis) Murrill [= *Poria incrassata* (Berkeley and Curtis) Burt], which produces dry, rotten wood (Hatch 1962). Chamberlin (1949) recovered *H. quadrulus* from Douglas-fir beams in Oregon, while Spencer (1958) reported this species from numerous houses in Vancouver, British Columbia.

Xestobium affine LeConte was somewhat less abundant and occurred in 2% of homes investigated. This anobiid had not previously been reported to infest structural timbers. On five separate occasions, adults of *X. affine* tapped their frons on a glass surface, approximately 20-30 times during a 5 sec period, and repeated this procedure 3-4 times. Rapid tapping with a wooden pencil also elicited a tapping response from the insect. Birch and Keenlyside (1991) reported similar behavior by *X. rufovillosum* which probably serves in mate location. At one time this tapping was associated with a death in the household and led to the name deathwatch beetles for the family Anobiidae (Gahan and Laing 1932). These, along with *H. gibbicollis*, were the only anobiids captured while sweeping forested areas.

Figure 1. *Hemicoelus gibbicollis* distribution, western United States.

Figure 2. *Hemicoelus gibbicollis* collection sites(+); Washington, 1987-91.

Priobium punctatum was found in 2% of the homes examined. Chamberlin (1949) reported this anobiid from oak flooring and furniture in California. The beetle was more common in eastern Washington and readily appeared at blacklight traps. Another structure-infesting member of this genus, *P. sericeum* (Say), had been collected in eastern Washington homes and damaged flooring, woodwork, and furniture (White 1982). It was not found in any structure during this study. No collections were made of *A. punctatum* or *X. rufovillosum*. Hatch (1938) reported *A. punctatum* as occurring in Washington, but this may have been a result of wood being imported from infested areas.

An unexpectedly large number of collections were made of the curculionid beetle, *Rhyncolus brunneus* Mannerheim. Although Hatch (1971) described members of this genus as living under the bark of dead trees, these insects were discovered in 8% of infested structures and appeared to move in after the wood had been attacked by an anobiid, usually *H. gibbicollis*. Larvae and adults were found in surface layers of the wood and produced round, shiny, golden brown frass that is quite distinct from that of anobiids. Chamberlin (1949) noted that *Rhyncolus* larvae live in sapwood and damage wood in much the same way as anobiid larvae. This species is found in the wood of many conifers but prefers the drier portions. Little is known about its habits (Hatch 1962).

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Characteristics of structures attacked by the wood-infesting beetle, *Hemicoelus gibbicollis* (Coleoptera: Anobiidae)

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ABSTRACT

The anobiid, *Hemicoelus gibbicollis* (LeConte), is the most serious structure-infesting beetle along the Pacific Coast. This species attacks damp timbers (13-19% moisture content) in crawl spaces, basements, and outbuildings. In structures monitored for anobiids, Douglas-fir, *Pseudotsuga menziesii* (Mirbel), was the most abundant and readily attacked wood species, but other timbers used in building construction were also infested. Sapwood is more seriously infested than heartwood, and wood of any age can be attacked. Sill plates, rim joists, and headers adjacent to concrete foundations are among the most seriously damaged timbers. Infested buildings ranged from 8 to 122 years old, $\bar{x} = 63.2$. Infestations persist for many years. New, air-tight houses built with an abundance of sapwood in construction timbers may be at risk of beetle attack unless moisture levels are kept at a minimum.

INTRODUCTION

Infestations attributed to powderpost beetles have been reported from structures along the Pacific Coast of western North America for more than 50 years (Doane et al. 1936, Hatch 1946, Chamberlin 1949). Examinations of infested timbers showed that deathwatch beetles (Coleoptera: Anobiidae) were responsible for most of the damage. Larval feeding over a period of years often resulted in a weakened structure, necessitating replacement of timbers. The anobiid, *Hemicoelus* (=*Hadrobregmus*) *gibbicollis* (LeConte), was ultimately implicated as the primary pest species (Linsley 1943). Despite the seriousness of numerous infestations, the biology of this beetle remained incompletely recorded for many years (Furniss and Carolin 1977).

Although lacking adequate biological information, pest control operators (PCOs) routinely apply insecticides as structural treatments for anobiids. Evaluation of beetle activity within timbers is extremely difficult and many buildings are still being treated for inactive infestations. Most PCOs rely on the presence of adult exit holes as their main indication of anobiid activity, but this has been shown to be unreliable (Suomi 1992). Williams et al. (1979) stated that the number of exit holes does not necessarily indicate the activity of an infestation; only the existence of larvae does. Radiography is the most reliable method for determining numbers of larvae present within wood but it is impractical for field use. The presence of larval frass expelled from adult beetle emergence holes can be used as an indicator of activity. Frass the color of freshly produced sawdust often reveals on-going larval feeding within timbers.

Hemicoelus gibbicollis is found primarily in damp timbers of crawl spaces, basements, barns, and outbuildings in humid coastal areas of western North America. Analyses of museum collections from western states and surveys conducted in Washington and Oregon have failed to identify this species from dry, inland areas (Suomi 1992).

MATERIALS AND METHODS

Data Collection From Infested Structures.

During 1987-91 PCOs, extension specialists and county agents, and homeowners contacted us with information on houses or outbuildings with possible anobiid beetle infestations. From >120 potential sites, we selected 90 structures (3 log houses, 11

outbuildings, and 76 frame houses; 9 with a basement and 67 with a crawl space) in western Washington and Oregon which were infested with *H. gibbicollis*. Buildings with inaccessible infestations, those having been chemically treated, or structures with unknown histories were excluded. A survey form (Suomi 1992: appendix 6) was developed to record site conditions. Efforts were made to collect all available historical data from each building owner.

In all cases, damaged timbers were collected for positive identification of the infesting insect species. Wood moisture content readings were taken with a Delmhorst Model RC-1C Moisture Meter (Delmhorst Instrument Company, Boonton, New Jersey) or a Mini-Super Wood Moisture Meter (Protimeter, Meter House, Marlow, Bucks, England). Efforts were made to take readings from sound and infested wood to check for differences. Temperature and relative humidity (RH) readings were recorded with a Hanna Thermohygrometer Model HI 8564 (Cole-Parmer Instrument Company, Chicago, Illinois). All readings were taken from five locations within the structure and mean values determined.

Simulated Crawl spaces.

In Pullman (eastern Washington) and Puyallup (western Washington), two simulated crawl spaces were made from 39.4 × 19.1 × 19.1 cm concrete foundation blocks. Each structure was located near buildings with crawl spaces, but away from areas that could be disturbed by humans. Interior dimensions of the simulated crawl spaces measured 161.3 × 41.9 × 58.4 cm. A peaked roof was constructed from 1.9 cm (3/4") plywood, covered with tar paper to allow water runoff, and mounted on hinges. The structure was partitioned into three separate compartments with 1.9 cm plywood (Fig. 1). The first compartment had a soil substrate and no ventilation, other than air entering between the wood/block interface; the second had no additional ventilation, but a 6 mil vapor barrier was used to cover the substrate; and the third compartment had a 6 mil vapor barrier and one vent (30.5 × 11.4 cm) which was covered by a metal screen (0.24 cm^2 openings). Temperature and RH within each compartment were registered on a Jumbo Dial (Thermometer Corporation of America, Springfield, Ohio) and recorded every two weeks for 18 months in Pullman and Puyallup. In addition, readings of wood moisture content were taken from two wood blocks kept in each of the three separate compartments for 18 months, at the Pullman site only.

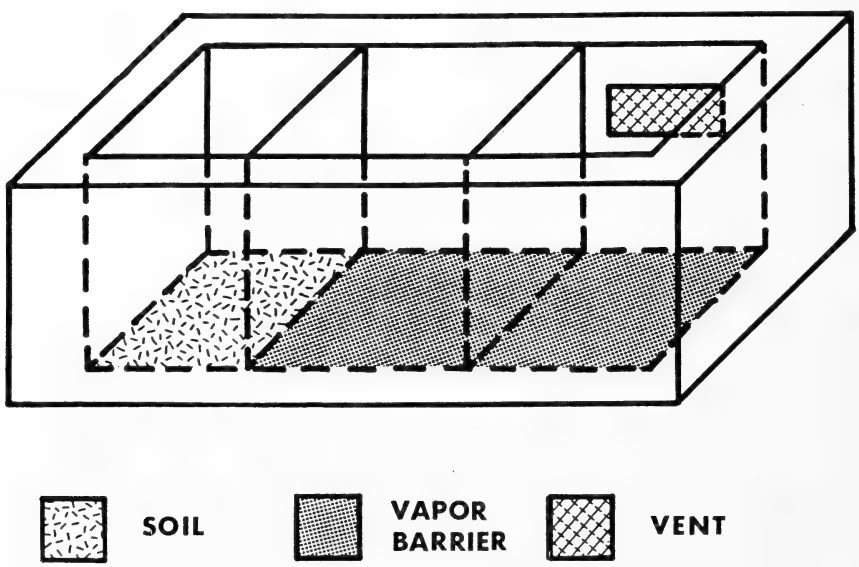

Figure 1. Simulated crawl space design for monitoring temperature and relative humidity. The compartments were of equal size.

Table 1
Wood moisture levels in structures[1] infested with *Hemicoelus gibbicollis*.

Wood moisture content (%)	No. of structures	% of structures
12	1	1.6
13	11	17.2
14	8	12.5
15	12	18.7
16	11	17.2
17	15	23.4
18	4	6.2
19	1	1.6
21	1	1.6

[1]total of 64 structures, wood moisture meters unavailable during 1987 field season.

RESULTS AND DISCUSSION

Natural Infestations.

Hemicoelus gibbicollis is primarily an economic concern in houses with crawl spaces or damp basements, but will infest any suitable structural timbers. Williams and Smythe (1978) reported that >99% of 673 beetle (primarily anobiid) infestations in Arkansas were located in crawl spaces beneath houses. The most susceptible wood for a natural anobiid infestation is sapwood from dead standing trees or stumps that remains undecayed for at least 3 years, because most wood-infesting anobiids have a 3 year life cycle in nature (Berry 1976). Sapwood in contact with the ground will be totally decayed by wood-destroying microorganisms in 3 years or less (Shigo 1968), so anobiids are often unable to complete development in this decomposing wood.

During these investigations we observed six structures that were probably infested from stumps left in the crawl space area. Wooden debris, in contact with the substrate, that remained after construction was completed could also serve as the initial infestation site. Undecayed stumps, plywood form boards, and even wooden tools often were seriously infested. The beetles would then move into the substructure.

Wood Moisture.

Probably the most important factor that allows these beetles to survive and reproduce is wood with a moisture content between 13 and 19% (Table 1). Levels above 19% led to development of molds or other microorganisms which effectively reduce the numbers of eggs and larvae. On two occasions, larvae were found in wall studs on shaded sides of homes (usually north) when the wood moisture content was >19% within the substructure. Wood with moisture content levels below 12% resulted in reduced larval populations (Suomi 1992). Areas of homes normally exposed to sunlight may dry out enough to reduce or prevent anobiid survival. Generally, the moisture content of wood in eastern Washington structures remains below 12%, which prevents *H. gibbicollis* from infesting structural timbers east of the Cascade Mountains. Relative humidity and therefore wood moisture content within the vapor barrier and vented compartments of mock crawl spaces in both eastern (Fig. 2a) and western Washington (Fig. 2b) remained significantly lower than the portion with only a vapor barrier or no treatment (Table 2). However, these values were considerably higher than are typically found in eastern Washington because the simulated crawl space was in a poorly drained location. Wood moisture content readings were approximately 2% less in simulated crawl space compartments with ventilation or a vapor barrier or both (Table 3).

Hosts.

In nature, *H. gibbicollis* larvae attack a wide variety of softwoods and hardwoods (Knutson 1963). Douglas-fir, *Pseudotsuga menziesii* (Mirbel), was the primary structural

timber species infested (97.8%), due in large part to its widespread use in building construction. Western red cedar, *Thuja plicata* Don, and western hemlock, *Tsuga heterophylla* (Rafinesque) were attacked in about 2% of the structures examined.

Table 2

Temperature and relative humidity data from simulated crawl spaces in eastern and western Washington.

Treatment	Temp. range (°C)	$\bar{x}$ ± SEM	RH range (%)	$\bar{x}$ ± SEM
Western Washington				
VB + V[1]	−4.0 - 25.5	11.7 ± 1.2	27 - 42	34.1 ± 0.7[a]
VB	−5.5 - 25.5	10.4 ± 1.3	30 - 41	37.1 ± 0.5[a]
NONE	−4.5 - 24.0	9.9 ± 1.1	31 - 44	37.9 ± 0.6[b]
Eastern Washington				
VB + V	−4.5 - 20.5	7.8 ± 1.1	37 - 50	45.1 ± 0.4[a]
VB	−4.0 - 21.0	7.8 ± 0.7	37 - 54	46.3 ± 0.5[a]
NONE	−3.5 - 20.0	7.7 ± 0.7	38 - 56	50.5 ± 0.5[b]

Means (RH) followed by the same letter do not differ significantly ($P = 0.05$) based on t tests (SAS Institute 1985).

[1]V = vent; VB = vapor barrier; NONE = neither treatment.

Authorities (Linsley 1943, Chamberlin 1949, Ebeling 1975, Hickin 1981, Mampe 1982) have stated that anobiid beetles will only attack wood that is well seasoned or has been in service at least 20 years. This is not always the case with *H. gibbicollis* (Table 4). Exit holes produced by emerging adult beetles may not become immediately obvious because the insect can spend up to six years as a larva (Suomi 1992). Moreover, the inaccessible nature of many infestations often prevents their discovery for 20 years or more.

New timbers, cut from trees containing increased sapwood grown in short rotation forests, can become seriously infested in only a few years. We have seen at least seven structures that showed signs of larval activity and adult emergence in replacement timbers that were present for <7 years. Infested buildings ranged from 8 to 122 years old, with an average age of 63.2 years. Williams and Smythe (1978) determined that anobiid-infested houses in Georgia and Mississippi ranged from 9 to >100 years old, with an average age of about 37 years.

Williams and Barnes (1979) have ascertained that well designed floor systems should adequately compensate for any weakening caused by the anobiid, *Euvrilletta peltata* (Harris) [=*Xyletinus pelatus* (Harris)]. Within structural timbers, numbers of *H. gibbicollis* larvae are often much greater (Suomi 1992) and therefore weakened timbers should be promptly replaced. Several PCOs in the Pacific Northwest have unwisely recommended placing an untreated floor joist between infested joists to strengthen the floor and avoid chemical treatment of the structure. Because of the potential for rapid anobiid attacks on these timbers, this practice must be discouraged.

Infestation Sites.

Hemicoelus gibbicollis adults are poor fliers, so many infestations may be established by beetles that walk to the structure (Suomi 1992). Natural openings such as crawl space entrances or vents usually serve as initial infestation sites. Sill plates, rim joists, and headers adjacent to concrete foundations are among the most seriously damaged timbers. As an infestation progresses, any area within the substructure can be attacked.

The outer edges of floor and rim joists were often seriously tunneled, while the interior of these timbers remained uninfested. This condition results from a high proportion of heartwood being found in construction lumber used in houses built earlier in this century. Heartwood contains extractives that repel many insects (Miller 1987) so *H. gibbicollis* larvae were usually found within the sapwood portion of timbers. In certain instances, larvae would tunnel in heartwood, generally when the sapwood had been depleted. Two other wood-infesting anobiids, *Anobium punctatum* (De Geer) and *E. peltata*, are also predominantly found in sapwood because it is higher in carbohydrates and nitrogen (Becker 1942, Bletchly and Farmer 1959, Williams and Mauldin 1981).

Characteristics of Infested Structures.

Many houses are now built with central heating and air conditioning units which lower the RH and wood moisture content below the threshold necessary for anobiid survival. However, the air-tight conditions found in some new buildings can also lead to wood moisture levels that encourage beetle attack. Relative humidity levels within western Washington substructures ranged from 47 to 95%, the average value being 69.7%. Clothes dryers vented into crawl spaces increased RH within the enclosed area and plumbing leaks may also lead to moisture-related insect problems. Improper placement of vents, inadequate ventilation, or obstructed air flow caused by excessive vegetation or debris can produce high wood moisture content, even in well built houses. In this study only 40% of houses had adequate vents (0.09 m^2 vent surface:13.80 m^2 crawl space area, minimally required) and 55% of those houses had vents which were obstructed in some way. Dead air spaces, resulting from little or no air movement within substructures, often result in areas of high wood moisture content.

Table 3
Wood moisture data from eastern Washington simulated crawl space.

Treatment	Wood moisture range (%)	$\bar{x} \pm$ SEM
VB + V1	10 - 19	15.2 ± 0.4[a]
VB	8 - 18	14.9 ± 0.4[a]
NONE	10 - 22	17.2 ± 0.4[b]

Means followed by the same letter do not differ significantly ($P = 0.05$) based on t tests (SAS Institute 1985).

1 V = vent; VB = vapor barrier; NONE = neither treatment.

Table 4
Construction dates of structures[1] infested with *Hemicoelus gibbicollis*.

Date structure built	No. of structures	% of structures
pre-1900	5	6.3
1900-19	24	30.4
1920-39	27	34.2
1940-59	16	20.3
1960-79	5	6.3
after 1979	2	2.5

[1]total of 79 structures, data unavailable for remaining 11 buildings.

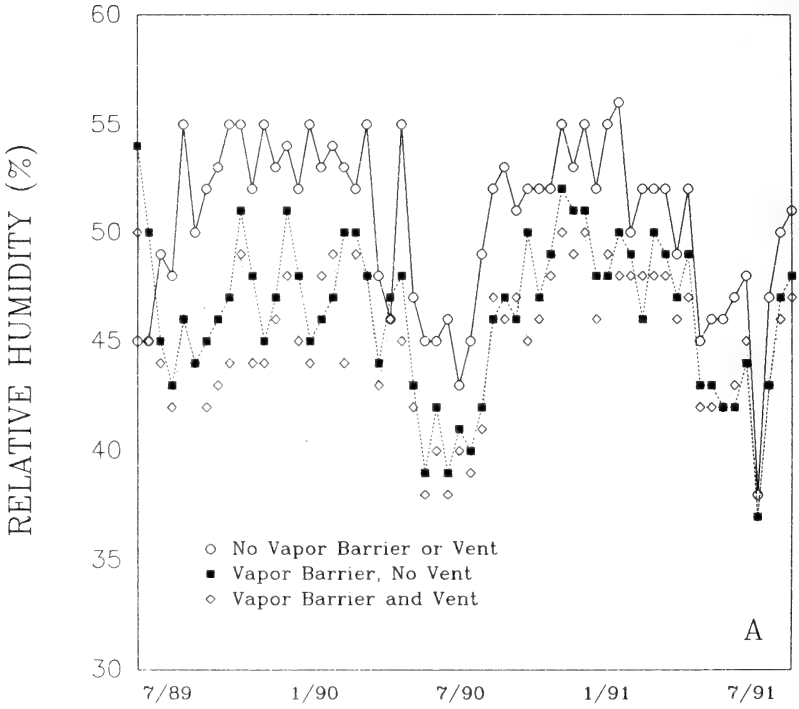

Figure 2a. Relative humidity in simulated crawl space with three partitioned compartments; eastern Washington.

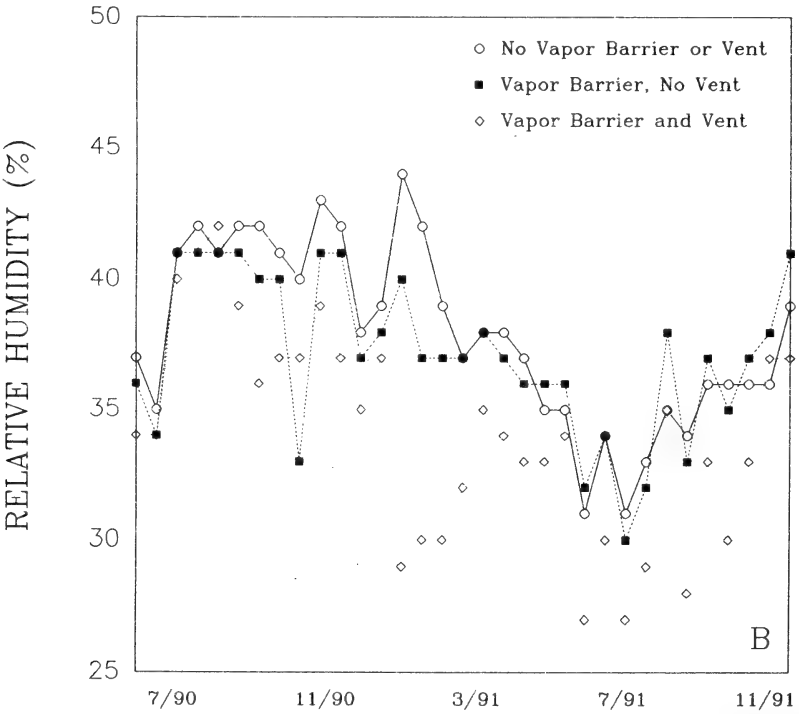

Figure 2b. Relative humidity in simulated crawl space with three partitioned compartments; western Washington.

Excessive wood moisture can be dependent on conditions created outside of the substructure. Contact between wood and soil was common in many houses. Moss or other organic debris on the roof often leads to improper water runoff. Non-functioning gutters may direct water into the crawl space or basement, thus increasing wood moisture content. Improper soil grade is a major contributor to increased water being found in lower levels of buildings. Greater than half of the structures in this study had inadequate gutters or soil grade which resulted in standing water in the substructure.

Barns and outbuildings are often seriously infested by *H. gibbicollis*. These unheated structures present ideal conditions for larval development. Often these outbuildings are continually reinfested until nothing remains but frass and a thin shell of wood. They can then serve as a source of infestation for other main structures. One house was examined that had an unheated, open attic area where conditions were similar to those in a barn. *Hemicoelus gibbicollis* was very active in this structure, infesting not only the ceiling and floor, but also maple and oak furniture stored in the attic. No larval activity was noted in the second floor area beneath the attic, most likely because the wood moisture content was 11-12%. In coastal areas of western Norway, Knudsen (1968) found that *A. punctatum* infested attics and crawl spaces equally.

Wood moisture content, being influenced by RH, is probably the major factor allowing anobiid infestations to develop. Structures located close to bodies of water often had higher than usual wood moisture content and more extensive damage (Suomi, unpublished observations). Clay and other heavy soils that retain water may also contribute to increased wood moisture within a substructure, especially if these soils are not covered with a vapor barrier. Temperature has a limited effect because it influences the amount of moisture remaining in air surrounding wooden timbers (Miller 1987). The average temperature during summer months in western Washington crawl spaces examined in this study was 16.6°C and ranged from 10 to 22°C. *Hemicoelus gibbicollis* is normally found in mild climates where temperature extremes are encountered infrequently. Photoperiod does not appear to have any role in the development of this insect because relatively low, unchanging light levels are normally found within timbers in most crawl spaces. Suomi (1992) showed that *H. gibbicollis* larvae remained active and continued feeding throughout the year, thus demonstrating that time of season does not influence larval activity.

Populations of anobiid larvae present in structural timbers can be reduced, and eventually eliminated, by controlling wood moisture content. One inexpensive method is to cover the entire crawl space floor with a 4-6 mil vapor barrier. Wooden debris and any construction lumber unnecessary to structural support should be removed. Adequate, unobstructed ventilation must be provided for free air movement. Buildings located near the ocean, despite all necessary precautions having been taken, were still found to have wood moisture levels of 14-15% and so remained at risk from beetle infestations. Knudsen (1968) noted that frequency of attacks by *A. punctatum* decreased as distances from coastal areas increased. This was also found to be true of *H. gibbicollis*.

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The authors thank Jan and Red Butler of Angeles Pest Control, Sequim, WA, Terry Whitworth of Whitworth Pest Control, Tacoma, WA, and the many other PCOs who donated their time to assist in our search for anobiid-infested structures. A special thanks is extended to Brian Raynes for assisting in data collection in some very unpleasant crawl spaces and to Dr. Art Antonelli for temperature and RH data collection at the western Washington research site. We also thank Liz Myhre for help with the drawing.

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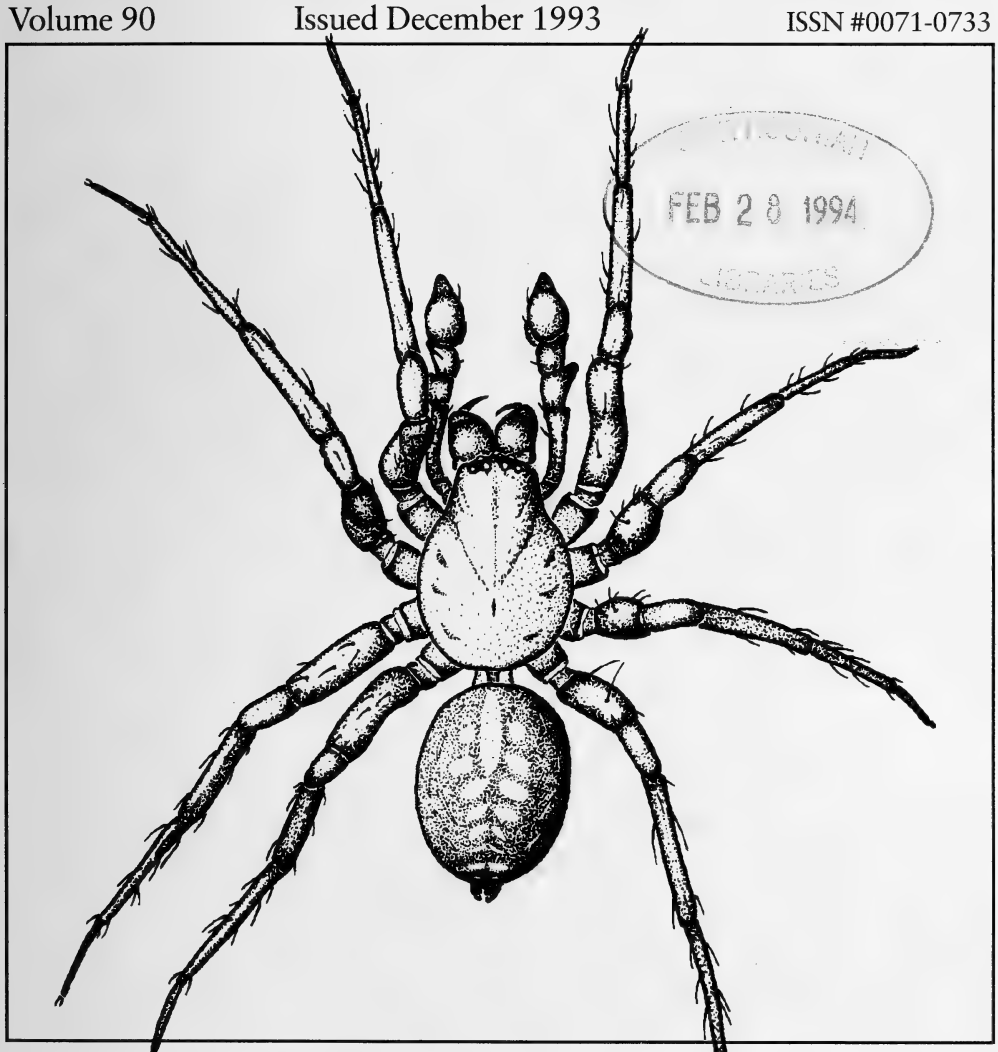

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COVER: Male *Cybaeus multnoma* Chamberlin and Ivie (Araneae, Cybaeidae) drawn by Robb Bennett. Scale bar = 2 mm. Individuals of about two dozen species of this Holarctic genus are dominant generalist predators in the forest floor arthropod community of the Pacific Northwest especially in coastal regions. Six species are known to occur in British Columbia. *Cybaeus reticulatus* Simon and *C. morosus* Simon are abundant in a variety of coastal habitats from San Francisco to the outer Aleutian Islands (in the Queen Charlotte Islands the former is found from sea level wet forests to alpine meadows). *Cybaeus signifer* Simon and *C. eutypus* Ch. and Ivie are very common in south eastern B.C. They range from mid-coastal B.C. south to Big Sur and the Yosemite area (*C. signifer*) and from the Queen Charlotte Islands to mid-coastal Oregon and the Willamette Valley (*C. eutypus*). Two other species have more restricted ranges: *C. sinuosus* Fox is apparently endemic to the Canadian Rockies in Banff, Jasper, and Yoho National Parks and a new species is found in south central B.C. and adjacent Washington from Lillooet through the Okanagan Valley to Okanogan County. Many species of *Cybaeus* (most notably in Japan, California, and Oregon) have extremely restricted ranges and are known from only a few specimens. From: Bennett, R.G. 1991. The systematics of the North American cybaeid spiders (Araneae, Dictynoidea, Cybaeidae). Ph.D. dissertation, Univ. of Guelph, 308 pp.

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Effects of soil type and moisture on emergence of tuber flea beetles, *Epitrix Tuberis* (Coleoptera: Chrysomelidae) from potato fields

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ABSTRACT

The numbers of adult tuber flea beetles, *Epitrix tuberis* Gentner, emerging from different soil types in the lower Fraser Valley of British Columbia were compared in 1987 and 1988. Overwintered beetles (P1) were released at known densities onto caged Russet Burbank potato plants grown in soils with different inorganic, organic, and moisture characteristics. The time from the introduction of P1 beetles in June to the mean initial emergence of first generation (F1) beetles ranged from 38 to 47.2 days during the two years of study. The female:male sex ratio of 2210 F1 beetles was 1:0.94, with a slight but significant bias in females early in the emergence period. Although significantly more F1 beetles emerged from some highly organic soils than from some mineral soils in both years, inorganic, organic and moisture factors of the test sites did not correlate consistently with the emergence of F1 beetles in time or numbers. F1 emergence from mineral soils was never significantly greater than that from highly organic soils. This work indicates that the economic injury level derived from studies of P1 beetles in highly organic soils could be applied to other soil types with minimal risk to potato crops.

INTRODUCTION

The tuber flea beetle, *Epitrix tuberis* Gentner, is a serious pest of potatoes grown commercially and domestically in the lower Fraser Valley of British Columbia. Adults overwinter in soil in and around potato fields (Vernon and Thomson 1991) and emerge from mid-May to early June. Although they are polyphagous, overwintered tuber flea beetles prefer to feed and oviposit on potato plants (Finlayson 1950), and in particular on late season varieties such as Russet Burbank. Oviposition by overwintered beetles (P1) occurs from late May to early July. The resulting first larval generation (F1) feeds on the seed pieces and developing roots of young potato plants, but generally causes little or no economic damage at this stage (Giles 1987). The ensuing F1 summer adults produce the second larval generation (F2) from mid-July through August when tubers are maturing. Feeding by F2 larvae results in tuber deformations, in surface channels and in sub-surface tunnelling that can seriously lower crop marketability.

To avoid damage from flea beetles, growers often apply sprays on a 7-10 day schedule, beginning at crop emergence. This can amount to as many as 10 sprays per season. To improve timing and thereby reduce the number of sprays, visual and sweep-net monitoring programs for adults of the P1 and F1 generations were developed (Vernon et al. 1990; Cusson et al. 1990) and are available to producers through commercially operated integrated pest management (IPM) programs. A major objective of these IPM programs is to improve control of the P1 adult generation so that spraying against the later F1 adults is not needed. By not having to spray F1 adults, mechanical plant damage and soil compaction caused by spray machinery is reduced, and the build-up of natural parasites and predators of aphids is augmented during the critical period of aphid outbreak in July and August.

Giles (1987) proposed that maintaining P1 beetles below 0.05 beetles per row- metre of potatoes would prevent economic damage to tubers from occurring without the need for F1 beetle sprays. This action threshold has been in use in potato IPM programs since 1988, and it has gen-

erally been found that P1 adults can be maintained below the action threshold with one or no sprays. Using sweep-net monitoring of F1 beetles as a backup, and a mean action threshold of one F1 beetle per sample of 10 sweeps (Anon. 1991), economic tuber damage has not occurred in any of the 700 fields monitored since 1988 (R.S. Vernon, unpublished data).

Giles' (1987) P1 action threshold was derived from research conducted near Cloverdale, a vegetable growing area of the lower Fraser Valley with soil high in organic matter and moisture. Population growth of the closely related potato flea beetle, *E. cucumeris* (Harris), was found to be greatly affected by differences in soil type and soil moisture (Daniels 1933; Hoerner and Gillette 1928). Their observations suggest that the P1 action threshold developed for *E. tuberis* may also vary depending on soil moisture, temperature and soil type. The question is important, since most potatoes in B.C. are grown in mineral soils low in organic matter and water-holding capacity, and monitoring programs that employ Giles' P1 action threshold are rapidly expanding into these areas.

This study was initiated to assess the effect of soil type and irrigation on E. tuberis populations from the P1 adult to the F1 adult generations. The importance of these findings for implementing and improving monitoring programs for *E. tuberis* in other potato growing areas of British Columbia is discussed.

MATERIALS AND METHODS

Emergence Cages: Pyramidal emergence cages, modified from Giles (1987), were constructed from 1.3 cm thick plywood, with a 46 x 105 cm open base tapering to a 5 x 5 cm flat top, and 35 cm in height. A 0.7 cm diam hole was drilled in the center of the cage top, and a clear plastic tygon tube (0.7 cm diameter by 4 cm long) pushed 1 cm into the plywood. Small clear plastic vials with a hole drilled in the cap were inserted cap down over the tubing to collect emerging beetles orienting upwards against gravity and towards the light. To ensure that light was entering the cages only from the hole at the top, all joints were sealed with fibreglass from the inside, and painted black.

Two experiments were done to determine the efficiency of the cages in collecting known numbers of beetles. Six cages were placed over bare ground, and the bases covered with soil. Twenty *E. tuberis* adults were collected and dropped through the top of each cage on 3 and 22 August, 1988. Beetles trapped in the vials atop each cage were counted for 2 days following each release.

Emergence Studies: Experiments were conducted in 1987 and 1988 to examine the effects of the inorganic, organic, and moisture characteristics of soil on the population growth of *E. tuberis* in commercial potato fields. Population increase was measured by caging known numbers of P1 adults for fixed intervals on plants in different soil types, and quantifying the subsequent emergence of F1 beetles over time using the emergence cages described. This approach gave an estimate of comparative habitat suitability for *E. tuberis* populations.

1987: The plantings of potato were established at three different sites in the lower Fraser Valley: at Abbotsford in an orthic humo ferric podzol; at Cloverdale in a highly organic peaty gleysol; and at Delta in a rego gleysol. The methods used to characterize the inorganic and organic fractions of each soil are described by McKeague (1976), and the physical characteristics of each soil are listed in Table 1. At each location, the soil was rotovated to a depth of 30 cm before planting. Whole tubers (cv. Russet Burbank) of uniform size were planted in pairs at a depth of 15 cm, with 30 cm between the pair of plants. A minimum of 1 m separated adjacent pairs. Seeding was done on 20, 21 and 25 May at the three sites, respectively, and all the plants were hilled once before emergence. Shortly after emergence, each pair of plants was enclosed in a wood-framed screen (.04 cm mesh) cage (80 x 69 x 63 cm) to prevent outside infestation by wild *E. tuberis*. Since wild *E. tuberis* typically infest potato fields along the outermost rows (Cusson et al. 1990), plots in both the 1987 and 1988 studies were located well inside commercial fields of potatoes to further reduce the threat of natural infestation.

The caged plants were infested with *E. tuberis* collected from a holding plot near the Abbotsford site. The holding plot consisted of a 0.04 ha planting of potatoes (cv. Russet Burbank) that was infested between 1 and 15 June with more than 10,000 beetles collected from backyard

gardens in Abbotsford. For release into each cage, a given number of mating pairs of beetles were aspirated from plants, placed into individual 10 cm lengths of tygon tubing and transported in coolers on the same day, to the three sites. Five mating pairs were released into each cage at each site on 19 June, and a further two mating pairs were added on 22 June. The cages were removed on 29 June, and the surviving beetles on each plant pair collected with aspirators over a period of 2 days. By 30 June, 78%, 70%, and 61% of the beetles at Abbotsford, Cloverdale and Delta, respectively, had been recaptured. Visual inspections of the exposed plants conducted each week between 2 and 24 July confirmed that reinfestation from outside the plots did not occur.

Beginning on 2 July at all sites, the uncovered paired plants were allocated watering regimes: 1) no watering (control plots); 2) 10 L water once every 2 weeks; 3) 10 L water once per week and; 4) 10 L water twice per week. At Abbotsford and Cloverdale, five and four replicates, respectively, of all watering regimes were used. At Delta, four replicates each of watering regimes 1, 2 and 3 were used. Watering was stopped on 23 July. The watering regimes (treatments) were arranged in randomized complete blocks at each site.

To prevent run-off of water, soil dykes were made (46 by 105 cm) around each pair of plants. Water was applied evenly inside the dykes with a watering can on Mondays (watering regimes 2, 3 and 4) and Thursdays (watering regime 4). Soil moisture samples (cores 2 cm diameter by 15 cm deep) were taken from between each pair of plants every Wednesday from 2-22 July. Each soil sample was weighed, dried in an oven, and the percent moisture content by weight determined.

On 24 July, the plants in each treatment were cut off just below soil level and the dyked area cleared of plant debris. Emergence cages were placed over the area where the plants had been removed, and the bases of the cages sealed with soil. The cages were examined for emerged beetles daily from 25 July until emergence had declined to one beetle per cage per day. At the Cloverdale and Delta sites, beetles emerging daily from each irrigation treatment were retained and their sex determined in the laboratory.

1988: The effect of soil type and moisture on tuber flea beetle emergence was further studied at 9 locations in the lower Fraser Valley. The characteristics of the soils at each location are listed in Table 2. On 9 June, all plots were prepared and planted as described for the 1987 study. On 22 June, ten mating pairs of beetles were collected from a new holding plot at Abbotsford and released into each of 5 or 6 cages at each site (Table 2). The cages were removed on 1 July, and the surviving beetles on each plant collected by aspiration during the next 2 days. An average of 65% of the beetles released had been collected from the plants (range = 57-81%) by 2 July. Visual inspections of the exposed plants were conducted each week between 2 and 28 July, which confirmed that reinfestation from outside the plots did not occur. On 28 July, emergence cages were installed, and the cages were examined for emerged beetles daily from 29 July until emergence at each site had declined to one beetle per cage per day.Seven of the 9 locations were chosen to provide a wide range of values of percent organic matter in the soil. At each location, mean daily air temperatures from the time of P1 release to the end of the F1 emergence were recorded using electronic hygrothermographs (Datapods, Model DP220, Omnidata International, Inc., Logan Utah) placed at ground level in Stevenson screens.

Two of the nine study locations were used to assess the effects of continuous irrigation on *E. tuberis* emergence (Table 2). Two adjacent rows of potatoes, 10 m long, were planted 4 m apart on 9 June. Potatoes in each row were planted in six pairs, with 30 cm between each paired plant, and 1.5 m between consecutive pairs. Each pair of plants was caged, and 10 mating pairs of beetles introduced to each cage. After beetle removal on 1 July, a perforated soaking hose was installed 2 cm below the surface, 30 cm along the north and south sides of plants in the northernmost potato row. Water was delivered continuously for the next 20 days so that the ground was visibly moist but not flooded. Soil samples were taken every 3-4 days from between each potato pair at all 9 locations in the study from 2-22 July, and their moisture content determined.

Statistical Analysis

Temporal Emergence Patterns: The number of days between the initial release of P1 bee-

Table 1

1987 Studies. Emergence of F1 adult tuber flea beetles from soils with different inorganic and organic characteristics and watering regimes in 3 potato growing areas of the lower Fraser Valley of British Columbia.

Study site and watering regime	Soil characteristics (% by weight)					Mean days to F1 adult emergence		F1 adult emergence	
	Inorganic fraction			Organic matter	H_20	Initial (± S.E.)	50% (± S.E.)	Mean/plot/ovip. day[1] (± S.E.)	Sex ratio Fem:Male
	Sand	Silt	Clay						
ABBOTSFORD (n = 5)									
No watering	38.3	55.1	6.6	3.9	17.4	43.2 ± 1.0	49.8 ± 0.9	1.03 ± 0.27	–
10 L water 1x/2 weeks	”	”	”	”	17.6	45.4 ± 1.0	50.6 ± 0.8	0.75 ± 0.11	–
10 L water 1X/1 week	”	”	”	”	19.9	43.8 ± 0.9	49.8 ± 0.4	1.03 ± 0.14	–
10 L water 2x/1 week	”	”	”	”	19.5	47.2 ± 1.1	51.4 ± 0.7	0.83 ± 0.09	–
CLOVERDALE (n = 4)									
No Watering	26.5	46.9	26.7	58.0	50.4	42.5 ± 0.5	49.5 ± 0.6	3.79 ± 0.39	1:0.80
10 L water 1x/2 weeks	”	”	”	”	51.1	42.2 ± 1.1	49.0 ± 0.4	2.38 ± 0.24	1:1.06
10 L water 1X/1 week	”	”	”	”	50.4	42.5 ± 1.0	50.3 ± 0.3	3.53 ± 0.29	
1:0.83									
10 L water 2x/1 week	”	”	”	”	53.2	41.7 ± 0.9	49.3 ± 0.9	3.81 ± 0.72	1:1.14
DELTA (n = 4)									
No Watering	4.2	76.5	19.4	3.4	16.5	38.3 ± 1.0	45.2 ± 0.9	2.28 ± 0.76	1:0.90
10 L water 1x/2 weeks	”	”	”	”	17.2	41.0 ± 0.7	45.8 ± 1.0	1.21 ± 0.23	1:1.22
10 L water 1X/1 week	”	”	”	”	18.0	40.0 ± 1.0	46.0 ± 0.6	1.41 ± 0.41	1:1.04

1. The number of female oviposition days is the number of P1 females released /plot times the number of days between P1 release and recapture. This amounted to a standard 64 oviposition days/plot for each of the three study sites.

tles and the mean initial and 50% emergence of F1 beetles was determined for each study site and for every watering regime. Mean days to initial and 50% emergence, both within and between study sites for each year, were compared by ANOVA, and Duncan's (1955) multiple range test. Mean daily air temperature in 1988 from the time of P1 release to the mean initial and 50% emergence of the F1 adult generation, respectively, were regressed on time to initial F1 emergence at each study site to investigate the effect of temperature on the rate of development of *E. tuberis*.

Sex Ratio at Emergence: Beetles emerging from each watering treatment at the Cloverdale and Delta sites in 1987 were grouped into 4 emergence periods. The first 3 periods were 5 days long and the last was 12 days. The effects of site, treatment and emergence period on the sex ratio of the emerging beetles were tested by analysis of Chi-square using the SAS procedure CATMOD (Grizzle et al. 1969). In this analysis, emergence period was treated as a continuous variable.

Effect of Soil Type and Moisture on Emergence: To facilitate comparisons between the two years, the numbers of F1 beetles emerging from soil into cages in each year were standardized by dividing the mean emergence per plot by the number of P1 female oviposition days per plot in each study. P1 female oviposition days were determined by multiplying the number of females released per plot by the number of days between release and recapture. The number of F1 beetles emerging per P1 female per plot per day of oviposition is referred to as the "F1 production". Differences in total F1 production between and within sites for each year were examined by ANOVA after log10 transformation. Differences in emergence were ranked using Duncan's multiple range test. A significance level of $P < 0.05$ was used throughout .

RESULTS AND DISCUSSION

Efficiency of Emergence cages: Numbers of beetles emerging from cages in the 3 Aug. release recapture study (85.8% recapture) were not significantly different from the 22 Aug. study (83.3% recapture), so the results were combined. Of twenty beetles released into each of 12 cages, an average of 16.2 beetles were recaptured on the first day after release (range = 13-20 beetles) and 0.8 beetles on the second day (range = 0-2 beetles). The average recapture per cage was 16.9 beetles (range = 14-20 beetles), or 84.6% of the 240 beetles released. Although a 100% recapture rate by the emergence cages was not a prerequisite for their use in the other emergence studies reported here, these results do show that the emergence cages would probably underestimate the absolute number of beetles emerging from the soil.

Temporal Emergence Patterns: Among unwatered plots at the three study sites in 1987, significant differences were observed in the time from P1 beetle release to mean initial emergence ($F = 6.24$; $df = 4,2$; $P = 0.034$), or 50% emergence ($F = 7.12$; $df = 4,2$; $P = 0.026$) of F1 beetles (Table 1). Initial and 50% F1 emergence were at least 4 days earlier in Delta than in Abbotsford or Cloverdale. Differences in initial or 50% emergence among watering regimes at any of the three sites were not statistically significant.

In the 1988 soil type study, significant differences were observed in the time from P1 beetle release to mean initial emergence ($F = 21.54$; $df = 4,6$; $P = 0.0001$), or 50% emergence ($F = 19.9$; $df = 4,6$; $P = 0.0001$) of F1 beetles between sites (Table 2). Mean initial emergence ranged from 38.0 days (site 4) to 45.2 days (site 7). Finlayson (1950) recorded a 42 day period from egg to initial F1 emergence, and a 39 day interval from egg to F2 emergence of *E. tuberis* in the interior of British Columbia.

Temperature affected the length of time from egg to adult of *E. cucumeris* in an insectary (Hill and Tate 1942). This may also explain the differences in the time from egg to adult occurring between sites in our studies. The regression of days to mean initial emergence on mean air temperature during that time (independent variable) for the 7 sites in the soil texture study of 1988, indicated that development time decreased with an increase in mean air temperature ($y = 183.18 - 8.545x$; $r^2 = 0.68$; $P = .02$). A similar trend was observed for mean development time to 50% emergence regressed on mean air temperature ($y = 147.97 - 6.005x$; $r^2 = 0.65$; $P = .03$). The results suggest that a more comprehensive day-degree model based on air temperatures could be developed to help predict the time of emergence of F1 beetles. The regression model for initial

Table 2

1988 Studies. Emergence of F1 adult tuber flea beetles from potato fields. The irrigation study examined F1 emergence from non-irrigated plots of potatoes compared to emergence from plots continuously irrigated below ground. The soil type study compared F1 emergence from 7 non-irrigated potato fields with different inorganic, organic and moisture characteristics.

Study and site description	Soil characteristics (%)					Mean days to F1 adult emergence[1]		F1 adult emergence
	Inorganic fraction			Organic		Initial	50%	Mean/plot/ovip. day[2]
	Sand	Silt	Clay	matter	H_20	(± S.E.)	(± S.E)	(± S.E.)
1. IRRIGATION STUDY (n = 6):								
No Irrigation	32.5	61.1	6.4	2.6	20.2	42.2±0.3	47.5±0.5	1.70±0.24
Continuous Irrigation	"	"	"	"	25.4	42.7±0.4	47.8±1.7	2.60±0.42
2. SOIL TYPE STUDY (n = 5):								
Site 1 'Abbotsford'	39.9	54.3	5.8	2.6	18.4	42.6±0.5c	50.0±0.3e	1.40±0.11a
Site 2 "	36.2	57.5	6.2	2.6	18.8	43.0±0.3c	49. ±0.6de	2.28±0.25bc
Site 3 'Cloverdale'	72.6	19.2	8.2	10.1	16.9	40.2±0.7b	45.8±0.8ab	1.83±0.19b
Site 4 "	4.9	56.7	38.4	20.8	35.9	38.0±0.0a	44.6±0.7a	2.60±0.18c
Site 5 "	6.5	53.5	40.1	24.0	34.8	40.4±b	46.6±0.2bc	2.59±0.11c
Site 6 "	29.3	49.4	21.3	35.9	40.9	42.4±0.7c	48.0±0.0cd	2.08±0.18bc
Site 7 "	9.2	52.7	38.2	39.6	53.5	45.2±0.4d	50. ±0.5e	2.27±0.27bc

1. Means followed by the same letters in columns are not significantly different (Duncan's multiple range test, P = 0.05).
2. The number of female oviposition days was the number of P1 females released /plot times the number of days between P1 release and recapture. Thisamounted to a standard 90 oviposition days/plot for each of the study sites.

emergence, however, is presently limited to the narrow range of mean temperatures encountered during the development period in 1988 (i.e. 16.4-16.9 degrees C). Since temperatures in June and July of 1988 were near the 30 year average for the Fraser Valley, the predictability of the model for mean air temperatures above or below the range of temperatures tested in 1988 would have to be determined with further research. This would be worthwhile, since air temperatures in many B.C. potato fields are already being recorded using Datapods for the prediction of potato late blight, *Phytophthora infestans* (De Bary).

In the absence of a comprehensive day-degree or regression model, existing *E. tuberis* monitoring programs could be immediately improved by ensuring that high risk fields are monitored more intensively for F1 beetles beginning no later than 38 days (the earliest development interval recorded in 1987 and 1988) following the initial detection of P1 beetles. In seasons where mean temperatures are above normal, monitoring should begin earlier than 38 days at the discretion of the consultants. Since F1 females have a pre-oviposition period of 6 days (Finlayson 1950), early detection of above threshold F1 beetles would allow growers to withold sprays up to 5 or 6 days, allowing time for additional emergence to occur to maximize the efficacy of sprays.

Sex Ratio at Emergence: The sex of 510, 889, 483 and 328 beetles was determined, respectively, for 4 consecutive emergence periods from the Delta and Cloverdale sites in 1987. The analysis of chi-square indicated that the sex ratio differed significantly ($P = 0.03$) between sites. The female:male sex ratios of F1 beetles emerging from the site in Delta ($n = 801$ beetles) and Cloverdale ($n = 1409$ beetles) were, respectively, 1:1.01 and 1:0.90. The percentage of females emerging (i.e. 53.3, 52.8, 49.9 and 48.2%) over the 4 emergence periods decreased slightly but significantly ($p = 0.04$) with time of emergence. Finlayson (1950), observed a 1:1 sex ratio in P1 beetles emerging from hibernation, but did not determine the sex ratio of F1 beetles emerging over time.

Effect of Soil Type and Moisture on Emergence: Watering regimes at various intervals in 1987 did not significantly affect beetle emergence at any of the three sites (Table 1). The average water content at each site was raised only slightly (Table 1), even in the most heavily watered treatments. Irrigating the soil continuously following the oviposition period in 1988 did significantly ($F = 162.8$; $df = 3,1$; $P = .001$) increase the soil moisture content (Table 2), but the effect on emergence was not significant ($F = 3.48$; $df = 1,5$; $P = 0.12$). Because watering began after beetles were removed from the plots in both years, the eggs that were layed during the oviposition period would have largely preceded the watering schedule. The egg stage of *E. tuberis* has a mean incubation period of 5.5 days (range 3-14 days, Hill and Tate, 1942). Watering, therefore, would have coincided more with the succeeding larval and pupal stages of *E. tuberis* in this study.

In the unwatered treatments in 1987, significantly more beetles emerged from the Cloverdale site than from the Abbotsford site, but not from the Delta site ($F = 6.01$; $df = 4,2$; $P = 0.037$) (Table 1). In the soil type study of 1988, significant differences ($F = 6.46$; $df = 6,4$; $P = 0.0004$) in emergence also occurred, with sites 4 and 5 having significantly more emergence than sites 1 and 3 (Table 2). Differences in F1 production between the Cloverdale and Abbotsford sites were more pronounced in 1987 (Table 1) than in 1988 (Table 2). F1 production was lower in 1987 than in 1988 in the Abbotsford soils, and higher in 1987 than in 1988 in the Cloverdale soils.

The significant differences observed in F1 production between certain sites in 1987 and 1988, can be attributed to biotic or abiotic effects on *E. tuberis* adult vigour, oviposition, or on the survival of immature stages in the soil. The amount of oviposition by many soil-ovipositing beetles is directly related to the texture and moisture content of the soil (Gaylor and Frankie 1979; Marrone and Stinner 1983a; Brust and House 1990). These variables also affect egg and larval survivorship in some beetle species (Gaylor and Frankie 1979; Marrone and Stinner 1983b). Generally, oviposition and subsequent survival of eggs and larvae are promoted in moist, organic soils. Organic matter and water content were highly correlated in our 1988 study (Pearson correlation coefficient = 0.954, $P < .0002$), but neither of these variables was significantly correlated with the production of F1 *E. tuberis*. Of the inorganic soil components, only clay was

significantly correlated (Pearson correlation coefficient = 0.810, $P < 0.02$) with the emergence of F1 *E. tuberis* in unwatered sites in 1988. Emergence in soils with less than 10% clay varied widely, however, (Table 2) making this relationship of little practical importance. The results from both years do show that F1 production from mineral soils was never significantly higher than from the organic soils. The reason, or reasons for the greater F1 production observed in certain Cloverdale soils, however, could not be determined from this study.

Soil Type and Action Thresholds

Giles (1987), working with a peaty gleysol (61.4% organic matter), proposed that maintaining P1 *E. tuberis* at levels below 0.05 P1 beetles per metre of row would keep numbers of F2 larvae below an economic damage level. Until now, this action threshold was valid only for *E. tuberis* monitoring programs conducted in regions of the Cloverdale area with similar, highly organic muck soils. The results reported here indicate that the P1 action threshold developed for the peaty gleysol of Cloverdale could also be used in potato growing areas with different soil types, such as Delta and Abbotsford, without risk to potato crops. This is because the same number of P1 beetles occurring on plants grown in Delta or Abbotsford would ultimately give rise to equal or fewer F1 adults than would the same number of P1 beetles on plants grown in Cloverdale. Since the F1 action threshold of 1 beetle per 10 sweeps is recommended for monitoring programs in any soil type (Anon. 1991), the use of Giles P1 action threshold in a mineral soil should not increase the need for F1 sprays.

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Hymenopterous parasites of the blackheaded budworm, *Acleris gloverana* on Vancouver Island, British Columbia, 1970-1974

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ABSTRACT

Thirteen hymenopterous parasites of the blackheaded budworm, *Acleris gloverana* Walsingham, from Vancouver Island are compared with those found in British Columbia during the 1940-44 outbreak and outbreaks in the early 1950's and mid-1960's in Alaska. Six species of the parasites reported were first records for British Columbia. Some of those reported may be new species.

INTRODUCTION

The range of the blackheaded budworm, *Acleris gloverana* Walsingham, extends from west-central Alaska along the Pacific Coast to northern California, and this insect occurs endemically in the Selkirk Mountains of British Columbia (B.C.). Outbreaks have occurred approximately every ten years (Prebble and Graham 1945b; Anonymous 1972). The decline of these cyclic infestations is not understood although some controlling factors suggested have been weather (Silver 1960, 1963) and natural control (non-chemical) factors (Prebble and Graham 1945a&b). The primary host of the budworm is western hemlock, *Tsuga* sp. but the larvae also feed on *Abies, Larix, Picea,* and *Pseudotsuga* (Powell 1962). During the 1940-44 outbreak, M.L. Prebble (unpublished report) listed 48 different species of parasites of the blackheaded budworm. Torgersen (1970) published a list of 16 different parasites which occurred in an Alaskan infestation. The parasites reported in this study were from the infestation that occurred on Vancouver Island from 1970 to 1974.

MATERIALS AND METHODS

During the outbreak period of 1970 to 1974, nine research plots were established to represent western hemlock stands on Vancouver Island. These plots were used to develop a sampling system (Shepherd and Gray 1990 a,b), and to investigate the population dynamics of this insect. The samples consisted of 100 45-cm branches from each of eight locations and 200 45-cm branches from another location for which defoliation estimates and the number of blackheaded budworm were recorded. Branch samples were taken when the blackheaded budworm was at the egg, early larval, late larval and pupal stages of development from 1972 to 1975. Blackheaded budworm larvae and pupae were placed individually in 3/4 oz. plastic containers to allow the parasites to emerge. Artificial diet (McMorran 1965) was provided for the larvae to complete their feeding. The adult parasites were pinned and labelled, and representatives of each species were sent to the Biosystematics Research Centre in Ottawa for identification.

RESULTS AND DISCUSSION

Percent parasitism during this infestation was initially quite low and, in fact, was undetectable in some plots. Parasitism had increased by the second year of the outbreak. In 1972 the average parasitism was 15% (7 plots, 2 plots had no parasitism), it increased to 53% (5 plots, 4 plots had no parasitism) in 1973, but decreased to 13.5% (7 plots, 2 plots had no parasitism) in 1974 when the outbreak collapsed. By 1975, the high populations had disappeared and larvae were not recovered from any of our study plots. Dipteran parasites were present in high numbers compared to hymenopteran parasites (46 in 1972 (6 plots, 3 plots had no dipteran parasites) and 423 in 1973 (5 plots, 4 plots had no dipteran parasites)) but no parasite adults were obtained

Table 1

Hymenopterous parasites of the blackheaded budworm occurring on Vancouver Island, 1972-1974.

Parasites	Family	Adults Emerged	Present in B.C. in 1940-44 (Pebble (unpubl.) 1945)	Years Present (Torgerson 1970)	Occurs in Alaska
Larval					
Ascogaster provancheri Dalla Torre	Braconidae	13	yes	1973-74	no
Charmon extensor (Linne)	"	12	no	1972-74	no
Meteorus argyrotaeniae (Joh.)	"	1	no	1972-73	yes
Meteorus sp.	"	1	no	1974	no
Microgaster peroneae (Walley)	"	18	yes	1972-74	yes
Habrocytus sp.	Chalcidoidea	2	yes	1972,1974	no
Campoplex sp.	Ichneumonidae	3	yes	1973-74	no
Mesochorus pictilis (Holmg.)	"	1	no	1974	no
Mesochorus sylvarum (Curtis)	"	4	no	1973-74	no
Mesopolobus sp.	Pteromalidae	15	no	1972,1974	no
2Pupal					
Itoplectis quadricingulata (Provancher)	Ichneumonidae	6	yes	1974	yes
Phaeogenes arcticus (Cush.)	"	1	yes	1974	yes
Phaeogenes hariolus (Cress.)	"	1	yes	1974	no

from the puparia. Torgersen (1970) also had difficulty in obtaining adult emergence even though he tried various temperatures and photoperiods to break what appears to be a parasite pupal diapause. There was considerable variation between the hymenopterous species recovered between outbreaks and also between locations (Table 1.). Of particular interest are: *Charmon* (= *Eubadizon*) *extensor, Mesochorus pictilis* and *M. sylvarum, Mesopolobus* sp. (possibly n. sp.), and *Meteorus* sp. (possibly n. sp.), which previously had not been reported attacking this host in British Columbia or Alaska. These species may be capable of changing hosts as the opportunity arises. Of the sixteen species identified during this outbreak six species were first records for British Columbia.

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Sex pheromone components of an undescribed *Choristoneura* species (Lepidoptera: Tortricidae) on lodgepole pine in British Columbia

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ABSTRACT

*E*11-tetradecenyl acetate (*E*11-14 OAc) and Z11-tetradecenyl acetate (*Z*11-14 OAc) are sex pheromone components of an undescribed, pine-feeding *Choristoneura* (*C.* n. sp. CPG=Prince George) in British Columbia. Compounds were identified by coupled gas chromatographic-electroantennographic (GC-EAD) and coupled gas chromatographic-mass spectroscopic (GC-

MS) analyses, and were field tested near Prince George, B.C. A 65:35 blend of *E*11-14 OAc and *Z*11-14 OAc attracted as many male *C.* n. sp. CPG as did the most attractive virgin females, suggesting that the natural sex pheromone has only two significant components. This two-component blend is suggested for detecting and monitoring *C.* n. sp. CPG populations.

INTRODUCTION

There is a large complex of *Choristoneura* species feeding on a variety of coniferous and deciduous trees in British Columbia (Freeman 1967; Powell 1980). The taxonomic relationships of these tortricid moths are not clear and new entities are still being discovered. Comparative morphology and ecology indicate that an undescribed *Choristoneura* species (*C.* n. sp. CPG = Prince George) occurs on lodgepole pine (*Pinus contorta* var. *latifolia*) in an area 200 km north to 40 km south of Prince George with concentrations near Bear and McLeod Lakes (T.G. Gray, unpublished observations). Approximately 35% of the larvae were found feeding in and around the staminate cones. They were difficult to detect unless disturbed. This feeding behaviour resembles that of *C. lambertiana* on lodgepole pine near Yahk, B.C. (T.G. Gray, unpublished observations) and that of another undescribed species (*C.* n. sp. CR = Richmond) on Scots pine (*Pinus sylvestris*) (Gray and Slessor 1989).

Because sex pheromones provide important information on the taxonomic relationships of moths (Roelofs and Comeau 1969; Roelofs and Brown 1982), we have conducted laboratory analyses and field experiments to characterize the sex pheromone components of this *C.* n. sp. CPG.

METHODS AND MATERIALS

Insect Rearing. In June 1989, three hundred larvae in the penultimate instar were collected from immature fringe lodgepole pine between Woodpecker and Carswell, B.C., for rearing and isozyme analysis. Twenty-five larvae were reared in each of twelve containers with ten cubes of artificial diet (Robertson 1979) at 23 C, 50% RH, and a photoperiod of 16:8 (L:D). Pupae were kept either in cages with potted lodgepole pines or in kraft paper bags with waxed paper strips to provide emerging females with oviposition sites. Eggs were transferred to petri dishes in black plastic bags (Stehr 1954) to induce first instar larvae to spin hibernacula. After 3 weeks at 20°C, the larvae were kept at 0°C for 3 months to satisfy diapause requirements. Following cold treatment, they were reared as above to pupation. Large larvae were subjected to electrophoretic analyses. Adults were used for pheromone identification. Dead males were checked for the presence of spicules on their aedeagi (Dang 1985).

Pheromone analysis. Sexed pupae were placed in petri dishes with moist filter paper at 17°C, 40-50% RH and a photoperiod of 16:8 (L:D) until adult eclosion. After 1.0, 1.5, 2.0 and 2.5 hrs into the scotophase, the last 3-4 abdominal segments of 2- to 5-day-old virgin females were removed. The abdominal tips were individually extracted for about 30 sec in 5 µl of redistilled hexane, rinsed with an additional 5 µl of hexane and discarded. Each gland extract was tested individually. Four µl were analyzed in a Hewlett Packard 5890 gas chromatograph, equipped with a 0.25 mm x 30 m DB-1 column and 2 µl of the same extract in a Hewlett-Packard 5890 gas chromatograph coupled to a Finnigan MAT 700 ion trap detector (GC-MS) which was equipped with a 0.25 mm x 20 m Supelcowax column. The oven temperature program for both chromatographs were: constant at 55°C for 1 min, heated at 25°C/min to 175°C, constant at 175°C for 1 min, and then heated at 6°C/min to 250°C. Injector and detector temperatures were 180°C and 295°C, respectively. Additional gland extracts were subjected to gas chromatographic analyses on a DB-210 column (0.25 mm x 30 m) utilizing both flame ionization (FID) and electroantennographic detection (EAD) (Arn et al. 1975) (Fig. 1).

Field bioassay of candidate pheromone components. Field experiments were conducted in a mature lodgepole pine stand 70 km north of Prince George. Each five-replicate experiment was set up in a randomized complete block with traps at 40 m intervals. The delta 2-litre milk-carton traps were suspended 2 m above ground and baited with polyvinylchloride dispensers (Daterman 1974) impregnated with candidate pheromone components in HPLC grade hexane. The 855 cm^2 trap surface was covered with the adhesive Tangle-Trap (Tanglefoot Company,

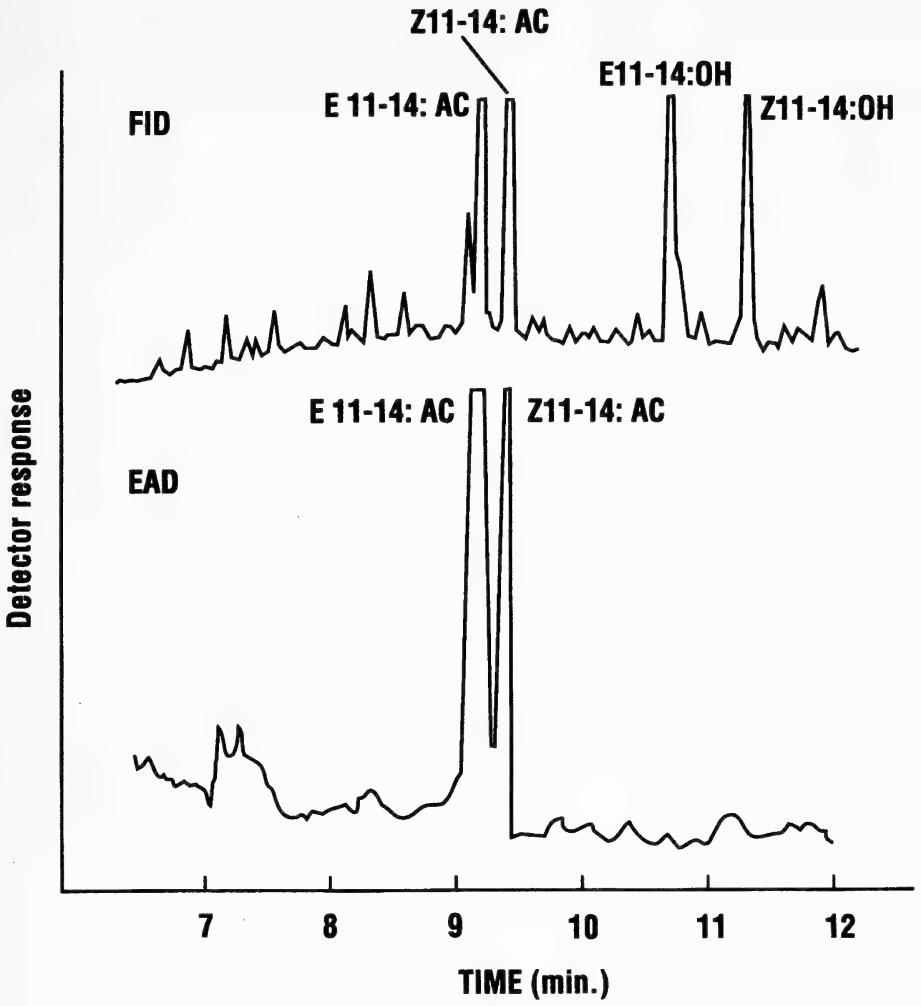

Figure 1: Detector responses to one female equivalent of pheromone extract chromatographed on a Hewlett Packard 5859A instrument (DB-210 column, 0.25 mm x 30 m I.D., 1 min at 100°C, 20°C/min to 180°C, 1°C/min to 220°C). The antennal recording was carried out with a single antenna of male *C.* n. sp. CPG (FID = flame ionization detector, EAD = electroantennographic detector).

Grand Rapids, MI 49504) to imobilize moths entering the trap. Traps were checked and advanced one position daily and those containing 20 or more males were replaced with a new trap using the same bait. The first experiment tested the attraction of *E*11-tetradecenyl acetate (*E*11-14 OAc), *Z*11-tetradecenyl acetate (*Z*11-14 OAc), *E*11-tetradecenol alcohol (*E*11-14 OH) and *Z*11-tetradecenol alcohol (*Z*11-14 OH) alone and in combinations (Table 1). The second five-replicate experiment tested the attraction of various doses of *E*11-14 OAc and *Z*11-14 OAc at the natural 65:35 ratio (Table 2).

RESULTS AND DISCUSSION

GC-EAD analyses of female gland extracts revealed four compounds two of which elicited antennal responses (Fig. 1). Retention indices and GC-MS analyses indicated *E*11-14 OAc, *Z*11-14 OAc, *E*11-14 OH and *Z*11-14 OH. Synthetic *E*11-14 OAc and *Z*11-14 OAc elicited strong electrophysiological responses, while the corresponding alcohols were hardly EAD-ac-

Table 1

Comparison of attractiveness of two acetate isomers and two alcohol isomers against *Choristoneura n.* sp. (CPG) at a loading of 5% w/w of chemicals polymerized in PVC, at Bear Lake, BC in August 1990. n = 45

Lure	Dose (μg)	Average No. males/ night/trap ± S.D.
E/*Z*-11-14 OAc	(750/500)	51.4 a* ± 21.0
E/*Z*-11-14 OAc + E-11-14 OH	(725/325/200)	45.4 a ± 16.3
E/*Z*-11-14 OAc + *E*/*Z*-11-14 OH	(725/325/100/100)	26.2 b ± 7.3
Female *Choristoneura n.* sp. (CPG)		10.2 c** ± 6.9
E-11-14 OAc	(1250)	2.8 c ± 3.8
*Z*11-14 OAc	(1250)	0.2 c ± 0.4
E-11-14 OH	(1250)	0.8 c ± 1.0
Z-11-14 OH	(1250)	0
Unbaited control trap		0

* Means followed by the same letter are not significantly different at $P < 0.05$ (Duncan's New Multiple Range Test).

** Average of five unmated females.

Table 2

Catches of male undescribed pine feeding *Choristoneura* (*C.* n. sp. CPG) in sticky traps baited with various doses of a 65:35 blend of *E*11-14 OAc and *Z*11-14 OAc, Bear Lake, British Columbia, August 1991. N=35.

Lure	Dose (μg)	Average No. trap/night	Males caught/ CI
E/*Z*-11-14:Ac	(750)	14.8 a*	8.15
E/*Z*-11-14:Ac	(2000)	14.6 ab	8.55
E/*Z*-11-14:Ac	(2500)	14.0 ab	12.95
E/*Z*-11-14:Ac	(1250)	9.0 abc	10.55
E/*Z*-11-14:Ac	(250)	6.4 bc	14.35
E/*Z*-11-14:Ac	(125)	0	

* Means followed by the same letter are not significantly different ($P<0.05$) Tukey's W Procedure.

tive, suggesting that they may not be part of the pheromone blend of female *C.* n. sp. CPG. Identical retention times on three columns with different retention characteristics (DB-1, DB-210, Supelcowax) and identical mass spectroscopic chacteristics of female-produced and authentic compounds confirmed our structural assignments.

*E*11-14 OAc, *E*11-14 OH, *Z*11-14 OAc and *Z*11-14 OH tested individually at 1250 μg each did not attract male *C.* n. sp. CPG in the field test (Table 1). However, a binary combination of *E*11-14 OAc and *Z*11-14 OAc at the 65:35 ratio found in gland extracts, attracted as many males as did the most attractive virgin females. Five of the latter attracted an average of 10.2 males each. Addition of 200 μg of *E*11-14 OH to the acetate blend did not affect the trap catches, while addition of 100 μg of both *E*11-14 OH and *Z*11-14 OH significantly decreased attraction (Table 1). Significant effects on trap catches of the alcohols, comprising 5-40% of the chemical lure, were not confirmed in subsequent experiments.

Pheromone quantity in gland extracts of female *C.* n. sp. CPG peaked 1.5 hours into the scotophase. With 80 ng per female it exceeded those of other *Choristoneura* up to four times. Only

C. orae produces similar large amounts of pheromone (Cory et al. 1982; Gray et al. 1984). A dose response test confirmed that large amounts of the acetate pheromone components are more attractive than lower concentrations (Table 2). In contrast, only 2.5 μg of *E*11-tetradecenal aldehyde (*E*11-14 Ald) was sufficent to attract large numbers of *C. occidentalis* and *C. biennis* (Cory et al. 1982). Lack of *E*11-14 Ald in the pheromone blend of *C.* n. sp. CPG contrasts with the pheromone blend of female *C. orae,* which do produce small amounts of *E*11-14 Ald in addition to large quantities of *E*11-14 OAc and *Z*11-14 OAc.

Isozymes and spicule numbers on the aedeagi of *C.* n. sp. CPG resembled those of other *Choristoneura* species in B.C., but differed from eastern species (G.T. Harvey, Forestry Canada, Sault Ste. Marie (retired) personal communication). Adults of *C.* n. sp. CPG are similar to *C.* n. sp. CR but the forewings have a lighter background colour and the black strigulae are absent. *C.* n. sp. CPG is close in size to *C. lambertiana* except that the forewings are not so light and creamy in colour but ochreous with distinctive orange-brown markings. The males are darker in wing colour than females, as observed in some other *Choristoneura* (Harvey, personal communication).

The two-component blend of *E*11-14 OAc and *Z*11-14 OAc in a 65:35 ratio with the corresponding alcohols being benign, and corresponding aldehydes being absent, differs from that of other western conifer-feeding *Choristoneura.* Occurrence on lodgepole pine and sexual dimorphism further indicate that *C.* n. sp. CPG may be a new species.

CONCLUSION

A population of *Choristoneura* was detected near Prince George, British Columbia. Morphological, ecological and pheromone characteristics are distinct from other *Choristoneura* species in British Columbia. Larvae feed on staminate flowers of lodgepole pine. Male moths are distinctly darker than female moths. The sex pheromone is comprised of *E*-11-tetradecenyl acetate and *Z*-11-tetradecenyl acetate at a unique 65:35 ratio. Corresponding aldehydes are not produced and corresponding alcohols are not behaviourally active. A lure containing 750 μg *E*/*Z*-11-14 OAc at a 65:35 ratio is recommended for detection and monitoring of *C.* n. sp. CPG.

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Response of *Trichogramma* sp. nr. *sibericum* (Hymenoptera: Trichogrammatidae) to age and density of its natural hosts, the eggs of *Rhopobota naevana* (Lepidoptera: Tortricidae)[1]

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ABSTRACT

Responses of an indigenous *Trichogramma* sp. nr. *sibericum* (Hymenoptera: Trichogrammatidae) to the age and density of eggs of the blackheaded fireworm, *Rhopobota naevana* (Hübner) (Lepidoptera: Tortricidae) were determined in the laboratory. The parasitoid wasp showed a significant ($P < 0.05$) preference for eggs 1-7-day-old over those 21-day-old. No significant differences ($P > 0.05$) in percentages of parasitized eggs, however, were found among groups of eggs below 7-day-old. At host egg densities below 20 per wasp, the number of eggs parasitized significantly ($P < 0.05$) increased with egg density, and tended to stabilize at densities above 30. The rate of parasitism decreased significantly ($P < 0.05$) with increased host egg density. Superparasitization occurred at densities of 5-10 host eggs, but was rarely observed at densities above 20 eggs. The mean number of progeny per wasp significantly ($P < 0.05$) increased with host density, whereas the clutch size (the number of parasitoid offspring per parasitized host) significantly ($P < 0.05$) decreased with an increase in host density.

INTRODUCTION

Although egg parasitic *Trichogramma* (Hymenoptera: Trichogrammatidae) species head the list of beneficial insects as biological control agents (Stinner 1977), no studies have been reported on using *Trichogramma* to control the blackheaded fireworm, *Rhopobota naevana* (Lepidoptera: Tortricidae), a major pest on cranberry in North America. However, the use of *Trichogramma* to control this pest may be realistic and possible because two species of *Trichogramma* have been discovered recently from natural fireworm populations in cranberry fields in British Columbia (Li et al. unpublished data). One of the two indigenous species, *Trichogramma* sp. nr. sibericum, showed a high affinity for fireworm eggs in the laboratory (Li *et al.* unpublished data.). If this fireworm-attacking *Trichogramma* can be successfully mass reared under laboratory conditions, field release for control of the fireworm may be realized.

Host age preference of *Trichogramma* towards a host is fundamental to a release program and is a critical factor in selection of an effective *Trichogramma* as a biological control agent (Marston and Ertle 1969; Schmidt 1970) because timing of a release is one of the most important factors influencing efficacy in the field. Thus, host age preference by *Trichogramma* must be determined before using the wasp in a biological control program. Knowledge of the relationship between host density and parasitism is also critical for both inundative releases in the field and mass rearing in the laboratory. In the present study, we report the effects under labo-

ratory conditions of host age and density on parasitism of fireworm eggs by a field-collected *T.* sp. nr. *sibericum*. Our objectives were: (1) to determine which host egg stages the wasp prefers to parasitize; (2) to determine the relationship between host egg density and parasitization; and (3) to study the effect of host egg density on mean progeny per wasp and on the number of wasp offspring per parasitized host egg (clutch size).

MATERIALS AND METHODS

Parasitoids

Parasitized fireworm eggs were collected from an abandoned cranberry field in Richmond, near Vancouver, British Columbia. Cranberry leaves bearing the parasitized eggs were incubated on moist filter paper in clear plastic Petri dishes (50 by 9 mm) at 24 ± 2°C, 90±10% RH, and 16L:8D photoperiod in the laboratory. Eclosed females were used in the following experiments.

Host eggs

Field-collected second-generation adult fireworm females were permitted to lay their eggs on cranberry uprights in a cage at 24 ± 2°C, 50±10% RH, and 16L:8D photoperiod in the laboratory. The uprights in the cage were replaced daily. Fireworm eggs obtained from the cage were used as hosts in the following experiments.

General Methods

The experiments were conducted in the open laboratory at 24 ± 2°C and 50±10% RH. The fireworm eggs on cranberry leaves were placed in the Petri dishes (50 by 9 mm) lined with moist filter paper, which was watered daily to prevent the leaves from drying out.

In each of the following experiments, single female parasitoids were transferred into a Petri dish (50 by 9 mm) with fireworm eggs using a fine artist's brush, and were maintained in the Petri dish till their death. Following introduction, the wasps were immediately observed under a dissecting microscope. If the wasps did not examine any of host eggs (*i.e.*, measure the host volume by their antennae) within 5 min following introduction, they were discarded and replaced. Seven days following introduction of the wasps, the host eggs were microscopically examined to determine if they were unparasitized, parasitized or superparasitized. The parasitized eggs turned black when the parasitoids reached the prepupal stage of development, whereas unparasitized eggs remained yellow. Superparasitized eggs are those in which more than one *Trichogramma* offspring has developed from a single host. Superparasitism was determined by counting the wasp offspring through the clear chorion of the parasitized host egg.

Host age preference

In this choice test, four each of 1, 3, 5, 7 and 21-day-old host eggs laid on cranberry leaves, at two equal-aged eggs per leaf, were placed in the center of a Petri dish (50 by 9 mm). Single

Table 1

Effects of host egg density of blackheaded fireworm, *Rhopobota naevana*, on number of progeny and the clutch size of *Trichogramma* sp. nr. *sibericum*[1]

Host density	Progeny±SE	Clutch size±SE
5	7.60±0.31 b	1.52±0.06 a
10	11.80±0.73 ab	1.46±0.06 a
20	11.70±1.53 ab	1.05±0.03 b
30	14.20±1.98 a	1.06±0.03 b
40	14.10±1.55 a	1.10±0.07 b
50	13.90±1.92 a	1.03±0.02 b

1. Mean values followed by the same letters in the same column are not significantly different at the 5% level of Scheffé's F-test.

female parasitoids were introduced in the center of the 10 leaves, which bore a total of 20 variously aged fireworm eggs. Each Petri dish was a replicate, 50 replications were tested.

Host density

Single female wasps were exposed to 1-day-old fireworm eggs at different densities in the Petri dishes (50 by 9 mm). The host egg densities were 5, 10, 20, 30, 40 and 50 eggs divided equally on five cranberry leaves, respectively. Each Petri dish was a replicate and each host density was replicated 10 times. The data recorded were: the percentage of parasitization and superparasitization; the number of progeny per parasitoid; and the clutch size.

Data analyses

Percentage of parasitism was calculated as the numbers of parasitized eggs divided by total eggs exposed in each group in the experiments. Percentage of superparasitism was calculated as the numbers of superparasitized eggs divided by total parasitized eggs. The data were transformed as either arcsin $\sqrt{P}$ or $\sqrt{x+0.5}$ before ANOVA (Zar 1984), where P represents the percentage of parasitization or superparasitization and x is mean progeny per wasp or the clutch size. One-way ANOVA was used to estimate significances ($P < 0.05$). Significant differences were compared among host age groups or among host densities, and were separated by Scheffé's F-test of multiple contrasts at $P = 0.05$ level.

RESULTS

The age of the host egg had a significant effect ($F = 7.0$; $df = 4, 245$; $P = 0.0001$) on parasitism of fireworm eggs by the wasps (Fig. 1). The percentage of parasitization was significantly lower ($P < 0.05$) for 21-day-old eggs than 1-7-day-old eggs, suggesting that T. sp. nr. *sibericum* prefers to parasitize young fireworm eggs. Although parasitism varied from 61% to 72.5% among eggs

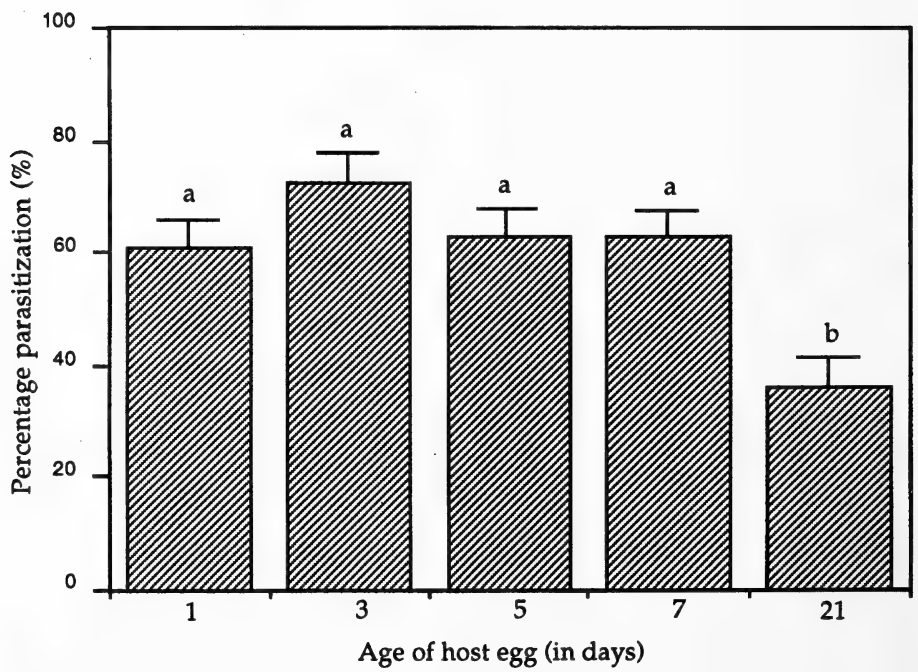

Figure 1. Effects of host age on parasitization of *Rhopobota naevana* eggs by an indigenous *Trichogramma* sp. nr. *sibericum*. Vertical bars indicate standard errors of mean parasitism. Bars with the same letters indicate that mean parasitism is not significantly different ($P > 0.05$; Scheffé's F-test) (Zar 1984).

aged from 1-7 days, no significant ($P > 0.05$) differences were found within this age group.

The number of parasitized fireworm eggs increased significantly ($F = 6.0$; $df = 4, 54$; $P = 0.0002$) with host egg density, and tended to stabilize at host densities higher than 30 eggs (Fig. 2: A). The maximum number of parasitized eggs was about 13, suggesting that females of the wasp had a limited supply of eggs. The percentage of parasitism significantly ($F = 42.1$; $df = 4, 54$; $P = 0.0001$) decreased with increased host egg density (Fig. 2: B). At a parasitoid/host ratio of 1/5, 100% of the host eggs were parasitized. However, only 30% of the eggs were parasitized at a ratio of 1/50. Superparasitization also significantly ($F = 22.5$; $df = 4, 54$; $P = 0.0001$) decreased as host density increased beyond 10 host eggs per wasp (Fig. 2: C). At high parasitoid/host ratios (1/5 - 1/10), 40-50% of the parasitized eggs were superparasitized, which was significantly higher ($P < 0.05$) than at low ratios (1/20 - 1/50).

The mean number of progeny produced per parasitoid at a host density of 5 eggs was significantly ($P< 0.05$) lower than at densities of 30 - 50 eggs (Table 1). At a host density of 30 eggs, the number of progeny reached its maximum of 14.2. Then the number tended to stabilize even though host density continued to increase. The clutch sizes at host densities of 5 - 10 eggs were significantly higher ($F = 22.3$; $df = 4, 54$; $P = 0.0001$) than those at higher densities of 20 - 50 eggs (Table 1).

DISCUSSION

Much research has been previously conducted on host-age selection by *Trichogramma* spp. (e.g., Marston and Ertle 1969; Pak et al. 1986). The relationships between a given *Trichogramma* and its host species may be different. Pak (1986) summarized six types of relationships between host age and parasitism by different combinations of *Trichogramma* species and their hosts. The observed effect of host age on parasitism of fireworm eggs in this study appeared to be Pak's type II-a: *i.e.,* reduced parasitism of the oldest host eggs. Female parasitoids may use physical (e.g., size, shape, texture, movement), physiological and/or chemical cues (e.g., kairomones) to recognize and parasitize their hosts (Arthur 1981; Pak *et al.* 1986). Hosts used in the present study were second-generation fireworm eggs. Because more than 80% of these eggs are in diapause (Fitzpatrick and Troubridge 1993), there may not be significant differences in physical and physiological between young and old eggs. Therefore, the wasp's preference for young eggs may be based on chemical cues. Vinson (1975) found a chemical factor present in *Heliothis virescens* F. (Lepidoptera: Noctuidae) eggs to be important in host acceptance by an egg-larval parasitoid, *Chelonus texanus* Cresson (Hymenoptera: Braconidae). A few studies have demonstrated that kairomones on moth scales play an important role in host-finding by *Trichogramma* (Lewis *et al.* 1971, 1975; Thomson and Stinner 1990). Whether fireworm eggs or scales of the adult moth contain such kairomones is unknown.

The parasitism of fireworm eggs by *T.* sp. nr. *sibericum* is host density dependent, i.e., an increase in host egg density leads to a reduction in the percentage of parasitized eggs as has been found by Hirose *et al.* (1976) and Morrison *et al.* (1978) with other species. Figure 2 C shows that the rate of superparasitism here decreases with an increase in host density. This is a common phenomena described by many researchers (e.g., Waage 1986, 1988). Wajnberg *et al.* (1989) showed that the control of superparasitism of *Ephestia kuehniella* Zeller (Lepidoptera: Pyralidae) by *Trichogramma maidis* Pintureau and Voegelé seems to be genetically determined. In this study, however, superparasitism at a host density of 5 eggs was 50%, whereas at a host density of 50 eggs it was 2.8%. Superparasitism of fireworm eggs by *T.* sp. nr. *sibericum* may be an example of adaptive reproductive strategy proposed by Strand (1988) and Waage (1988). Superparasitism is often viewed as a maladaptive mistake (Van Lenteren 1981). As long as a parasitoid egg deposited in a host still has a finite probability of survival in competition with a previously laid clutch, however, superparasitism may be advantageous (Bakker *et al.* 1985; Strand 1988; Waage 1988). In the present study, two adult *Trichogramma* often were eclosed successfully from single fireworm eggs. It would therefore be of prime interest to conduct experiments to determine the relationship between fitness per host and the clutch size of the parasitoid.

Although *T.* sp. nr. *sibericum* prefers to parasitize young eggs (Fig. 1), they still parasitized

21-day-old eggs at the rate of 36%. In order to obtain maximum efficacy as a control in the field, *Trichogramma* should be released within one week of egg deposition. The results, however, also suggest that releasing *Trichogramma* three weeks following egg deposition may still have a positive effect on the reduction of fireworm populations. The total fecundity per female *T.* sp. nr. *sibericum* observed in this study was lower than those reported previously with other species (Yu *et al.* 1984; Smith and Hubbes 1986; Hohmann *et al.* 1988). The low fecundity of the wasp reported here may be due to unfed adults with honey. Yu *et al.* (1984) found that fed *Trichogramma minutum* Riley with honey produced 6 times of eggs as much as unfed wasps. The

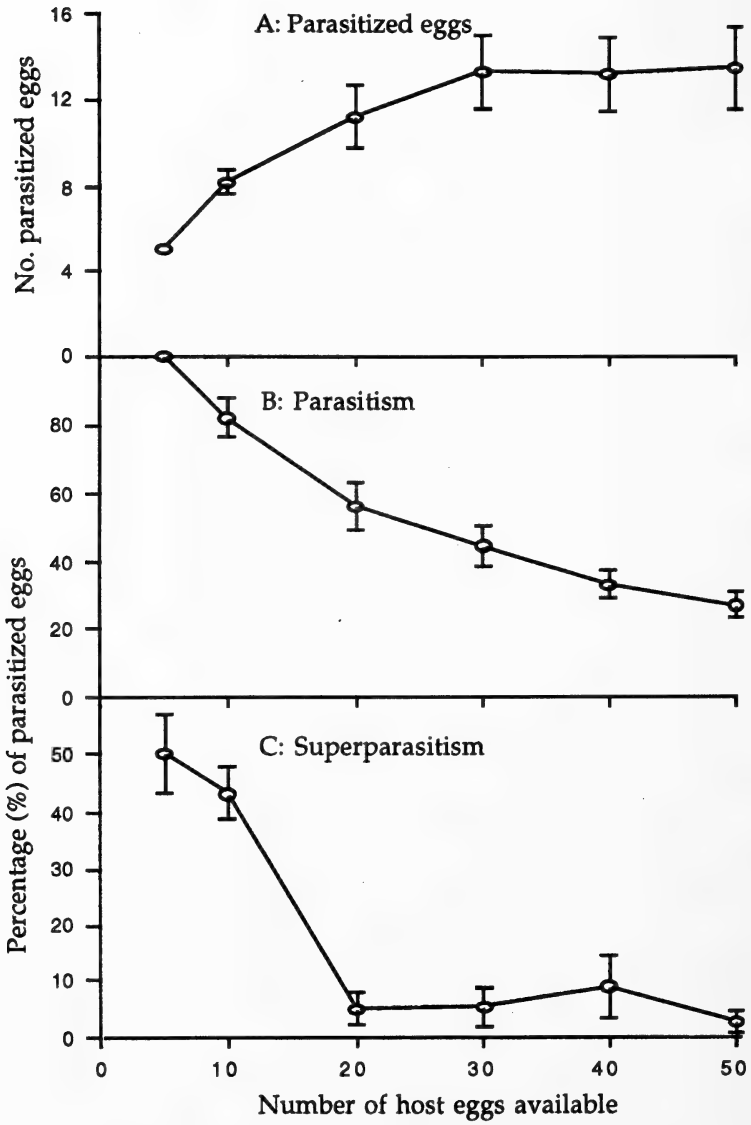

Figure 2. Effects of host egg density on the number of parasitized eggs (A), percentage parasitism (B), and percentage superparasitism (C) of *Rhopobota naevana* eggs by an indigenous *Trichogramma* sp. nr. *sibericum*. Vertical bars indicate standard errors of means.

findings that single female *T.* sp. nr. *sibericum* can parasitize about 13 fireworm eggs (Fig. 2: A) and that a negative relationship between host density and parasitism exists (Fig. 2: B), should be taken into account in both mass rearing this species in the laboratory and commercial release in the field.

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NOTE

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Variation in attack by Sitka spruce weevil, *Pissodes strobi* (Peck), within a resistant provenance of Sitka spruce

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ABSTRACT

Variation in tree height and numbers of attacks by the Sitka spruce weevil (= white pine weevil), *Pissodes strobi* (Peck), were studied among families of a resistant provenance of *Picea sitchensis* (Bong.) Carr. at two Vancouver Island sites. At Sayward, after 14 years, the number of trees attacked varied by family from 0 to 80%. A significant association was found between the percentage of trees attacked in a family and the mean height of the family. Tall families were generally attacked more. At Fair Harbour (a clonal test), only 12% of the trees from the resistant provenance have been attacked after seven years, with all but one of the attacks concentrated on one of the two families tested. A multigenic or multicomponent basis for resistance is proposed and discussed.

INTRODUCTION

The Sitka spruce weevil (=white pine weevil), *Pissodes strobi* (Peck), is a major cause of failure in reforestation programs with Sitka spruce, *Picea sitchensis* (Bong.) Carr., in coastal British Columbia (B.C.), Washington, and Oregon (Furniss and Carolin 1977). The adults emerge from overwintering in early spring, and move to the 1-year old terminal shoot (leader) where the females lay eggs under the bark near the tip. If the weevil larvae become established, they move downwards, mining and consuming the phloem and eventually killing the leader (Silver 1968). In the literature, the successful colonization and destruction of the tree leader by *P. strobi* is generally called a weevil attack; this terminology is also used here. Repeated leader destruction causes height-growth loss and stem deformities which reduce the tree's value (Alfaro 1989a, 1992). Although the tree survives the attack, stunted trees are often suppressed by competing vegetation (Alfaro 1982). Other important tree species damaged by this insect are eastern white pine, *Pinus strobus* L., in eastern North America (MacAloney 1930), Engelmann spruce, *Picea engelmannii* Parry, and white spruce, *Picea glauca* (Moench) Voss., in central British Columbia and the prairie provinces (Stevenson 1967).

Analysis of several trials in British Columbia provided strong evidence of genetic variation

in the susceptibility of Sitka spruce to weevil damage (Ying 1991, Alfaro and Ying 1990). Genetic resistance to weevil attack was also demonstrated for interior spruce by Kiss and Yanchuk (1991). These analyses indicate that some provenances and families show resistance in the form of reduced numbers of weevil attacks. This was the case in Sitka spruce trees from the Haney provenance in trials at Sayward and Fair Harbour, which grew well and were the least damaged (Ying 1991, Alfaro and Ying 1990). Mechanisms of resistance are currently under investigation; one based on supernumerary resin canals has been proposed (E. Tomlin and J.H. Borden, personal communication, Simon Fraser University).

Ying (1991) noted that resistant provenances of Sitka spruce originate from areas of high weevil hazard, such as Haney or Squamish on the B.C. mainland. He hypothesized that herbivore selection may have favored a resistant gene pool in these areas so that survivors have high levels of resistance. Alfaro and Ying (1990) identified the Skeena River area of B.C. as another area where higher frequency of resistant individuals could be found. In this area, extensive hybridization of Sitka with white spruce occurs. Variation in susceptibility among different *Picea* species and their hybrids has been reported (Mitchell *et al.* 1990).

Alfaro and Ying (1990) also demonstrated variation in the ability of trees to recover from weevil damage, since the type of defect formed after attack varied by provenance and family. Some provenances had above-average numbers of attacks per tree but still were able to develop into merchantable trees. An example of tolerance to weevil damage was the Big Qualicum provenance, which was among the tallest at the Sayward trial even though it sustained repeated attacks.

The objectives of this paper were to examine the rates of repeated attacks among families, trees and clones of the most resistant provenance found to date in B.C. (the Haney provenance), and to describe some of the factors that determined attacks on individuals of this provenance. In particular, we tested whether the demonstrated preference of the weevil for the tallest and fastest growing trees in a plantation (Mitchell *et al.* 1990, Alfaro 1989b, Gara *et al.* 1971, Silver 1968) also holds true within the Haney provenance. For this study, we used data collected at Sayward and Fair Harbour in 1988, 1991 and 1992.

MATERIALS AND METHODS

The Sayward provenance test was established in the spring of 1974 in the Salmon Valley, near Sayward, B.C., with the purpose of comparing growth and survival of a collection of open-pollination families from several B.C. provenances. The plantation was first attacked by *P. strobi* when the trees were 5 years old. The site was assessed in the fall of 1988; for every tree we recorded: total height, diameter at breast height (DBH), and the number of times the trees had sustained weevil attack. Weevil attacks were recognized because, in most cases, remains of the destroyed leader were present and pupal chambers were evident. The plantation originally consisted of two blocks, A and B, but only Block B was assessed because Block A had suffered flood damage. Block B consisted of 141 rows occupying 2.8 ha, and contained 4389 living trees from 34 provenances. Each provenance consisted of a variable number of wind-pollinated families. The resistant Haney provenance, which was the object of this study, was represented by 81 trees from 8 families. Further details on this plantation and on the geographic location of provenance sources can be found in Alfaro and Ying (1990).

The 1988 records for the Sayward plantation (Block B) were assessed to determine the number of past attacks and the height of trees in the Haney provenance. Because of limitations of the experimental design of this test no attempt was made to analyze the components of the variance or to calculate other genetic parameters. Instead, we relied on non-parametric tests of variance and association. The Kruskal-Wallis test (Sokal and Rohlf 1969) was used to test for family variation in mean number of attacks per tree. The Spearman rank correlation coefficient (Sokal and Rohlf 1969) was used to test for a significant association between percentage of trees attacked in a family and mean family height. The same procedure was used to test for association between the mean number of attacks per tree in a family and mean family height.

The Fair Harbour plantation is a clonal trial (grafting) established in 1984 to test the repeatability of provenance resistance to weevil attack observed in provenance tests (Ying 1991). The

donor parents (ortets) originated from trees in eight provenances tested at the Sayward site, plus two trees from the Green Timbers plantation which showed high resistance to weevil attack (Alfaro 1982). Eight trees from the resistant Haney provenance (four trees each from family 0 and 1) were included in the test. The layout of the test consisted of 16 blocks in which a total of 640 grafts were tested; each ortet was represented by 16 grafts (ramets), one ramet in each block.

The attacks on the ramets at Fair Harbour were counted in October 1991 and on the ortets at Sayward in October 1992.

To determine if attacks on trees occurred independently of each other or if the presence of one attack enhanced the probability of a subsequent attack on the same tree, the distribution of the attacks per tree at both sites was compared to that expected from a Poisson distribution. Data collected in 1988 were used for the analysis of the Sayward site and 1991 data for the Fair Harbour site. However, because of the low attack rates at Fair Harbour, a Chi-square-test of goodness-of-fit (Sokal and Rohlf 1969) was done only for the Sayward data.

Table 1

Mean tree height, number of Sitka spruce weevil attacks per tree and percent of trees attacked among trees of the resistant Sitka spruce Haney provenance (standard deviation in brackets). Data collected in 1988 at Sayward and in 1991 at Fair Harbour.

Location and family No.	Number of trees	Mean Ht (m)	Mean No. attacks per tree	% trees attacked
Sayward				
0	6	6.6 (1.6)	0.3 (0.5)	33
1*	5	—	–	–
3	30	6.0 (1.2)	1.1 (1.1)	60
4	22	5.3 (1.9)	0.5 (0.7)	32
5	4	4.0 (1.0)	0.0 (0.0)	0
8	7	4.2 (0.6)	0.9 (1.6)	29
12	7	5.1 (0.6)	0.4 (0.8)	29
13	5	6.0 (1.0)	1.8 (1.1)	80
Fair Harbour				
0	62	4.6 (0.9)	0.03 (0.25)	2
1	63	4.7 (0.9)	0.25 (0.54)	22

* This family was present only at Sayward Block A, which was not assessed in 1988. An assessment in 1992 indicated that 60% of the trees in this family had been attacked at least once.

Table 2

Frequency distribution of Sitka spruce weevil attacks per tree among trees from the resistant Sitka spruce Haney provenance. The expected frequencies from a Poisson distribution are given in brackets. Data collected in 1988 at Sayward and in 1991 at Fair Harbour.

Attacks per tree	Sayward No. trees[1]	Fair Harbour No. trees[1]
0	46 (36)	111 (109)
1	14 (29)	10 (15)
2	15 (12)	4 (1)
3	5 (3)	–
4	1 (1)	–

1. For the Sayward site, a Chi-square-test detected a significant departure of the number of attacks per tree from predicted Poisson frequencies ($P<0.01$). Because of the small number of attacks, and low cell frequencies, no statistical tests were done on the Fair Harbour data.

RESULTS

Sayward Test

The 1988 attack records indicated that only 43% of trees from the Haney provenance were attacked one or more times, whereas 76% of the trees in the entire Sayward Block B had been attacked. The percentage of trees attacked among families within the Haney provenance varied significantly (Chi-square test, $P<0.05$) by family from 0% (Family 5) to 80% (Family 13) (Table 1). The mean number of attacks per tree for the Haney provenance was 0.8 (ranging from 0 to 4) which was about half of the mean number of attacks per tree recorded for the entire Block at 1.5 (range 0 to 7, Alfaro and Ying 1990). The mean number of attacks per tree varied significantly among the Haney families from 0 (Family 5) to 1.8 (Family 13) (Table 1) (Kruskal-Wallis Test, $P<0.05$).

The distribution of the number of attacks per tree departed significantly (Chi-square test, $P<0.01$) from the values expected from the Poisson distribution, indicating a clumped distribution. There were higher numbers of trees that remained undamaged and higher numbers having repeated attacks than expected if the attacks occurred at random (Table 2). This allowed us to conclude that the presence of one attack on a tree enhanced the chances of a tree being attacked again. Alfaro and Ying (1990) arrived at the same conclusion when they examined the attack distribution for the entire Sayward Block B plantation.

In 1988, the Haney provenance trees averaged 5.5 m in height, almost 2 m taller than the average height for the entire site (3.6 m). However, there was considerable variation in height by family (range 4.0 to 6.6 m). The Spearman rank correlation test detected a significant association between the percentage of trees attacked in a family and the mean height of the family ($rs = 0.88$, $P= 0.01$) (Fig. 1). Because of the negative effect of weevil damage on height growth, this correlation is only a measure of association, rather than a cause-effect relationship. No significant correlation was found between the number of times an individual tree was attacked and tree height.

Fair Harbour Test

Overall, 12% of the trees from the Haney provenance at the Fair Harbour site were attacked (14 trees up to 1991). This is much lower than the 69% found for the entire site. As at the Sayward site, more trees had repeated attacks than predicted by the Poisson distribution (Table 2). There were four trees attacked twice; if attacks occurred at random, only one tree would have been so attacked (Table 2). However, because at this site weevil damage is still light and this resulted in low cell frequencies, a Chi-square test was not done. All but one of the attacks occurred among trees of Family 1, resulting in attack rates of 2% for Family 0 and 21% for Family 1 (Table 3). Mean height of the Haney ramets varied from 4.0 to 5.2 m. No correlation was found between the percentage of trees attacked in a clone and mean clonal height (Spearman rank correlation test not significant).

A comparison of the attack rates on the Fair Harbour ramets with attack rates on the respective ortets at Sayward indicated a very good correspondence (Table 3). There was a very low attack rate on both ortets and ramets from Family 0, with only one tree being attacked at each site. Both ortets and ramets from Family 1 had sustained higher attack rates than Family 0, with three of the four ortets at Sayward and 13 of 63 ramets at Fair Harbour being attacked (Table 3). In both families there was one ortet attacked at Sayward but no attack among the respective Fair Harbour ramets. There were also attacks among ramets from ortets which remained free from attack at Sayward, e.g. tree No. 6 from Family 1.

DISCUSSION

The low attack rate of the Haney provenance at the Sayward and Fair Harbour sites confirms the existence of resistance to weevil attack in this provenance (Ying 1991, Alfaro and Ying 1990). This study also suggests that individual trees and families from the same Haney provenance differ in degree of resistance.

The large number of trees of the Haney provenance that remained free from weevil attack at both sites is probably not due solely to genetic resistance. One factor influencing the probabil-

Table 3

Attacks by the Sitka spruce weevil on two Sitka spruce families planted at the Sayward site and cloned at the Fair Harbour site. Data collected in 1992 at Sayward and in 1991 at Fair Harbour.

		Plantation				
		Sayward Ortets		Fair Harbour Ramets		
Family No.	Tree No.	Trees	Attacks per tree	Grafts alive	Grafts attacked	Attacks* per graft
0	2	1	0	16	0	0
	5	1	0	14	0	0
	6	1	0	16	1	2
	7	1	1	15	0	0
1	1	1	1	15	0	0
	2	1	2	16	3	1
	3	1	2	14	8	1.4
	6	1	0	15	2	1

* Mean number of attacks on attacked grafts.

ity of attack on a tree is its rate of growth. Several reports indicate that the Sitka spruce weevil prefers the fastest-growing trees in a stand (Mitchell *et al.* 1990, Alfaro 1989b, Gara *et al.* 1971, Silver 1968). Alfaro and Ying (1990) found that, at the Sayward site, trees growing in patches of severe attack were significantly taller (3.8 m) than trees growing in areas of low attack (3.5 m). This preference was also evident in this study among the trees of the resistant provenance (Fig. 1). The only Haney family at Sayward which was free from weevil attack was Family 5, which was also the shortest.

The preference of *P. strobi* for the fastest-growing families (even among the resistant provenance) is different from the findings of Kiss and Yanchuk (1991) who found the opposite among families of white spruce attacked by the same insect. A possible explanation for this apparent contradiction is that *P. strobi* may seek to maximize the amount of larval food during host selection. *P. strobi* larvae consume the leader phloem, therefore, leaders with thicker phloem are probably more attractive than leaders with thin phloem. In Sitka spruce, thick phloem is correlated with long leaders (Alfaro, unpublished data). It is possible that, because of the different growth characteristics of white spruce (much slower growth than Sitka spruce) thick phloem may be negatively correlated with leader length in this species. Therefore, a negative correlation between attack rate and rate of growth would result. However, further research is required to prove or disprove this hypothesis.

The spatial distribution of weevil attacks in a plantation is highly clumped (Alfaro and Ying 1990, Graham 1951). This study demonstrated that, at both test sites, attacks on trees from the resistant provenance were also aggregated and that, once trees were attacked, their chances of further attack increased. This distribution probably results from the low dispersal ability of the weevil and from the tendency of the weevils to overwinter near the attacked tree. Moreover, the formation of multiple leaders on attacked trees increases the probability of further attack. This aggregation in the weevil population must be considered when selecting for resistance. A susceptible tree may appear resistant and be undamaged if it happened to occur in an area of low weevil density. Therefore, selection for resistant trees should be done in areas of the plantation of high weevil density.

The low overall attack rates among the Haney trees at the Fair Harbour site as compared with the Sayward site (Table 2) could result from several factors which are different between the two plantations. The Fair Harbour test was initiated 10 yr after the Sayward test, therefore trees have had a shorter exposure to the weevil. The Fair Harbour trees were clones produced by grafting, and thus could differ from the wind-pollination trees at Sayward due to an influence of

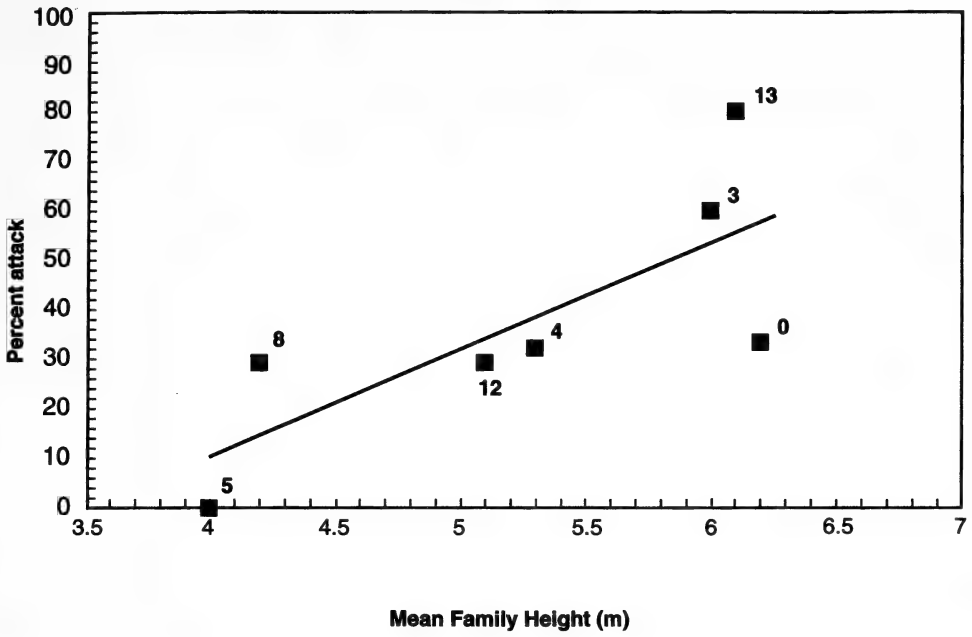

Figure 1. Relationship between the percentage of Sitka spruce trees in a family attacked by the Sitka spruce weevil at Sayward and mean family height. All families (indicated by numbers) are from the resistant Haney provenance. Data collected in 1988.

the root stock on the physiology of the tree. However, the ranking of resistance among the two families was the same at both sites: Family 0 was more resistant than Family 1 (Table 3). This indicated that selection for resistance at an early age (9 years at Sayward) may be reliable.

The large variation in the percentage of trees attacked among the wind-pollination families of the Haney provenance, as well as the existence of a gradation in resistance with several provenances showing intermediate resistance, e.g. Squamish (Alfaro and Ying 1990), suggest a resistance mechanism that has a multi-allelic or multigenic basis or to the existence of several resistance mechanisms which accumulate and perhaps synergize in different trees. Future research should concentrate on the elucidation of the resistance mechanisms and on understanding their genetic basis. Ying (1991) noted the desirability of developing varieties which combine different resistance mechanisms and thus run a lower risk of inducing the evolution of weevil populations which can overcome tree resistance. However confirmation of this hypothesis requires the establishment and evaluation of progeny tests.

Ultimately, it is likely that the degree of attack by *P. strobi* on a Sitka spruce tree, family, or provenance is due to a combination of factors: resistance factors and growth characteristics of the trees which are subject to both genetic and environmental influences, plus an element of chance. Some of these factors could be manipulated, along with silvicultural treatments such as shading (McLean 1989) or spacing (Alfaro and Omule 1990), in an integrated pest management program for control of this destructive insect.

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Life history and pheromone response in *Pissodes schwarzi* Hopk. (Coleoptera: Curculionidae)

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ABSTRACT

Pitfall traps baited with live *Pissodes schwarzi* Hopk. males plus pine sections captured 46 female *P. schwarzi* from 1 June to 1 September, 1989, indicating the presence of a male-produced sex pheromone. No weevils were captured in unbaited traps, or those baited with females on pine or pine sections alone. Seasonal response of *P. schwarzi* females to the male-baited pifall traps indicated peak periods of activity in early June, representing overwintered adults, and mid- to late July, corresponding to the emergence of new adults. Development time of *P. schwarzi* varied depending on oviposition location on the tree. Overwintered brood adults began to oviposit in May and continued through August.

INTRODUCTION

The Yosemite bark weevil, *Pissodes schwarzi* Hopk., attacks and breeds in the bole, root collar and large roots of stressed or dying trees (Wood 1964; Stevens 1966). Hopkins (1911) and

Smith and Sugden (1969) list its hosts as *Larix occidentalis* Nutt. (western larch), *Picea engelmannii* Parry ex Engelm. (Engelmann spruce), *P. glauca* (Moench) Voss.(white spruce), *P. mariana* (Mill.) B.S.P. (Black spruce), *P. pungens* Engelm. (blue spruce), *Pinus ponderosa* Laws. (ponderosa pine), *P. albicaulis* Engelm. (whitebark pine), *P. contorta* Dougl. (lodgepole pine), *P. flexilis* James (limber pine) and *P. monticola* Dougl. (western white pine). In British Columbia, *P. schwarzi* is commonly found in lodgepole pine infected with comandra blister rust, *Cronartium comandrae* Pk. (Furniss and Carolin 1977) or other damaging agents.

Host selection by another root-inhabiting *Pissodes, P. nemorensis,* has been shown to be pheromone mediated (Fontaine and Foltz 1982). Males release grandisol and grandisal, originally found in the boll weevil, *Anthonomus grandis* Boheman (Tumlinson *et al.* 1969), which attract both males and females (Phillips *et al.* 1984). Both *P. schwarzi* and *P. nemorensis* exhibit similar habits, attacking boles and root collars of young trees. This study investigates the hypothesis that *P. schwarzi* produces an aggregation pheromone and describes some aspects of the weevil's life history and habits.

MATERIALS AND METHODS

Pitfall traps modified slightly from those used to catch *Hylobius abietis* (L.) (Tilles *et al.* 1986a,b; Nordlander 1987) were constructed from 30 cm lengths of PVC plastic drainpipe with a 10 cm inside diameter. The pipes were inserted into the soil so that 8 equidistant holes (6 mm diam.) drilled around the circumference at mid-point of the pipe were at ground level. A thin coating of Tanglefoot® was applied every 3 weeks to the above-ground portion of the trap to catch any responding weevils that might climb the trap. Experimental traps all had a 4-5 cm long section of fresh lodgepole pine wrapped in a fine mesh fabric and suspended at ground level inside the trap. The four treatments were: 1) one male inside the mesh fabric on a pine section; 2) one female inside the mesh fabric on a pine section; 3) pine alone; and 4) an unbaited control. The bait weevils were collected 20 May 1989 on lodgepole pines infected with comandra blister rust. Responding weevils that entered the holes in the trap fell into the bottom of the trap where a plastic dish filled with anti-freeze fluid would trap and kill the insects. The inside of the traps were coated weekly with Tri-flo® (teflon lubricant) to keep responding weevils from climbing up the inside walls and escaping.

The traps were placed in a naturally-regenerated stand of lodgepole pine (average age 12 years) at Ellis Creek located in the montane spruce zone (Table 1) (Lloyd *et al.* 1990), 15 km east of Penticton, B.C. The stand was juvenile-spaced in 1983 and had sustained about 35% infection by *C. comandrae*. Approximately one third of the infected trees, or 10% of the trees in the stand, showed past or current evidence of *P. schwarzi* infestation.

Between 21-23 May 1989, 60 traps were placed in 4 rows of 15 traps each, spaced about 12 m apart, with 15 m between rows. Treatments were assigned in 15 systematic, repetative complete blocks, beginning at the start of the first row and ending at the last trap of the fourth row.

Table 1

Description of biogeoclimatic zones and subzones sampled in this study. Zones are generally named after one or two dominant climax tree species and two lower-case alphabetic characters are used to denote climatically based subzone names (Lloyd *et al.* 1990; Meidinger and Pojar 1991). The single numeric character following a subzone's alphabetic character indicates a variant, numbered geographically from south to north.

Characteristics	IDFdm1	MSdm1	ESSFdc1
Site	Okanagan Falls	Ellis Creek	Daves Creek
Zone	Interior Douglas-fir	Montane spruce	Engelmann spruce-subalpine fir
Subzone	dry, mild	dry, mild	dry, cold
Elevation (m)	560-1,300	1,300-1,600	1,600-1,950
Annual mean temperature (°C)	3.8	3.2	2.0

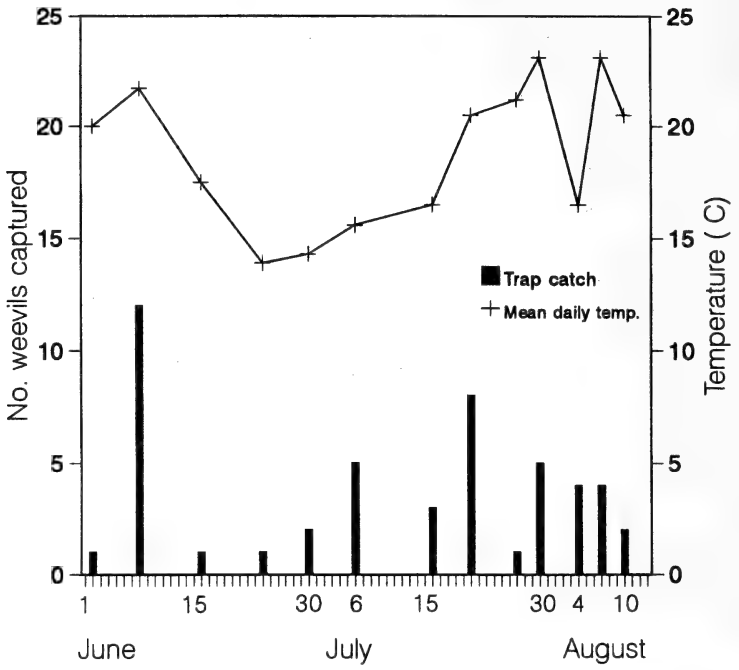

Figure 1. Numbers of *Pissodes schwarzi* caught in pitfall traps, by collection date, from June 1 to September 1, 1989, and corresponding average daily temperature for each period of elapsed time between collection dates. All pitfall traps were located in the Ellis Creek drainage.

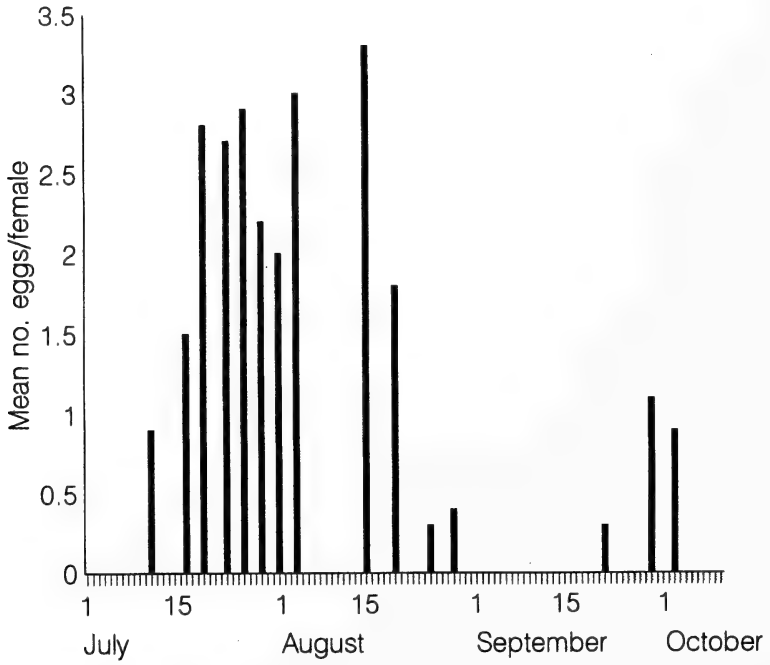

Figure 2. Seasonal trend in numbers of eggs laid by newly emerged *Pissodes schwarzi* females per 3-7 day periods, from July through October, 1989.

At approximately weekly intervals from 1 June to 1 September 1989, captured weevils were collected, and the pine, and weevil baits if necessary, were replaced. Captured weevils were separated by sex (Harman and Kulman 1966).

To study the bionomics of *P. schwarzi,* 5 to 8 infested pine roots were collected at approximately weekly intervals from 1 June to 23 August 1988 from 3 sites, located in three different biogeoclimatic zones and subzones, in the Penticton area (Okanagan Falls, Daves Creek, and the trapping site, Ellis Creek) (Table 1). The roots were subdivided into bole, root-ball, and lateral roots, and dissected; the numbers of weevils in each life stage, as well as empty chip cocoons were recorded.

Infested roots were collected from Ellis Creek on 21 May 1989 and the adults were allowed to emerge in the laboratory. The weevils used in the study emerged between 9-20 June 1989. Oviposition by emergent weevils was studied by placing 39 male-female pairs of *P. schwarzi* on 6 cm lengths of fresh pine in a 15 x 2.5 cm petri dish on 21 June, 1989. The 39 petri dishes containing the weevils were kept in a sceen house under natural light:dark and temperature conditions. The pine was replaced every 3-5 days and assessed for oviposition. Observations from dissections and the trapping study were related to weather recorded by the B.C. Forest Service about 2 km from the Ellis Creek site, at the same elevation.

RESULTS AND DISCUSSION

Forty-eight *P. schwarzi* were captured throughout the summer in traps baited with males on pine sections (two of these were captured in the Tanglefoot). No weevils were captured in unbaited traps, or those baited with females on pine or pine sections alone. Forty-six of the *P. schwarzi* captured were females, indicating a male-produced sex pheromone. The lack of response to all but the males-on-pine treatment suggests that *P. schwarzi* does not respond to an attractive tree trunk silhouette for visual orientation, with or without host volatiles, similar to results obtained with *H. radicus* Buchanan (Hunt and Raffa 1989). Three *Hylobius warreni* and one *Magdalis* sp. were caught in response to the male-on-pine treatment.

The seasonal response of female *P. schwarzi* to the male-baited pitfall traps indicates peak periods of activity in early June and mid- to late July (Fig. 1). Trap catches were generally highest in warm weather. The first seasonal peak probably represents overwintered adults, and the second peak newly emerged adults. Adults were collected from around the boles of stressed pines on 10 May 1989 and all 6 of the females collected were ovipositing. These females when paired with males laid 4.1 ± 0.3 eggs per day (mean + S.E.) from 10 May to 1 June 1989.

Dissections of infested roots collected periodically from the three locations throughout the summer revealed a fairly high frequency of larvae in the host from early June, to the end of August. The frequency of pupae increased from late June through late July, and decreased in August. The frequency of adults in the host varied only slightly between sites, and generally increased from late July to early August. Separation of larval instars visually into early *versus* late disclosed that late instars were most frequent in early June and August, and early instars from mid-June through late July, corresponding to the observed activity of overwintered adults in the field. As also noted by Stevens (1966), all developmental stages were represented during July and August. However, in B.C. overwintered adults can be found mating, feeding and ovipositing on boles as early as May and this has been observed to continue through August, as opposed observations in California (Stevens 1966) where the first sign of oviposition was noticed in July. Because of the protracted oviposition period, overwintering larvae of all stages may be encountered (Stevens 1966; personal observations).

Developmental time varied depending on the oviposition site on the tree. The preferred oviposition site was the lower bole (>80%) with the remainder occurring equally in the root-ball and lateral roots. Developmental time in the bole can be as much as a year shorter than in the root ball or lateral roots due to higher above-ground temperatures (personal observation). Some infested trees were identified and checked periodically throughout the summer to observe development in the field. Weevils developed and emerged from the above-ground portions of the trees whereas many weevils in the below-ground portions of the trees overwintered as larvae or pupae for a second winter. About 50% of infested trees that were dissected from the three sites

had empty chip cocoons, from which adults had already emerged and the majority of the emergence was from the bole. The collections made from Daves Creek (ESSF), had >90% of the cocoons located in the above ground portion of the bole. This could be due to a preference for ovipositing on the bole in the cool temperature regime in this biogeoclimatic zone.

From 12-18 July 1989, 22 to 28 days after being placed on host sections in petri dishes, the females began ovipositing and continued until 2 Oct. (Fig. 2). There appeared to be a major peak in late July through August, and then a lesser one in October. Weevils could be found ovipositing on boles in the field until late September in 1989. The mean number of eggs laid per female (± S.E.) was 22.6 ± 1.82, with a maximum of 92 eggs laid by one female. There were up to 5 eggs deposited per puncture; however, of the 904 oviposition punctures examined, 86% contained 1 egg and 12%, 2 eggs.

According to Stevens (1966) mating occurs on the foliage, with oviposition taking place throughout the summer. Our observations and data (Fig. 2) support Stevens (1966) observation regarding oviposition; however, mating was only observed on the bole of lodgepole pine. Mating locations may differ between geographic areas or climatic regimes, or perhaps Stevens (1966) observed *Pissodes terminalis* mating on the foliage and did not distinguish it from *P. schwarzi*.

Aggregation pheromones were reported for *P. nemorensis* by Booth and Lanier (1974). Males produced a pheromone that when deployed with host odors attracted conspecific males and females (Booth *et al.* 1983). *P. strobi* and *P. nemorensis* both produce grandisol (*cis*-2-isopropenyl-1-methylcyclobutaneethanol), and its corresponding aldehyde, grandisal, which act together as aggregation pheromones for *P. nemorensis* (Booth *et al.* 1983; Phillips and Lanier 1986). Phillips and Lanier (1986) found that male *P. strobi* produce an unknown allelochemical that interrupts the response of *P. nemorensis* to its natural or synthetic aggregation pheromone. Although Booth and Lanier (1974) postulated that *P. strobi* uses a male-produced aggregation pheromone, repeated field tests have indicated that grandisol and grandisal are not pheromones for *P. strobi* (Booth and Lanier 1974; Phillips 1981; Booth *et al.* 1983). We hypothesize that a similar relationship to that between *P. nemorensis* and *P. strobi* could occur between the lodgepole terminal weevil, *P. terminalis* Hopping, and *P. schwarzi,* which spatially occupy similar host sites.

Commonly, *P. schwarzi* infests trees stressed by rusts, *Cronartium comandrae,* root rots and other insects, such as *Cylindrocopturus* spp. (Coleoptera: Curculionidae) (Wood 1964; Stevens 1966; Coulson and Franklin 1970), which are in themselves damaging or fatal. Therefore, *P. schwarzi* is not economically important at present, but with increasingly intensive silvicultural practices, e.g. spacing, and the probable onset of climatic warming trends, *P. schwarzi* could well emerge as a problem in some circumstances, particularly because of its tendency to infest apparently drought-stressed trees (personal observation).

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NOTES

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A versatile wind-resistant insect cage

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ABSTRACT

Ecological field studies often require cages that can withstand adverse weather conditions such as high winds, without greatly altering environmental conditions within them. A large field cage was designed, fabricated and tested for predator-prey studies on raspberry plantings. It consisted of a wood base and screening suspended with loops of canvas from a framework of PVC pipe. The cage withstood gusts above 70 km/h, did not appreciably alter temperature or RH, but did reduce light by 40% and rainfall by 25%. The cage design is simple and can be adapted to many experimental situations.

INTRODUCTION

Field cages have traditionally been designed with vertical walls and right-angled corners (e.g. Fay and Meats 1987; Grant and Shepard 1985; and Savinelli *et al.* 1988). This shape provides ample standing room. However, rectangular cages have stability problems, particularly in

the 40 km/h winds frequently experienced in the Lower Fraser Valley of British Columbia. A cage, 4.3 m long x 2.6 m wide x 2.1 m high and semi-elliptical, was designed and tested through three field seasons during predator-prey studies in raspberry field plots.

MATERIALS AND METHODS

The cage (Fig. 1A) was made from a rectangular piece of fabric (Fig. 2) suspended from a frame of PVC pipe (Table 1). The frame consisted of four poles arched between two sides of a rectangular wooden base and made rigid at the top by one ridge-and two lateral-poles (Fig. 1:A,C). The fabric was sewn so that the seams lay along the length of the ridge- and lateral-poles (Figs. 1A, 2). Cages constructed in 1990 were made entirely of grey noseeum screening while those constructed in 1991 and 1992 were made of white noseeum screening, (Table 1) except for the woven synthetic Lumite® roof panels [(Table 1; Fig. 2 (grey area)]. Fabric width was determined as:

$$\text{width} = 2.22 \times \sqrt{(\text{cage height})2 + (\text{cage width}/2)^2}$$

Canvas reinforcing strips 8 cm wide were sewn onto the screen along the lines where the PVC poles would lie (Fig. 2). Sleeves for the poles were made from a folded piece of canvas 13 cm wide, that was sewn along the centre of the reinforcing strip. The sleeves extended to within

Table 1
Materials used in field cage.

Item	Specifications
Lumite® Saran screening (light gold color)	20.5 x 20.5 threads/cm Chicopee P.O. Box 2537 Gainesville, Georgia 30503-2537
Noseeum screening (100% polyester)	11.0 x 59.0 threads/cm Seattle Textile Co. 16 South Idaho, Seattle, WA 98134
Canvas	waterproof, 283.5 gm weight (10oz.)
Nylon	waterproof, medium weight
Velcro	2.54 cm width
Poles	PR 200 solvent-weld PVC pipe, O.D. 2.67 cm, 4 x 5.7m (arch-poles), 3 x 4.3m (ridge- and lateral-poles)
Wood	rough cedar, 10 x 10 cm (4″x4″), 2 x 2.6m and 2 x 4.3 m
Poly-fastener®	PR 800 plastic track Curry Industries Ltd. Unit 5, 1031 Springfield Road Winnipeg, Manitoba R2G 3T2
Aluminium	flat bar, 0.48 x 7.6 cm (3/16″x3.0″) 30.5 cm per corner
Hardware – pole assembly	hex head bolts, 0.64 x 6.4 cm (¼″x 2½″) National coarse threaded nyloc nuts 0.64 cm (¼″) fender washers 0.64 (¼″)
– base assembly	wood screws, # 12 x 5.1cm (2″) Robertson round head, cadmium plated drywall screws – flat head, length 2.54-3.18 cm (1″-1¼″)

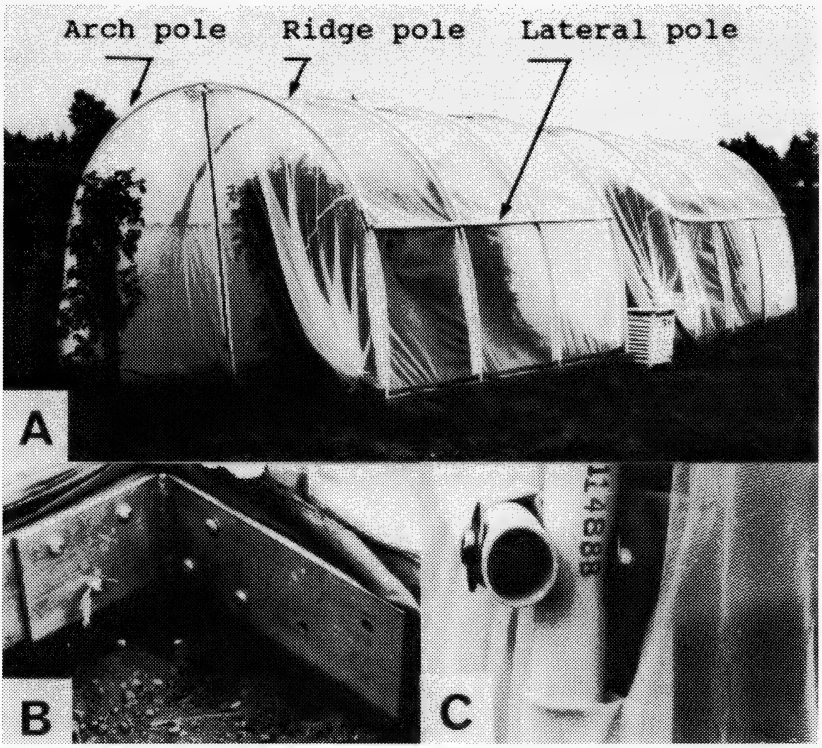

Figure 1. Field cage overview (A); aluminium corner bracket on wood base (B); assembled lateral-pole and arch-pole (C).

8 cm of the pole intersections to allow room to bolt the ridge- and lateral-poles to the arch-poles. A 12 cm strip of medium-weight, waterproof nylon was sewn around the edge of the fabric, serving as the point of attachment between the fabric and the Poly-fastener® plastic track (Table 1) that was screwed to the wooden base. All seams were lock stitched on industrial machines with Koban (cotton wrapped polyester) thread.

Cage assembly proceeded as follows: four 2.7 cm holes were drilled through each of the two longest pieces of 10 x 10 cm wood in correct alignment to receive the arch-poles. The wood base was bolted together with aluminium corner brackets (Fig. 1B). The channel portion of the Poly-fastener® plastic track was attached near the top inside face of the wooden base with dry-wall screws. With the netting laid flat on the ground (Fig. 2), the four PVC arch-poles were pushed through their respective sleeves. Next the ridge-pole and two lateral-poles were inserted through their sleeves so that they lay on top of the arch-poles. The ridge-pole was bolted in the middle of the intersecting arch-poles (Fig. 1A). The arch-poles were bent and installed into their respective holes in the 10 x 10 cm base. The nylon edge of the fabric (Fig. 2) was attached to the base by snapping the insert strip into the channel of the Poly-fastener® track. The lateral-poles were bolted to the arch-poles (Fig. 1C). The large piece of excess fabric remaining at each corner was sealed off by looping the fabric in a knot and fastening the velcro strips (Fig. 2). Soil was packed around the outer edge of the base to position the cage and limit insect movement. Guy ropes and stakes were not used to stabilize the cage.

The cages were tested from Dec. 1989 - Oct. 1990, May - Nov. 1991 and Jun. - Sep. 1992 at Abbotsford, British Columbia. Wind speed was measured with an RM Young anemometer placed 2 m above the ground, 10 Jan. - 22 May 1990, and temperature and RH were measured with HMP-112A Vaisala probes, 25 May - 3 Sep. 1990, and 12 Jun. - 11 Sep. 1992. All instruments were linked to an Easylogger® 824-GP field unit which recorded hourly, averages of readings taken at 5 min intervals for wind and 10 min intervals for temperature and RH. The

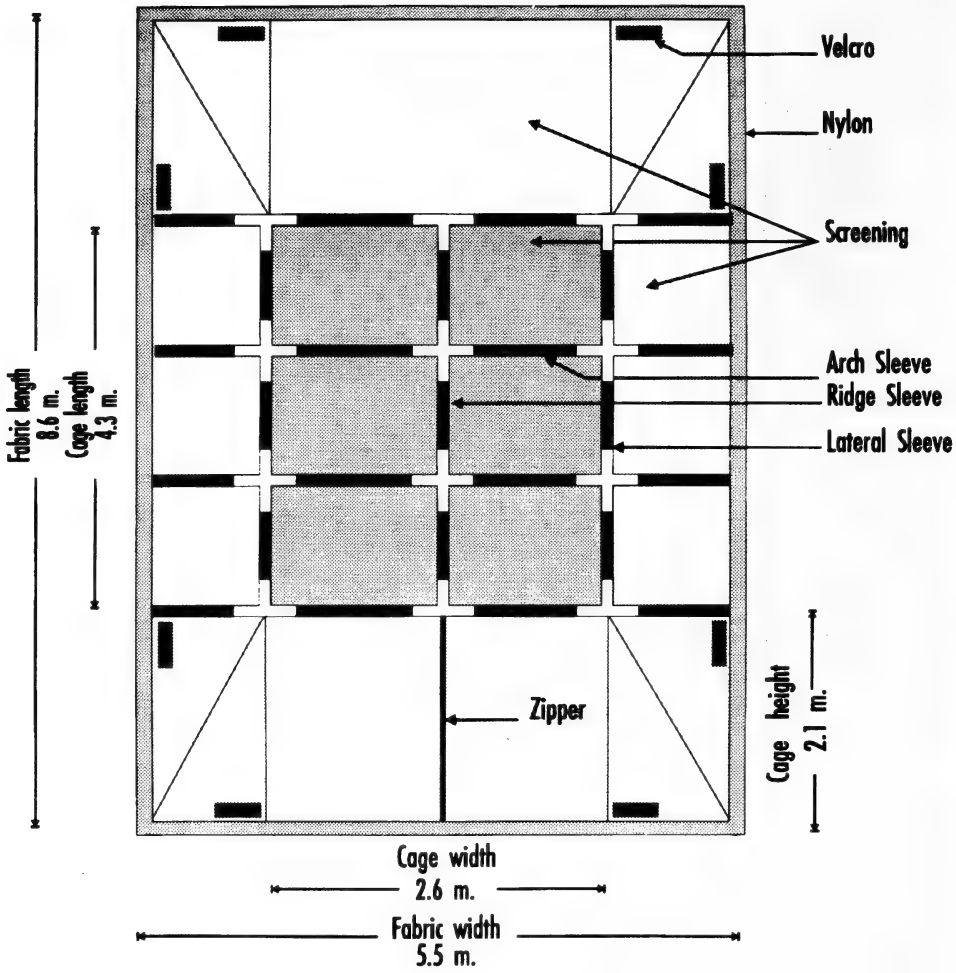

Figure 2. Pattern for cage screening.

temperature and humidity probes were shielded by a 15 X 15 X 30 cm open-ended white box located 1 m above the ground both inside and outside the cages. The wind data were augmented with Environment Canada readings of daily maximum wind speed above 30 km/h, recorded 10 m above the ground, 1 km from the field site. Photosynthetically active radiation was measured with a Li-Cor® 188-B photometer placed on the ground and 1.2 m above the ground inside and outside of a cage on clear sunny days, 21 Jun. 1990 and 17 Jun. 1992. Rainfall was measured with funnel rain gauges placed on the ground inside and outside of a cage, 7 and 13 Jun. 1990.

RESULTS AND DISCUSSION

Wind speeds recorded at 5 min intervals from 10 Jan. - 22 May 1990 were often greater than 30 - 40 km/h (Fig. 3). Maximum daily gusts recorded by Environment Canada during 3 yr that the cages were field tested were: 30-40 (km/h), 29 times; 40-50, 23 times; 50-60, 10 times; 60-70, 9 times; and 70-80, twice. Throughout, the PVC pipe simply flexed, allowing the wind to spill off the top of the cage. One leeward arch-pole cracked near the base during winds of 40 km/h, but this was replaced and the event did not recur. Temperatures, measured inside a cage constructed entirely of grey noseeum screening, were higher than outside; the opposite trend was observed for RH, (Fig. 4). The difference between average daily temperature inside and

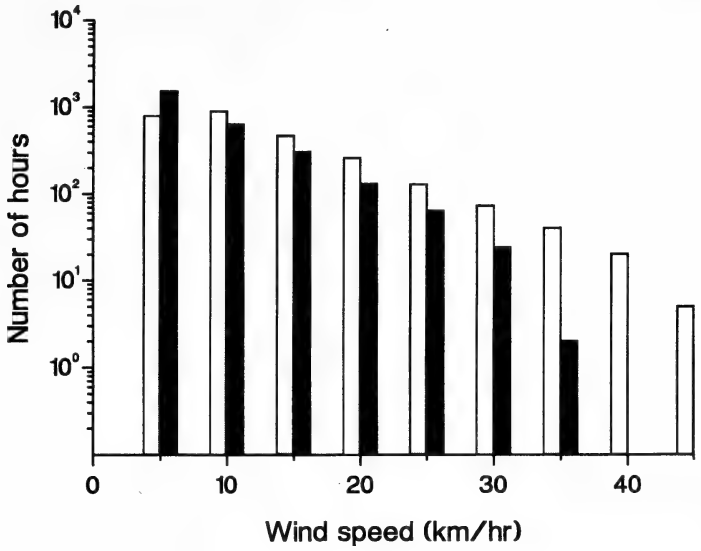

Figure 3. Field cage exposure to winds from Jan. - May 1990. From readings taken at 5 min intervals, the light bars indicate the number of hours in which the given maximum wind speed occurred and the dark bars indicate the number of hours of a given average wind speed. The bars are plotted at the top of the wind-speed interval (e.g. 0-5 km/h).

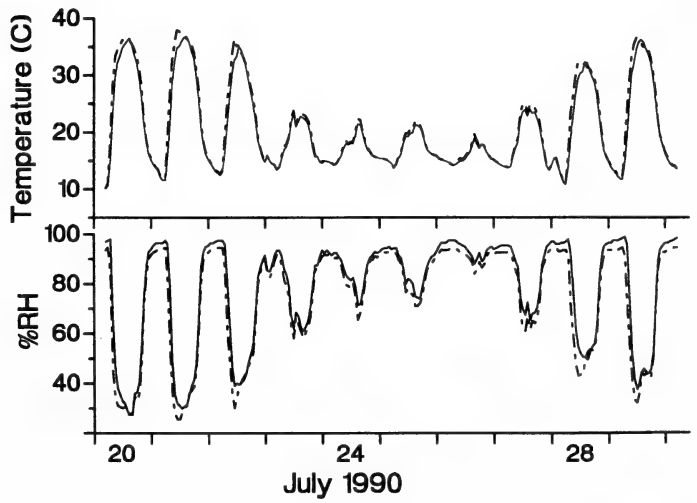

Figure 4. Temperature and RH inside (dotted line) and outside (solid line) a field cage made entirely of grey noseeum screening (1990).

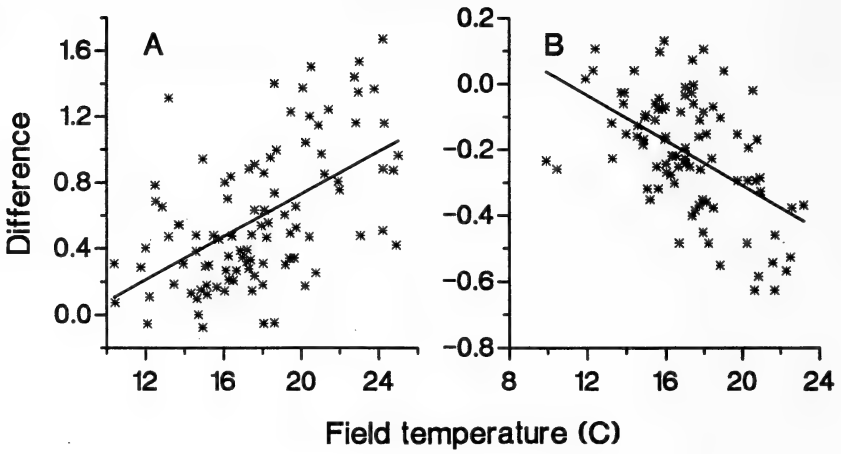

Figure 5. The difference between average daily temperature inside and outside a cage plotted as a function of temperatures outside: A, cage constructed with grey noseeum screening (1990) ($y = -0.569 + 0.0650 x$; $p < 0.01$; $r = 0.54$; $n = 99$); and B, cage constructed with white noseeum screen and a Lumite® roof (1992) ($y = 0.376 - 0.0341 x$; $p < 0.01$; $r = 0.52$; $n = 90$).

outside a cage increased during hotter weather, (Fig. 5A). This pattern was reversed in 1992 in cages constructed with white noseeum screening and a Lumite® roof, (Fig. 5B). The difference between the two cage types was probably due to differences in screen reflectance, grey screen (1990) *vs* white and light gold (1992). Radiation was reduced by 40% in the grey noseeum cage and by 45% in the white noseeum, Lumite® cage. Rainfall was reduced by 25% inside the cage constructed entirely of noseeum screening.

The cage cost $750.00: 1/3 for screening, 1/3 for all additional materials and 1/3 for sewing. It can be constructed on site, or lifted over a field plot. It is easily dismantled by reversing the order of assembly and all the parts can be stored in a linear bundle. The design and the nature of the component parts make modifications for other plot sizes or other field crops exceedingly simple. The component parts could also be modified for other experimental situations. For example, in a wet environment, 10 cm black PVC pipe and corners could be substituted for the 10X10 cm rough cedar base. Given the strength of the cage, the ease of assembly, the similarity of temperature and RH in and outside the cage, and the small storage requirements, it will be very useful for ecological field studies.

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Effect of burning alfalfa stubble for insect pest control on seed yield[1]

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ABSTRACT

Burning alfalfa (*Medicago sativa* (L.)) stubble in the spring has been shown to be effective in reducing some insect pest populations. A study was conducted to determine the long-term effect of this practice on seed yield. Plots were established at Lethbridge, Alberta, and burned in the spring or fall at various heights of plant growth from 1983 to 1989, with one half of each plot treated annually with insecticides when the pest insects were in their most vulnerable stage. Yields from burned treatments were not significantly different from unburned ones for the years 1983 to 1986, and 1988. In 1987, treatments burned in the fall had significantly higher yields than other treatments. Burning at 15-20 cm of growth significantly reduced yield compared to burning before spring growth. In 1989, yields from plots burned at 15-20 cm of growth were significantly lower than those burned every fall or spring. Insecticide treated plots had significantly higher yields in all years except 1983. Burning in the fall, or in the spring before growth, increased gross economic returns, but insecticide treatment gave the highest returns.

INTRODUCTION

Burning alfalfa stubble is widely used by commercial growers of seed alfalfa (*Medicago sativa* (L.)) as a method of controlling insect pests. Increased yields of alfalfa seed have been reported from various cultivation and sanitation practices (burning) attempted by commercial seed growers in Alberta and Saskatchewan (Lilly and Hobbs 1962; Bolton and Peck 1946). In the short term, burning has been reported to reduce pest insect populations and increase seed yields (Carlson 1940; Bolton and Peck 1946; Lilly and Hobbs 1962; Schaber and Entz 1988; Tippens 1964). Despite lack of long term studies, alfalfa seed producers on the Canadian prairies generally burn their seed fields in the spring of every second year.

An Integrated Pest Management (IPM) program was initiated and implemented in alfalfa seed production areas of southern Alberta in 1978 (Schaber and Richards 1979). Such a system should enable producers to increase the sustainability of their operations by reducing dependence on costly pesticides which may also have adverse effects on the environment. Accurate targeting of pesticides to control only damaging stages of insects, combined with other cultural practices, should increase profits and reduce chemical use. Although this system has been in use for some time, its scientific basis and practical merits had not been tested. This study was conducted to assess the long-term effects on seed yield of annual or biennial burning of alfalfa stubble in the fall, in the spring before growth, and at 5-10 cm and 10-15 cm of growth in the spring.

MATERIALS AND METHODS

Experiments were conducted for 7 years (1983-1989) at Lethbridge, Alberta, in an alfalfa seed field (cv. Beaver), grown on a Dark Brown Chernozemic Lethbridge silty clay-loam soil. The plots were seeded in 70 cm rows at 1.21 kg/ha. A split-plot design was used with five burn treatments (12 X 15 m main plots) and two insecticide treatments (split-plots) with four replicates. These small plots were established in order to have a high degree of control and uniformity. Factors that we attempted to control were: irrigation, fertility, weeds, plot distance from shelters for pollinating alfalfa leafcutter bees, and burning. Burn treatments were chosen as representative of local seed producers' management practices as follows: burned every fall (BEF) (in October after harvest); burned every spring before growth (BES); burned alternate springs before growth (BAS); burned alternate springs at 5-10 cm of new growth (BA2); burned alter-

nate springs at 15-20 cm of new growth (BA4); and control, no burn (UNB). The alternate burn treatments occurred in 1983, 1985, 1987, and 1989. The plots were set aflame on the windward side by a propane torch. To control the fire, one quarter of each plot was burned at a time.

Each burn treatment plot was divided in half and the same half was treated annually with insecticides when the pest insects were most vulnerable. To control the plant bugs, *Lygus spp.*, and *Adelphocoris lineolatus* (Goeze), trichlorfon (1150 g AI/ha per 110 l H_2O) was applied two or three times during the growing season when these bugs were in the fourth or fifth nymphal instars, and their numbers had reached the economic threshold of 2/90° sweep. Phosmet (1125 g AI/ha per 110 l H_2O) was applied in early June for control of the alfalfa weevil, *Hypera postica* (Gyll.), when most of the larvae were in the third- or fourth-instars, and the numbers had reached the economic threshold of 25/90° sweep. All treatments were randomly assigned at the start of the experiment in 1983, and each plot received its assigned treatment for the 6 years of the study.

The whole field received an application of 11-48-0 fertilizer (110 kg/ha) each year. The plots were irrigated by sprinkler (12 hr at 12 mm/hr) twice during the growing season, once in late May, and again about 1 wk before alfalfa leafcutter bees (*Megachile rotundata* F.) were placed in the alfalfa fields, which was just as bloom commenced in late June. The stocking rate was approximately 60,000 bees/ha. In mid-September, fields were desiccated with diquat (0.6 kg AI/ha per 200 l H_2O, plus 0.1% of the total volume of the superfactant, Agral 90). About 7-10 d later, two 2.45 m-wide cuts were straight combined using a Massey Harris combine (1963 model Super 35, Brantford, ON). Alfalfa seed samples were cleaned before weighing.

Table 1

Alfalfa seed yields in kg/ha for each year from plots treated and not treated with insecticides at Lethbridge, Alberta.

Treatment	1983	1984	1986	1987	1988	1989
Insecticide:	161 ± 13a*	427 ± 16.2a	390 ± 22.8a	267 ± 25.9a	477 ± 19.7a	276 ± 12.6a
No-insecticide:	150 ± 15a	105 ± 11.8b	266 ± 20.7b	210 ± 19.9b	247 ± 8.3b	212 ± 8.7b

a,b Means within a given year followed by the same letter are not significantly different ($P = 0.05$, Ryan's Q test).

* Mean and standard error of the mean.

Table 2

Alfalfa seed yields in kg/ha for each year from plots variously treated at Lethbridge, Alberta.

Treatment*	1983	1984	1986	1987	1988	1989
UNB	156 ± 15.0a@	265 ± 60.0a	278 ± 50.3a	201 ± 28.9a	325 ± 35.0a	230 ± 17.2abc
BES	153 ± 22.6a	315 ± 76.6a	336 ± 47.2a	274 ± 45.9b	348 ± 50.7a	272 ± 24.2ab
BEF	212 ± 33.6a	269 ± 51.6a	334 ± 30.0a	404 ± 28.0c	402 ± 56.7a	295 ± 22.5a
BAS†	138 ± 30.3a	251 ± 66.7a	407 ± 42.2a	260 ± 18.1b	352 ± 54.8a	264 ± 18.5abc
BA2†	148 ± 19.8a	227 ± 66.3a	266 ± 29.5a	166 ± 16.2ab	327 ± 47.4a	218 ± 18.5bc
BA4†	124 ± 12.3a	269 ± 68.0a	346 ± 49.2a	134 ± 20.9a	416 ± 50.0a	196 ± 14.3c

a,b,c Means within a given year followed by the same letter are not significantly different ($P = 0.05$, Ryan's Q test).

† Burned in 1983, 1985, 1987, and 1989.

* UNB = control; BES = burned every spring; BEF = burned every fall; BAS = burned alternate springs; BA2 = burned alternate springs 5-10 cm; BA4 = burned alternate springs 15-20 cm.

@ Mean and standard error of the mean.

The data were analyzed as a split-plot design. The GLM procedure from SAS (SAS Institute Inc., 1985) was used to perform analyses of variance, and Ryan's Q test (Ryan 1960) was used to evaluate differences among treatment means. Separate analyses were performed for each year. Seed prices from each year were used to calculate the gross income per ha for each burn treatment. The average alfalfa seed selling prices per kg were: in 1983, $2.20; 1984, $2.20; 1986, $3.19; 1987, $2.97; 1988, $2.31; and 1989, $1.98 (Gold Medal Seeds, Brooks, Alberta). Seed yield data for 1985 are not included because very strong winds, up to 125 km/h, 1 wk after desiccation caused excessive shattering, and the amount of seed harvested was too small to be included in the analysis.

RESULTS

The interaction between burning and insecticide treatment was significant only in 1983 (P = 0.02). Because the interaction occurred only in the year of stand establishment, the insecticide and burn treatment effects are interpreted independently.

Insecticide treated plots had significantly higher yields for all years except 1983 (Table 1). Seed yields increased from 1983 to 1986 (Table 2). Yields from burned treatments did not differ significantly from unburned, control treatments for 1983 to 1986, and 1988. In 1987, the BEF treatment had a significantly higher yield than all other treatments, while plots burned at 15-20 cm of growth (BA4) had significantly lower yield than those burned before growth (BEF, BES, BAS). In 1989, BA4 treatment yielded significantly less than BES and BEF treatments. However, there was a consistent trend in the burn treatments as economic returns were higher in the plots burned in the fall or before spring growth (Table 3).

DISCUSSION

Significant differences from burning were detected only in 1987 and 1989, however, the long-term economic implications are still important. The mean economic returns for 6 of the 7 years are presented in Table 3 for the treatments with and without insecticides, so the economic returns due to burning can be calculated. Maximum economic gain was from BEF; $188/ha over UNB, $461 vs $649, (Table 3). Thus, the economic returns from BEF were 41% higher than those from UNB. This is even more evident when burning and insecticides are applied to seed alfalfa fields. No economic gains were realized from the BA2 and BA4 treatments. The difference in economic return between the insecticide and no insecticide treatments for UNB was $282, indicating a substantial economic gain from insecticide application.

The fall burn treatment resulted in the highest yield (Table 2), but the average yield for the unburned insecticide treatment was 14% higher than that for the BEF treatment (Table 3). However, if the cost of insecticide treatments is considered ($20-25/ha per application, usually two treatments per year), then the returns from the BEF treatments are quite comparable ($649 vs $700/ha). The average income was similar for the BES and BAS treatments, which may explain why seed growers in this area generally burn their alfalfa seed fields in the spring before growth once every two years. Although the BEF treatment produced the highest economic returns over the 6 years, seed producers in southern Alberta generally don't burn alfalfa stubble in the fall because of the possibility of soil erosion during the winter.

Insecticide treatments were applied when the damaging threshold for each pest species was approached, but after early August insecticides were not applied, because it was believed that late season (those occurring in alfalfa fields in mid- to late-August) pest insects did not cause economic damage to alfalfa. Subsequently Schaber *et al.* (1990), showed that plant bugs can indeed cause economic damage in late August and need to be controlled. It is possible that these late-season populations were responsible for the lack of consistent differences in yields between treatments.

Schaber and Entz (1988) showed that small plots in a commercial seed alfalfa field, in Alberta, burned before growth in the spring had a significantly higher yield than unburned plots. However, our experimental plots were surrounded by unburned untreated plots which provided a ready supply of pest insects which moved into the treated plots within weeks after the insec-

Table 3

Gross income per ha (mean and standard error) from alfalfa grown for seed in six years* on plots treated and not treated with insecticides.

Burn Treatment@	No Insecticide	Insecticide
UNB	$461 ± 48ab	$743 ± 69ab++
BES	518 ± 59ab	889 ± 84ab
BEF	649 ± 59a	982 ± 82a
BAS	528 ± 69ab	892 ± 86ab
BA2	422 ± 41b	697 ± 67b
BA4	448 ± 65ab	791 ± 91ab

* 1985 data not included because of high winds and excessive shattering before harvest.

@ UNB = control; BES = burned every spring; BEF = burned every fall; BAS = burned alternate springs; BA2 = burned alternate springs 5-10 cm; BA4 = burned alternate springs 15-20 cm.

+, ++ burn treatment means not followed by the same letter are significantly different at $P = 0.10$ and $P = 0.15$, respectively, (Ryan's Q test).

ticide treatment (Schaber and Entz 1991). Despite this, differences in yield were observable in our small plots where immigration of pest insects readily occurred. Much greater yield differences might be expected in producers' fields where immigration is less rapid. Likewise, Bacon *et al.* (1983) and Kogan (1984) reported no strong correlations between alfalfa seed yields and observed insect populations in experiments conducted on the control of pest insects.

Yield is only one factor of IPM, and focusing only on maximizing yield can result in excessive costs and potentially detrimental environmental effects. Therefore, an IPM strategy that stabilizes yield over time and is associated with acceptable profit might be preferred to one that maximizes yield or profit in any one year. Thus, the cultural method of fall or spring burning of alfalfa stubble before growth, as we have shown herein, is compatible with IPM principles and sustainable agriculture.

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NOTE

1. LRS Contribution no. 3879143.

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Phytoseiid mites associated with spider mites on hops in the Willamette Valley, Oregon

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ABSTRACT

Densities and damage by twospotted spider mites, *Tetranychus urticae* Koch and levels of phytoseiid mites on hops were assessed in 34 commercial fields and at 11-19 sites of escaped hops in the Willamette valley of western Oregon in 1991-1992. *Amblyseius fallacis* (Garman), *Typhlodromus pyri* Scheuten, *Amblyseius andersoni* Chant and *Metaseiulus occidentalis* (Nesbitt) were most common. On escaped hops, *T. pyri* was more common than other phytoseiids. It occurred widely on plants surrounding commercial hops including blackberry and other rosaceous plants and probably is a vagrant on escaped hops. *A. fallacis* was most common in commercial hops making up 88% of all specimens, followed by many fewer *M. occidentalis* and *T. pyri*. Early spring survival of *A. fallacis* in commercial hops was poor because of certain cultural practices used in the spring. Means to improve biological control of spider mites on hops are discussed including amended methods of hop culture, use of selective pesticides and inoculative releases of predaceous mites.

Additional keywords: *Amblyseius fallacis, Metaseiulus occidentalis, Typhlodromus pyri, Amblyseius andersoni, Tetranychus urticae*

INTRODUCTION

Two-spotted spider mite (*Tetranychus urticae* Koch) (TSSM) is a major pest of hops and associated crops in the Willamette valley, Oregon. It overwinters in dead plant materials or on the hop crown, emerging in early spring to feed on weeds and new hops shoots (Cone *et al.* 1986, Cranham 1985). Control of TSSM usually requires from one to several miticide sprays each summer. Other pesticides such as aphicides sprayed for hop aphid (*Phorodon humuli* (Shrank)) and fungicides used for disease control may also affect TSSM and its predators. Because of pesticide resistance in TSSM on hops (Campbell 1985), chemical control has been difficult. A biological control program for TSSM would be a desirable alternative to replace pesticides or to augment their use.

Several biological control agents against TSSM have been reported from hops in arid regions of western North America, but their usefulness has been limited because of non-selective pesticide use (Pruszynski & Cone, 1972). These agents include several insect predators and phytoseiid mites. In central Washington, *Metaseiulus occidentalis* (Nesbitt) was the most common phytoseiid; it emerged from the subterrenian crowns of hops in early April and then became sparse, reappearing in July (Pruszynski & Cone, 1973). Although there appeared to be some pesticide tolerance in the central Washington strain of *M. occidentalis*, it did not control TSSM to low levels.

Little is known about biological control on hops in the milder, more humid regions of western North America. This study was conducted to determine the beneficial species composition and incidence of phytoseiids and spider mites on escaped and commercial hops in the more hu-

mid regions of Oregon, to measure early spring mortality of phytoseiids, and to monitor the dispersal of phytoseiids and TSSMs within and between hops and other crops.

MATERIALS AND METHODS

Commercial fields survey

Thirty-four commercial hop fields were surveyed 3 times each in 1991 and again in 1992. From each field, 50 leaves were taken, 5 each from plants near 10 support poles. These poles support wires at a height of 6 m, from which heavy twine is suspended; the hop vines grow up the twine. Cracks in the wooden poles and in debris at the soil-pole interface are overwintering sites for TSSM (Cone *et al.* 1986) and presumably for phytoseiids. Poles were selected from the field edge to about 50 m toward the field interior. In May, all leaves were collected from near the ground. In 1991, later samples were from 0-2 m, since TSSMs (and phytoseiids) are con-

Table 1

Tetranychus urticae levels and phytoseiid mites found in commercial hop surveys, 1991-1992.

	1991			1992		
	Early	Mid	Late	Early	Mid	Late
Fields	34	34	34	32	31	29
% fields with mites	38%	76%	97%	81%	100%	86%
Mites/leaf in fields with mites[1]	.31±.16	.66±.25	3.15± .87	.91±.30	3.06±1.34	.93± .46
Mean damage on infested leaves in fields with mites[1]	1.10±.13	1.30±.08	2.16± .27	1.29±.08	1.46± .08	1.70± .07
Phytoseiids/field	.06±.04	.15±.09	2.85±1.87	.63±.37	3.65±1.57	25.2 ±14.5
A. fallacis	2		76	10	83	688
T. pyri		4		6	3	
M. occidentalis					2	24
Unknown (immatures)		1	21	4	25	18
Total phytoseiids	2	5	97	20	113	730

1. means ± SE

Table 2

Commercial hop fields with elevated levels of *Tetranychus urticae* and/or *Amblyseius fallacis*.

Year	Period	Field	Mites/leaf[1]	Damage/infested leaf	Phytoseiids/leaf
1991	late	19	2.30±0.99	1.83±0.42	0.13±0.10
1991	late	24	16.91±3.15	2.74±0.18	0.69±0.24
1991	late	27	15.50±1.97	2.24±0.13	0.02±0.02
1991	late	28	19.82±4.56	2.59±0.20	0
1991	late	29	10.08±1.87	1.83±0.14	0
1991	late	30	6.40±1.88	3.04±0.15	1.20±0.22
1991	late	34	6.64±1.46	1.93±0.14	0
1992	Mid	18	20.02±4.47	2.58±0.14	0.86±0.40
1992	Mid	23	38.24±8.17	2.87±0.18	0.04±0.03
1992	Late	7	10.48±1.28	2.77±0.12	6.28±1.17
1992	Late	11	2.24±0.33	1.61±0.10	5.92±1.06

1. means ± SE

centrated in these areas at these times (Sites & Cone, 1985). Later samples in 1992 were taken from the ground to 6 m.

Survey times were early-season (May 3-10 in 1991, May 18-28 in 1992), when basal leaves were present but before the hop shoots started climbing the twine; mid-season (June 14 in 1991, June 8-23 in 1992), when shoots had twined 2-3 m up the twine; and pre-harvest (Aug 3, 1991; Aug 17-18, 1992), when flowers had formed on side-arms growing from the main hop stem.

The hop leaves were observed under a binocular microscope at 10X; all life stages of phytoseiids were counted and adults were mounted in Hoyer's solution on a microscope slide for species identification. TSSM adult females were counted, and leaves were scored for damage on a scale of 0 to 5 (0= no damage, 1= light damage to one leaf lobe, 2= light damage to 2 lobes, 3= light damage to 3 or more lobes, 4= heavy damage to 3 or more lobes, and 5= heavy damage over entire leaf surface).

Escaped hops survey

Several sites in the Willamette Valley were found with escaped, unsprayed hops. Typical sites were in field headlands, road verges, and along ditches and fencerows. Most sites were near commercial hops or other crops, which could harbor spider mites or predatory mites. Hop leaf collections were made from 0-2 m; leaves with TSSM were selected where possible. In 1991, 14 samples of 50 leaves each were taken from July 9 to August 5 from 11 sites. In 1992, three surveys of 25 leaves per sample were made on May 8 (13 sites), between June 8-18 (19 sites) and on July 29 (16 sites). Adult female TSSM were counted and phytoseiids were counted and identified.

Early Spring Survival study

A single field of the Perle variety of hops (Field #30 in the commercial fields survey), which had large numbers of phytoseiids the previous fall, was selected in 1992. On March 16, before the hop plants started growing (hop plants are perennial and die back every year), 4 bags of live bean plants in vermiculite were leaned against poles. The bean plants had light infestations of spider mites to attract phytoseiids; they were replaced with fresh plants on March 30, April 6 (2 extra bags were added to total 6), and April 13. On the latter two dates 35 and 50 hop leaves, respectively, were also collected from new shoots. Hop leaves and bean plants were observed for mites and the phytoseiids were collected for identification.

Transect surveys

Two commercial hop fields were selected to monitor dispersal of TSSM and phytoseiids from adjacent crops (berries). Field #27 had strawberries upwind; field #33 had strawberries downwind and caneberries upwind. At each hop/berry interface, 50 leaves were collected from a transect running from 40 m within the berry field to 40 m within the hop field. Five leaves were collected at each of 10 sites along the transect: at 0, 10, 20, 30, and 40 m from the interface. Leaves from hop fields were collected from plants near support poles. Predators were counted and each leaf scored for damage on the 0-5 scale described above. This procedure was repeated three times in 1991, on the same dates that commercial fields were surveyed.

RESULTS AND DISCUSSION

Commercial fields survey

TSSMs were generally low in number in 1991, presumably due to the cool, wet weather that prevailed (Table 1). In early-season, infestations were detected in 13 fields (38% of total) but mean densities of females/leaf in infested fields and mean damage ratings on infested leaves of infested fields were all low. Only two predator specimens, both *Amblyseius fallacis* (Garman), were found in early-season. At mid-season, more fields had TSSMs, infested fields had more mites/leaf, and damage was higher on infested leaves in infested fields (these figures are not significant at $P \leq .05$ in 1991). Again, few predators were found (5 specimens). At preharvest, most fields had TSSMs (97%), there were significantly higher ($P < .05$) densities in infested fields, and damage was significantly higher ($P < .05$) with some leaves rating 5. TSSMs in four fields exceeded 10/leaf (Table 2), levels high enough to cause economic damage (Jim Todd[1],

pers. comm.). However, more predators were found at this time (Table 1); most were *A. fallacis*. These predators mostly were found in three fields, with high concentrations in fields #24 and #30 (Table 2).

In 1992, TSSMs were generally more dense than in 1991 (Table 1). Percent fields infested, mean number of TSSMs, and mean damage levels on infested leaves in infested fields were all higher in early- and mid-season. However, late-season samples were lower in all three categories than in 1991. This decline was probably due to spraying in response to perceived conditions favourable for TSSM (1992 was warmer and dryer than 1991). By mid-season, two fields had TSSM levels higher than 10/leaf, and a third had elevated levels in late-season (Table 2). Eighteen of all 1992 samples had TSSM levels at 1-6 per leaf; all 71 other samples were below 1 TSSM/leaf. Thus despite early and mid-season TSSMs being significantly ($P < .02$) higher in 1992 than 1991, they posed no greater threat to the crop in 1992.

In both years, the most common phytoseiid collected in commercial hops was *A. fallacis*. It was the only species found in late-season 1991. *Typhlodromus pyri* Scheuten was found in early and mid-season, but was absent by late-season. Cultural practices such as spraying may be detrimental to *T. pyri* which probably migrates into hops. *M. occidentalis* was not found in 1991, but it occurred in late-season, 1992. Its occurrence may have been related to the hot dry weather of 1992 (Croft *et al.* 1990).

Table 3

Tetranychus urticae and phytoseiid mites found in escaped hop sites.

	1991	Early 92	Mid 92	Late 92
Samples	14	13	19	16
Sample n	50	25	25	25
Mites/sample	8.5 ±2.07	12.0 ±6.26	25.60±6.37	31.10±8.90
Mites/leaf	.24± .07	.48± .15	1.04± .14	1.17± .35
Phytoseiids/sample[1]	4.70±1.28	6.38±2.87	6.74±2.27	3.19±1.29
Amblyseius fallacis	2	4	2	2
Typhlodromus pyri	58	57	32	31
Metaseiulus occidentalis	2	22	3	
Amblyseius andersoni	2	7	27	4
Amblyseius exopodalis		3		
Typhlodromus arboreus	2			
Typhlodromus mahri		2		
Typhlodromus caudiglans	2			
Unknown phytoseiids[2]	6	10	45	11
Total phytoseiids	74	83	128	51

1 Means ± SE.

2 Unknowns were immatures which are unidentifiable.

Table 4

Spring trapping of overwintered *Amblyseius fallacis* in field #30, 1992.

		PHYTOSEIIDS				
DATE	pots	Females	Males	Juveniles	Eggs	Bean Plant Condition
March 30	2	19	0	2	Many	Dry, some green
April 6	4	6	1	0	Few	Frosted, some green
April 13	6	0	0	0	0	Frosted, some green
April 20	5	0	0	0	0	Good, slightly dry

Phytoseiids increased in commercial hops from low (very low in 1991) to substantial by late-season, especially in 1992 (Table 1). Despite the presence of some TSSM, predators were not abundant in early- and mid-season (highest level was 3.65 +– 1.57 predators / field, or 0.073 predators / leaf). At pre-harvest, predators were abundant in only two of the fields in 1991 (Table 2), but were abundant in more fields in 1992. Of nine fields where TSSMs exceeded 5 mites/leaf (Table 2), five had few predators (similar to other fields with low TSSM counts), while four had some of the highest predator numbers sampled. This indicated that phytoseiids, when present in commercial fields, may respond numerically to TSSM. Their ability to regulate TSSM probably depends on their timing of entry into hops.

Two fields in 1992 had very high levels of phytoseiids (Table 2). Although the cultural and pesticide histories of these fields were examined, no consistent differences were found between these fields and others which might explain the greater incidence of phytoseiids.

Escaped hops survey

Mite numbers were very low on escaped hops in 1991 (Table 3). This season was cool and wet, which was not conducive to buildup of TSSM. 1992 was warmer and drier than 1991 though. TSSM numbers in 1992 started low and increased through to late-season, reaching a mean density of 1.17±.36 mites/leaf. Although this was nearly 5-fold more than in 1991, it still was a non-economic level of mites from a grower's point of view. In none of the 1991 samples did the TSSM adults exceed 1/leaf. In 1992, the sample with the most TSSMs (excluding the outlier) was 3.52/leaf. Thus it seems that favorable conditions for mites in 1992 resulted in increased TSSM over 1991 but still below those that would be of economic concern if present in commercial hops.

In both years the majority of predators found on escaped hops were *T. pyri,* which is a generalist feeder usually associated with rosaceous plants (Hadam et al. 1986). *T. pyri* may be a vagrant on hops as a result of its association with other plant species, including wild blackberry or other rosaceous plants. *A. fallacis* was infrequently found on escaped hops, although it was common in commercial hops. Twenty-five *M. occidentalis* were found on escaped plants in 1992 but only 2 were found in 1991, possibly because this is a heat- and dry-adapted predator (Croft *et al.,* 1990) and 1992 was the hotter, drier year. Nearly all *Amblyseius andersoni* (Chant) found in 1992 were from a single humid site near a river; *A. andersoni* is a humidity-adapted predator (Messing & Croft, 1991). Otherwise its abundance was like that of *A. fallacis*. Other species were found infrequently.

Thus it appears that biological control is occurring actively on escaped hops. TSSM numbers from unsprayed sites compared favorably with those in commercial hops, in which mite control is largely brought about with pesticides. The low variation in mite numbers in escaped hops (no high peaks) compared to commercial hops indicates that biological control of TSSM may be effective and dependable.

There was a wide variation in the habitat and vegetation surrounding unsprayed hops, ranging from dry in full sunshine with low floral diversity nearby (*e.g.* road verges) to humid and shady with high floral diversity (*e.g.* forested areas next to fields). The incidence of phytoseiids and TSSMs seemed unrelated to habitat, indicating that the habitat of a commercial field might be suitable for biological control of TSSM by phytoseiids.

Early Spring Survival study.

Phytoseiids (*A. fallacis*) were active and out of diapause by March 30 (Table 4), before the hop vines started growing. However, by April 13 no more were found on trap plants. Up to April 6 there was virtually no vegetation in the field, either weeds or hop vines, which is normal in overwintering hop fields. The 1991/92 winter was very warm with no prolonged frost; it seems likely that phytoseiids were active at times during the winter and early spring before plant growth occurred, feeding upon TSSM. Since there was no green matter present for spider mites to feed on, the phytoseiids may have overexploited TSSM and then starved.

Early hop leaf collections contained two *A. fallacis* females, one juvenile and several eggs found on April 6, a single female on April 13, and no predators on April 20. A few TSSMs were found on the hop leaves from April 13 and 20; any predators present would probably have been

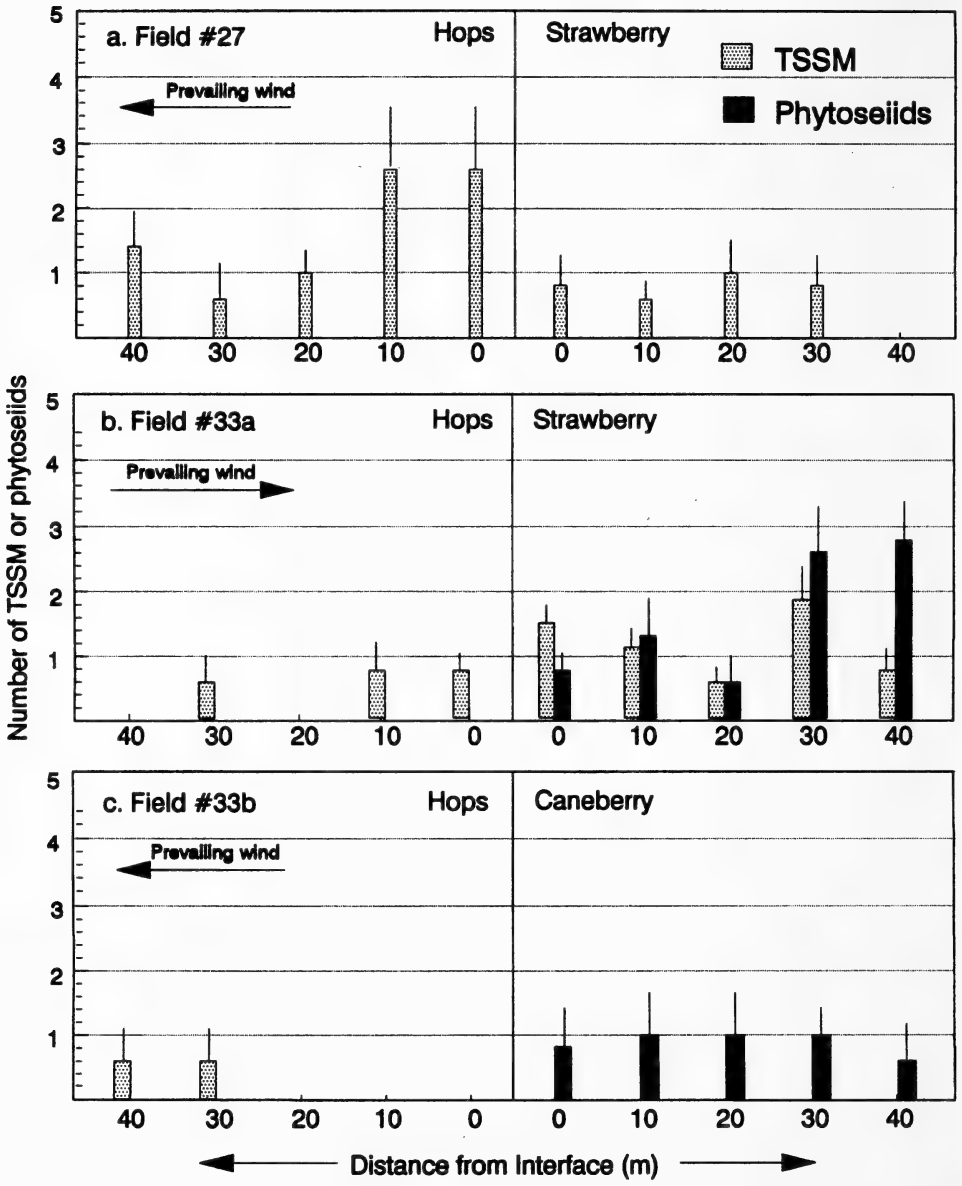

Figure 1. Levels of Tetranychus urticae (TSSM) and phytoseiid mites (Amblyseius fallacis, Typhlodromus pyri) found in mid-season transect surveys of hop yards and adjacent crops, 1991 (lines are SE's).

associated with these TSSMs. It appears that although the phytoseiids overwintered successfully, hop plants may become active too late to support the early spider mite colonies required for early spring survival of phytoseiids .

Transect surveys

A general trend was noted that TSSMs often were present in crops surrounding hops at higher levels than in hops in early-season and that they dispersed into the hops as the season progressed. Three examples of this are presented in Figure 1, all of which are from the mid-season sample period. In Field #27, no TSSM were found in hops in early-season despite levels in the adjacent strawberries of .24 TSSM/leaf, but by mid-season an edge effect was apparent (Figure 1a). Possibly the TSSM moved into the hops on prevailing winds; both TSSM and phytoseiids are capable of dispersing on wind (Johnson & Croft, 1976; Kennedy & Smitley, 1985; Sabelis & Dicke, 1985). As the season progressed, this apparent edge effect diminished. In contrast, field #33a had a prevailing wind blowing the opposite way. Again, in early-season there were neither TSSM nor phytoseiids in the hops; by mid-season there was an apparent edge effect but at much lower numbers than Field #27 (Figure 1b). Also, the abundant phytoseiids in strawberry never moved over into hops, despite being the highly dispersive species, *A. fallacis* (Johnson & Croft, 1976). The data from Field #33b indicate that the species of phytoseiid is also important in dispersal (Figure 1c). Despite prevailing winds from the caneberries to the hops, phytoseiids were not detected in the hops. The phytoseiid found in the caneberries was exclusively *T. pyri,* which is known to be a relatively poor disperser (Boller *et al.,* 1988; Croft *et al.,* 1990).

Apparently both spider mites and predators overwinter well in surrounding crops but poorly in hops; they then disperse into hops at rates depending on species, prevailing wind direction, and possibly other factors. Although the data in Figure 1 are from limited sites and show considerable variability, they indicate the need for further investigation into early-season movement of predators and TSSM in relation to surrounding crops and prevailing wind direction.

CONCLUSIONS

It appears that despite intensive spraying, TSSMs and damage from these pests increase seasonally in most commercial hop fields. In six fields at pre-harvest, TSSMs exceeded 10 per leaf, a large proportion of leaves had mites, and damage ratings were high. Although economic impact of these TSSM levels needs more definitive research, an alternative management method to pesticides is desirable.

Presumably biological control of TSSM using phytoseiids would be possible in hops except for 3 conditions: limited ability of phytoseiids to establish populations in the early spring, their lack of early-season dispersal into hops, and use of pesticides and cultural practices harmful to predators. The differential early-spring survivorship of phytoseiids and TSSM makes hops similar to a perennial crop for TSSM, but more like an annual crop for phytoseiids. With their low dispersal rates into hop fields from surrounding crops, phytoseiids may need re-introduction each year. This was the conclusion of Cranham (1985) who felt that stable biological control in hops was unlikey due to the annual nature of the crop.

Use of some cultural practices and insecticides in hop culture are difficult to avoid, but others may be modified. Planting ground covers favorable to survival of phytoseiids, and eliminating leaf stripping and hilling around hops, both of which remove leaves haboring phytoseiids early in spring may be helpful. Pesticide changes may include eliminating pyrethroids and using insecticides more compatible with phytoseiids (Croft 1990). However, even with these modifications, the early spring pool of phytoseiids may be too small to ensure biological control and thus supplementary releases may be required.

Supplementary releases would be most economical when used in an inoculative manner. From these studies, the key time to release would be early spring, when TSSM start to develop but naturally-occurring phytoseiids are rare. The number of releases, release location (within and between plants) and release density of phytoseiids have yet to be determined. The results of this study indicate that four species should be tried: *T. pyri* and *A. andersoni,* found mostly on escaped hops; *M. occidentalis,* found on both escaped and commercial hops; and *A. fallacis,*

found mostly in commercial hops. The other phytoseiids collected in this study were probably incidentals and unlikely to play a major role in biological control. It is likely that *A. fallacis* and *M. occidentalis* will have the greatest commercial impact, since they were the only species that were abundant in commercial hops. A mixture of both species might be advisable. The microhabitat on a hop plant may vary from cool and humid (suitable for *A. fallacis*) at the bottom to warm and dry (suitable for *M. occidentalis*) near the top. Moreover, since future weather conditions at the time of release are unpredictable, releasing both species might ensure control regardless of weather conditions.

NOTE

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Relationships between catches in flight and emergence traps of the mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Col.: Scolytidae)

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ABSTRACT

Daily emergence of the mountain pine beetle from lodgepole pine trees was monitored in the field by using caged bolts and by counting emergence holes on standing trees. Flying mountain pine beetles, pine engraver beetles and *Pityogenes plagiatus knechteli* (Swaine) were captured daily in two types of barrier traps. Daily totals of emergence holes and emergence into cages were moderately correlated with daily captures by both types of barrier traps. A simple model of daily emergence was developed based on estimates of brood density, daily proportions of brood adults, and daily proportions of brood adults ready to emerge. Daily catches of pine engravers and *P. plagiatus knechteli* were highly intercorrelated, but correlations with catches of mountain pine beetle were low for both species. The results are discussed in relation to beetle emergence and flight behaviour.

INTRODUCTION

The onset and timing of the emergence of mountain pine beetles, *Dendroctonus ponderosae* Hopkins or mpb, depend on a number of factors. In combination, the distribution in time of attacks by the parent beetles and accumulation of heat above the temperature threshold for development (Bentz *et al.* 1991, Safranyik 1978, Safranyik and Whitney 1985), are the major determinants of the life-stage distribution of broods. Moisture conditions during adult maturation are also important because new adults need a period of feeding of up to 10 days (more during cool, rainy weather). Mature beetles begin emerging when ambient temperatures reach about 16°C (Reid 1962, Schmid 1972, Billings and Gara 1975) and the emergence rate increases with temperature up to about 30°C (Rasmussen 1974). Above 30°C, both hourly and daily emergence decline. As a consequence of these relationships, once emergence has started, and the age structure and density of broods are known, the diurnal pattern of emergence during the flight period (i.e., relative frequencies of emerged beetles per unit of time during the day) can be predicted based on heat accumulation above the temperature threshold for emergence (Safranyik *et al* 1989).

Traps or host materials are often used to monitor bark beetle emergence and flight activity, sometimes in combination with population aggregation pheromones. Trapping can provide relative measures of populations or expected damage levels (Brown 1977, Lie and Bakke 1981, Hübertz *et al* 1991). A variety of trap types have been used for trapping the beetles, both when flying (e.g. barrier and funnel traps, sweep nets) and emerging (e.g. emergence cages, sleeve traps) (Chapman and Kinghorn 1955, Avis 1971, Hines and Heikkenen 1977, Hosking 1979, Lindgren 1983, Schmitz 1984, Safranyik and Linton 1985). Emergence holes may also be counted to monitor daily or seasonal emergence.

A high positive correlation between the number of beetles emerging and numbers flying in a given period is implicit in the use of flight traps for monitoring emergence or population levels. Spatial and temporal variations in emergence behaviour are common results of differences in attack history, tree and site conditions, weather factors, and the distribution and abundance of suitable host materials. The design, density, and deployment (location and timing) of traps are important factors affecting the strength of the association between trap catches and emergence or population levels.

The objectives of this study were to:

a) describe the relationship between daily captures of flying mpb in passive barrier traps and daily emergence from caged bolts;

b) develop an empirical model of mpb emergence density based on temperature, pre-emergence density and age structure of broods;

c) relate the emergence pattern of two common associates of mpb, *Ips pini* (Swaine) (pine engraver beetle or peb), and *Pityogenes plagiatus knechteli* (Swaine) (ppk) to temperature and the emergence pattern of mpb.

The results and discussion concentrate on mpb, as it is the primary pest species. Peb and ppk are normally secondary attackers, usually incapable of successfully attacking a healthy host. They normally infest mpb attacked trees, or trees weakened by some other agent.

MATERIALS AND METHODS

The study area was located approximately 100 kilometers west of Williams Lake, B.C., near Tsuh Lake. The site was generally flat, uniformly forested, 5.86 ha in area, with about 2 ha. of 2-3m high esker-like ridges in the southeast portion. Within the stand were three groups of 15-20 mature lodgepole pine *Pinus contorta* var. *latifolia* Dougl. attacked in 1984 and containing brood mpb which would mature and emerge in the summer of 1985. The three groups occupied the corners of a triangle of about 100 m per side. The study area was surrounded on three sides by open meadows 10-40 m wide, and on the fourth side by an immature (<40 yr. old) lodgepole pine stand containing a few veteran Douglas-fir (*Pseudotsuga menziesii* (Mirb.)Franco). Within the study area, the tree cover averaged 592.3 stems ≥5 cm dbh per ha, which consisted of 83% lodgepole pine, 11% engelmann spruce (*Picea engelmannii* Parry)(mainly in depressions), and the balance scattered Douglas-fir and aspen (*Populus tremuloides* Michx.). The average age of the pine in 1985 was 102 years with an average DBH of 25.02cm. All trap installations were completed by the last week of June 1985.

Two types of passive (unbaited) barrier traps were used. Six pairs of nondirectional traps were hung from uninfested pine trees at 60° intervals surrounding each group of infested trees. These were similar to traps described in Schmitz *et al* (1980), and had four 15X30 cm barriers at right angles to each other above a funnel leading to a single collecting jar. They were suspended from ropes so that the bottoms of the barriers were 2 m above the ground. In addition, four larger (90X150cm) unidirectional traps were hung in the approximate center of each group of infested trees. These large traps were suspended from poles between trees in such a way that one trap in each group faced each cardinal direction, and would thus capture insects flying from that direction. The lower edges of the large barriers were also 2 m above the ground.

One bolt, 35 cm long, was cut from the base of each of six pines infested in 1984. The bolts were then placed in individual window screen emergence cages placed near the stumps from which the bolts were cut in order to observe daily emergence of mpb. The 35 cm bolt length corresponded to the depth of the previous winter's snow; above that virtually all of the mpb were killed during the winter (the mean maximum height at which live larvae were found was 53 cm (Safranyik and Linton 1991)).

A .5 m wide band extending from the duff line to the height of the estimated snow depth during the previous winter on each of four 1984 infested trees in one group was painted with light-colored latex paint to enhance the visibility of newly-made exit holes (Safranyik and Linton 1985). In order to exclude them from the 1985 counts, all existing exit/entrance holes were marked before 1985 emergence began. Three times during the flight period, 15X15 cm bark samples were removed from eighteen 1984 infested trees and the brood examined to determine stage of maturity.

Insects were collected from all traps and new exit holes through the painted bands were counted and marked each morning from July 09 to August 10, and on August 12. The collections were preserved in 70% alcohol and stored until examined and counted. In the lab, the total captures of mpb, peb and ppk were recorded, and their sex determined.

Air temperatures were obtained using Campbell Scientific Instruments Ltd. model 201 thermistor sensors mounted in Stevenson screens. Underbark temperatures were taken using thermocouples inserted under the bark of the caged bolts. Data were recorded on a Campbell Sci-

entific Instruments Ltd. CR-21 data logger having a ten second scan rate, outputting summary statistics every 30 minutes. Degree-days were calculated by counting the number of hours when the air temperature exceeded 16°C and dividing the sum by 24.

The relationship between catches of beetles in flight traps and emergence traps was analysed using regression and correlation analysis. A general model of daily mpb emergence was developed based on attack and emergence behaviour, and the effects of temperature on maturation, emergence and flight activity. Model parameters were estimated from field data.

RESULTS AND DISCUSSION

A model of beetle emergence

The following empirical model for daily emergence (E_k) is based on estimates of pre-emergence brood density (D), daily proportions of the unemerged brood that are mature (tanned) adults (P_k), and daily proportions of the mature brood adults ready to emerge (Q_k). The following is a brief description of model development. For the 1st, 2nd and 3rd days of emergence, the corresponding numbers of emerged beetles ($E_{i=1,3}$) are given by the series DP_1Q_1, $(D\text{-}DP_1Q_1)P_2Q_2$, and $(D\text{-}DP_1Q_1(D\text{-}DP_1Q_1)P_2Q_2)P_3Q_3$, respectively. It can be shown that these series can be written in the following equivalent forms to express emergence on any given day K in terms of D, P and Q.

$$E_k=D[\sum_{i=0}^{k-1}(1-P_iQ_i)]P_kQ_k \qquad (1a)$$

$$E_k=(D-\sum_{i=1}^{k-1}E_i)P_kQ_k \qquad (1b)$$

Equation (1b) is more transparent since it is readily seen that E_k is simply the product of unemerged brood density (the terms inside the brackets) and the values of P and Q for day K following the onset of beetle emergence. An empirical formula was developed for estimating P_k ($\hat{p}_k$) as a function of time (T) in days since the first occurrence of young adults (assumed to be July 1), based on sampling 18 infested trees 3 times during the study period. P_k was a humpbacked function on T in the experimental area because some parent beetles that survived the winter extended their galleries and laid more eggs in late May-early June of 1985 which resulted in a highly skewed brood age distribution. Consequently, as the brood resulting from eggs laid in 1984 matured and emerged, the young larvae from eggs laid in the spring of the current year constituted the bulk of the unemerged broods. Hence, P_k at first increased on T and later declined. When mpb flight is not protracted and all eggs hatch before the onset of winter the relationship curve between P_k and T is sigmoid (Bentz *et al* 1991). Equation (2) was developed by plotting both the mean of P_k and the mean proportion of 1984 broods (Z) over the corresponding T-values for each of the three sampling times. A sigmoid curve (Bentz *et al* 1991) was fitted by eye to the P_k *vs* T relationship (the expression inside the first set of square brackets on the right side of eqn (2)) and the parameters were determined by graphical analysis. The expression inside the second set of square brackets on the right hand side of eqn (2), also fitted by graphical analysis, represents the relationship between z and t.

$$\hat{p}k=[(0.0131)/(0.01+0.99\exp(-0.28t))][1-\exp(-5.36+0.16t)] \quad (2)$$
$$t>33, \hat{p}_k=0$$

q_k was estimated ($\hat{q}_k$) as a function of daily degree-days (h_k) above a threshold of 16°c:

$$\hat{q}k=(1/6)h_k, \quad h_k\leq 6$$
$$\hat{q}k=1 \quad , \quad h_k>6 \qquad (3)$$

This formula was used for simplicity, recognizing that most mature adults emerged when daily maximum temperatures were near or above 25°c.

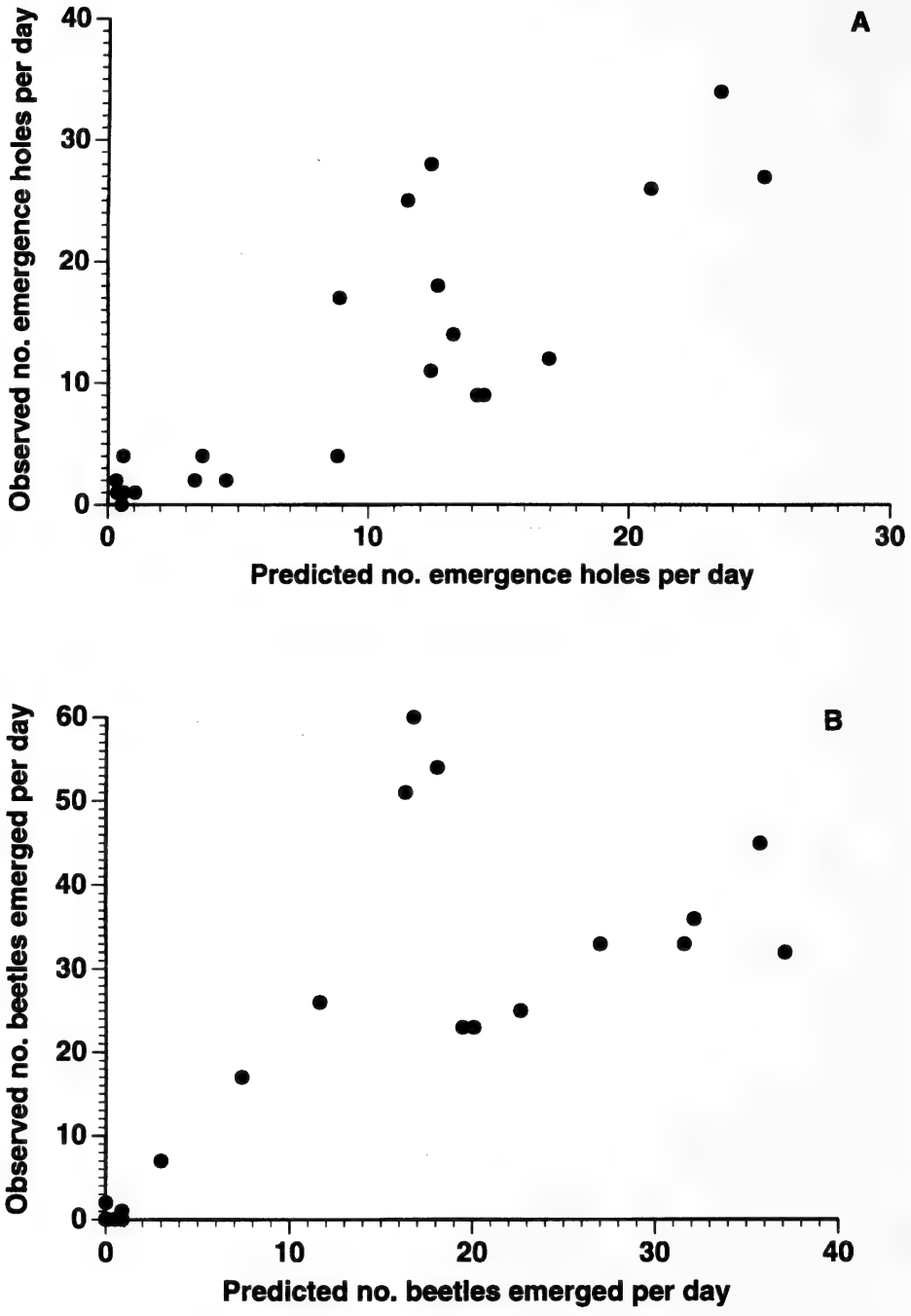

Figure 1. Relationship between observed daily accumulation of emergence holes (A) and beetle emergence (B) for the mountain pine beetle and predicted density from eqn. 1. Estimates of Qk in eqn. 1 were based on ambient temperature data from Tsuh Lake 1985.

The numbers of beetles (720) under the bark of 6 caged trees (lower boles, total bark area 4.05 m^2) and the number of emergence holes (362) on the painted areas of 4 trees were used as estimates of D in conjunction with eqns (2) and (3) to model daily emergence and daily accumulations of emergence holes (E_k) during 23-days from July 9 to July 31, inclusive. Both ambient and underbark temperatures were used in eqn (3) to model emergence. Estimates of E_k from eqn. 1 were regressed on corresponding observed E_k-values (regression was conditioned to have 0 intercept) to assess the performance of the model (Fig. 1). The slopes (b) of regressions of observed *vs* predicted daily counts of emerged beetles were comparable and were not significantly different from unity ($p>0.05$) when either ambient ($b=1.056$) or underbark temperatures ($b=1.042$) were used in calculating Q_k in eqn 2. The corresponding coefficients of determination (r^2) were 0.685 and 0.638. The corresponding statistics for predicting daily accumulations of emergence holes were ($b=1.107$ and 1.132) and ($r^2=0.781$ and 0.787). The fit of the model to the daily beetle emergence and emergence hole data is satisfactory considering that P was estimated from observation of beetle maturation only on three occasions and a limited number of samples, and that the formula for Q (eqn. 3) was derived from conceptual relations between heat accumulation and beetle emergence. However, in addition to these factors, the variation between observed and predicted values in Fig. 1 could have been affected by formulation of the model. In particular, in eqn 1, the fate of those mature beetles that did not emerge in any given day owing to inadequate heat accumulation (as estimated by eqn 3) is not considered explicitly. Therefore, even if Q was modelled very precisely, eqn 1 would tend to underestimate daily beetle emergence, especially following days for which the value of Q was less than 1. This problem of model formulation needs further research.

Comparison of mpb emergence, trap catches and trap types

Daily emergence of mpb/m^2 of bark from caged trees (Y_c), daily catches/m^2 of trap area in large barrier traps (Y_e) and smaller barrier (flight) traps (Y_f), were all linearly related to daily emergence hole numbers per m^2 (X) on the painted trees. The respective equations were as follows:

$$Y_c=0.1507+0.4155X \quad (4)$$
$$n=26,\ r^2=0.693,\ Syx=2.540$$

$$Y_e=0.4275+0.0148X \quad (5)$$
$$n=22,\ r^2=0.090,\ Syx=0.426$$

$$Y_f=0.5031+0.0580X \quad (6)$$
$$n=26,\ r^2=0.239,\ Syx=0.670$$

$$Y_f=0.0619+0.1935\ Y_e \quad (7)$$
$$n=25,\ r^2=0.155,\ Syx=0.215$$

Regression eqns (4), (6) and (7) were statistically significant; the first two at the 99% and the third at the 95% probability level. However, with the exception of eqn (4), only up to about 24% of the total variation in the respective independant variables was explained by the regression equations. The intercepts of regressions (5) and (6) were significantly different from 0 at the 99% and 95% probability levels, respectively.

Excluding variation in daily counts of emergence holes and emerged beetles due to experimental techniques, these two variables are normally highly correlated but have a non-linear relationship (Safranyik and Linton 1985). However, when they were measured on different samples, as was done in our experiment, differences in host characteristics, attack history and microclimate were reflected in different rates of beetle emergence among infested hosts. The reliability of emergence hole counts may be affected by the presence of holes made by other species of subcortical insects. Moreover because of differences in underbark and ambient temperatures, the beetles may cut emergence holes up to several days before they emerge. For these reasons, when measured on small and separate samples, the densities of emerged beetles and emergence holes will normally have only moderate correlation.

Emerged beetles may disperse over large areas and search for suitable hosts to attack. Con-

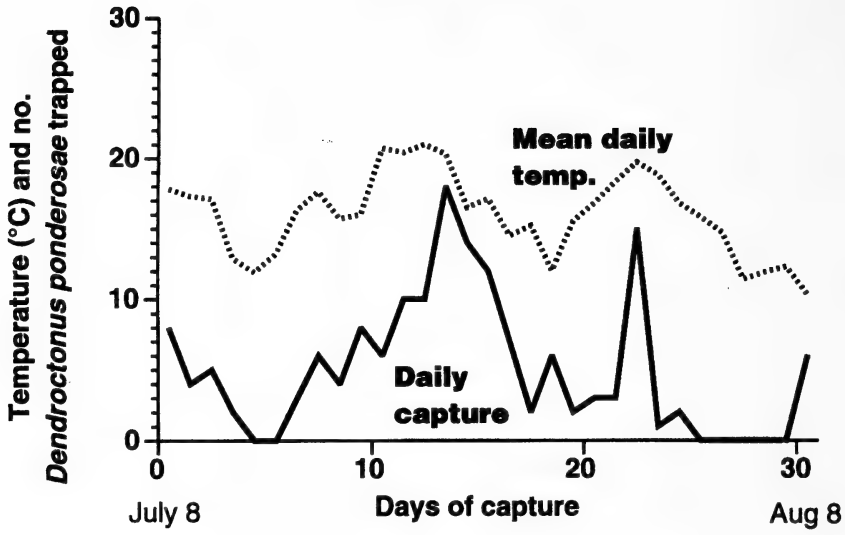

Figure 2. Mean daily temperature and daily capture of mountain pine beetle in passive barrier traps, Tsuh Lake, 1985.

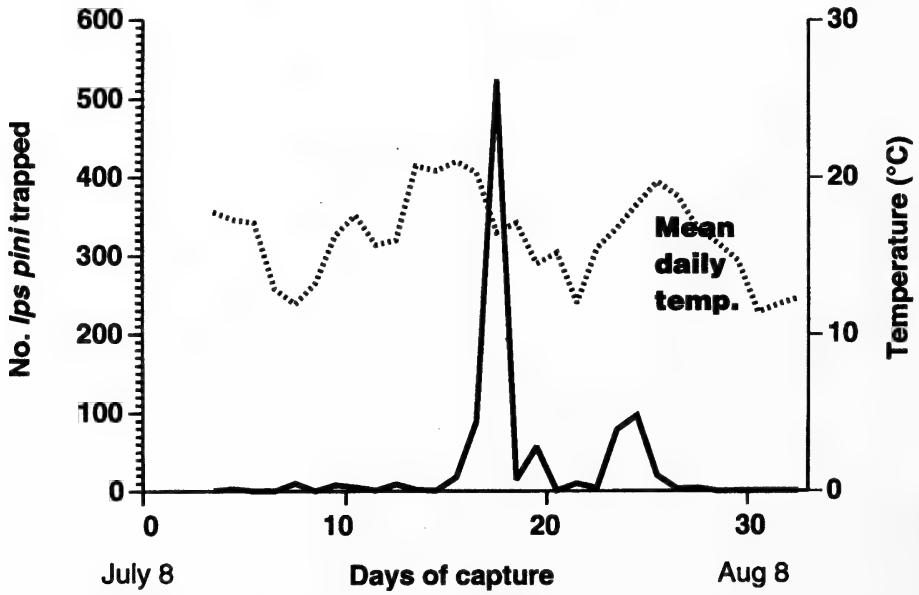

Figure 3. Mean daily temperature and daily capture of pine engraver beetles in passive barrier traps, Tsuh Lake, 1985.

sequently, it is likely that most passive barrier traps sample the beetle population of a large area. Therefore, unless emergence or emergence holes were monitored over the same general area and sampling intensity was high, passive trap catches may be poorly correlated with these variables.

Although the experiments spanned 22-26 days of observation, the samples for beetle emergence and emergence holes were based on only 6 bolts and 4 trees, 36 small barrier traps (eqn 6) and 12 large barrier traps (eqn 5). These small sample sizes notwithstanding, the correlations between daily emergence holes and trap catches were unexpectedly low (eqns 5 and 6). Further studies are needed to determine whether catches in passive barrier traps should be used for monitoring beetle emergence. Likewise, the low correlation between catches in the two types of barrier traps (eqn 7) indicate that results from experiments using different trap designs may not be directly comparable.

Emergence and flight of mpb, peb and ppk.

During the study, 194 mpb, 681 peb and 1171 ppk were trapped. Daily capture of mpb (Fig. 2), peb (Fig. 3) and ppk (Fig. 4) during a 37-day period varied with average temperatures (Fig. 2). The greatest catches of all three species occurred following a period when average daily temperature was greater than 20°C for at least 3 consecutive days (Fig. 2). Daily maximum temperatures during the same period ranged from 31.8 to 34.3°C. Catches of mpb were broadly distributed throughout the observation period whereas catches of the other two species peaked sharply on July 15, a day later than peak mpb catch, and then declined (Figs. 2-4). Daily catches of ppk and peb were highly correlated (r=0.89, N=25). On the other hand, the correlation between daily catches of ppk and mpb was not significant (r=0.31, N=25) and that between peb and mpb was barely significant at $p<0.05$ (r=.40, N=25). The asynchrony of catches of mpb and the other two species is probably a consequence of differences among the species in emergence and flight in relation to temperature. For mpb, daily degree-day accumulation above a threshold temperature of 16°C was not significantly correlated ($p>0.05$) with daily trap catches (r=0.30, n=25), daily emergence from caged bolts (r=0.10, n=25) or with daily accumulation of

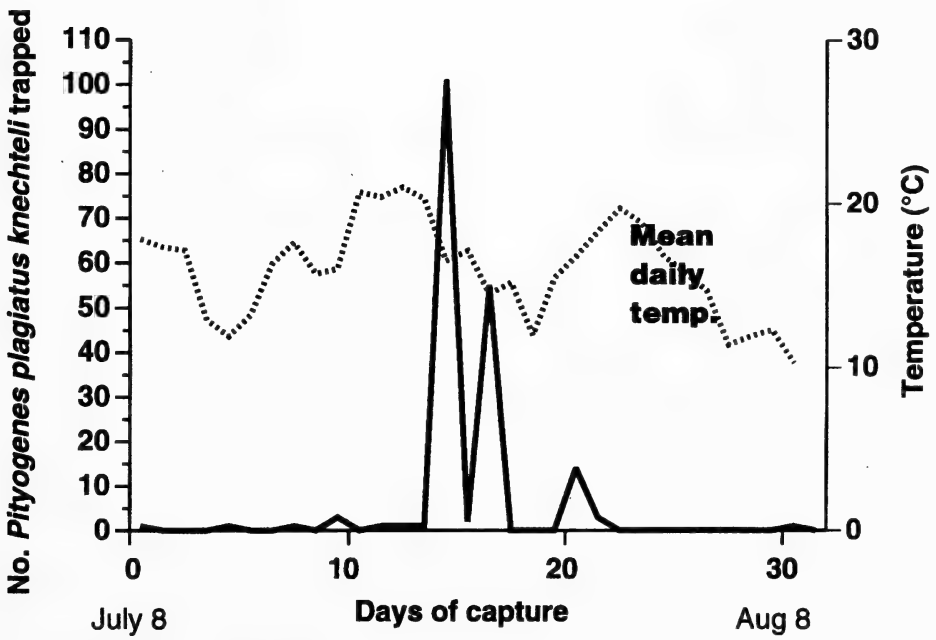

Figure 4. Mean daily temperature and daily capture of Pityogenes plagiatus knechteli in passive barrier traps, Tsuh Lake, 1985.

emergence holes on sample trees (r=0.35, n=25). There is no information on the other species regarding temperature thresholds and heat unit requirements for emergence and flight activity.

In British Columbia, particularly in the Cariboo region, peb produces 1 or 2 generations per year, depending on spring and summer temperatures. The first flight, made by overwintering adults emerging from the duff normally occurs during May and early June, and the second flight, made by reemerging parents plus their brood normally occurs during July-August (Reid 1955). Therefore, the beetles trapped in our experiments were mostly reemerged and first generation beetles. Ppk overwinters both in adult and immature stages (Reid 1955). It appears that during the experimental period, most of the dispersing mature adult pine engravers and ppk originated from broods of parents that overwintered in the adult stage. The mpb trapped were part of the main flight of brood adults that developed in a 1-year life cycle.

The overall female ratio (± one standard deviation) was 0.68 (±0.051) for mpb, 0.76 (±0.041) for peb and 0.91 (±0.069) for ppk. These ratios did not change significantly during the study period. There was no significant difference ($p>0.05$) between the female ratios for mpb and peb from those reported from field populations (0.67 for mpb (Reid 1962, Safranyik and Whitney 1985; 0.75 for *Ips pini* (Schmitz 1972)). There is no sex ratio information available for ppk. Ppk is, however, polygamous and 3 to 10 females may be associated with one male in gallery systems (Chamberlin 1958). Reid (1955) reported 4-6 egg galleries associated with one nuptial chamber in lodgepole pine slash in Alberta.

Our results indicate that daily rates of mpb emergence can be reliably modelled based on estimates of pre-emergence density, age structure, and daily heat accumulation above the flight threshold temperature. Sample-based estimates of mpb emergence hole densities are highly correlated with corresponding estimates of beetle emergence, indicating that the estimate are a reliable index. However, sample-based daily estimates of both these variables were poorly correlated with daily catches in passive barrier traps. Therefore, daily emergence patterns of mpb cannot be reliably inferred from daily captures in passive barrier traps. Daily flights of mpb, peb and ppk are all closely related to daily mean temperature; daily flights of the latter two species are highly correlated.

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Effects of female mating status and age on fecundity, longevity and sex ratio in *Trichogramma minutum* (Hymenoptera: Trichogrammatidae)

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ABSTRACT

Effects of female mating status and age of *Trichogramma minutum* Riley on its fecundity, longevity and offspring sex ratio were determined in the laboratory, using eggs of the variegated cutworm as hosts. Although the mating status of female *T. minutum* did not affect their total fecundity significantly ($P > 0.05$), mated and unmated females showed different allocations of progeny. Mated females deposited significantly more eggs ($P < 0.05$) than those unmated on the first day of exposure to hosts. On subsequent days, however, unmated females parasitized significantly more hosts ($P < 0.05$) than those mated. Mated females laid 82.4% of their total fecundity on the first day of oviposition, whereas unmated females laid 58.3%. The number of eggs parasitized by both groups of females decreased significantly ($P < 0.05$) with parasitoid age. Unmated females lived longer ($P < 0.05$) than their mated counterparts. No significant differences ($P > 0.05$) in clutch size (the number of parasitoid offspring produced per parasitized host) and emergence rate were found between the offspring of mated and unmated female parasitoids. The sex ratio of the offspring of mated females changed significantly ($P < 0.05$) with maternal age: younger females produced a higher proportion of daughters than did older parasitoids. Unmated females produced male offspring only.

INTRODUCTION

The effects of host size (Stinner *et al.* 1974; Southard *et al.* 1982; Bai *et al.* 1992), rearing temperatures (Smith and Hubbes 1986; Jalali and Singh 1992), and food availability to females (Bai *et al.* 1992) upon reproductive potential of *Trichogramma* have been well documented. However, maternal mating status and age may influence longevity, fecundity and sex allocation in *Trichogramma*. Although Partridge (1986) reported that mated females of insects are generally shorter lived than virgins, the effect of maternal mating on reproductive potential of *Trichogramma* remains uncertain. Lund (1938) observed that there were no differences in longevity between mated and unmated females of *Trichogramma evanescens* Westwood, but there was a significant difference in fecundity. In contrast, Yu *et al.* (1984) found that longevity in mated and unmated *Trichogramma minutum* Riley differed significantly, but there was no significant difference in fecundity.

Reduced fecundity with maternal age has been documented in various insect species. However, a recent study by Navasero and Elzen (1992) demonstrated that the clutch size in mated *Microplitis croceipes* (Cresson) (Hymenoptera: Braconidae) varied cyclically over their life spans with egg production peaking in intermediately-aged parasitoids. Previous studies have shown that offspring sex ratio in *Trichogramma* is affected by maternal age. In studies on *T. minutum,* Houseweart *et al.* (1983) and Smith and Hubbes (1986) both reported that young females produced a higher proportion of female offspring than old females.

Although reproductive biology of *T. minutum* associated with other hosts has been studied (Yu et al. 1984; Smith and Hubbes 1986), no reports have been documented on this species with the variegated cutworm, *Peridroma saucia* (Hübner), a minor pest on field crops in British Columbia. In recent years, however, *P. saucia* becomes more and more abundant on small fruit crops. An ongoing field release of *Trichogramma* to control *P. saucia* on raspberry is currently conducting in the Fraser Valley (Henderson *et al.* unpub. data). The reproductive characteristics of commercial *T. minutum* with *P. saucia* may be different from that of field collected parasitoids with other hosts studied by others (Yu *et al.* 1984). The objectives of this study were to investigate the effects of female mating status on progeny allocation, longevity and fecundity in a commercial strain of *T. minutum;* and to determine sex allocation over the lifespan of mated female *T. minutum,* using eggs of *P. saucia* as hosts.

MATERIALS AND METHODS

Host eggs.

The host eggs used in this study were obtained from a laboratory culture of *P. saucia* and were less than 24 h old.

Parasitoids.

Trichogramma minutum was obtained from a commercial source, reared on eggs of the Mediterranean flour moth, *Ephestia* (= *Anagasta*) *kuehniella* Zeller, and then reared in the laboratory on eggs of *P. saucia* for four generations prior to this study at 21 ± 2°C, 50 ± 10% RH, and under 14L:10D photoperiod.

Parasitized *P. saucia* eggs were isolated individually in gelatin capsules (20mm X 5 mm) to obtain individual parasitoids for the following experiments. Only newly (≤ 3 h old) and singly eclosed individuals (one parasitoid developed from each parasitized host) were used to prevent any age and size factors of the parasitoids from influencing the results. Mated females were obtained by placing two pairs of virgin females and males in a gelatin capsule (20 mm X 5 mm) for 3-4 h. Because mating among virgin *Trichogramma* adults occurs readily (Nagarkatti and Nagaraja 1978), it was expected that all females would be inseminated in such a situation. Both mated and unmated females were unfed.

Fecundity and longevity.

Each of the mated and unmated females was transferred individually into a clear plastic Petri dish (50 mm X 9 mm) containing 75 host eggs. Twenty-four hours following introduction, each parasitoid was transferred into a second Petri dish containing 60 host eggs. The host eggs (= 60)

were then changed every second day until the *T. minutum* died. Each female was a replicate and each of two treatment groups (mated and unmated) contained initially 59 females (= replicates). The experiments were conducted at 25 ± 1°C and 60 ± 10% RH with a 16L:8D photoperiod. Following incubation for 7 days under the above conditions, the parasitized eggs were counted using a dissecting microscope at 15X. To determine longevity, the parasitoids from the above experiment were observed at 8 h intervals until they died. Fecundity of *T. minutum* was evaluated as the average number of parasitized host eggs per female, and longevity as the average lifespan in hours.

Clutch size, emergence rate and sex ratio of F1 progeny.

A maximum of 20 parasitized host eggs per Petri dish were selected randomly and incubated until adult parasitoids emerged. The numbers of male and female progeny and the uneclosed parasitized eggs were counted. Uneclosed parasitized eggs were individually dissected to determine the number of developing parasitoid offspring. Clutch size (the number of parasitoid offspring produced per parasitized host) and emergence rate were calculated as:

$$\text{Clutch size} = \frac{\text{total eclosed progeny + total uneclosed progeny}}{\text{total parasitized host eggs incubated}}$$

$$\text{Emergence rate} = \frac{\text{total eclosed parasitized eggs}}{\text{total parasitized eggs incubated}} \text{ X } 100\%$$

Trichogramma minutum is an arrhenotokous species in which virgin females produce only male offspring, whereas mated females produce both male and female progeny. Therefore, the sex ratio of F1 progeny was only comparable among age groups of the mated females.

Data analyses.

The data were transformed as either arcsin $\sqrt{P}$ or $\sqrt{x+0.5}$ before ANOVA (Zar 1984), where P represents the percentage of emergence rate or sex ratio, and x is mean number of the parasitized eggs, clutch size, or longevity. One-way ANOVA was used to estimate significances. Significant differences were separated by Duncan's multiple range test at $P = 0.05$ level.

RESULTS AND DISCUSSION

Fecundity and longevity.

Mating status of female parasitoids significantly affected their daily fecundity ($F = 15.34$; df = 1, 116; $P = 0.0002$) (Table 1). Mated females parasitized more host eggs than unmated counterparts on the first day of oviposition, but fewer on subsequent days. The results suggest that mating stimulates female *T. minutum* to deposit eggs quickly. The fecundity of *T. minutum* on the first day of emergence in this study was greater than that reported by Yu *et al.* (1984) and Smith and Hubbes (1986). Although mated and unmated *T. minutum* followed different progeny allocation strategies in their lifetimes, their respective total fecundities per female were not significantly different ($F = 0.23$; df = 1, 116; $P = 0.6355$). Yu *et al.* (1984) reported similar re-

Table 1

Effects of female age and mating status on fecundity of *Trichogramma minutum*.

	Parasitized eggs per female ± SE			
Status	1st day	2nd & 3rd day	4th & 5th day	Avg total
Mated	64.0±3.0 a[1] (59)[2]	16.9±1.8 b (47)	3.7±0.9 b (3)	77.6±3.2 a (59)
Unmated	47.5±2.9 b (59)	35.1±2.2 a (55)	14.4±4.0 a (5)	81.4±4.0 a (59)

1. Values in the same column followed by the same letters are not significantly different at the 5% level of Duncan's multiple range test.
2. Numbers in parentheses represent replicates.

sults for *T. minutum* but Lund (1938) found that the total fecundity of unmated female *T. evanescens* was significantly higher than that of mated females.

The total fecundity for *T. minutum* in this study was lower than that reported by Yu *et al.* (1984), 200 eggs, and Smith and Hubbes (1986), 128 eggs. However, Peterson (1930) found that *T. minutum* deposited an average of 40.2 eggs in eggs of the oriental fruit moth, *Grapholita molesta* (Busck). These differences in fecundity may be attributable to host differences (Smith and Hubbes 1986). The relatively low fecundities reported here may also be due to lack of food for the females. Yu *et al.* (1984) found that *T. minutum* fed with honey produced 236.8 eggs, whereas unfed females deposited only 39.3 eggs.

The daily fecundity of *T. minutum* decreased significantly with age (mated: $F = 96.16$; df = 2, 106; $P = 0.0001$; unmated: $F = 11.92$; df = 2, 116; $P = 0.0001$), indicating that female Trichogramma had most of their eggs ready for deposition at or shortly after emergence. Mated and unmated females produced 82.4% and 58.3% of their total progeny on the first day. This pattern is similar to previous observations (Yu *et al.* 1984; Smith and Hubbes 1986). The fact that *Trichogramma* may lay a large proportion of their eggs on the first day of emergence should be taken into account when timing inundative field releases of *Trichogramma* in biological control programs.

Average longevity was different for mated and unmated *T. minutum* females, 53.6 ± 2.1 (SE) vs 59.6 ± 2.1 h, (F = 4.12; df = 1, 116; P = 0.0446). Yu *et al.* (1984) observed similar results with *T. minutum* reared on *E. kuehniella*, but Lund (1938) found no difference for *T. evanescens*. Mating is known to reduce female lifespan in many insects (Partridge 1986) and may also do so with *T. minutum*.

The longevity of *T. minutum* observed in this study with unfed female parasitoids was much shorter than that reported by Yu *et al.* (1984) or Smith and Hubbes (1986). Yu *et al.* (1984) found that *T. minutum* fed on honey lived for 612 h, whereas unfed females survived only 64 h. Starvation may be partly responsible for differences between measurement of female longevity

Table 2

Effects of female age and mating status on progeny emergence rate, clutch size and sex ratio of *Trichogramma minutum*.

Status		Emergence rate (%) ± SE		
		1st day	2nd & 3rd day	4th & 5th day
Mated		95.7±1.1 a[1] (59)[2]	96.0±1.4 a (47)	95.7±8.3 a (3)
Unmated		96.6±0.8 a (59)	95.2±2.0 a (55)	98.4±1.6 a (5)
		Clutch size		
Mated	X±SE	1.31±0.04 a (59)	1.25±0.04 a (47)	1.33±0.33 a (3)
	Minimum	1	1	1
	Maximum	5	4	4
	Percentage of both sexes in the clutch size of two: 76.7±5.4			
Unmated	X±SE	1.32±0.04 a (59)	1.28±0.04 a (55)	1.25±0.30 a (5)
	Minimum	1	1	1
	Maximum	5	4	4
		Male proportion (%) ± SE		
Mated[3]		20.1±2.1 b (59)	32.5±3.0 a (47)	46.1±12.2 a (3)

1. Values in the same column within each of emergence rates and clutch size followed by the same letters are not significantly different at the 5% level of Duncan's multiple range test.
2. Numbers in parentheses represent replicates.
3. Values in this row followed by the same letters are not significantly different at the 5% level of Duncan's multiple range test.

here and those from previous studies. Differences in hosts may also have contributed to different measurements of longevity, because host species appear to have significant effects on parasitoid lifespans (Smith and Hubbes 1986).

Clutch size, emergence rate and sex ratio of F1 progeny.

Mating status and age of female *T. minutum* did not significantly ($P > 0.05$) affect emergence rate (Table 2). The emergence rate of parasitized eggs was above 95% for both mated and unmated parasitoids, higher than the 82.5% reported by Smith and Hubbes (1986). Although offspring clutch size varied from 1.25 to 1.32 offspring per parasitized egg, no significant ($P > 0.05$) differences were found either between mated and unmated females or among maternal ages (Table 2).

The overall sex ratio of *T. minutum* was female-biased and significantly affected by maternal age ($F = 8.31$; $df = 2, 106$; $P = 0.0004$) (Table 2). Mated *T. minutum* produced a significantly lower proportion of male offspring on the first day of oviposition than on subsequent days. A similar increase in the proportion of male progeny with maternal age of *T. minutum* was reported by Houseweart *et al.* (1983) and Smith and Hubbes (1986).

Adult sex ratio was estimated in this study. In this haplodiploid parasitoid, adult sex ratio could reflect the initial sex ratio of the parasitoid eggs allocated to hosts at oviposition or differential larval mortality between sexes or both. We found that a single *P. saucia* egg can support up to five *T. minutum,* but this rarely occurs and average clutch size was only 1.3 offspring per parasitized host (Table 2). Furthermore, it was observed that if two *T. minutum* developed from a single cutworm egg, majority of them were one male and one female (see Table 2). Thus, differential larval mortality of *T. minutum* in this study is unlikely. Therefore, the observed adult sex ratio is probably determined by the initial sex ratio of the wasp eggs. In arrhenotokous Hymenoptera, males develop from unfertilized eggs and females from fertilized eggs. An increase in the proportion of males with maternal age may be due to depletion of sperm but further study is needed.

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Assessment of sweepnet and suction sampling for evaluating pest insect populations in hay alfalfa[1]

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ABSTRACT

Insect populations in alfalfa grown for hay can be sampled using several methods. However, in a pest management program a relatively easy, quick, and reliable method of sampling is essential for making effective pest control decisions. A study was conducted to determine if two different sampling methods, sweepnet sampling and suction sampling, led to similar pest control decisions. Differences between sweepnet and D-Vac insect population estimates varied over sampling dates and years and were dependent on the insect species, their developmental stages, and abiotic factors. Our results indicate that, for many sampling dates, decisions on control of some pest insects would be similar for the two sampling methods.

Insecta, *Medicago sativa*, alfalfa weevil, pea aphid

INTRODUCTION

Economically viable, environmentally responsible pest insect management depends on regular, accurate assessments of insect populations. The correlation between estimates from samples and absolute population estimates varies with crop growth factors (Bechinski and Pedigo 1982, Saugstad *et al.* 1967), the insects being sampled (Sedivy and Kocourek 1988), wind, and air temperature (Saugstad *et al.* 1967). The sampling method used is also a source of error in estimating insect populations. The method chosen must be sufficiently accurate to identify population fluctuations, but also simple and quick enough that it can be done frequently to allow timely management decisions.

Comparisons of sampling methods have been inconclusive. In lentils, population estimates of *Lygus hesperus* Knight from absolute, D-Vac, and sweepnet sampling were similar, but nymphal numbers were lower with sweepnet sampling (Schotzko and O'Keefe, 1986a). In soybeans, Bechinski and Pedigo (1982) found that for the predators, *Nabis* spp., *Chrysopa* spp. and Coccinellidae, sweepnet sampling was superior, in terms of cost and variability, to plant shake, absolute and vacuum sampling. Vacuum sampling was the least efficient method. However, Shepard *et al.* (1974) found no significant differences among insect samples collected from soybeans by

D-Vac, sweepnet, and plant shake. The Insectavac was reported to sample more insects per unit area per volume of cotton sampled and, therefore, give a more accurate estimate of population density than did the sweepnet (Ellington *et al.* 1984). Smith *et al.* (1976), however, reported that both sweepnet and D-Vac sampling were adequate to identify population fluctuations and indicate absolute populations in cotton. In alfalfa, Sedivy and Kocourek (1988) found that D-Vac did not collect large, heavy insects such as caterpillars.

The objective of this study was to determine whether sweepnet and D-Vac sampling show

similar trends of pest insect populations in hay alfalfa and lead to similar decisions regarding insect control in a variety of weather and crop conditions.

MATERIALS AND METHODS

At two sites in southern Alberta, insect populations in alfalfa (*Medicago sativa* L.) were sampled weekly from May to October by a sweepnet and a D-Vac suction sampler (Dietrich 1961) both before and after cutting for hay. The sites were located at the Agriculture Canada Research Station at Lethbridge, Alberta. At Site 1, there were six plots, 10 x 20 m, of "Beaver" alfalfa, and at Site 2, four plots, 10 x 15 m, of "Vernal" alfalfa. Both sites were sampled in 1978 and 1979. The two sites were about 1 km apart.

The insect samples consisted of five full-arm (180°) sweeps taken with a 38 cm diameter sweepnet from half of each plot, and 10 suction samples (30.4 cm diameter) taken from the other half of the plot with a D-Vac suction sampler (Model 1-A, D-Vac Company, Riverside, CA). All sampling was conducted by the same person between 10:00 am and 12:00 am MST. The samples were taken under dry conditions when the wind was less than 15 km/hour. In 1978, the crop was cut for the first time on 26 June and again on 29 August. In 1979, the first cut was on 5 July and the second on 7 September.

The pest insects identified and counted in the studies were: alfalfa weevil, *Hypera postica* (Gyllenhal); pea aphid, *Acyrthosiphon pisum* (Harris); leafhoppers, Cicadellidae; lygus, *Lygus* spp., and alfalfa root curculio, *Sitona scissifrons* Say. With the exception of the alfalfa root curculio, the pest insects were separated into mature and immature groups. The larvae of the alfalfa root curculio are subterranean and, therefore, were not sampled.

With any sampling method, the actual number of insects obtained is directly dependent on the volume of herbage sampled, regardless of the efficiency of the sampling method. Schotzko and O'Keeffe (1989) determined that sampled herbage volume provided a better estimate of absolute insect counts than considering only the area that was sampled. With sweepnet sampling, the volume of herbage sampled is determined by the net diameter, the number of sweeps, the length of each sweep, and the penetration of the crop canopy. The net size and the number of sweeps can be kept constant, but the length of the sweeps and canopy penetration vary. Therefore, the volume of herbage sampled is not fixed. Similarly for D-Vac sampling, the net size, the number of samples, and the height of the canopy determine the volume of herbage sampled. The height of the canopy varies, so the sampling volume is not constant for D-Vac sampling. Using a conversion factor to obtain similar sampling volumes assumes a simple relationship between insect densities and herbage volume, which may not be valid. As pointed out by Schotzko and O'Keeffe (1989), volume adjustments do not compensate for the location of the insects in the canopy; they merely attempt to standardize the amount of canopy sampled. In our case, the height of the canopy was different at each sampling date, so any attempt at standardizing the sampled volume would have been unfeasible; therefore, we can provide only approximations of the sampled volume.

The handle on the sweepnet was 0.90 m, the net opening had a 0.19-m radius, and five 180° sweeps were taken. Therefore, from the volume equation for a torus, the theoretical sampled volume is about 1.94-m^3 (volume = pi^2 X 0.19^2 X (0.90 + 0.19) X 5). In practice, no more than half of the sweepnet would usually penetrate the canopy, so the actual volume of herbage sampled was less than 1.0 m^3. The D-Vac had a net opening with a 0.152-m radius, and 10 samples were taken each consisting of moving from the top of the canopy to the ground. Therefore, its volume is V = pi X H X 0.152^2 X 10, where H is the height of the canopy. From the forgoing, the sweepnet and D-Vac appear to sample similar volumes when V = 1.0 m^3, or when H = 1.38 m. Alfalfa is cut two to three times per year, generally before it reaches a height of 1.38 m; therefore, in our study the sweepnet probably sampled a larger volume of the canopy than the D-Vac.

Owing to the problems in sampling volumes as discussed above and because exact sampled volumes were not obtained in this study, no statistical tests were made to compare directly the differences in actual insect counts between the two sampling methods. Therefore, for our study, the decision on control for an insect pest is based on the population trends obtained by the two methods, not on specific economic thresholds. We followed procedures similar to those of Bra-

man and Yeargan (1990) to compare the two sampling methods. The means of the replicates and their standard errors were calculated for each sampling date and plotted in order to display discrepancies in insect counts between the sampling methods over the growing season. Each year's data were treated separately. Correlations between sweepnet and D-Vac insect counts were calculated using estimates obtained from each replication throughout the sampling period. This provided estimates of the trends over all sampling dates. Correlations were also calculated between insect counts obtained on a given sampling date and those obtained from the previous sampling date (lag 1 correlations). In the absence of eradication measures, insect populations generally should not change drastically within one week. Therefore, if the sampling methods provide consistent estimates of insect populations, these lag 1 correlations should be high. All calculations were made with SAS (SAS Institute Inc. 1985).

Table 1

Correlations (r) between sweepnet and D-Vac sampling estimates for five insects, two years, and two locations

	1978		1979	
Insect	Site 1 (n = 56)	Site 2 (n = 83)	Site 1 (n = 56)	Site 2 (n = 84)
Aphid				
Wingless	0.54**	0.81**	0.94**	0.86**
Winged	0.50**	0.54**	0.84**	0.87**
Lygus				
Nymphs	0.20	0.51**	0.92**	0.76**
Adults	0.53**	0.06	0.48**	0.63**
Alfalfa weevil				
Larvae	0.64**	0.54**	0.64**	0.79**
Adults	0.15	0.36**	0.25	0.35**
Leafhoppers				
Nymphs	0.38**	0.11	0.78**	0.14
Adults	0.54**	0.73**	0.55**	0.68**
Alfalfa root curculio	0.17	0.40**	–0.02	0.54**

** Indicate significant correlations between the two sampling methods at p = 0.01.

Table 2

The lag 1 correlations (r) between observations from a given sampling date and those from the previous sampling date for sweepnet and D-Vac sampling for five insects, two years, and two locations

	1978				1979			
	Site 1 (n = 55)		Site 2 (n = 82)		Site 1 (n = 55)		Site 2 (n = 83)	
Insect	Sweep	D-Vac	Sweep	D-Vac	Swee	D-Vac	Sweep	D-Vac
Aphids	0.80**	0.75**	0.80**	0.78**	0.84**	0.84**	0.85**	0.90**
Lygus	0.40**	0.54**	0.79**	0.65**	0.80**	0.71**	0.80**	0.83**
Alfalfa weevil	0.72**	0.60**	0.80**	0.68**	0.40**	0.81**	0.71**	0.72**
Leaf hopper	0.33*	0.31*	0.62**	0.56**	0.16	0.34*	0.53**	0.67**
Alfalfa root curculio	–0.05	0.16	0.52**	0.37**	–0.03	–0.02	0.57**	0.47**

**,* Indicate significant correlations at p = 0.01 and p = 0.05, respectively.

RESULTS AND DISCUSSION

Pea aphids

Correlations between sweepnet and D-Vac sampling ranged from 0.54 to 0.94 for the wingless and from 0.50 to 0.87 for the winged pea aphids (Table 1). Within a given year and location, the correlations for the two aphid groups were quite similar. The lag 1 correlations ranged from 0.75 to .90, indicating that the two sampling methods generally provided consistent estimates of pea aphid populations over time (Table 2). In 1978, few large differences between sampling methods were observed, the only exception being the fifth sampling date at Site 1 for wingless aphids (Fig. 1). There the sweepnet sampling indicated almost 10 times as many wingless aphids as the D-Vac. In 1979, the D-Vac counts tended to be higher for winged and wingless aphids at peak population levels at both locations (Fig. 1).

Pea aphid counts in alfalfa are influenced by temperature, RH, cloud cover, the height of the alfalfa, and wind speed (Saugstad *et al.* 1967). For this insect, sweepnet sampling may not be sufficiently precise to make absolute insect population comparisons, but may be useful for determining population trends (Saugstad *et al.* 1967). Butin and Isenhour (1989) found that stem and sweepnet counts were highly correlated for pea aphids in alfalfa. Our high correlations between sampling methods in 1978 and 1979 indicate a generally good agreement throughout the sampling period (Table 1). Therefore, decisions on control of pea aphid populations would probably have been similar for the two sampling methods (Fig. 1).

Lygus spp.

Correlations of lygus counts between sweepnet and D-Vac sampling ranged from 0.06 to 0.92, but the two sampling methods were inconsistent in detecting trends (Table 1). Lag 1 correlations ranged from 0.40 to 0.83, indicating low agreement between successive sampling date estimates at some locations (Table 2). The lag 1 correlations for the two sampling methods were generally similar. In 1978, lygus nymphs at Site 2 and lygus adults at Site 1 showed few consistent trends (Fig. 2). For 1979 at Site 1, the agreement between the two sampling methods was consistent throughout most of the season. Neither sampling method consistently provided higher lygus population estimates.

Schotzko and O'Keeffe (1986a) found that lygus nymph counts with sweep-net sampling in lentils were influenced by RH, temperature and light intensity, but adult lygus were not influenced by any of the abiotic factors. These authors also found that the appropriate time for sampling adult lygus bugs with the sweepnet did not coincide with that for sampling lygus nymphs. In our study, the sweepnet and D-Vac sampling methods probably sampled different areas of the alfalfa canopy; therefore, differences in counts between the two sampling methods for lygus nymphs and adults, as well as the low lag 1 correlations, seem to indicate that both were influenced by abiotic factors. Schotzko and O'Keeffe (1986b) concluded that sweepnet sampling provided reliable estimates of adult lygus in lentils, but D-Vac sampling probably overestimated both lygus adults and nymphs. Since the two sampling methods in our study provided almost identical lygus counts on some sampling dates and significantly different counts on others (lygus nymphs at Site 2 in 1978 and 1979), we can make no statement about the reliability of either method for sampling lygus in alfalfa. The sweepnet probably sampled a larger volume of alfalfa and often provided higher lygus counts; nevertheless, for some sampling dates the D-Vac produced much higher counts than the sweepnet. This lack of consistency makes decisions about the need to control lygus in alfalfa dependent in part on the sampling method and abiotic factors at the time of sampling.

Alfalfa weevil

Correlations for adult alfalfa weevil ranged from 0.15 to 0.36, while correlations for larvae ranged from 0.54 to 0.79 (Table 1). Within a given location and weevil growth stage, the correlations for the two years were similar. In 1978, the lag 1 correlations for the two sampling methods were similar (Table 2). Lag 1 correlations ranged from 0.40 to 0.81, and were different for the two sampling methods at site 1 in 1979. For 1978, the sweepnet sampling produced higher larval counts for most of the sampling dates at both locations (Fig. 3). In 1979, both sampling methods provided similar larval counts for most sampling dates. Adult alfalfa weevil counts

were low for both locations in both years (Fig. 3). Neither sampling method produced consistently higher adult weevil counts, but for some sampling dates, the D-Vac produced substantially higher counts than the sweepnet.

Cothran and Summers (1972) compared alfalfa weevil counts obtained from sweepnet and square-foot, absolute sampling, and found that the sweepnet underestimated the actual populations, with the most severe underestimations occurred early in the developmental period of the weevil larvae. They suggest replacing the sweepnet with another sampling method when accurate estimates of alfalfa weevil are required. In our study, the alfalfa weevil larval population estimates obtained from sweepnet sampling in 1978 were substantially higher than D-Vac counts for most of the sampling periods at both sites (Fig. 3). The higher counts obtained by the sweep-

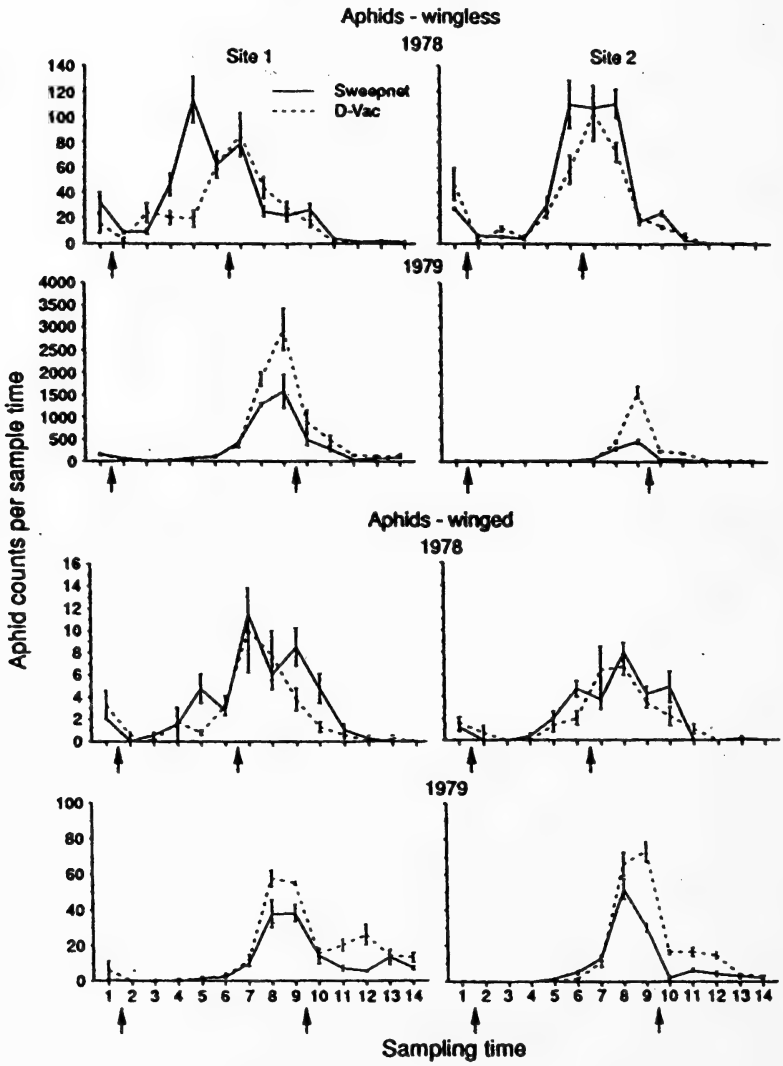

Figure 1. Influence of sampling method on counts of aphids.
^ = Time of cut.

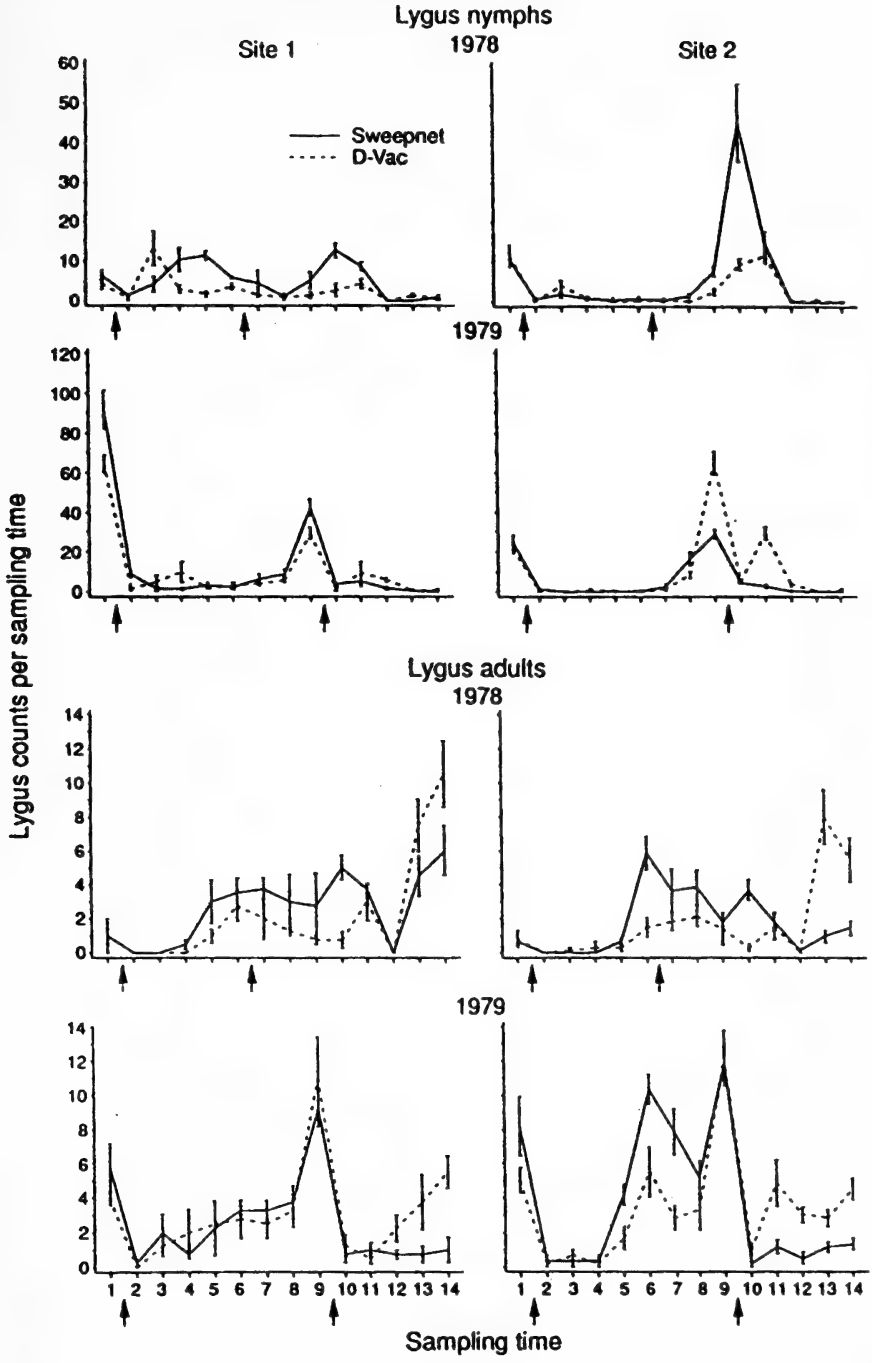

Figure 2. Influence of sampling method on counts of lygus bugs.
^ = Time of cut.

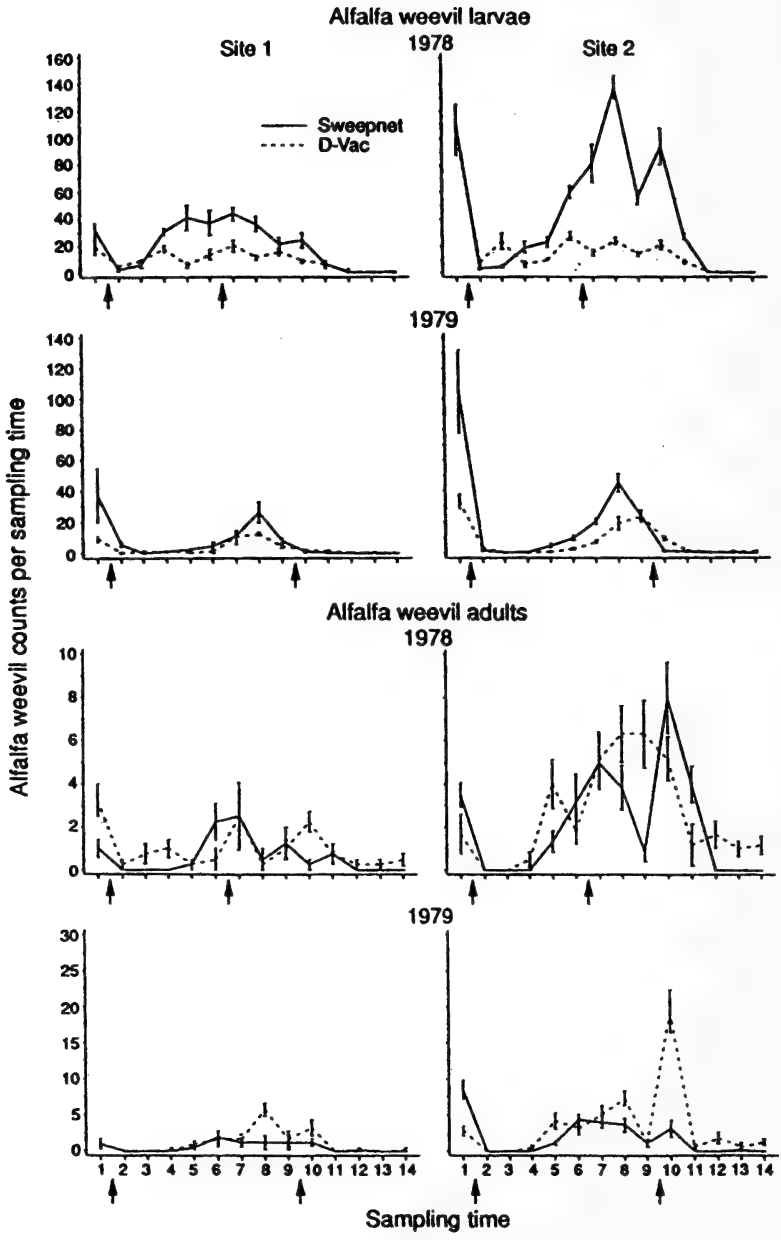

Figure 3. Influence of sampling method on counts of alfalfa weevils.
^ = Time of cut.

net could be due to a larger sampled volume, but if that is the case, why did the two sampling methods produce very similar counts for some sampling dates? The D-Vac captured higher numbers of adult alfalfa weevils than the sweepnet for some sampling dates, but there was no consistency (Fig. 3). The early larval instars are located in the newly developing leaf and flower buds and are not easily dislodged, whereas the late instar larvae and adults are found on the leaves and are easily captured; therefore, the location of alfalfa weevil within the canopy may have favoured one sampling method over the other on certain sampling dates. The low lag 1 correlations for the sweepnet at site 1 in 1979 seem to support this suggestion.

Decisions about the need to control the alfalfa weevil would probably have been different for the two sampling methods in 1978, but would not have differed in 1979. If sweepnet sampling drastically underestimates alfalfa weevil larvae populations, as Cothran and Summers (1972) found, then the underestimations from D-Vac sampling in our study seem to be even more severe. However, the differences between D-Vac and sweepnet in alfalfa weevil population estimates appear to be related to abiotic factors and weevil development.

Leafhoppers

Correlations between the two sampling methods for adult leafhoppers ranged from 0.54 to 0.73, and correlations for leafhopper nymphs ranged from 0.11 to 0.78 (Table 1). Lag 1 correlations were generally low and ranged from 0.16 to 0.67, indicating that neither sampling method provided consistent population estimates (Table 2). Nymphal leafhopper counts were quite low for most sampling dates and few practically significant deviations were observed between the two sampling methods (Fig. 4). Some noticeable exceptions were very high counts for the D-Vac on the third sampling date in 1978 at Site 1, and the first sampling date at Site 2 in both 1978 and 1979. D-Vac sampling produced higher adult leafhopper counts for most of the sampling dates at both locations in 1979 (Fig. 4). Differences between sampling methods for adult leafhoppers in 1978 were not as consistent as in 1979, but D-Vac sampling tended to have higher counts.

Delong (1932) discussed some of the problems involved with sweepnet sampling and concluded that, for active insects such as leafhoppers, sweepnet sampling is not very useful for obtaining accurate population estimates. Saugstad *et al.* (1967) obtained a high positive correlation between leafhopper counts from sweepnet sampling and the height of the alfalfa, whereas Cherry *et al.* (1977) found that wind and temperature were the two most important factors in sweepnet estimates of adult leafhopper populations in alfalfa. These findings may explain some of the variability between sampling methods and the low lag 1 correlations that we observed over years, locations, and sampling dates. In 1979, adult leafhopper counts were higher in D-Vac samples than in sweepnet samples for the whole sampling period. We can only speculate that abiotic factors favoured D-Vac sampling because, theoretically, the volume of alfalfa sampled by the sweepnet should have been higher than the volume sampled by the D-Vac. In 1979, decisions to control leafhopper populations would have been different for the two sampling methods.

Alfalfa root curculio

Correlations between sampling methods ranged from -0.02 to 0.54 (Table 1). The small negative correlation was the result of very low alfalfa root curculio counts at Site 1 in 1979 (Fig. 5). The D-Vac samples had higher curculio counts than the sweepnet for the latter half of the sampling period at both sites in 1978, and at Site 2 in 1979. The location of the curculio within the alfalfa canopy was probably responsible for the higher counts obtained with D-Vac sampling, even though the sweepnet may have sampled a larger volume. The very low lag 1 correlations for both sampling methods indicate that neither sampling method provided consistent population estimates (Table 2).

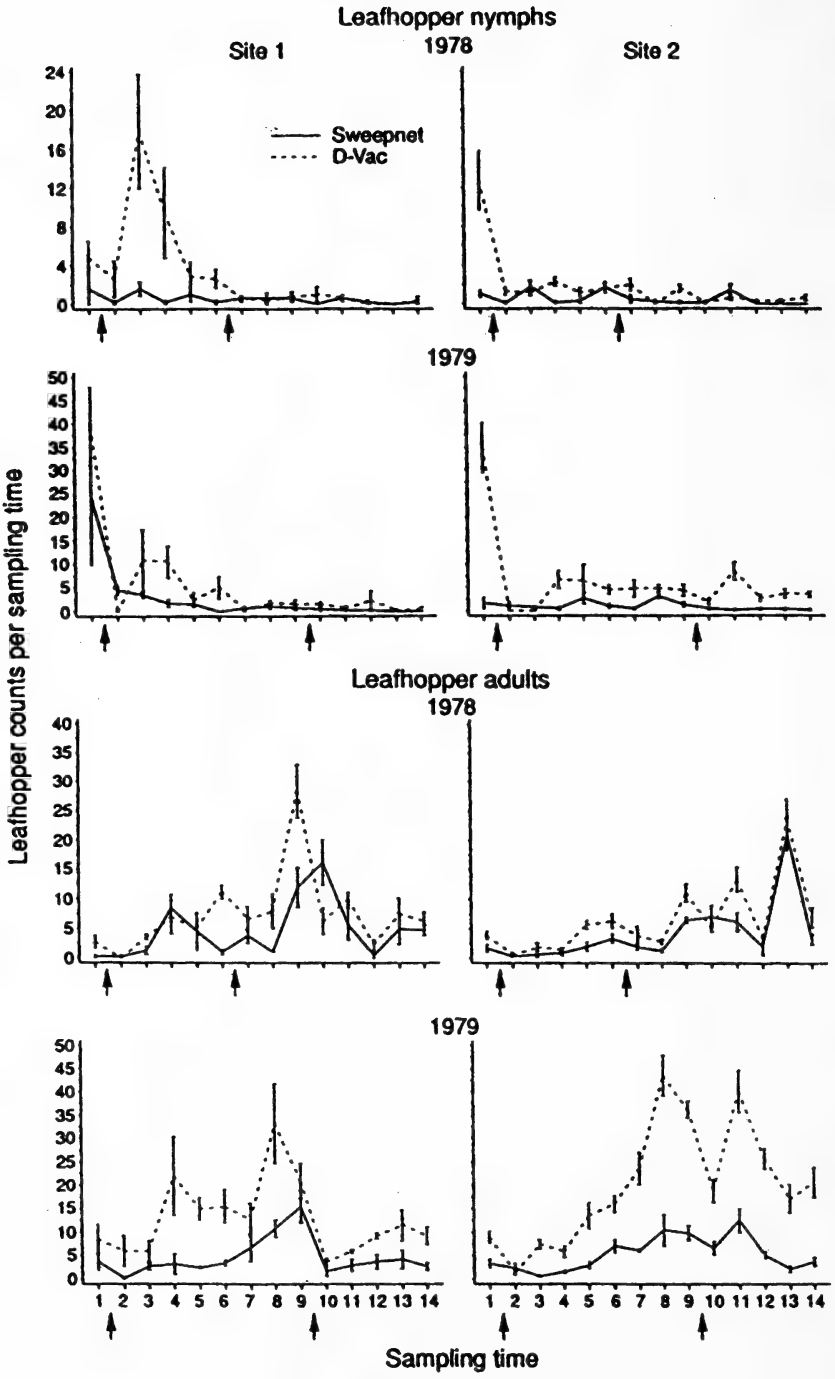

Figure 4. Influence of sampling method on counts of leafhoppers.
^ = Time of cut.

CONCLUSIONS

From our results, we conclude that, to obtain reasonable estimates of insect populations on which to base insect control decisions with sweepnet or D-Vac sampling, the behaviour and feeding patterns of the target insect need to be understood. Sampling conditions should optimize the probability of capturing the target insect. This implies that sampling on fixed dates at fixed times will probably influence the estimated insect populations since the abiotic factors will not necessarily be optimal at the preselected sampling times. Furthermore, the optimal sampling conditions vary among insect species and their developmental stages.

We also conclude that higher sampling volumes do not necessarily produce higher insect counts, since the location of the insect in the alfalfa canopy and other factors are also important. This makes the validity of post-sampling volume and area standardization questionable. After alfalfa growth reaches 30 to 35 cm in height the sweepnet generally only samples the top portion of the alfalfa canopy and, therefore, underestimates insects dwelling mainly in the lower portion of the canopy. Sweepnet and D-Vac insect estimates are dependent on the insect species, their stage of development, their location within the canopy, the crop being sampled, and abiotic factors. Therefore, when making pest control decisions, any sampling scheme that incorporates either of these two sampling methods must consider the above factors to obtain accurate population estimates or trends.

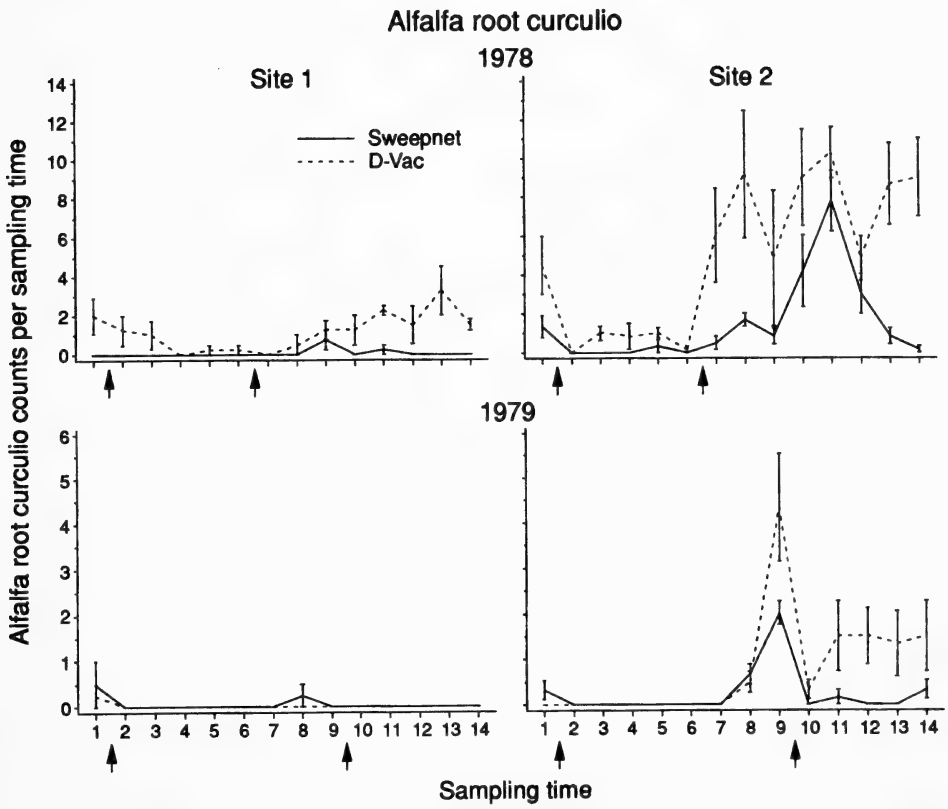

Figure 5. Influence of sampling method on counts of alfalfa root curculio.
^ = Time of cut.

NOTES

1. Contribution 3878943.
2. Retired.

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The Aphids (Homoptera: Aphididae) of British Columbia 21. Further Additions

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ABSTRACT

Seven species are added to the aphid fauna of British Columbia. Sixty-five of the 113 new aphid-host associations of plant species are newly recorded.

INTRODUCTION

Four-hundred-and-five species of aphids collected from 1178 host plant species or in traps, and 2321 aphid-host associations were recorded in previous lists of the aphids of British Columbia (Forbes and Chan 1989a, 1989b, 1991). The present list adds 7 aphid species (indicated with an asterisk in the list) and 113 aphid-host plant associations to the previous lists. Sixty-five of the new aphid-host associations of plant species are recorded for the first time. The additions bring the number of known aphid species in British Columbia to 412. Aphids have now been collected from 1243 different host plants and the total number of aphid-host associations is 2434.

The aphid names are in conformity with Eastop and Hille Ris Lambers (1976) and are listed alphabetically by species. Names of native host plants are based on Anonymous (1982) and Taylor and MacBryde (1977). Names of cultivated host plants are based on Anonymous (1976). Thirteen new collection sites are given in Table 1. The reference points are the same as those shown on the map which accompanies the basic list (Forbes et al. 1973). Most of the aphids were collected by the authors.

LIST OF SPECIES

AEGOPODII (Scopoli 1763), CAVARIELLA
Apium graveolens 'Prize Pink': Vancouver (UBC), Aug19/93.
Oenanthe sarmentosa: Amphitrite Point, Sep02/92.

AGATHONICA Hottes 1950, AMPHOROPHORA
Rubus idaeus 'Algonquin': Abbotsford, Jul30/93.
Rubus idaeus 'Chilliwack': Abbotsford, Jul30/93.
Rubus idaeus 'Comox': Abbotsford, Jul30/93.
Rubus idaeus 'Meeker': Abbotsford, Jul30/93.

AMERICANUM (Riley 1879), ERIOSOMA
Ulmus carpinifolia: Vancouver, May18/93.

ANTIRRHINII (Macchiati 1883), MYZUS
Symphoricarpos x chenaultii: Vancouver (UBC), Jun16/93.
Vinca minor: Vancouver (UBC), Jun09/93.

*ARUNDICOLENS (Clarke 1903), TAKECALLIS
Arundinaria pygmaea: Vancouver (UBC), Sep16/92, Oct23/92, Nov25/92.

ASCALONICUS Doncaster 1946, MYZUS,
Arabidopsis thaliana: Vancouver (UBC), May06/83.
Corydalis aurea ssp. aurea: Vancouver (UBC), Mar22/85, May11/83, Nov07/84, Nov28/83.
Potentilla fruticosa ssp. floribunda: Vancouver (UBC), May20/93.
Spergularia rubra: Vancouver (UBC), Nov03/83.

AVENAE (Fabricius 1775), SITOBION
Agrotis exarata ssp. exarata var. exarata: Abbotsford, Jul21/93.

Bromus mollis: Abbotsford, Jul21/93.
Bromus pacificus: Abbotsford, Jul21/93.
Digitaria ischaemum: Cumberland, Sep03/92.
Digitaria sanguinalis: Abbotsford, Jul21/93.
Hordeum murinum: Abbotsford, Jul21/93.
Phalaris arundinacea: Abbotsford, Jul23/93.
Poa annua: Abbotsford, Jul21/93.
Zea mays 'Miracle': Vancouver (UBC), Aug19/93.

AZALEAE (Mason 1925), ILLINOIA
Vaccinium corymbosum: Richmond, May22/93; Aug15/90.

BETAE Doane 1900, PEMPHIGUS
Lactuca sativa: Vancouver, Sep15/83.

*BETAE Westwood 1849, SMYNTHURODES
Phaseolus vulgaris var. humulis: Vancouver, Jul23/93.

*BLACKMANI Forbes & Chan 1993, SITOBION
Holodiscus discolor ssp. discolor: Vancouver (UBC), Mar19/84, Mar26/84, Apr14/86, Apr16/86, Apr24/84, Apr30/86, May01/86, May08/84 Aug25/86, Sep20/84, Oct18/85, Oct20/86, Oct21/86, Oct25/86, Nov02/83, Nov07/85, Nov08/85, Nov10/81 (Forbes & Chan 1993).

BRASSICAE (Linnaeus 1758), BREVICORYNE
Capsella bursa-pastoris: Abbotsford, Jul15/91.

Table 1
Collection sites of aphids, with airline distances from reference points.

Locality	Reference Point	Dir	Distance km	Distance mi
Amphitrite Point (Vancouver Island)	Victoria	NW	172	108
Chester Beach (Vancouver Island)	Victoria	NW	193	121
Combers Beach (Vancouver Island)	Victoria	NW	193	121
Cumberland (Vancouver Island)	Victoria	NW	182	114
Forbidden Plateau (Vancouver Island)	Victoria	NW	207	129
Gabriola Island	Vancouver	W	51	32
Green Lake (near Whistler)	Vancouver	NE	103	64
Grouse Mountain	Vancouver	N	12	8
Long Beach (Vancouver Island)	Vancouver	W	210	130
Mount Washington (Vancouver Island)	Victoria	NW	207	129
Radar Hill (Vancouver Island)	Vancouver	W	210	130
Royston (Vancouver Island)	Victoria	NW	179	112
Ucluelet (Vancouver Island)	Victoria	NW	173	108

Brassica oleracea 'Minaret': Vancouver (UBC), Aug19/93.
Brassica oleracea var. capitata 'Red Rodan': Vancouver (UBC), Aug19/93.
Brassica oleracea var. capitata 'Savoy King': Vancouver (UBC), Aug19/93.

CARAGANAE (Cholodkovsky 1907), ACYRTHOSIPHON
Caragana arborescens: Vancouver (UBC), Jun17/93.
Colutea arborescens: Vancouver (UBC), May18/93.

CARICIS (Glendenning 1926), SITOBION
Carex mertensii: Mount Washington, Sep04/92.

CARNOSUM (Buckton 1876), MICROLOPHIUM
Urtica dioica ssp. gracilis var. lyallii: Abbotsford, Jun04/93; Vancouver, Aug18/89.

CERASI (Fabricius 1775), MYZUS
Prunus x yedoensis: Vancouver (UBC), May20/93.

CERTUS (Walker 1849), MYZUS
Spergularia rubra: Abbotsford, Jun21/92.

CIRCUMFLEXUM (Buckton 1876), AULACORTHUM,
Notholirion campanulatum: Vancouver (UBC), May20/93.
Potentilla fruticosa ssp. floribunda: Vancouver (UBC), May20/93.

CORNI (Fabricius 1775), ANOECIA
Agropyron repens: Abbotsford, Aug05/93, Oct13/92; Cumberland, Sep03/92.

CORYLI (Goeze 1778), MYZOCALLIS
Corylus cornuta var. californica: Abbotsford, Jun19/93.

CRACCIVORA Koch 1854, APHIS
Laburnum anagyroides: Vancouver (UBC), May20/93.
Laburnum x watereri: Vancouver (UBC), Jun25/93.

CRYSTLEAE (Smith & Knowlton 1939), ILLINOIA
Holodiscus discolor ssp. discolor: Vancouver (UBC), Jun15/93.

CYPERI (Walker 1848), THRIPSAPHIS
Carex mertensii: Mount Washington, Sep04/92.

DIRHODUM (Walker 1849), METOPOLOPHIUM
Echinochloa crusgalli: Westham Island, Aug12/93.
Phalaris arundinacea: Abbotsford, Jul23/93.
Rosa 'Roseraie de L' Hay': Vancouver (UBC), Nov09/84.

DORSATUM Richards 1967, AULACORTHUM
Gaultheria shallon: Chester Beach, Sep03/92.

EQUISETI Holman 1961, SITOBION
Equisetum arvense: Vancouver, May29/93, Jun25/86.

EUPHORBIAE (Thomas 1878), MACROSIPHUM
Fagopyron esculentum: Abbotsford, Aug12/92.
Solanum nigrum: Abbotsford, Aug12/92.
Solanum sarrachoides: Abbotsford, Aug12/92.

FABAE Scopoli 1763, APHIS
Euonymus hamiltoniana var. hans: Vancouver (UBC), Jun03/89.
Staphylea pinnata: Vancouver (UBC), Jul30/93.

FAGI (Linnaeus 1767), PHYLLAPHIS
Fagus sylvatica: Vancouver, May18/93.

FARINOSA Gmelin 1790, APHIS
Salix sp.: Vancouver, Jun14/87.

FIMBRIATA Richards 1959, FIMBRIAPHIS
Capsella bursa-pastoris: Abbotsford, May25/93.
Fragaria x ananassa 'Totem': Abbotsford, Oct13/92.

FOENICULI (Passerini 1860), HYADAPHIS
Lonicera ciliosa: Gabriola Island, Jul10/93.

FRAGAEFOLII (Cockerell 1901), CHAETOSIPHON,
Fragaria x ananassa 'Sakuma': Vancouver (UBC), Nov04/85.
Fragaria chiloensis: Long Beach, Sep03/92.

FRAGARIAE (Walker 1848), SITOBION
Fragaria x ananassa 'Burlington': Vancouver (UBC), Nov04/85.
Fragaria x ananassa 'Totem': Abbotsford, Sep29/92.

FRAXINIFOLII (Riley 1879), PROCIPHILUS
Fraxinus latifolia: Vancouver (UBC), May19/93.
Fraxinus oxycarpa: Vancouver, May18/93.
Fraxinus pennsylvanica: Vancouver, May18/93.

FREQUENS,(Walker 1848), DIURAPHIS,
Agropyron caninum: Abbotsford, Jul15/93, Aug05/93, Aug20/93.
Agropyronn repens: Abbotsford, Jul15/93, Aug05/93, Aug20/93.
Bromus pacificus: Abbotsford, Aug17/93, Aug20/93.

GENTNERI (Mason 1947), FIMBRIAPHIS
Crataegus mollis: Vancouver (UBC), May19/93.
Crataegus phaenopyrum: Vancouver, May18/93.

GLYCERIAE (Kaltenbach 1843), SIPHA
Glyceria grandis: Vancouver, Sep15/89.

GOSSYPII Glover 1877, APHIS
Datura stramonium: Vancouver (CDA), Jun15/93.

HEDERAE Kaltenbach 1843, APHIS
Hedera helix: Combers Beach, Sep03/92.

HELICHRYSI (Kaltenbach 1843), BRACHYCAUDUS
Adelocaryum anchusoides: Vancouver (UBC), May31/89.
Crataegus mollis: Vancouver (UBC), May19/93.
Petasites palmatus: Vancouver, Jun22/87.
Symphytum officinale: Vancouver, Jun09/93.

HUMULI (Schrank 1801), PHORODON
Humulus lupulus 'Nugget': Sardis, May14/93, Jul22/93.

*INCOGNITA Hottes & Frison 1931, CEDOAPHIS
Symphoricarpos x chenaultii: Vancouver (UBC), May20/93; Jun16/93.

LACTUCAE (Linnaeus 1758), HYPEROMYZUS
Ribes sativum 'Red Lake': Vancouver (UBC), Sep24/84.

LYTHRI (Schrank 1801), MYZUS
Prunus emarginata: Vancouver (UBC), May17/93.

MACROSIPHUM (Wilson 1912), ACYRTHOSIPHON
Amelanchier alnifolla: Green Lake, Nov05/92.

MANITOBENSE (Robinson 1965), SITOBION
Cornus alba 'Sibirica': Squamish, Nov20/92.

NERVATA (Gillette 1908), WAHLGRENIELLA
Arbutus menziesii: Nanaimo, Oct13/92.

NICOTIANAE Blackman 1987, MYZUS
Solanum tuberosum 'Russet Burbank': Abbotsford, Jul30/93.

NOXIA (Mordvilko ex Kurdjumov 1913), DIURAPHIS
Capsella bursa-pastoris: Vancouver (CDA), May15/93.

ORNATUS Laing 1932, MYZUS
Alyogyne hakeifolia: Vancouver (UBC), May20/93.

Androsace geraniifolia: Vancouver (UBC), May20/93.
Arnica latifolia var. latifolia: Vancouver (UBC), Jun15/87.
Astartea fascicularis: Vancouver (UBC), May20/93.
Cuphea cyanea: Vancouver (UBC), Oct25/83.
Lithodora diffusa 'Heavenly Blue': Vancouver (UBC), Jun21/85.
Phyllodoce empetriformis: Vancouver (UBC), May20/93.
Spergularia rubra: Vancouver (UBC), Nov03/83.

PADI (Linnaeus 1758), RHOPALOSIPHUM
Agropyron caninum: Abbotsford, Jul21/93.
Zea mays: Chilliwack, Aug29/83.

PARVIFOLII (Richards 1967), SITOBION
Vaccinium alaskaense: Forbidden Plateau, Sep03/92; Grouse Mountain, Jul24/93; Mount Washington, Sep03/92.
Vaccinium ovalifolium: Grouse Mountain, Jul24/93.

PASTINACAE (Linnaeus 1758), CAVARIELLA
Heracleum sphondylium ssp. montanum: Ucluelet, Sep02/92.

PERSICAE (Sulzer 1776), MYZUS
Fagopyron esculentum: Abbotsford, Jun21/92.
Rorippa palustris ssp. palustris var. palustris: Abbotsford, Sep15/92.
Solanum nigrum: Abbotsford, Aug15/92.
Solanum sarrachoides: Abbotsford, Aug15/92.
Solanum tuberosum 'Norchip': Ladner, Jul27/93.
Solanum tuberosum 'Russet Norkotah': Ladner, Jul27/93.

*PHLOXAE (Sampson 1939), OVATUS
Capsella bursa-pastoris: Abbotsford, May15/92.

PISUM (Harris 1776), ACYRTHOSIPHON
Cytisus austriacus: Vancouver (UBC), May18/93, Oct04/84.

POAE (Gillette 1908), RHOPALOMYZUS
Phalaris arundinacea: Abbotsford, Jul23/93.

POPULIVENAE Fitch 1859, PEMPHIGUS
Rumex acetosella: Abbotsford, May11/93.

PRUNI (Geoffroy 1762), HYALOPTERUS
Phalaris arundinacea: Abbotsford, Jul23/93.
Prunus cerasifera 'Bradshaw': Vancouver (UBC), Aug19/93.

PTERINIGRUM Richards 1972, AULACORTHUM
Vaccinium alaskaense: Grouse Mountain, Jul24/93.

ROSAE (Linnaeus 1758), MACROSIPHUM
Centranthus ruber 'Albiflorus': Vancouver (UBC), Jun26/87.
Fragaria x ananassa 'Burlington': Vancouver (UBC), Nov04/85.
Rosa multibracteata: Vancouver (UBC), Sep16/92.
Rosa soulieana: Vancouver (UBC), Sep16/92.

ROSARUM (Kaltenbach 1843), MYZAPHIS
Potentilla fruticosa: Cumberland, Sep03/92.
Rosa virginiana: Vancouver (UBC), Nov09/84.

RUMICIS Linnaeus 1758, APHIS
Rumex crispa: Abbotsford, Jun04/93.

SALICARIAE Koch 1855, APHIS
Cornus alba 'Sibirica': Squamish, Nov20/92.

SOLANI (Kaltenbach 1843), AULACORTHUM
Adelocaryum anchusoides: Vancouver (UBC), May31/89.
Amelanchier laevis: Vancouver (UBC), May20/93.

Arnica latifolia var. latifolia: Vancouver (UBC), Jun15/87.
Cardiocrinum giganteum: Vancouver (UBC), May16/93.
Eryngium varifolium: Vancouver (UBC), Jul13/87.
Hedera helix: Combers Beach, Sep02/92.
Hibiscus syriacus: Horseshoe Bay, Sep01/92.
Oxalis stricta: Vancouver (UBC), Jul13/87.
Rubus x loganobaccus: Vancouver (UBC), Oct16/92.
Symphytum officinale: Vancouver, Jun09/93.

SPYROTHECAE Passerini 1856, PEMPHIGUS
Populus nigra 'Italica': Ladner, Jul30/93; Royston, Sep04/92; Westham Island, Aug20/93.

*STACHYOPHILA Hille Ris Lambers 1966, AMPHOROPHORA
Stachys cooleyae: Radar Hill, Sep03/92.

STAPHYLEAE (Koch 1854), RHOPALOSIPHONINUS
Buxus harlandi: Vancouver (UBC), Apr18/86.
Dianthus uralensis: Vancouver (UBC), Feb28/87.
Euonymus hamiltoniana var. hans: Vancouver (UBC), Jun03/89.
Staphylea pinnata: Vancouver (UBC), Jun03/89.

TENUICAUDA Bartholomew 1932, MACROSIPHUM
Urtica dioica ssp. gracilis var. lyallii: Abbotsford, Jun04/93; Vancouver, Aug18/89.

TESTUDINACEUS (Fernie 1852), PERIPHYLLUS
Acer platanoides 'Harlequin': Cumberland, Sep03/93.
Aesculus x carnea: Vancouver, May18/93.
Aesculus hippocastanum 'Rubricunda': Vancouver (UBC), May24/89.

TILIAE (Linnaeus 1758), EUCALLIPTERUS
Tilia platyphyllos: Vancouver, May18/93.
Tilia tomentosa 'Brabant': Vancouver (UBC), Oct16/92.

*TOLMIEA (Essig 1942), MACROSIPHUM
Tellima grandiflora: Vancouver (UBC), May29/93.

WAKIBAE (Hottes 1934), FIMBRIAPHIS
Vaccinium parvifolium: Vancouver (UBC), May18/93.

ACKNOWLEDGEMENTS

We wish to thank Dr. R.L. Blackman, British Museum (Natural History), London, England for valuable aid and advice in identifying the aphids; and Dr. G.B. Straley, U.B.C. Botanical Garden, Vancouver, B.C. for identifying host plants.

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First record of *Pseudohaida rothi* Hatch (Coleoptera: Staphylinidae: Omaliinae) from Canada

J. M. CAMPBELL[1] AND N. N. WINCHESTER[2]

ABSTRACT

Pseudohaida rothi Hatch is reported for the first time from Canada from an old-growth, temperate rain forest on Vancouver Island, B.C. Records of other rare species of the subfamily Omaliinae are given together with a brief discussion of the importance of the remaining intact old-growth forests in preserving the biodiversity contained in the forest regions of Canada.

DISCUSSION

Pseudohaida rothi was described by Hatch (1957), from two specimens collected by Vincent Roth from the Corvallis, Oregon area. No additional specimens had been found when *Pseudohaida* and related genera were revised by Campbell (1978), and until recently, the species continued to be known only from the two original types.

One of us (Campbell) recently examined several large collections of staphylinid beetles made by the second author (Winchester) in his systematic survey of the insects of a northern temperate, coastal, old-growth rain forest in the Upper Carmanah Valley on the west coast of Vancouver Island, British Columbia. These contained five specimens of *Pseudohaida rothi*, collected by Malaise traps between the dates of September 30 to October 27, 1991. In addition to these specimens, members of a number of other species of rare omaliine staphylinids were discovered, including three specimens of *Coryphium arizonense* (Bernhauer), a long series of *Subhaida ingrata* Hatch, one specimen of *Tanyrhinus singularis* Mannerheim, three specimens of *Trigonodemus fasciatus* Leech, and specimens of several new species of Omaliinae which will be described in later papers.

Specimens of each of these species are preserved in the Canadian National Collection of Insects, Centre for Land and Biological Resources Research, Ottawa. It is hoped that these discoveries will contribute to increased appreciation of the importance of intact old-growth forests as reservoirs of biological diversity in the Pacific Rain Forests of Canada. Many species of Coleoptera are restricted to old-growth forests where two important conditions for survival are met: first, a supply of over mature, fallen logs which are allowed to decay under natural conditions in the shade of the forest canopy and, secondly, the maintenance of deep layers of undisturbed forest floor litter which has not been eradicated by the extreme conditions of clear-cutting and subsequent exposure to desiccation and erosion. Forest litter and decaying logs are rich in a large variety of species of fungi, many of which also serve as hosts for species of beetles. It should be noted that many of the species living in these mature forests have minimal dispersal capabilities, thus limiting their ability to repopulate new forests.

ACKNOWLEDGEMENTS

Field work in the rainforest of the Carmanah Valley was supported by operating grants to R.A. Ring and N.N. Winchester from the B.C. Ministry of Forests, Research Branch. Acknowledgement is made to A. Mackinnon for his continued support. Special thanks are extended to our research assistants, S. Hughes, K. Jordan and B. Lund.

NOTES

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2. Dept. of Biology, University of Victoria, Victoria, British Columbia, Canada, V8W 2Y2

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ERRATA

Volume 89, December 1992

Please note the following corrections to Volume 89 of the *Journal of the Entomological Society of British Columbia:*

Blacker, N.C. 1992. Some ants (Hymenoptera: Formicidae) from Southern Vancouver Island, British Columbia. Entomol. Soc. Brit. Columbia 89:3–12.

1. Page 5, line 15. Add "Table 1" before "Table 2".
2. Page 7, line 36. "species" should read "specimens".
3. Page 9, line 7. Add "but was never abundant. The colonies seen contained" before "a few hundred".
4. Page 9, line 37. Add "twice" between "than" and "that".
5. Page 12, line 15. Add "not" between "species" and "recorded".

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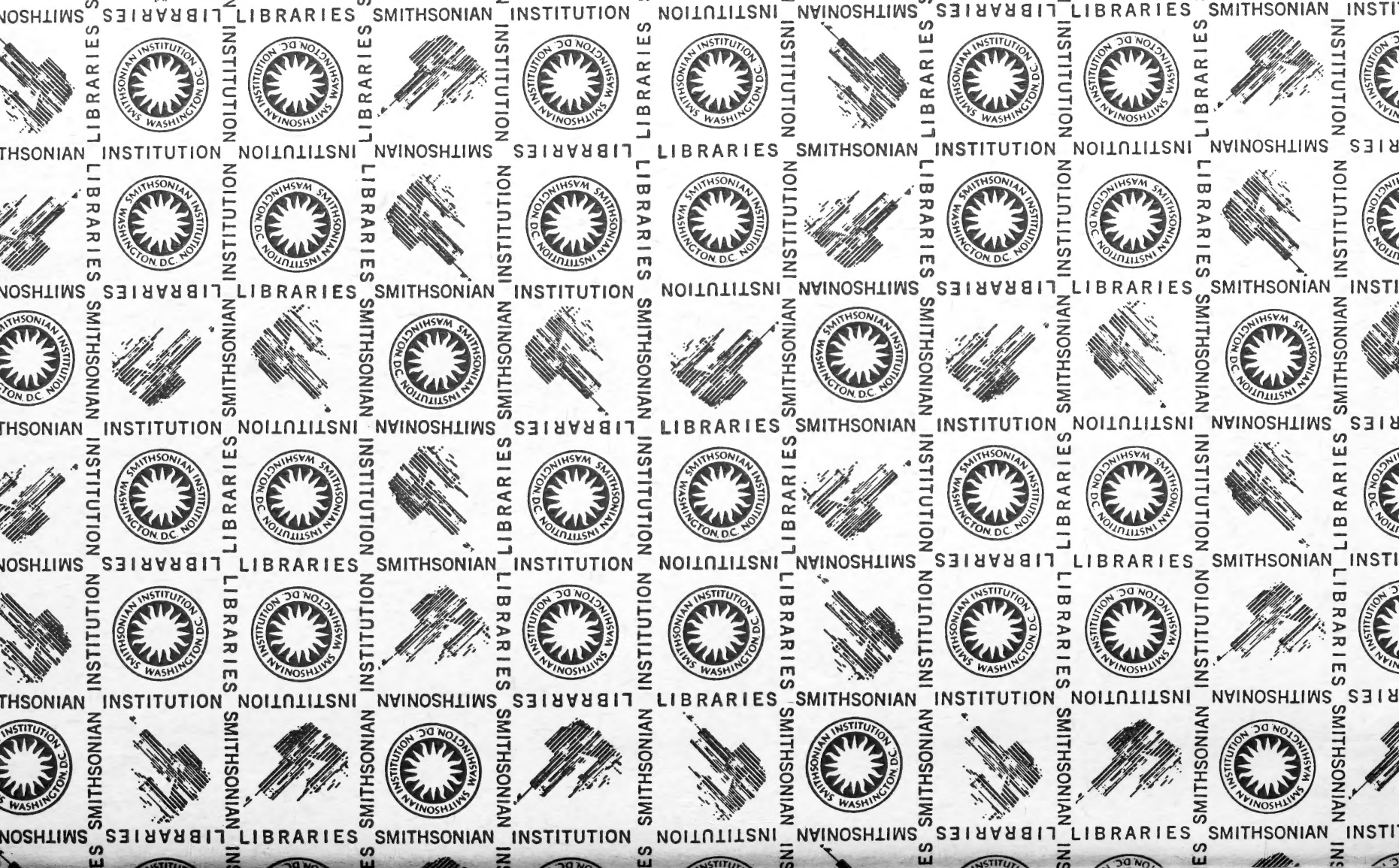
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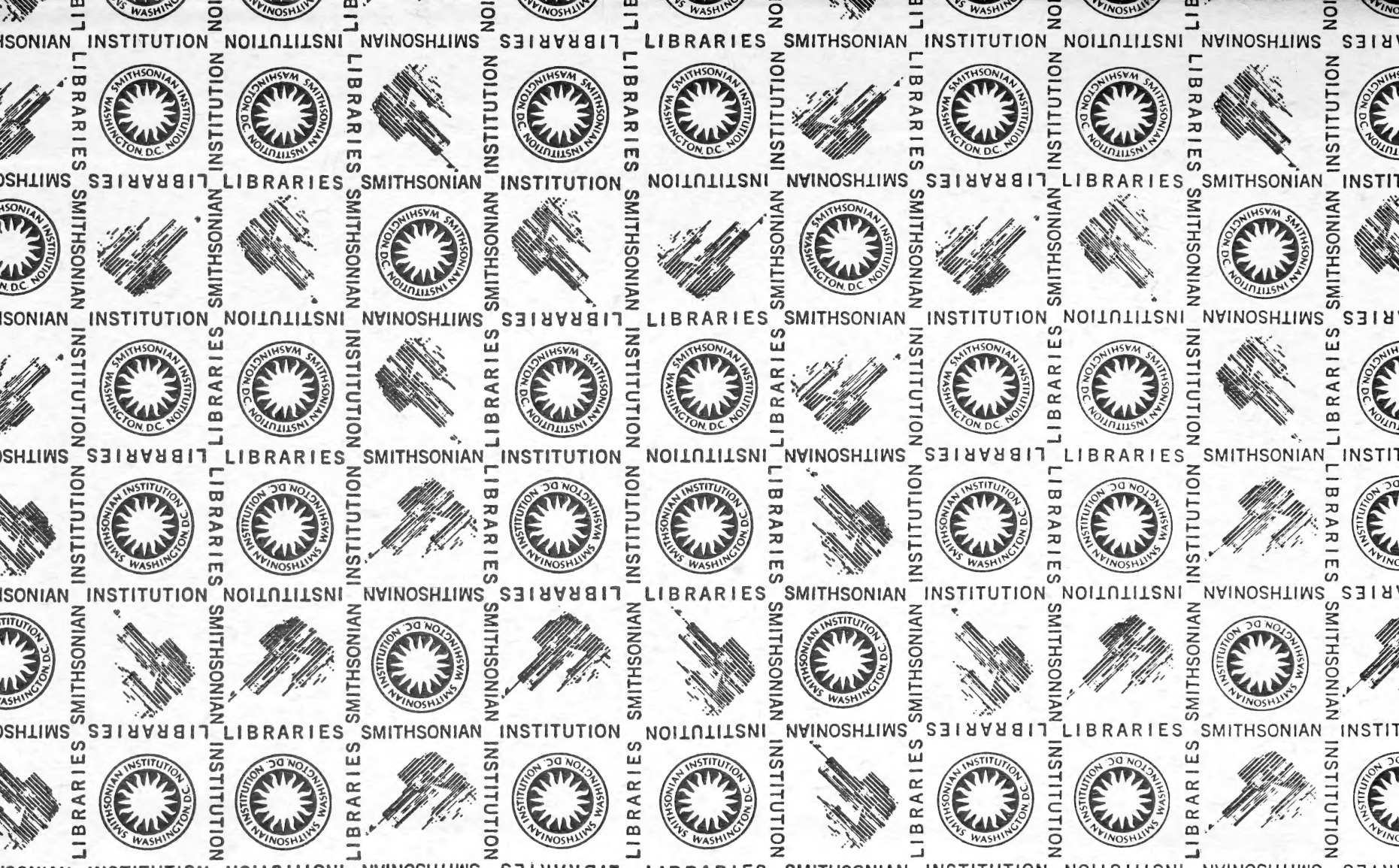
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